2013 Medical Imaging

9-14 February 2013

Technical Summaries

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Conferences & Courses
9-14 February 2013

Location
Disney Coronado Springs Resort
Lake Buena Vista (Orlando Area)
Florida, USA

Nico Karssemeijer
Radboud Univ.
Nijmegen Medical Ctr.
(Netherlands)

Ehsan Samei,
Duke Univ. (USA)

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2013 Medical Imaging

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Disney's Coronado Springs Resort
Lake Buena Vista (Orlando Area)
Florida, USA

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8668-1, Session 1

Volumetrics of the brain: a tale of missiles, mice, rain, hydrocephalus, and epilepsy *(Keynote Presentation)*

Steven J. Schiff, The Pennsylvania State Univ. (United States)

The growth of brain and its structures, and the dynamics of cerebrospinal fluid accumulation, are critical phenomena to characterize in order to develop predictive therapy of hydrocephalus, as well as to explore the use of CT to substitute for MRI in the developing world where MRI technology is infeasible. We explore murine hydrocephalus at high field strength MRI, and follow with the development of a particle filter segmentation tool that creates a pathway towards automated use in clinical settings. We develop normative human growth curves of brain and cerebrospinal fluid, and apply such normative curves to hydrocephalus and neurocognitive development. Lastly, we explore the intersection of brain volume and asymmetry of lobar volumes to predict the outcome of epilepsy surgical resection. A forthcoming NIH Phase III randomized controlled surgical trial in East Africa will employ these methods for the evaluation of alternative methods of treating postinfectious hydrocephalus, where a strong connection to climate rainfall dynamics has recently been shown. Our near-term goal is to evolve these volumetric methods from a research tool to an automated a 3D segmentation strategy that can be readily incorporated in clinical settings.

8668-2, Session 1

Possible dose reduction by dose-rate measurements using mobile phones/tablets combined with tabulated imaging procedure/ radiation doses

Christoph Hoeschen, Helmholtz Zentrum München GmbH (Germany); William W. Orrison M.D., Nevada Imaging Ctrs. (United States); Rolf-Dieter Klein, Ingenieurbuero Klein (Germany); Mathias M. A. Reichl, RGB Lasersystems GmbH (Germany); Peter Cartwright, Nevada Imaging Ctrs. (United States)

The purpose of our study is to demonstrate the effectiveness of using smartphones for measuring ionizing radiation and to combine the findings with radiation exposure from medical imaging procedures for recording individual annual/life-time radiation dose and provide improved radiation protection.

We developed an application for smartphones which can use the properties of the video camera chip in such smartphones together with highly sufficient statistical evaluation of the signals to detect ionizing radiation. We could show that this application can be used in a large range of dose rates from natural backgrounds to high dose rate pulsed radiation like in fluoroscopic radiation or CT investigations.

We could also show that these kinds of systems might help to provide better radiation protection by advising medical staff to use radiation protection material in best dose saving ways.

8668-3, Session 1

Development of matched virtual and physical breast phantoms based on patient data

Nooshin Kiarashi, Gregory M. Sturgeon, Loren W. Nolte, Joseph Y. Lo, William P. Segars, Ehsan Samei, Duke Univ. (United States)

Physical phantoms are essential for the development, optimization, and clinical evaluation of x-ray systems. These phantoms are used for various tests such as quality assurance testing, system characterization, reconstruction evaluation, and dosimetry. They should ideally be capable of serving as the variable ground truth for purposes such as virtual clinical trials. Currently, there is no anthropomorphic 3D phantom commercially available. We present our development of a new suite of physical breast phantoms based on real patient data, which can be used in 2D and 3D x-ray imaging quality assurance, optimization, and evaluation. The phantoms are generated from the NURBS-based extended cardiac-torso (XCAT) breast phantoms, which were segmented from patient dedicated breast computed tomography data. This adaptation enables comparison of simulations using virtual phantoms with physical tests. High-resolution multi-material 3D printing technology is used to fabricate the physical models. Glandular tissue and skin are presented by the most radiographically-dense photopolymer available to the printer, mimicking a 50% glandular tissue, and adipose tissue is presented by the least radiographically-dense photopolymer, mimicking a 20% glandular tissue. The glandular equivalency was measured by comparing x-ray images of samples of the photopolymers with those of breast tissue-equivalent materials. The mammographic projections and tomosynthesis reconstructed images of fabricated models show great improvement over available phantoms, presenting a more realistic breast background. The level of detail, contrast, and realism of the models may be enhanced by applying varying compression to the models and introducing alternative photopolymers or resins.

8668-4, Session 2

Design considerations for a new, high resolution micro-angiographic fluoroscope based on a CMOS sensor (MAF-CMOS)

Brendan Loughran, Toshiba Stroke and Vascular Research Ctr. Univ. at Buffalo (United States); Setlur Nagesh Setlur Nagesh, Vivek Singh, Ciprian N. Ionita, Amit Jain, Daniel R. Bednarek, Toshiba Stroke and Vascular Research Ctr., Univ. at Buffalo (United States); Albert H. Titus, Univ. at Buffalo (United States); Stephen Rudin, Toshiba Stroke and Vascular Research Ctr., Univ. at Buffalo (United States)

The detectors that are used for endovascular image guided interventions (EIGI), particularly neurovascular interventions, do not provide clinicians with adequate visualization to ensure the best possible treatment outcomes. Developing an improved x-ray imaging detector requires the determination of expected clinical x-ray entrance exposures to the detector. The range of exposures to the detector in clinical studies was found for the three modes of operation: fluoroscopic mode, high frame-rate digital angiographic mode (HD fluoroscopic mode), and DSA mode. Using these expected detector exposure ranges and available CMOS detector technical specifications, design requirements were developed to pursue a quantum limited, high resolution, dynamic x-ray detector based on a CMOS sensor with 50 μm pixel size. For the proposed MAF-CMOS, the expected charge collected within the full exposure range was found to be within the estimated full well capacity of the pixels. The expected instrumentation noise for the proposed detector was estimated to be 50-1,300 electrons. Adding either a gain stage such as a light image intensifier or a recursive temporal filter, would minimize the effect of the estimated instrumentation noise and ensure that the detector is quantum limited at low exposure levels. The temporal filter alone, at reasonable temporal weights of 3-5, decreases the effective instrumentation noise by 2.24-3 times, allowing for the system to be quantum noise limited at the lowest expected exposures. This work can serve as a guide for further development of dynamic x-ray imaging prototypes or improvements for existing dynamic x-ray imaging systems.

8668-5, Session 2

Image performances of multi-resolution technology for dynamic detector

Fumito Nariyuki, Takaaki Ito, Yoshihiro Okada, FUJIFILM Corp. (Japan)

A dynamic detector is required both a fluoroscopy mode with high signal to noise ratio and high-speed readout and a radiography mode with high resolution. The new dynamic detector presented in this paper is equipped with multi-resolution technology. Multi-resolution technology makes it possible to change the sampling size of the detector dynamically between the 1 x 1 mode (150 µm square) and the 2 x 2 mode (300 µm square) by using unique structure thin film transistor (TFT). In the 2 x 2 mode, the detector has 4 times sensitivity by integrating signals from 4 pixels. The detective quantum efficiency (DQE) value in the 2 x 2 mode was much higher than that in the 1 x 1 mode at a low radiation dose because signal to noise ratio is improved by multi-resolution technology. Under the RQA5 20 nGy radiation, the DQE value is as high as 40 % in the 2 x 2 mode and 20 % in the 1 x 1 mode.

The new detector has a 17” x 17” active area, a 2880 x 2880 matrix, and a 150 µm pixel pitch. The readout time was very fast to enable 17” x 17” fluoroscopy to operate 30 fps in the 2 x 2 mode. This is the first detector to achieve 17” x 17” fluoroscopy at 30 fps in the 2 x 2 mode at presents to our knowledge.

8668-6, Session 2

Design of a 3-dimensional field emission electron source with improved emission current density and cathode life

Yiming Xu, Dongsong Li, Shanghai Advanced Research Institute (China); Jian Zhang, Shanghai Advanced Research Institute (China) and United Imaging Healthcare (China) and Univ. of North Carolina at Chapel Hill (United States)

Field emission electron sources have been increasingly investigated and practiced as cold electron sources in many X-ray generation mechanisms especially in certain medical imaging applications, such as computed tomography (CT). In a field emission electron source, the emission current and cathode life are the two key performance parameters of interests. Conventional field emission electron source in the form of a 2-dimensional single surface cathode design is often undergoing the bottleneck of limited emission current. Higher current can be obtained by increasing the strength of driving electric field. However this is at the expense of a reduced cathode lifetime. In this paper we present a novel field emission electron source design based on a 3-dimensional semi-enclosed cavity structure, by utilizing the cavity’s multiple inner faces as electron emission surfaces. The cavity has one face open for electron ejection, the area of which was kept the same as a conventional single surface cathode to maintain the same initial electron beam cross section. The extended emission area of the new cathode design due to its 3-dimensional structure provides a higher electron emission current while maintaining the same beam cross section, resulting in an improved emission current density. We have demonstrated a significantly increased electron emission current from this 3-dimensional cathode under a constant electric field, without over-driving the field emitter. Alternatively this new cathode design can also achieve the same total emission current with a lower electric field compared with a conventional 2-dimensional cathode, which will significantly extend its lifetime.

8668-7, Session 2

A novel sensor for high throughput preclinical radiotracer imaging

Haris Kudrolli, Harish B. Bhandari, Radiation Monitoring Devices, Inc. (United States); Katherine L. Byrne, Simon R. Cherry, Gregory S. Mitchell, Univ. of California, Davis (United States); Hamid Sabet, Vivek V. Nagarkar, Radiation Monitoring Devices, Inc. (United States)

Preclinical imaging is a cornerstone of translational research, as all therapeutic drugs need to be tested for efficacy and toxicity on animals prior to human trials. Optical imaging techniques, such as bioluminescence and multispectral fluorescence imaging, currently dominate preclinical functional imaging despite their depth dependent limitations on quantitation and sensitivity. Translating drugs developed with these techniques to clinical models can therefore be difficult. Hence, clinically relevant nuclear imaging techniques, such as SPECT and PET, are therefore becoming increasingly used in preclinical imaging. Dedicated preclinical SPECT and PET systems are now available, but for many preclinical research groups this requires a significant investment in new equipment.

We demonstrate a method to acquire high resolution planar images with a SPECT radiotracer by retrofitting a IVIS Spectrum (Caliper Life Sciences) optical imaging system with a pinhole collimator and a large area CsI:Tl scintillator with a novel morphology. We report on the development of a novel thick, transparent, crystalline microcolumnar CsI:Tl scintillator structure (Crystalline Microcolumnar Structure (CMS) scintillator) that simultaneously provides high gamma-ray absorption efficiency, high intrinsic spatial resolution, and bright light emission. We present animal and phantom images acquired using a 4 mm thick, 15 cm diameter scintillator and a 2 mm diameter tungsten pinhole collimator with a IVIS Spectrum. The ability to use an existing commercial preclinical optical imaging system to rapidly acquire planar gamma ray images with good spatial resolution of one or multiple animals would be a new and useful tool for high throughput screening of molecular imaging probes.

8668-8, Session 2

Performance analysis of several generations of flat-panel x-ray imagers based on polycrystalline silicon TFTs

Larry E. Antonuk, Youcef El-Mohri, Qihua Zhao, Martin Koniczek, Albert K. Liang, Hao Jiang, Univ. of Michigan (United States); Robert A. Street, Jeng-Ping Lu, Palo Alto Research Center, Inc. (United States)

Active matrix flat-panel imagers (AMFPIs) have become ubiquitous in medical imaging environments. AMFPIs are based on two-dimensional pixelated arrays coupled to various x-ray converter materials that provide either indirect or direct detection of the incident x-ray radiation. However, the capabilities of this technology are severely constrained by the underlying solid-state properties of the amorphous silicon semiconductor material employed in the thin-film transistors present in each array pixel. The considerably higher electron and hole mobilities of polycrystalline silicon, a semiconductor material that (like amorphous silicon) is well suited to fabrication of transistors for large area electronics, provide the potential to overcome these constraints. To explore this potential, a series of prototype arrays based on increasingly complex pixel designs employing polycrystalline silicon transistors is under development by our collaboration. The designs include three generations of active pixel prototypes designed for fluence mode operation that incorporate sophisticated circuits with the goal of improving imaging performance – as well as circuit elements created to facilitate initial explorations of single photon counting with polycrystalline silicon circuits. In this presentation, the design and operation of these devices will be described and an early analysis of their signal and noise performance will be presented. The results will be based on various forms of theoretical modeling involving

techniques such as cascaded systems analysis and circuit simulations, supplemented with information obtained from empirical studies of prototype poly-Si devices. The research is supported by NIH grant R01 EB000558.

8668-9, Session 2

4D molecular imaging using coded aperture x-ray scatter imaging

Anuj J. Kapadia, Kalyani Krishnamurthy, Duke Univ. (United States); Pooyan Sahbaee, North Carolina State Univ. (United States); Amarpreet Chawla, Scott Wolter, Kenneth Maccabe, David Brady, Ehsan Samei, Duke Univ. (United States)

In this work, we demonstrate the ability to determine the material composition of a sample by measuring coherent scatter diffraction patterns generated using a coded-aperture x-ray scatter imaging (CAXSI) system. While most materials are known to exhibit unique diffraction patterns through coherent scattering of low-energy x-rays, clinical x-ray imagers typically discard scatter radiation as noise that degrades image quality. Through the addition of a coded aperture, the system can be sensitized to coherent scattered photons that carry information about the identity and location of the scattering material. Here we demonstrate this process using a Monte-Carlo simulation of a CAXSI system. A simulation of a CAXSI system was developed in GEANT4 with modified physics libraries to model coherent scatter diffraction patterns in materials. Simulated images were generated from 10 materials including plastics, hydrocarbons, and elements irradiated using collimated pencil- and fan-beams with energies up to 150 kVp. The diffraction patterns were imaged using a simulated 2D detector and deconvolved with the known x-ray source spectrum using an analytical projection model. The ring-patterns observed in the deconvolved images were then matched with a library of known coherent scatter form-factors of different materials to determine the identity of the scatterer at different locations in the object. The results showed an excellent match between the measured and known scatter patterns, demonstrating the ability to image and identify materials (1D) at different 3D locations within an object using a projection-based CAXSI system.

8668-10, Session 3

Effect of denoising on the quality of reconstructed images in digital breast tomosynthesis

Marcelo A. Vieira, Univ. de São Paulo (Brazil); Predrag R. Bakic, Andrew D. A. Maidment, Univ. of Pennsylvania (United States)

Projection images in Digital Breast Tomosynthesis (DBT) should be acquired with low levels of radiation, which may increase the level of quantum noise. This work proposes an investigation of the influence of a denoising algorithm, specifically designed for quantum noise reduction, in the quality of the DBT reconstructed images. Denoising is performed using the Anscombe transformation to convert the signal-dependent quantum noise into an approximately signal-independent Gaussian additive noise. In the Anscombe domain, image noise is removed through an adaptive Wiener filter, whose parameters are obtained considering local image statistics. Denoising was applied on synthetic projections images generated based upon an anthropomorphic software breast phantom. Reference projections images without noise were also generated in order to provide ground truth information. The method was also applied in the noisy reconstructed images for comparison. Preliminary assessment of the denoising method was performed using image quality metrics, such as peak signal-to-noise ratio (PSNR) and mean structural similarity index (MSSIM). Results suggested that denoising works better for tomosynthesis when applied in each projection image before reconstruction. In this case, an average increase of 5.0 dB in PSNR and of 39% in MSSIM measurements was reported. Considering the images reconstructed created with denoised projections, an average increase of 2.5 dB in PSNR and of 1.2% in MSSIM measurements was reported. No significant improvement was reported when the denoising was applied to the reconstructed images, suggesting that the filtering backpropagation algorithm modifies the noise properties in DBT projections.

8668-11, Session 3

Comparative studies on exposure conditions and reconstruction algorithms in limited angle tomography

Kwang Eun Jang, Jiyoung Choi, Jongha Lee, Younghun Sung, Jae Hak Lee, SeongDeok Lee, Samsung Advanced Institute of Technology (Korea, Republic of)

Digital breast tomosynthesis (DBT) has been investigated as a promising alternative to conventional X-ray mammography for breast cancer screening. By reconstructing 3D volumetric images from multiple 2D projections measured over a limited angular range, it can offer the depth-directional information and improve both sensitivity and specificity of cancer detection in dense breasts.

The diagnostic performance of DBT can be affected by a number of imaging parameters. The angular range of scan orbit is one of the most crucial factors, since it determines the depth-directional resolution.

Recently, we proposed the wide angle tomosynthesis based on voltage modulations of X-ray source. Note that projections correspond to outer angles are prone to statistical noise due to the slanted, elongated pathway of X-ray photons. By using X-rays with large penetration power on exterior positions, it can acquire high-SNR projections over a wide angular range.

In this paper, we present comparative studies on exposure conditions in DBT, including narrow and wide angle scan using an invariant tube voltage of X-ray source, and wide angle scan with the voltage modulation technique.

In addition, we compare the conventional reconstruction methods with recently proposed IDIR algorithms.

In preliminary studies, the wide-angle scheme with proposed IDIR algorithm showed superior performances in detecting abnormal lesions over conventional approaches.

8668-12, Session 3

Stationary chest tomosynthesis using a CNT x-ray source array

Jing Shan, Pavel Chtcheprov, Andrew W. Tucker, Yueh Z. Lee, The Univ. of North Carolina at Chapel Hill (United States); Xiaohui Wang, David Foos, Michael D. Heath, Carestream Health, Inc. (United States); Jianping Lu, Otto Z. Zhou, The Univ. of North Carolina at Chapel Hill (United States)

Chest tomosynthesis is an imaging modality that provides 3D sectional information of a patient chest using limited angle x-ray projections. Previous studies show that chest tomosynthesis can improve the detection of subtle lung nodules when compared to conventional radiography, but at a lower radiation dose than CT. However, the conventional chest tomosynthesis system, using a continuously moving x-ray source, can introduce source-motion blur and degrade image quality. In this paper, we report the preliminary results of developing a bench-top stationary chest tomosynthesis system using a distributed CNT x-ray source array. The linear x-ray source array has seventy-five CNT x-ray generating focal spots, reliable up to 3.5mA anode current. The tube is designed to operate at up to 100kVp anode voltage. Phantom images have been acquired to evaluate the system's performance. Images taken using different focal spots along the linear array demonstrate the feasibility of desktop stationary chest tomosynthesis.

8668-13, Session 3

Proposing a new velocity profile for continuous x-ray tube motion in digital breast tomosynthesis

Raymond J. Acciavatti, Predrag R. Bakic, The Univ. of Pennsylvania Health System (United States); Andrew D. A. Maidment, The Univ. of Pennsylvania Health System (United States)

In digital breast tomosynthesis (DBT), a 3D image of the breast is generated from x-ray projections at various angles. There are two mechanisms for acquiring projection images in DBT, step-and-shoot motion and continuous tube motion. The benefit of continuous tube motion is shorter scan time and hence less patient motion; the trade-off is focal spot blurring. To minimize focal spot blurring in a system with continuous tube motion, this study proposes a new velocity profile for the x-ray tube during the scan time. Unlike existing systems for which the x-ray tube has constant angular velocity, we investigate a smoothly-varying tube velocity that approaches zero during each projection and is larger between projections. With this unique design, the filtered backprojection reconstruction of a sinusoidal test object was calculated, and modulation was determined at various frequencies. It is shown that the newly proposed tube velocity yields increased modulation in the reconstruction relative to a conventional system with continuous tube motion. The modulation in the re-designed system differs minimally from an analogous step-and-shoot system operated with the same scan time. This improvement in image quality was validated with reconstructions of microcalcifications in computer breast phantoms. It is known that continuous tube motion reduces the contrast of microcalcifications relative to step-and-shoot systems; we show that the newly proposed tube motion increases the contrast of microcalcifications compared against conventional continuous tube motion. In conclusion, this work proposes a strategy for optimizing the velocity of tube motion in DBT.

8668-14, Session 3

Optimization of clinical protocols for contrast enhanced breast imaging

Yue-Houng Hu, Wei Zhao, Stony Brook Univ. Medical Ctr. (United States)

Contrast enhanced (CE) breast imaging has been proposed as a method to increase the sensitivity and specificity of breast cancer detection. Because malignant lesions often exhibit angiogenesis, the injection of radio-opaque contrast agents (i.e. iodine) results in increased attenuation compared to the background tissue. Both planar CE digital mammography (CE-DM) and digital breast tomosynthesis (CE-DBT) have been proposed, using either dual energy (DE) or temporal (TS) subtraction to remove tissue backgrounds. In the current study, we apply a cascaded linear systems approach to analyze both DE and TS subtraction methods in the context of a full diagnostic CE imaging study, including the effects of contrast dynamics. We apply the model to both CE-DM and CE-DBT to calculate the ideal observer signal-to-noise ratio (SNR) for a detection task for a large (5 mm), Gaussian object. The calculation of this figure-of-merit will be used to optimize protocol for iodinated contrast studies, including the effect of contrast dynamics.

8668-15, Session 3

Demonstration of a scatter correction technique in digital breast tomosynthesis

Christy R. Inscoe, Andrew W. Tucker, Jianping Lu, Otto Z. Zhou, The Univ. of North Carolina at Chapel Hill (United States)

We have recently developed a method of using a distributed x-ray source array to obtain image with scatter correction for tomographic reconstruction of an object. The method consists of obtaining x-ray images of the object with and without the primary beam sampling apparatus. In this study, we report the results of applying the scatter correction method for breast tomosynthesis imaging using the carbon nanotube x-ray based stationary Digital Breast Tomosynthesis (s-DBT) system developed at UNC. BR3D phantom slabs were imaged to investigate the effectiveness of the scattering method. The unique design of s-DBT system makes it possible to estimate the image of the scatter profile of the object with very low dose, and without significant increase in scanning time. Preliminary results suggest the scatter correction method is effective and the implementation for s-DBT is practical.

8668-16, Session 3

Study of image quality in digital breast tomosynthesis by subpixel reconstruction

Yao Lu, Heang-Ping Chan, Jun Wei, Lubomir M. Hadjiiski, Ravi Samala, Univ. of Michigan Health System (United States)

In digital breast tomosynthesis (DBT), the reconstructed image quality of small objects such as microcalcifications are limited by the detector resolution and the reconstruction voxel dimensions used, in addition to the inherent in-plane and out-of-plane blurring by the limited-angle image acquisition. We are investigating the effects of subpixel reconstruction on the image quality of microcalcifications. In this study, subpixel projection images were generated by polynomial interpolation of the gray level values of the original projection images to reduce the pixel pitch by a factor of 2 to 4. The voxel dimensions in the reconstruction volume were set to match the pitch in the subpixel projection images. DBT scans of human subjects with microcalcifications were acquired with a GE prototype DBT system at 0.1 mm pixel pitch. In addition, computer modeling of the same system was used to generate simulated DBT projections of geometric objects. DBT volumes corresponding to the subpixel projections were reconstructed with SART. The FWHMs of the line profiles of microcalcifications on their in-focus DBT slices and FWHMs of the inter-plane artifact spread function (ASF) in the z-direction were used for comparison of reconstruction quality. The results indicated that subpixel reconstruction increased the signal contrast and reduced the out-of-plane blurring to a certain extent. Further work is underway to study the dependence of the trade-off between image quality and reconstruction voxel dimensions on the image acquisition parameters (total scan angle, angular increment) of the DBT system and the properties of the objects of interest.

8668-501, Session PL

Critical path technology: volumetric analyses in the interpretation of CT data

Geoffrey D. Rubin M.D., Duke Univ. Medical Ctr. (United States)

Computed tomography has evolved from a planar to a volumetric imaging modality. Initiated in the 1990s by the introduction of spiral CT scanning, the evolution was complete with the development of multi-detector row CT scanners capable of acquiring clinically practical isotropic datasets. This capability has been accompanied by an explosion in imaging applications, particularly in the planning and monitoring of minimally invasive therapies. As an accurate characterization of the diseased anatomy is critical to the selection and sizing of medical devices, volumetric analyses, both qualitative

and quantitative have become necessary elements of clinical CT examinations. This presentation will review the development, evolution, and application of volumetric analyses in CT and how they have become critical elements for maximizing the utility of the CT scan.

8668-17, Session 4

Quantitative analysis of an enlarged area solid state x-ray image intensifier (SSXII) detector based on electron multiplying charge coupled device (EMCCD) technology

Setlur Nagesh Swetadri Vasan, Prateek Sharma, Vivek Singh, Amit Jain, Ciprian N. Ionita, Toshiba Stroke and Vascular Research Ctr. (United States); Albert H. Titus, Alexander N. Cartwright, Univ. at Buffalo (United States); Daniel R. Bednarek, Stephen Rudin, Toshiba Stroke and Vascular Research Ctr. (United States)

Present day treatment for neurovascular pathological conditions involves the use of devices with very small features such as stents, coils, and balloons; hence, these interventional procedures demand high resolution x-ray imaging under fluoroscopic conditions to provide the capability to guide the deployment of these fine endovascular devices. To address this issue, a high resolution x-ray detector based on EMCCD technology is being developed. The detector features an effective pixel size of 37µm giving it a Nyquist frequency of 13.5 lp/mm which is significantly higher than that of the state of the art Flat Panel Detectors (FPD). Quantitative analysis of the detector, including gain calibration, instrumentation noise equivalent exposure (INEE) and modulation transfer function (MTF) determination, are presented in this work. The gain of the detector is a function of the detector temperature; with the detector cooled to 50C, the highest relative gain that could be achieved was calculated to be 116 times. At this gain setting, the lowest INEE was measured to be 0.6µR/ frame. The MTF, measured using the edge method, was over 2% up to 7 cycles/ mm. To evaluate the performance of the detector under clinical conditions, an aneurysm model was placed over an anthropomorphic head phantom and a coil was guided into the aneurysm under fluoroscopic guidance using the detector. Image sequences from the procedure are presented demonstrating the high resolution of this SSXII.

8668-18, Session 4

Intrinsic and total system performance evaluation for a newly developed solid state x-ray image intensifier (SSXII) detector

Vivek Singh, Setlur Nagesh Swetadri Vasan, Amit Jain, Univ. at Buffalo (United States); Prateek Sharma, State University of New York at Buffalo (United States); Daniel R. Bednarek, Stephen Rudin, Univ. at Buffalo (United States)

The new Solid State X-ray Image Intensifier (SSXII) is a high-resolution, high-sensitivity, real-time region-of-interest (ROI) x-ray imaging detector. Evaluations were made of both standard linear metrics (MTF, DQE) and total system performance with generalized linear metrics (GMTF, GDQE) including scatter and geometric un-sharpness for simulated clinical conditions.

The SSXII is based on a 1k x 1k EMCCD sensor coupled to a 300 ?m thick CsI(Tl) phosphor through a 2.88:1 fiber optic taper resulting in a 37 ?m effective pixel size and a 3.7 cm diameter effective field-of-view (FOV). Standard methods were used to calculate MTF, NNPS and DQE. Generalized metrics were calculated and compared for three different magnifications (1.03, 1.11 and 1.2) and three different focal spots (0.3 mm, 0.5 mm and 0.8 mm) for a scatter fraction of 0.28.

For an RQA5 spectrum, at 5 cycles/mm the MTF was found to be 0.06 and DQE was 0.04, while the DQE(0) was 0.60. Focal spot un-sharpness and scatter significantly degrades the GMTF and GDQE performance of the detector. A low frequency drop is caused by scatter and is almost independent of focal spot size and magnification. The degradation for middle range frequencies is caused by geometric un-sharpness and increases with focal spot size and magnification. This degradation was least in the case of the small focal spot and almost independent of magnification.

In spite of this degradation, the high resolution SSXII with a small FOV may have a significant impact on ROI image-guided neuro-interventions since it demonstrates far better performance than standard current detectors.

8668-19, Session 4

Uncertainty of Monte Carlo variance estimates: application to the simulation of x-ray imaging detectors

Aldo Badano, Frank W. Samuelson, U.S. Food and Drug Administration (United States)

Knowledge of the uncertainty associated with Monte Carlo estimates is useful for determining when to stop a simulation run when statistical fluctuations fall below a desired tolerance level, and for designing and analyzing variance reduction techniques. In this work, we discuss how to analytically calculate the uncertainty of Monte Carlo variance estimates from higher order moments of the distribution of events. In addition, we show how these expressions can be incorporated in the study of x-ray imaging detectors to manage runtime and precision of the simulation. Our analysis can be used to design variance reduction techniques for Monte Carlo simulations when, as in many cases in imaging, the variance and not the mean, is the quantity of interest.

8668-20, Session 4

Two methods for simulation of dense tissue distribution in software breast phantoms

Joseph H. Chui, The Univ. of Pennsylvania Health System (United States); Rongping Zeng, U.S. Food and Drug Administration (United States); David D. Pokrajac, Delaware State Univ. (United States); Subok Park, Kyle J. Myers, U.S. Food and Drug Administration (United States); Andrew D. A. Maidment, Predrag R. Bakic, The Univ. of Pennsylvania Health System (United States)

Software breast phantoms have been developed for the use in evaluation of novel breast imaging systems. Software phantoms are flexible to simulate wide variations in breast anatomy and provide ground truth about simulated tissue structures. Different levels of phantom realism are required depending on the intended application. Realistic simulation of dense (fibroglandular) tissue is of particular importance; the properties of dense tissue – breast percent density and the spatial distribution – have been related to the risk of breast cancer. In this work we have compared two methods for simulation of dense tissue distribution in a software breast phantom previously developed at the University of Pennsylvania. The compared methods include (1) the previously used Gaussian distribution centered at the phantom nipple point, and (2) the proposed combination of two Beta functions, one modeling the dense tissue distribution along the chest wall-to-nipple direction, and another modeling the radial distribution in each coronal section of the phantom. Dense tissue distributions obtained using these methods have been compared with the distribution reported in the literature estimated from the analysis of breast CT images. Qualitatively, two methods produced rather similar dense tissue distributions. The simulation based upon the use of Beta functions provide more control over the simulated distributions by selecting Beta function parameters. Both methods showed good agreement to the clinical data, suggesting high level of realism.

8668-21, Session 4

Synthesis of CT anatomical texture in voxelized XCAT phantoms

Jason Bond, Anum Minhas, Donald Frush, Duke Univ. Medical Ctr. (United States); Mannudeep K. Kalra, Sarabjeet Singh, Massachusetts General Hospital (United States); William P. Segars, Duke Univ. Medical Ctr. (United States); Ehsan Samei, Duke Univ. Medical Ctr. (United States) and Massachusetts General Hospital (United States)

While great advances are made toward making highly realistic, surface models of the human anatomy (such as our line of XCAT phantoms) very little has been done to fill these bounded surfaces with models of anatomical texture. We propose a method whereby realistic CT anatomical textures can be rapidly incorporated into voxel phantoms. Our source of texture comes from a set of repeated CT cadaver scans over a range of doses. To test our method, we first investigate the texture of the liver. The cadaver images were averaged to reduce the effects of noise. An ROI was defined within the liver to serve as an input texture. The target phantom was then selected from our library of XCAT models. The liver texture was propagated within a voxelized image of the XCAT phantom liver using the image quilting algorithm developed by Efros and Freeman. The effects of the modulation transfer function (MTF) on organ texture were then investigated. Simulations with and without the MTF were compared with reconstructions of the cadaver CT data, using the integrated noise power spectrum (NPS) as a metric. Early results demonstrate the ability of our method to simulate realistic CT textures. It is anticipated that this method when applied to other organs and structures will find a great use in making x-ray simulations of the XCAT phantom look more realistic and allow for the phantom to not only be utilized in dosimetrical evaluations, but in image quality studies as well.

8668-22, Session 5

Multi-energy performance of a research prototype CT scanner with small-pixel counting detector

Steffen G. Kappler, Andre Henning, Bernhard Krauss, Friederike Schöck, Karl Stierstorfer, Thomas Weidinger, Thomas G. Flohr, Siemens AG, Healthcare Sector (Germany)

We have investigated the multi-energy performance of our most recent prototype CT scanner with CdTe-based counting detector. With its small pixel pitch of 225 micron this device is prepared for the high X-ray fluxes occurring in clinical CT. Each of these pixels is equipped with two adjustable counters. The ASIC architecture of the detector allows configuration of the counter thresholds in chess patterns, enabling data acquisition in up to four energy bins. We have studied the material separation capability of this system with respect to potential clinical applications. Therefore we have analyzed contrast and noise properties in material decomposed CT images using up to four base materials: contrast agents containing iodine, gadolinium or gold, and a body-like compound of bone, fat and water. We describe the mathematical framework used in this work and demonstrate the general multi-energy capability of our prototype scanner in simulations and real CT scans. To prove the clinical relevance of our studies we compare the results to those obtained with well-established dual-kVp techniques recorded at same patient dose and with identical image sharpness.

8668-23, Session 5

Quantitative breast imaging using photon counting detector

Seokmin Han, Dong-Goo Kang, Sunghoon Kang, Samsung Advanced Institute of Technology (Korea, Republic of); Younghun Sung, Samsung Advanced Institute of Technology (Korea, Republic of)

Possible limitations of current dual energy Contrast Enhanced Digital Mammography(CEDM) are that overlapping normal breast tissue structures can obscure the visualization of iodine, and that the only two images acquired provide solution for two variable equations while three variables are required as the breast consists of three materials - adipose and glandular tissues and iodine.

To solve this problem with dual energy CEDM, it requires knowledge of the breast thickness at each pixel.

However, in many clinical mammography systems employing a spring-loaded paddle, the physical thickness of the breast may not be uniform due to deformation and tilt of the compression paddle.

Therefore, we chose to use triple energy CEDM to overcome these limitations, which can provide a third image.

However, the radiation dose can remain a major concern due to three exposures.

Photon counting detector(PCD) can provide triple energy radiography without mentioned extra exposures.

For triple energy CEDM, an iodine quantification method for breast imaging was suggested in this research.

We acquired triple energy images of calibration phantom of different iodine concentrations first, using PCD.

Then, intensity values at each energy of imaging object could be mapped pixel by pixel to different locations on the calibration phantom images of different iodine thicknesses(concentrations).

Interpolation surface of iodine concentration was constructed from the mapped locations at each energy.

Resultant triple surfaces were combined to find out the intersection of the three iodine thickness surfaces from the three energy images, which tells the estimated iodine thickness from the input intensity value.

The result shows that the proposed method could quantify iodine inserts in breast phantom accurately, which simulate lesions in breast filled with different iodine concentrations.

8668-24, Session 5

Measurements of a dual-energy fast photon counting CdTe detector with integrated charge sharing correction

Christer Ullberg, Mattias Urech, Niclas Weber, Anders Engman, Anna Redz, Fredrik Henckel, XCounter AB (Sweden)

Photon counting detectors offer some unique features for x-ray imaging. If designed correctly, photon counting detectors have no readout noise and no dark counts. This is an important feature in for example low dose CT imaging where the total dose is distributed over a large number of projections from different angles. In addition of this it is also possible to incorporate pulse height discrimination of each photon event, thus enabling the recording of images from multiple energy intervals in a single exposure.

We demonstrate the performance of a newly developed dual-energy fast photon counting detector with 100µm pixel size that can be read out with up to 1000fps. It is a three side buttable device that is bump bonded to a CdTe converter. The very high conversion efficiency of CdTe makes the detector suitable for a wide range of applications requiring high spatial resolution at low doses. The efficiency of the detector is maintained all the way out to the edge of the chip which opens up the possibility to

build larger detectors still fulfilling medical requirements.

The novel detector incorporates a charge sharing correction feature and the effect of this function is demonstrated using the DQE measurements over a wide range of doses as well as with spectrum reconstruction from Cd109 and Am241 radioactive sources. We show that this charge sharing correction feature affects the properties of NPS and MTF, and the energy resolution is greatly enhanced.

Measurements are also compared to a simulation model for the detector system.

8668-25, Session 5

Threshold optimization for CNR-enhanced CT images with photon-counting detectors

Thomas Weidinger, Thorsten M. Buzug, Univ. zu Lübeck (Germany); Thomas G. Flohr, Steffen G. Kappler, Friederike Schöck, Karl Stierstorfer, Siemens Healthcare (Germany)

Photon counting detectors are expected to bring along various clinical benefits in CT imaging. Among the benefits of these detectors is their intrinsic spectral sensitivity which allows to resolve the incident X-ray spectrum. Besides the principal multi-energy imaging capability of those devices, it is also possible to use the spectral information to create fused gray-scale CT images with improved imaging properties.

We have developed and investigated an optimization method that makes use of the data recorded with up to six energy thresholds. The resulting gray-scale CT images feature significantly improved contrast-to-noise ratios (CNR) for a number of clinically established and novel contrast agents in the thin absorber limit.

In this work we motivate and describe the optimization method, provide the deduced optimal set of threshold energies and mixing weights, and summarize the maximally achievable gain in CNR for each contrast agent under study.

8668-26, Session 5

Modeling photon-counting detectors for x-ray CT: spectral response and pulse-pileup effects and evaluation using real data

Jochen Cammin, Jennifer Xu, Johns Hopkins Univ. (United States); William C. Barber, Jan S. Iwanczyk, Neil E. Hartsough, DxRay, Inc. (United States); Katsuyuki Taguchi, Johns Hopkins Univ. (United States)

Spectral computed tomography (CT) with photon-counting detectors (PCDs) has the potential to substantially advance diagnostic CT imaging by reducing image noise and dose to the patient, by improving contrast and tissue specificity, and by enabling molecular and functional imaging. The current PCD technology, however, is limited by two main factors: imperfect energy measurement (spectral response effects, SRE) and limited count rate (pulse-pileup effects, PPE, due to detector dead-times). The overall goal of our research is to develop compensation algorithms for these sources of data distortions, to demonstrate that PCDs are suitable for clinical CT, and to identify key clinical applications for spectral CT with PCDs. We have already developed an iterative compensation scheme that includes a forward projection model of the imaging chain and that can compensate for either SRE or PPE distortions separately by maximizing a penalized log-likelihood function. In this paper we describe the evaluation of a combined, cascaded SRE and PPE model for PCDs and compare the models to data acquired with an experimental table-top PCD-CT system. The separation into count-rate independent effects (SRE) and count-rate dependent effects (PPE) allows cascading the forward model. First, the SRE model is evaluated using low count rates. Then the PPE model is cascaded and the combined SRE+PPE model is evaluated. Several different attenuators were used, including K-edge materials and the models and data were compared for various count-rate conditions.

8668-27, Session 5

Spatial resolution in single-photon-counting x-ray imaging

Jesse Tanguay, Robarts Research Institute (Canada); Seungman Yun, Pusan National Univ. (Korea, Republic of); Ian A. Cunningham, Robarts Research Institute (Canada)

Purpose: Single-photon counting (SPC) x-ray detectors have a number of potential benefits over the usual approach in which the detector signal is proportional to the total energy deposited during an image-acquisition interval. While SPC detectors are an exciting alternative, reabsorption of scattered x-rays and charge sharing in neighboring pixels may result in a loss of spatial information. The purpose of this work is to describe the inherent spatial resolution, expressed in terms of the modulation transfer function (MTF), of SPC x-ray detectors.

Methods: We develop a theoretical formalism for calculating the point-spread function (PSF) and MTF of SPC x-ray detectors. The formalism is used to describe the effects of element cross-talk on the MTF of SPC x-ray detectors and compare with that of energy-integrating detectors. We also consider an adaptive-binning approach in which the signals from a number of elements surrounding a primary interaction are summed and a counter is incremented at the position corresponding to the centroid. Results are compared with Monte Carlo simulation.

Results: For Gaussian point-spread functions (PSFs), the MTF of SPC x-ray detectors decreases with decreasing threshold values over all spatial frequencies and in some situations can be lower than that of energy-integrating x-ray detectors. Adaptive approaches, however, were shown to result in substantial increases in the MTF for low threshold values.

Conclusions: We have presented a theoretical comparison of spatial resolution, expressed in terms of the MTF, of SPC and conventional energy-integrating x-ray detectors. Low threshold values in SPC detectors will result in a decrease in spatial resolution, however, adaptive binning strategies in which in which the signals from a number of elements surrounding a primary interaction are summed and a counter is incremented at the position corresponding to the centroid resulted in a substantial increase in the MTF.

8668-28, Session 6

Dual energy iodine contrast imaging with mammography and tomosynthesis

Baorui Ren, Chris Ruth, Yiheng Zhang, Andrew Smith, Don Kennedy, Bernadette O'Keefe, Ian Shaw, Cornell Williams, Zhen Ye, Zhenxue Jing, Hologic, Inc. (United States)

We have developed dual energy (DE) iodine contrast imaging functions with a commercial mammography and tomosynthesis system. Our system uses a tungsten target x-ray tube and selenium direct conversion detector. Conventional low energy (LE) images were acquired with existing Rh, Ag and Al filters at the screening doses while the new high energy images (HE) were acquired with new Cu filters at half of the screening doses. In DE 2D mode, a pair of LE and HE images was taken with one second delay time between and with anti-scatter grid. In DE 3D mode, 22 views of alternating LE and HE were taken over 15 degrees angle in seven seconds without grid while tube was scanned continuously. We used log-subtraction algorithm to obtain clean DE images with the subtraction factor K derived empirically. In 3D mode, the subtraction was applied to each pair of LE and HE slices after reconstruction. The x-ray technique optimization was done with simulation and phantom study. We did both phantom and patient study to demonstrate the advantage of iodine contrast imaging. Among several

new things in our work, a new selenium detector aimed for DE imaging was tested and large dose advantage was demonstrated; 2D and 3D DE images of a breast under same compression were acquired with a unique DE combo mode of the system, allowing direct image quality comparison between 2D and 3D modes. Our study showed that new DE system achieved good image quality and DE imaging could be a promising modality to fight breast cancer.

8668-29, Session 6

An application of Pre-computed Backprojection based Penalized-likelihood (PPL) Image Reconstruction on stationary Digital Breast Tomosynthesis

Shiyu Xu, Southern Illinois Univ. Carbondale (United States); Jianping Lu, Otto Z. Zhou, The Univ. of North Carolina Chapel Hill (United States); Ying Chen, Southern Illinois Univ. Carbondale (United States)

Stationary Digital Breast Tomosysthesis (s-DBT) is a carbon nanotube based breast imaging device with fast image acquisition and decent resolution. In this paper, we investigated several representative reconstruction methods with the recently improved s-DBT system and also introduced a two-step reconstruction strategy withpre-computing based penalized-likelihood (PPL). This strategy reconstructs image with a desired quality by selecting the corresponding smoothing parameter. The influences of it are represented as Modulation Transfer Function (MTF) of a impulse response and standard deviation of noise in the tables generated by system simulations. Our experiments show that the current s-DBT system has been greatly improved with respectto the performance of image reconstruction. The two-step strategy presents a controllable tradeoff between pixel precision and noise of reconstructed image.

8668-30, Session 6

Efficient synthesis of virtual projections from a tomosynthesis data set using a 2D image processing method

Frank Dennerlein, Anna Jerebko, Andreas Fieselmann, Thomas Mertelmeier, Siemens AG (Germany)

A new algorithm is suggested to compute one or several virtual projection images directly from cone-beam data acquired in a tomosynthesis geometry. One main feature of this algorithm is that it does not involve the explicit computation of a 3D volume, and a subsequent forward-projection operation, but rather operates using solely 2D image processing steps. The required 2D processing is furthermore based on the use of pre-computed entities, so that a significant speed-up in the computations can be obtained. The presented algorithm is applicable to mammography applications, to simulate virtual, high quality mammograms from a set of low-dose tomosynthesis projection images.

8668-31, Session 6

Towards visual-search model observers for mass detection in breast tomosynthesis

Beverly A. Lau, Howard C. Gifford, Mini Das, Univ. of Houston (United States)

We are investigating human-observer models that perform clinically realistic tasks as a means of making reliable assessments of breast tomosynthesis (BT) images. Previous work has tested visual-search (VS) observers against human observers for microcalcification (MC) detection and localization. A VS model attempts to mimic trained radiologists by implementing a two-phase process of initial holistic search followed by directed analysis and decision-making. The current work considers VS models for mass detection and localization. As with the MC studies, the intent is to evaluate the models using human-observer data. A localization ROC study is looking at the effects of acquisition geometry on filtered backprojection BT images. In this abstract, we compare Initial human results against scanning observer results obtained in an earlier study. This scanning observer performed mass detection-localization, but under a ``background-known-exactly" paradigm.

8668-32, Session 6

Simulation of 3D DLA masses in digital breast tomosynthesis

Alaleh Rashidnasab, Premkumar Elangovan, Univ. of Surrey (United Kingdom); Alistair Mackenzie, National Coordinating Ctr. for the Physics of Mammography (United Kingdom); Oliver Diaz, Univ. of Surrey (United Kingdom); Kenneth C. Young, David R. Dance, National Coordinating Ctr. for the Physics of Mammography (United Kingdom); Kevin Wells, Univ. of Surrey (United Kingdom)

Digital breast tomosynthesis (DBT) is suggested to have superior performance compared to 2D mammography in terms of cancer visibility, especially in the case of dense breasts. However, the overall performance of tomosynthesis for screening applications, and the manner in which tomosynthesis should be optimally used for screening remains unclear. This motivates the development of software tools that can insert user-defined synthetic pathology of realistic appearance into clinical tomosynthesis images for subsequent use in virtual clinical trials.

In this new work diffusion limited aggregation (DLA), a type of fractal growth, was used to simulate 3D breast masses for insertion into clinical tomosynthesis projection images. Previously, these simulated masses were inserted into 2D digital mammograms and then validated for their realism. In this latest work we present a method for inserting such masses into tomosynthesis projections using ray tracing taking into account system degradation and local scatter in the insertion process. Preliminary results suggest that DLA masses can be successfully inserted and appear visually authentic. The collection of pathology-proven, benign and normal clinical tomosynthesis image data for the purpose of an observer study is currently underway. A detailed pilot study into the realism of appearance of the simulated masses in tomosynthesis planes using expert radiologists will be presented in the final paper.

8668-33, Session 7

Reconstruction method incorporating the object-position dependence of visibility loss in dark-field imaging

Udo van Stevendaal, Philips Technologie GmbH (Germany); Zhentian Wang, Paul Scherrer Institut (Switzerland); Thomas Koehler, Gerhard Martens, Philips Technologie GmbH (Germany); Marco Stampanoni, Paul Scherrer Institut (Switzerland) and Institute for Biomedical Engineering, Univ. and ETH Zurich (Switzerland); Ewald Roessl, Philips Technologie GmbH (Germany)

Differential phase-contrast imaging in the x-ray domain provides three physically complementary signals: the attenuation, the differential phase-contrast, related to the refractive index, and the dark-field signal, related to the total amount of radiation scattered into very small angles. In cases where different forms of tissue with similar absorption cross-sections are under investigation, e.g. mammography or angiography, the x-ray absorption contrast is relatively poor. Consequently, differentiating pathologic from non-pathologic tissue in an absorption radiograph obtained with a current hospital-based x-ray system remains practically

impossible for certain tissue compositions. Dark-field imaging overcomes limitations in, for example, CT investigating relatively weakly absorbing material. However, using fan-angle apertures and field of views as those in human CT scanners leads to capping or cupping artifacts in the reconstructed images. In this contribution, this scenario is considered and a dedicated reconstruction algorithm is developed taking into account the effect that two complementary x-rays are scattered in a different manner depending on the object position and the size of the scattering features within the object. The application of the described reconstruction algorithm eliminates such artifacts and may be used for dark-field imaging in human CT.

8668-34, Session 7

Grating-based darkfield breast imaging

Jens Rieger, Florian Bayer, Jürgen Durst, Karl C. Gödel, Wilhelm Haas, Florian Horn, Thilo Michel, Georg Pelzer, André Ritter, Thomas Weber, Andrea Zang, Gisela Anton, Friedrich-Alexander-Univ. Erlangen-Nürnberg (Germany)

Grating-based X-ray phase-contrast imaging (XPCI) is a promising modality to increase soft-tissue contrast in medical imaging and especially in the case of mammography. Several groups worldwide have performed investigations on grating-based Talbot-Lau X-ray imaging of breast tissue, but in most cases focussed on the soft tissue contrast enhancement of the differential phase image.

In this contribution, we present promising measurements with a Talbot-Lau interferometer of several mas- tectomy breast tissue samples especially focussed on the sensitivity of the darkfield signal of microcalcifications and for the first time with a comparable dose value to conventional mammography. We can present a contrast improvement for calcifications in surrounding breast tissue for the darkfield image by a factor of 10 related to the absorption image. We also clearly see an agreement between histological findings of very small calcifications and a strong darkfield signal in the same region of the sample.

In the future, we are going to take additional measurements of several breast samples to receive information about the diagnostic importance of detecting such small calcifications.

8668-35, Session 7

How to determine detection performance of a DPC-CT system from a conventional cone beam CT system?

Ke Li, Univ. of Wisconsin School of Medicine and Public Health (United States); Nicholas B. Bevins, Univ. of Wisconsin-Madison (United States); Joseph N. Zambelli, Guang-Hong Chen, Univ. of Wisconsin School of Medicine and Public Health (United States)

Although the relative ease of implementation and compactness of grating-based DPC-CT sparked tremendous enthusiasm for potential medical applications, the pros and cons of this imaging method remain to be addressed before an actual clinical system can be constructed. To address these unknowns, either numerical simulations or direct hardware implementations can be used. However, both approaches have their limitations. It is highly desirable to develop a research method to enable imaging performance prediction for a future DPC-CT system from the performance of an available absorption CT system. In this paper, a new method is developed to accurately predict the detection performance of DPC-CT from that of conventional absorption-based CT (ACT). The method is based on a fundamental signal/noise relationship between DPC-CT and ACT and is expected to become an efficient and accurate tool to address the following questions: (i) With the radiation dose being fixed in a clinical application, how well a specific detection/discrimination imaging task can be performed provided that an existing ACT scanner is modified to a DPC-CT by inserting a grating interferometer, which is characterized by a few design parameters (e.g., pitches and duty cycles of the gratings, relative distance between the gratings, etc.) into the ACT system? (ii) If a DPC-CT system can outperform an ACT in some specific detection/discrimination tasks per unit x-ray exposure from a given tube, how would one optimize the interferometer parameters in order to maximize the potential clinical benefit?

8668-36, Session 7

Edge illumination and coded-aperture X-ray phase-contrast imaging: increased sensitivity at synchrotrons and lab-based translations into medicine, biology and materials science

Marco Endrizzi, Paul C. Diemoz, Magdalena B. Szafraniec, Charlotte K. Hagen, Thomas P. Millard, Cesar E. Zapata, Peter R. T. Munro, Konstantin Ignatyev, Univ. College London (United Kingdom); Massimo Marenzana, Department of Bioengineering, Imperial College, London (United Kingdom); Robert D. Speller, Alessandro Olivo, Univ. College London (United Kingdom)

The edge illumination principle was first proposed at Elettra (Italy) in the late nineties, as an alternative method for achieving high phase sensitivity with a very simple and flexible setup, and has since been under continuous development in the radiation physics group at UCL. Edge illumination allows overcoming most of the limitations of other phase-contrast techniques, which have until now restricted their use mostly to synchrotron radiation. In particular, it is relatively insensitive to setup instabilities and it can be adapted, with the use of appropriate masks, to the divergent and polychromatic beams provided by laboratory X-ray sources. In this case the method is usually referred to as coded-aperture technique, and has been demonstrated to work efficiently even with source sizes up to 100 ?m, compatible with state-of-the-art mammography sources. Two full prototypes have been built and are operational at UCL: recent research has focused on various applications, such as breast and cartilage imaging, homeland security, detection of defects in composite materials etc, showing great improvements in image quality. Furthermore, new methods such as dark field imaging, tomosynthesis, computed tomography and phase retrieval algorithms are being investigated theoretically and experimentally with the aim of exploiting the full potential of the technique. The ability to achieve unprecedented angular sensitivity (< 2 nrad) when applied to synchrotron radiation has also been demonstrated in recent experiments. These results strongly indicate the technique as an extremely powerful and versatile tool for X-ray imaging for a wide range of applications.

8668-37, Session 8

Compact hard X-ray grating interferometry for table top phase contrast micro CT

Thomas Thuering, Paul Scherrer Institut (Switzerland) and ETH Zuerich (Switzerland); Stefan Haemmerle, Stephan Weiss, Joachim Nuesch, SCANCO Medical AG (Switzerland); Jan Meiser, Karlsruhe Institute of Technology (Germany); Jürgen Mohr, Karlsruhe Institute of Technology (KIT) (Germany); Christian David, Paul Scherrer Institut (Switzerland); Marco Stampanoni, Paul Scherrer Institut (Switzerland) and ETH Zuerich (Switzerland)

Today's commercial X-ray micro computed tomography (CT) specimen systems are based on microfocus sources, 2D pixel array cameras and short source-to-detector distances (i.e. cone-beam configurations). High resolution is achieved by means of geometric magnification. The further development of such devices towards phase contrast techniques can dramatically enhance their range of applications. Among the variety of available PC techniques, X-ray grating interferometry (GI) has favorable properties for differential phase contrast and dark field contrast imaging on conventional X-ray tubes. Exploiting phase and dark field contrast can lead to a significant contrast enhancement compared to standard

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absorption based X-ray imaging.

Up to now, the application of GI on compact micro CT systems was limited due to the incompatibility of planar gratings with the highly divergent wave front, resulting in a severe reduction of the field of view.

Here, we report on the development of compact hard X-ray grating interferometry, which paves the road towards the first generation of industrial micro CT phase and scattering (dark field) contrast scanners. The development includes a novel grating fabrication method, which aims to develop bendable gratings on thin Titanium substrates and to solve the problem of the incompatibility between the divergent wave front and the planar gratings. This opens the path for table top X-ray microscopy for the first time.

In the presentation, we will report on various compact designs with bendable gratings, on their analytical, numerical and experimental optimization regarding sensitivity and on the imaging pipeline consisting of data acquisition, post processing tools and cone-beam image reconstruction.

8668-38, Session 8

High energy x-ray phase-contrast imaging using glancing angle grating interferometers

Dan Stutman, Johns Hopkins Univ. (United States); Joseph W. Stayman, Johns Hopkins Univ. (United States) and Johns Hopkins Univ. (United States); Michael Finkenthal, Jeffrey H. Siewerdsen, Johns Hopkins Univ. (United States)

Talbot-Lau grating interferometry enables differential X-ray phase-contrast (DPC) or refraction based imaging with conventional incoherent X-ray sources, offering the promise of new imaging modalities in medicine, industry, and material sciences. The fringe contrast of the conventional normal incidence Talbot-Lau grating interferometer is however limited at X-ray energies above a few tens of keV, because the thin Au absorption gratings used in the interferometer become increasingly transparent with increasing energy. To alleviate this problem we developed a new interferometer design using gratings at glancing incidence instead of normal. For instance, by inclining 90 μm thick Au gratings at an angle α~18° we increased the effective thickness by a factor of ~3.3, which in turn increased nearly fourfold the interferometer contrast at a mean X-ray energy of 43 keV. Initial experiments with glancing angle interferometers and medically relevant specimens show strong potential for clinical application of high energy DPC imaging. Fresh animal bones immersed in thick (100 and 150 mm) water layers were imaged at mean spectral energies of 43 and 55 keV (60 and 80 kVp). The results show that phase contrast enables imaging of cartilage as well as fine structures in cortical and trabecular bone. The bone results suggest that high energy DPC has potential also for diagnostic imaging of osteoporosis. Together with high energy Talbot interferometry, we are also developing suitable DPC-CT algorithms that exploit the ability to image with a higher-energy beam. The first results confirm the power of phase contrast CT for imaging soft tissues such as cartilage or liver specimens.

8668-39, Session 8

Improvements in data processing and iterative tomographic reconstruction in grating-based phase-contrast imaging

Dieter Hahn, Pierre Thibault, Peter B. Noël, Martin Bech, Franz Pfeiffer, Technische Univ. München (Germany)

The purpose of this work is to evaluate the performance of a novel statistical iterative reconstruction algorithm for grating-based phase-contrast computed tomography. The algorithm is based on maximum-a-posteriori principles and fully integrates statistical properties of the interferometric raw data in a physical model.

In grating-based imaging, a series of interferometric intensity images are acquired at each angular position. These images have to be further processed in order to extract maps for phase-contrast, absorption and dark-field signals.

To include statistical uncertainties of the original raw data into this cost function, measurement errors of the raw projections need to be propagated through the processing steps. To a good approximation these uncertainties follow a Gaussian probability distribution. This Gaussian behavior leads to the formulation of a penalized log-likelihood cost function with a weighted least-squares data-fidelity term, complemented with one or more regularization terms incorporating prior knowledge of the reconstructed image.

For the evaluation of our algorithm we employed data from numerical as well as experimental (biological) measurements. We analyzed the performance of our algorithm by introducing the following cases of data corruption: noisy data, detection gaps, few-view scans, non-uniformly spaced acquisitions and datasets containing very dense materials. The results of our investigation illustrate that the presented algorithm is highly superior in image quality compared to the conventional filtered back projection. Our novel algorithm is able to prevent and reduce artifacts, and proves to be more robust and accurate.

8668-40, Session 8

Type II beam hardening artifacts in phase contrast imaging

Nicholas B. Bevins, Henry Ford Health System (United States) and Univ. of Wisconsin-Madison (United States); Ke Li, Univ. of Wisconsin School of Medicine and Public Health (United States); Joseph N. Zambelli, Univ. of Wisconsin School of Medicine and Public Health (United States) and Spectrum Health System (United States); Guang-Hong Chen, Univ. of Wisconsin School of Medicine and Public Health (United States)

The effects of beam hardening have previously been extended from absorption imaging to phase contrast imaging, showing a similar, albeit reduced, effect in the phase images. The effect of beam hardening on the interferometer performance, however, has not been demonstrated. In this work, the visibility reduction on a differential phase contrast imaging system due to spectral changes as a result of beam hardening is demonstrated. The implication of this reduction is an artificial increase in noise for the phase contrast image through highly-attenuating regions of the object. In addition, false signal will be recorded in the dark-field image, which normally shows only highly-scattering objects. The results show that with added beam filtration, the effect is reduced, just as with more traditional beam hardening artifacts. However, the effect also means that one must also take into account the desired imaging task when determining the system's design energy.

8668-41, Session 8

Model observer and human observer performance studies in differential phase contrast CT

Ke Li, Univ. of Wisconsin School of Medicine and Public Health (United States); Nicholas B. Bevins, Univ. of Wisconsin-Madison (United States); Joseph N. Zambelli, Guang-Hong Chen, Univ. of Wisconsin School of Medicine and Public Health (United States)

Published studies have demonstrated model observer's efficiency and accuracy in predicting human detection performance in conventional absorption-based CT. This study investigates the possibility of extending statistical decision theory to the estimation of detection performance in DPC-CT, whose noise properties are fundamentally different from those of absorption CT. Both model observer and human observer studies were performed with the purpose of identifying the most accurate observer model for DPC-CT. Hybrid images with either numerical discs

or digitized contrast-enhanced breast tumors added to experimentally acquired DPC-CT noise-only images were used in a series of 2AFC experiments involving three physicist observers, results of which generate the contrast threshold required for 92% correction decision rate and were used as the ground truth for the model observer studies. Among the four model observers (prewhitening with eye filter and internal noise (PWEi), non-prewhitening (NPW), NPW with eye filter (NPWE), and channelized Hotelling observer (CHO)), the NPW observer leads to the best overall agreement with human observers. Relative errors of the NPW results for the breast lesion detection tasks are within 2%. Those results demonstrate that model observers, which are of much higher time-efficiency compared to human observers, can be used to accurately determine the detection performance in DPC-CT.

8668-42, Session 9

Intensity modulated CT implemented with a dynamic bowtie filter

Timothy P. Szczykutowicz, Charles A. Mistretta, Univ. of Wisconsin-Madison (United States)

Current advances in CT dose reduction and image quality improvement mechanisms rely on moving towards a more patient/image specific approach. For example, statistical reconstruction algorithms tailor reconstruction weights to patient attenuation values and CT protocols make use of different kVp and mAs settings for different body regions and sizes. In this paper, for the first time to our knowledge, experimental results are presented in which a dynamic bowtie filter was used to tailor the imaging dose during a CT acquisition. A non-DBA (non- modulated) CT scan was also performed for comparison. At half of the imaging dose, the noise uniformity of the DBA CT images was 37% better than the non-DBA scan. The use of a dynamic bowtie filter may also prove useful in photon counting CT (PCCT) where high fluence rates and large differences in fluence across projections and from view to view make implementing PCCT difficult. Results are presented in this paper showing dynamic range requirements of 7.9 and 13.8 for DBA and non-DBA scans respectively. This difference in dynamic range is somewhat small compared to what would be seen clinically due to the small size of the phantom used in the study. Using a more clinically relevant phantom dynamic range differences of 22 times can be observed in which the effects of the DBA will be more dramatic.

8668-43, Session 9

Noise reduction in material decomposition for low-dose dual-energy cone-beam CT

Wojciech Zbijewski, Grace J. Gang, Adam S. Wang, Joseph W. Stayman, Katsuyuki Taguchi, John A. Carrino, Jeffrey H. Siewerdsen, Johns Hopkins Univ. (United States)

Purpose: Dual-energy cone-beam CT (DE-CBCT) is an emerging technology with potential application in diagnostic imaging and image-guided interventions. This paper reports DE-CBCT feasibility, decomposition algorithms for maximizing low-dose performance (including reconstruction-based, projection-based, and iterative methods), and differential filtering / regularization of low (LE) and high-energy (HE) data.

Methods: Accurate DE-CBCT decomposition requires consideration of all system noise components. Filtered backprojection (FBP) reconstruction-based decomposition was investigated with differential filtering of LE and HE data. Penalized likelihood (PL) reconstruction-based decomposition with differential regularization was hypothesized to further improve low-dose performance. Projection-based decomposition was evaluated using noise reduction techniques including anti-correlated noise reduction (ACNR) and penalized weighted least-squares (PWLS) sinogram restoration. Performance was assessed in terms of noise and accuracy of decomposition in a binary hypothesis framework. Studies involved experiments on a DE-CBCT testbench, phantoms of variable material type and concentration, and cadavers (knee).

Results: Studies support the overall feasibility of accurate, low-dose DE-CBCT at concentration down to 5 mg/ml (iodine), dose ~3-6 mGy, and accuracy of material classification ~80-90%. Reconstruction-based decomposition with quadratic PL performed comparably to FBP and identifies the need for edge-preserving, non-quadratic penalties. Projection-based ACNR and PWLS offered significant gains in accuracy (>10%), supported qualitatively in DE-CBCT contrast-enhanced arthrography of a cadaveric knee.

Conclusions: Accurate material decomposition with DE-CBCT is feasible at low dose and benefits from a rigorous assessment of noise mechanisms among various reconstruction- and projection-based techniques. The work points to the potential for non-linear iterative methods for high-quality decomposition at low material concentration and dose.

8668-44, Session 9

A novel temporal deconvolution technique to enable cone beam CT perfusion imaging using an interventional C-arm system

Jie Tang, Univ. of Wisconsin-Madison (United States); Min Xu, Beihang Univ. (China) and Univ. of Wisconsin-Madison (United States); Kai Niu, Univ. of Wisconsin-Madison (United States); Kevin Royalty, Siemens Medical Solutions USA, Inc. (United States) and Univ. of Wisconsin-Madison (United States); Kari Pulfer, Charles M. Strother, Univ. of Wisconsin-Madison (United States); Guang-Hong Chen, Univ. of Wisconsin School of Medicine and Public Health (United States)

In the current workflow of ischemic stroke management, it is highly desirable to obtain perfusion information with the C-arm CBCT system in the interventional room. Due to hardware limitations, the data acquisition speed of the current C-arm CBCT systems is relatively slow and only 7 time frames are available for a 45 s perfusion study. In this study, a novel deconvolution method was proposed to recover temporal enhancement curves in C-arm CBCT perfusion studies. The proposed deconvolution problem is a constrained optimization problem. Two numerical methods were used to solve the proposed deconvolution problem. The feasibility of proposed deconvolution method was validated with numerical experiments. Both solvers can achieve a satisfactory solution for the deconvolution problem, while the result of the Bregman algorithm is more accurate than that from the CG. In vivo animal studies were used to demonstrated the improvement of the proposed method in C-arm CBCT perfusion. A stoked canine model was scanned with both C-arm CBCT and diagnostic CT. Perfusion defects can be clearly indentified from the cerebral blood flow (CBF) map of diagnostic CT perfusion. Without deconvolution technique, these defects can hardly be identified from the CBCT CBF map. After applying the proposed deconvolution method, the CBCT CBF map well correlates with the CBF map from diagnostic CT.

8668-45, Session 9

Algebraic reconstruction technique with motion compensation

Roman Krylov, Univ. of Central Florida (United States); Alexander A. Zamyatin, Toshiba Medical Research Institute USA (United States)

This work was inspired by the results of the research on 2D ART with motion compensation (Pack & Noo, 2004). We describe an approach for 3D implementation of motion compensated ART. Numerical experiment is used to validate our approach.

8668-46, Session 9

Reconstruction from truncated projections in cone-beam CT using an efficient 1D filtering

Yan Xia, Friedrich-Alexander-Univ. Erlangen-Nuremberg (Germany); Andreas K. Maier, Siemens AG (Germany); Hannes G. Hofmann, Friedrich-Alexander-Univ. Erlangen-Nürnberg (Germany); Frank Dennerlein, Siemens AG (Germany); Kerstin Müller, Joachim Hornegger, Friedrich-Alexander-Univ. Erlangen-Nürnberg (Germany)

In this paper, we presented a novel method that adapts the ATRACT method in one dimension by decomposing the standard ramp filter into the 1D Laplace filter and a 1D convolution-based filter. The corresponding convolution kernel was numerically estimated by computing the 1D impulse response of the standard ramp filtering coupled with the second order anti-derivative operation. The proposed algorithm showed the improvement in computational performance due to reduced computational complexity and less padding required in 1D FFT with respect to the native ATRACT algorithm. Furthermore, reconstructions of high accuracy were maintained by the new method even in presence of data truncation.

ACKNOWLEDGMENTS

This work was supported by Siemens AG, Healthcare Sector. All reconstruction results were computed with a Siemens prototype software, not a clinical product. The concepts and information in this paper were never submitted, published, or presented before.

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8668-47, Session 9

Development and spatial resolution characterization of a dedicated pulsed x-ray, cone-beam breast CT system

Peymon Gazi, Kai Yang, George Burkett, Univ. of California, Davis (United States); John M. Boone, Univ. of California, Davis (United States)

Dedicated breast CT (bCT) technology may be useful for patients with high risk of developing breast cancer. Previous studies show that bCT outperforms mammography in the visualization of mass lesions, but mammography shows better results in finding microcalcifications. The Breast Tomography Project at UC Davis has led to development of three dedicated breast CT scanners that produce high resolution, fully tomographic images, overcoming tissue superposition effects found in mammography while maintaining an equivalent radiation dose. Over 400 patients have been imaged in an ongoing clinical trial. The first patient scan was performed on the latest bCT scanner developed at UC Davis, called Cambria, on April 12, 2012. The main differences between Cambria and the previous scanners are in using a pulsed x-ray source (generator and tube) instead of continuous x-ray sources, and also in using the non-binning mode of the flat-panel fluoroscopic detector. The spatial resolution characteristics of the new scanner were investigated and the results show significant improvement in the overall MTF properties. Based on these results, it was concluded that using the pulsed x-ray tube, we were able to restore the MTF degradation caused by motion blurring effect that exists in previous generations of bCT. Moreover, MTF analysis show that using the detector in the native acquisition mode results in visibility of smaller details in the scanned object.

8668-48, Session 10

Development of a phantom-based methodology for the assessment of quantification performance in CT

Baiyu Chen, Ehsan Samei, Duke Univ. (United States)

The direct assessment of the volume quantification precision (variance) involves multiple steps and can become intractable for a multiplicative of protocols. We have developed a new phantom-based methodology that enables measuring surrogates of precision based on a limited number of scans. To assess the quantification precision, the noise and resolution property of the system with respect to each object contrast and image noise level was collected from a serial scans of the ACR Phantom. The quantification task and software property were mathematically modeled in the Fourier domain. A surrogate of quantification precision, named estimability index (e'), was calculated by incorporating all aforementioned information. To validate our methodology as well as to benchmark e' to empirical precision, e' was calculated for 9.5 mm acrylic nodules under 45 protocols, with empirical precision measured under the same protocols. Results showed good correlation between e' and empirical precision with linear relationships established. Finally, a recipe for phantom-based precision assessment was created, which allows indirect calculation of precision for a range of protocols with limited number of scans. The recipe was used to predict the quantification precision of 4.8 mm nodules under a range of protocols, and show that to achieve a 5% precision, the quantification with FBP reconstruction requires a slice thickness thinner than or equal to 1.25 mm, and a dose higher than or equal to 3.8 mGy. To our knowledge, this is the first systematic approach to predict quantification performance with basic figures of merit measurements.

8668-49, Session 10

Soft-tissue imaging in low-dose, C-arm cone-beam CT using statistical image reconstruction

Adam S. Wang, Sebastian Schafer, Joseph W. Stayman, Yoshito Otake, Marc S. Sussman, A. J. Khanna, Gary L. Gallia, Jeffrey H. Siewerdsen, Johns Hopkins Univ. (United States)

PURPOSE: C-arm cone-beam CT (CBCT) is an emerging tool for intraoperative imaging, but current embodiments exhibit modest soft-tissue imaging capability and are largely constrained to high-contrast imaging tasks. A major advance in image quality is facilitated by statistical iterative reconstruction techniques. This work adapts a

spectrum of penalized likelihood (PL) reconstruction approaches to C-arm CBCT and investigates performance in imaging of large (>10 mm), low-contrast (<100 HU) tasks pertinent to soft-tissue surgical guidance.

METHODS: Experiments involved a mobile C-arm for CBCT and phantoms and cadavers presenting soft-tissue structures imaged using 3D filtered backprojection (FBP), quadratic, and non-quadratic PL reconstruction. Polyethylene phantoms with various tissue-equivalent inserts were used to quantify contrast-to-noise / resolution tradeoffs in low-contrast (40 HU) structures, and the optimal reconstruction parameters were translated to imaging an anthropomorphic head phantom with low-contrasts targets and a cadaveric torso.

RESULTS: Statistical reconstruction - especially non-quadratic PL variants - boosted soft-tissue image quality through reduction of noise and artifacts (e.g., 2-4 fold increase in CNR at “equivalent” spatial resolution). For tasks relating to large, low-contrast tissues, even greater gains were possible using non-quadratic penalties and strong regularization that sacrificed spatial resolution in a manner still consistent with the imaging task.

CONCLUSION: The advances in image quality offered by statistical reconstruction present promise and new challenges for interventional imaging, with high-speed computing facilitating realistic application. Careful investigation of performance relative to specific imaging tasks permits knowledgeable application of such techniques in a manner that overcomes conventional tradeoffs in noise, resolution, and dose.

8668-50, Session 10

Modeling and control of nonstationary noise characteristics in filtered-backprojection and penalized likelihood image reconstruction

Grace J. Gang, Joseph W. Stayman, Wojciech Zbijewski, Jeffrey H. Siewerdsen, Johns Hopkins Univ. (United States)

Purpose: Nonstationarity of CT noise presents a major challenge to the assessment of imaging performance. This work investigates the extent of nonstationarity in both filtered backprojection (FBP) and penalized likelihood (PL) reconstruction and demonstrates the ability to impart control in a manner suitable to a given task.

Methods: A cascaded systems analysis model was used to model the local noise-power spectrum (NPS) and modulation transfer function (MTF) for FBP reconstruction, with locality achieved by separate calculation of fluence and system gain for each view as a function of detector location. The covariance and impulse response function for PL reconstruction (quadratic penalty) were computed using the implicit function theorem and Taylor expansion. Detectability index was calculated under the assumption of local stationarity (within a few voxels). Control of noise magnitude and correlation was achieved by applying a spatially varying roughness penalty.

Results: For both FBP and PL, noise is anisotropic and varies in a manner dependent on the path length of each view traversing the object. The anisotropy in turn affects task performance, where detectability is enhanced or diminished depending on the frequency content of the task relative to that of the NPS. Spatial variation of the roughness penalty can be exploited to control noise magnitude and correlation (and hence detectability).

Conclusions: Noise nonstationarity is a significant effect that can be modeled in both FBP and PL image reconstruction. Knowledgeable selection of a spatially-varying roughness penalty in PL can achieve desired local noise and resolution tuned to a given task.

8668-51, Session 10

Preliminary investigation of the frequency response and distortion properties of nonlinear image processing algorithms

Jered R. Wells, James T. Dobbins III, Duke Univ. (United States)

Assessment of the resolution properties of nonlinear imaging systems is a useful but challenging task. While the modulation transfer function (MTF) fully describes contrast resolution as a function of spatial frequency for linear systems, an equivalent metric does not exist for systems with significant nonlinearity. Therefore, this preliminary investigation attempts to classify and quantify the amount of scaling and distortion imposed on a given image signal as the result of a nonlinear process (nonlinear image processing algorithm).

As a proof-of-concept, a median filter is assessed in terms of its principle frequency response (PFR) and distortion response (DR) functions. These metrics are derived in frequency space using a sinusoidal basis function, and it is shown that, for a narrow-band sinusoidal input signal, the scaling and distortion properties of the nonlinear filter are described exactly by PFR and DR, respectively. The use of matched sinusoidal basis and input functions accurately reveals the frequency response to long linear structures of different scale. However, when more complex (multi-band) input signals are considered, PFR and DR fail to adequately characterize the frequency response due to nonlinear interaction effects between different frequency components during processing.

Overall, the results reveal the context-dependent nature of nonlinear image processing algorithm performance, and they emphasize the importance of the basis function choice in algorithm assessment. In the future, more complex forms of nonlinear systems analysis may be necessary to fully characterize the frequency response properties of nonlinear algorithms in a context-dependent manner.

8668-52, Session 10

Scatter correction with kernel perturbation

Josh M. Star-Lack, Mingshan Sun, Varian Medical Systems, Inc. (United States)

X-ray scatter degrades image contrast, uniformity and CT number accuracy in cone-beam computed tomography. Correction methods based on the scatter kernel superposition (SKS) technique are efficient and suitable for many clinical applications but still produce residual errors. To reduce these errors, which stem to limitations in the scatter kernel model, we propose to generate a first-pass reconstruction using default SKS parameters for scatter correction followed by limited Monte Carlo simulations that are then used to perturb and refine key kernel parameters in order to obtain an improved second-pass correction. To test the approach, we performed simulation and experimental CBCT studies on large objects with scatter-to-primary ratios greater than one using the adaptive scatter model. The results show that less than 10 projections require simulation in order to adequately refine scatter kernel parameters for all projections. Compared to the default asymmetric kernels, the refined kernels reduced the maximum primary error in projection space from 15% to 3%. Correspondingly, HU errors were reduced by over a factor of two from 39HU to 17HU.

8668-53, Session 11

Splitting-based statistical x-ray CT image reconstruction with blind gain correction

Hung Nien, Jeffrey A. Fessler, Univ. of Michigan (United States)

Variational methods are useful for solving ill-posed inverse imaging problems by minimizing a cost function with a data fidelity term and a regularization term. For statistical X-ray computed tomography (CT) image reconstruction, penalized weighted least-squares (PWLS)

criteria with edge-preserving regularization can improve quality of the reconstructed image compared to traditional filtered back-projection (FBP) reconstruction. Nevertheless, the huge dynamic range of the statistical weights used in PWLS image reconstruction leads to a highly shift-variant local impulse response, making effective preconditioning difficult. To overcome this problem, iterative algorithms based on variable splitting were proposed recently. However, existing splitting-based iterative algorithms do not consider the (unknown) gain fluctuations that can occur between views. This paper proposes a new variational formulation for splitting-based iterative algorithms where the unknown gain parameter vector and the image are estimated jointly with just simple changes to the original algorithms. Simulations show that the proposed algorithm greatly reduces the shading artifacts caused by gain fluctuations yet with almost unchanged computational complexity per iteration.

8668-54, Session 11

Tradeoff between noise properties and local impulse response in statistical prior image constrained compressed sensing

Pascal Theriault Lauzier, Guang-Hong Chen, Univ. of Wisconsin School of Medicine and Public Health (United States)

The increase in the use of CT scanning in the clinical setting is raising concerns from the medical community. In order to reduce the dose of ionizing radiation imparted to patients during CT scans, statistical image reconstruction was proposed. This family of algorithm aims at improving image noise characteristics by modeling the stochastic x-ray detection process in the reconstruction algorithm. It was shown however that statistical reconstruction may lead to an anisotropic spatial resolution. In this abstract, we study this tradeoff in the context of a statistical formulation of the dose reduction using prior image constrained compressed sensing framework (DR-PICCS). Two numerically-simulated phantoms and a dataset acquired in vivo were used for this evaluation. It is demonstrated that the inclusion of a statistical model in DR-PICCS may whiten the NPS and uniformize the noise spatial distribution in the image. However, the images may suffer from an anisotropic spatial resolution while the images reconstructed using DR-PICCS without statistical model have more isotropic spatial resolution. Due to the flexibility offered in PICCS, a specially-designed prior image processing method has been used in statistical DR-PICCS to palliate for the anisotropy in spatial resolution.

8668-55, Session 11

Overcoming nonlinear partial volume effects in known-component reconstruction of cochlear implants

Joseph W. Stayman, Hao Dang, Yoshito Otake, Wojciech Zbijewski, Johns Hopkins Univ. (United States); Jack H. Noble, Benoit M. Dawant, Robert F. Labadie, Vanderbilt Univ. (United States); John P. Carey, Jeffrey H. Siewerdsen, Johns Hopkins Univ. (United States)

Nonlinear partial volume (NLPV) effects can be significant for objects with large attenuation differences and fine detail structures near the spatial resolution limits of a tomographic system. This is particularly true for small metal devices like cochlear implants. While traditional model-based approaches might alleviate these artifacts through very fine sampling of the image volume and subsampling of rays to each detector element, such solutions can be extremely burdensome in terms of memory and computational requirements. The work presented in this paper leverages the model-based approach called “known-component reconstruction” (KCR) where prior knowledge of a surgical device is integrated into the estimation. In KCR, the parameterization of the object separates the volume into an unknown background anatomy and a known component with unknown registration. Thus, one can model projections of an implant at very high spatial resolution while limiting the spatial resolution of the anatomy - in effect, modeling NLPV effects where they are most significant. We present modifications of the KCR approach that can be used to largely eliminate NLPV artifacts, and demonstrate the efficacy of the modified technique (with improved image quality and accurate implant position estimates) for the cochlear implant imaging scenario.

8668-56, Session 11

Impact of norm selections on the performance of prior image constrained compressed sensing (PICCS)

Yinsheng Li, Jie Tang, Univ. of Wisconsin-Madison (United States); Guang-Hong Chen, Univ. of Wisconsin School of Medicine and Public Health (United States)

Advances have been made in recent years in computed tomography (CT) as a result of the development and implementation of new iterative reconstruction methods. Compressed sensing has been one such iterative reconstruction method that has been shown to be promising, as it can allow accurate image reconstruction from vastly undersampled data. One approach to compressed sensing is to incorporate prior information, in particular, in an image reconstruction framework known as Prior Image Constrained Compressed Sensing (PICCS). In the PICCS implementation, an objective function is minimized to iteratively approach a target image. To date, published studies have employed the L1 norm in the minimization of the objective function, as the L1 norm has been shown to promote sparsity in compressed sensing studies. However, p does not necessarily need to be unity. The Lp norm could be adjusted so that p>1, which can lead to less computationally expensive solutions. Therefore, the purpose of this study is two-fold: (1) How does image quality depend on the Lp norm used in the minimization of the objective function? (2) In the minimization of the Lp norm, is there any improvement in image quality, when alternative weighting strategies are used, such as the iterative reweighted methods? To address these issues, a dynamic contrast enhancement phantom is generated. In this study, the performance of Lp norm PICCS is compared with and without incorporating iterative reweighted method, and image quality is evaluated in terms of reconstruction accuracy and spatial resolution performance.

8668-57, Session 11

Comparative evaluation of linear interpolation models for iterative reconstruction in x-ray CT

Katharina Schmitt, Utah Ctr. for Advanced Imaging Research (United States) and Univ. of Erlangen-Nuremberg (Germany) and Siemens AG, Healthcare Sector (Germany); Harald Schoendube, Karl Stierstorfer, Siemens AG, Healthcare Sector (Germany); Frederic Noo, The Univ. of Utah (United States)

The forward projection operator is a key component of every iterative reconstruction method in X-ray computed tomography (CT). Besides the choices being made in the definition of the objective function and associated constraints, the forward projection model affects both bias and noise properties of the reconstruction. In this work, we compare three important forward projection models that rely on linear interpolation: the Joseph method, the distance-driven method, and the image representation using B-splines of order n = 1. The comparison focuses on bias and noise in the image as a function of the resolution. X-ray CT data that are simulated in fan-beam geometry with two different magnification factors are used.

8668-58, Session 11

Dose reduction in CT with correlated-polarity noise reduction: comparable image quality at half the dose with projection space processing

James T. Dobbins III, Jered R. Wells, William P. Segars, Duke Univ. (United States)

Correlated-polarity noise reduction (CPNR) is a novel noise reduction technique that uses a statistical approach to reducing noise while maintaining excellent resolution and a “normal” noise appearance. It is applicable to any type of medical imaging, and we introduced it at SPIE 2011 for reducing dose three-fold in radiography while maintaining excellent image quality. In this current work, we demonstrate for the first time its use in reducing the noise in CT images as a means to reduce the dose in CT. Simulated chest CT images were generated using the XCAT phantom and Poisson noise was added to simulate a conventional full-dose CT image and a half-dose CT image. CPNR was applied to the half-dose images in projection image space, and then the images were reconstructed using filtered backprojection with a Feldkamp methodology. The resulting CPNR processed half-dose images showed essentially equivalent relative standard deviation in the central heart region to the full-dose images, and about 0.7 times that in half-dose images that were not processed with CPNR. This noise reduction was consistent with a two-fold reduction in dose that is possible with CPNR in CT. The CPNR images demonstrated virtually identical sharpness of vessels and no apparent artifacts. We conclude that CPNR shows strong promise as a new noise reduction method for dose reduction in CT. CPNR could also be used in combination with model-based iterative reconstruction techniques for yet further dose reduction.

8668-59, Session 12

A moving blocker system for cone-beam computed tomography scatter correction

Luo Ouyang, Kwang Song, Timothy Solberg, Jing Wang, The Univ. of Texas Southwestern Medical Ctr. at Dallas (United States)

Scatter contamination in cone-beam computed tomography (CBCT) degrades the image quality by introducing shading artifacts that lead to decreased image contrast and inaccurate CT number. In our previous study, a moving-blocker-based approach was proposed to simultaneously estimate scatter signal and reconstruct the complete volume within the field of view (FOV) from a single CBCT scan. Promising results were obtained from simulation studies. In this work, we implemented the moving blocker system on a LINAC on-board kV CBCT imaging system. A physical attenuator (i.e., “blocker”) consisting equal spaced lead strips is mounted on a linear actuator. The linear actuator converts rotation of a bipolar step motor into linear motion of the blocker. The blocker moves back and forth along z-axis during CBCT image acquisition. Scatter signal is estimated from the blocked region of imaging panel, and interpolated into the un-blocked region. An iterative reconstruction algorithm based on the constraint optimization is used to reconstruct CBCT images from un-blocked projection data after the scatter signal is subtracted. An experimental study is performed on a CatPhan phantom to evaluate the performance of the moving blocker system. The scatter-induced shading artifacts are substantially reduced in the image acquired with the moving blocker system. CT number error in the selected regions of interest is reduced from 279 to 22. We demonstrated for the first time that the moving blocker system can successfully estimate the scatter signal in projection data, reduces the imaging dose and obtains complete volumetric information within the FOV using a single scan.

8668-60, Session 12

Optimized control of a dynamic, pre-patient attenuator

Scott S. Hsieh, Norbert J. Pelc, Stanford Univ. (United States)

A dynamic, pre-patient attenuator capable of achieving a piecewise-linear attenuation profile in fan angle has been proposed. The attenuator consists of a series of wedges, with axially-dependent triangular cross-section. Translation in the axial direction modulates the thickness of the attenuator, allowing the x-ray illumination field to be customized in both view and fan angle. The dynamic attenuator can optimize the radiation dose for a given image variance metric, reduce the dynamic range or reduce the scatter-to-primary ratio (SPR). Many control options are possible for the attenuator. With the addition of a low dose pre-scan, the dynamic attenuator control sequence can be computed by solving a convex optimization problem. Absent this low dose pre-scan, various heuristics can be used. We develop and compare several control strategies and evaluate their performance on simulated data. The radiation dose and SPR are estimated using Monte Carlo simulations, and the noise is calculated analytically. As an example of our results, a radiation dose reduction of 40% is possible in a simulated scan of a pelvis while maintaining the peak variance of the image. The dynamic attenuator also reduces the SPR by 20% in this scan.

8668-61, Session 12

Technical feasibility of CT perfusion using a C-arm CBCT system

Min Xu, Beihang Univ. (China) and Univ. of Wisconsin-Madison (United States); Jie Tang, Univ. of Wisconsin-Madison (United States); Kevin Royalty, Siemens Medical Solutions USA, Inc. (United States) and Univ. of Wisconsin-Madison (United States); Guang-Hong Chen, Univ. of Wisconsin School of Medicine and Public Health (United States)

It is highly desirable to obtain perfusion information with the C-arm CBCT system in the interventional room. However, due to hardware limitations, it is still elusive to achieve cone-beam CT perfusion measurements. In this study, we performed a systematic study to investigate what the main limiting factors are that need to be addressed for future C-arm cone beam CT perfusion imaging. To do so, we performed systematic numerical simulation studies using a diagnostic CT perfusion data set. Specifically, a forward projection was performed to simulate cone-beam CT perfusion experiment with C-arm CBCT geometry and temporal behavior. Different x-ray delays after contrast injection have been simulated with this method. The view angle undersampling artifacts, shading artifacts from dynamic objects, and the importance of arterial input function (AIF) for perfusion study were investigated in this study with different x-ray delay times. From the simulation results, it was found that the view angle undersampling artifacts do not have much impact on perfusion maps. The shading artifacts from dynamic object were shown to have a negligible effect on the NRMSE in perfusion maps. The accuracy of AIF is an important but not a dominating factor for perfusion studies. C-arm CBCT cannot accurately recover the slowly changing contrast in brain tissues due to the low temporal resolution. Therefore, to enable cone beam C-arm CT perfusion measurement, it is critical to improve the temporal behavior of CBCT by either employing new hardware upgrades or introducing new software methods.

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8668-62, Session 12

An online motion- and misalignment-correction method for medical flat-detector CT

Julia Wicklein, Willi A. Kalender, Institut für Medizinische Physik (Germany); Yiannis Kyriakou, Holger Kunze, Siemens AG, Healthcare Sector (Germany)

Misalignment-Correction in C-arm-based flat-detector CT (FD-CT) is a frequently discussed problem. To avoid artifacts caused by geometrical instabilities, numerous methods for misalignment correction were investigated. Most of them make use of a foregoing calibration routine, based on scanning a specific phantom. The aim of this study is to develop and evaluate an online image-content-based calibration technique without using any kind of marker or calibration phantom.

The introduced method is based on a gradient descent method, minimizing an entropy criterion which is used to optimize the underlying geometry parameters of the acquisition system. It is formed as multistep approach, including a global, local and projection wise optimization. This enables the elimination of general system misalignments, as well as a reduction of streak artifacts and the adjustment of patient motion artifacts.

Phantom and patient measurements with the C-arm FD-CT system Artis Zeego (Siemens AG, Healthcare Sector, Forchheim, Germany) were used to validate the algorithm for realistic applications.

It reduced most of the actual misalignment and increased image quality drastically. Phantom-studies, starting from the standard system geometry without a foregoing calibration showed very good results. Online-calibration is possible with our approach and therefore, the limitation to predefined scan-protocols is obsolete. The evaluation of patient datasets brought out the same conclusions and provides the implication of simultaneous patient motion compensation.

8668-63, Session 12

Can motion compensated reconstruction improve best phase reconstruction in Cardiac CT?

Herbert K. Bruder, Christopher Rohkohl, Siemens Medical Solutions GmbH (Germany); Thomas Allmendinger, Harald Schoendube, Siemens, HealthCare (Germany); Rainer Raupach, Siemens HealthCare (Germany); Karl Stierstorfer, Siemens Medical Solutions GmbH (Germany); Thomas G. Flohr, Siemens Medical Solutions GmbH (Germany) and Siemens, HealthCare (Germany)

Based on a thought experiment and a simulation study with a realistic coronary vessel phan-tom, we investigate if motion compensated cardiac CT reconstruction can improve best phase image quality with respect to motion artifacts and patency of coronary vessels. Basically, tracking based methods (with and without improvement of temporal resolution), deriving the motion vector fields by a registration-like procedure will be compared to optimization based methods optimizing objective functions while minimizing artifact levels (e.g. Motion Artifact Metric Optimization (MAM) method (1)).

Using the MAM technique, the motion vector field is iteratively calculated with a steepest descent update equation minimizing a motion artifact metric. No specific motion model is needed. The motion vector field is only constrained by regularization guaranteeing consistent motion vectors. The method introduced by Schaefer et al. (2) has been used for motion com-pensated backprojection.

We evaluated the normalized cross correlation of the respective reconstructions with the template of the simulated vessel and a best phase improvement index correlating the motion compensated reconstructions to the non-compensated reconstruction at the same cardiac phase. It will be shown that the MAM technique is superior to the known tracking methods. The tracking methods proved to be highly susceptible to inaccurate registration.

In contrast to most of the tracking methods, the MAM technique does not require multi-phase data and therefore minimizes the required X-ray exposure. In addition, the MAM technique also compensates for the non-exactness of the method presented by Schaefer et al.. The value of MAM is also demonstrated evaluating a variety of clinical data. In particular, it is benefi-cial for patients with high heart rates and/or for CT systems with slow gantry rotation time.

8668-64, Session 13

Positron emission tomography coincidence detection with photon polarization correlation

Aimee L. McNamara, The Univ. of Sydney (Australia) and Australian Nuclear Science and Technology Organisation (Australia); Kinwah Wu, Univ. College London (United Kingdom); David Boardman, Mark I. Reinhard, Australian Nuclear Science and Technology Organisation (Australia); Zdenka Kuncic, The Univ. of Sydney (Australia)

In two-photon positron annihilation, the photon pair is emitted in a pure quantum state and when detected in coincidence possess orthogonal polarizations. We propose that this polarization correlation can be exploited in Positron Emission Tomography (PET), which relies crucially on accurate coincidence detection of photon pairs. With conventional PET systems, this is currently accomplished with an energy acceptance criterion. Scattered or multiple photons detected in coincidence can contaminate the primary data set and usually a set of correction techniques is applied to the data during or prior to reconstruction. These correction techniques, however, generally involve the removal of suspected false coincidence pairs which result in overall image degradation. Current PET detectors utilize energy and time-of-flight measurements but neglect the additional information carried by the polarization correlation of the photon pairs. We demonstrate using Monte Carlo simulations that the unique identification of true coincidence photon pairs with their polarization correlation can enhance overall PET image quality, especially for high emission rates, when conventional, energy-based coincidence detection methods become increasingly unreliable. Our results suggest that polarization-based coincidence detection offers new prospects for in vivo imaging with next-generation PET systems.

8668-65, Session 13

Liver imaging: image quality evaluation and comparison between single and dual energy protocols

Yuan Yao, Stanford Univ. (United States); Alec Magibow, New York Univ. Langone Medical Ctr. (United States); Norbert J. Pelc, Stanford Univ. (United States)

Purpose: Some radiologists report a preference for blended dual-energy (DE) CT images over single energy (SE) images for liver disease diagnosis at the same dose. This is counter to theoretical expectations for simple tasks. We hypothesized that perhaps the broad spectrum of DE might be beneficial for a combination of tasks. We compare the CNR of SE and blended DE images for single and composite tasks, in part to see if they explain the preference.

Methods: We simulated pre- and post-contrast SE abdominal CT imaging at various kVp but at constant average dose. Next, 80kVp and 140kVp scans with different dose allocations, dose matched to the SE images, were simulated. DE images were blended linearly with optimized blending ratios. The CNRs of liver against other soft tissues were used as the metric for evaluation and comparison between the SE and DE protocols, including the combination of many tissue pairs pre- and post-contrast.

Results: The CNR of pre-contrast single kVp image mostly increases as the energy steps up while 90kVp or lower energy yields higher CNR for post-contrast image, depending on the differential iodine concentration of each tissue. Similar trends are seen in the DE blended CNR curves as to those from SE protocols. Results from a composited multi-CNR study demonstrate that SE protocol has better performance.

Conclusions: Our study showed that an optimized SE protocol produces higher CNR, even for a range of tasks. This suggests that the reason for the radiologist preference must be something else.

8668-66, Session 13

A maximum-likelihood expectation-maximization approach to simultaneously reconstruct the activity and attenuation map in SPECT imaging

Abhinav K. Jha, Eric Clarkson, Matthew A. Kupinski, Harrison H. Barrett, The Univ. of Arizona (United States)

Performing attenuation and scatter correction in single photon emission computed tomography (SPECT) imaging often requires an extra computed tomography (CT) scan to be performed on the patient to determine the attenuation map. These CT-based attenuation correction schemes result in increased radiation dose for the patient, and also have other disadvantages such as increased costs, acquisition time, and hardware complexity. In this paper, we suggest a maximum-likelihood (ML) scheme that uses only the emission data in SPECT to perform scatter and attenuation correction. The approach uses the fact that attenuation in SPECT is a direct consequence of Compton scattering, and thus the scattered-photon data, which is often discarded in SPECT imaging through energy window, can be used to retrieve information about the attenuation map. The algorithm works on list-mode data that has not suffered information loss due to the binning process. We also suggest an expectation-maximization (EM) algorithm to compute the ML solution. Using this algorithm, we can simultaneously reconstruct the activity and attenuation map of the tissue, apart from performing attenuation and scatter correction.

8668-67, Session 13

Experimental study of optimal energy weighting in energy-resolved CT using a CZT detector

Franco Rupcich, Taly Gilat-Schmidt, Marquette Univ. (United States)

Recent advances in energy-resolved CT can potentially improve contrast-to-noise ratio (CNR), which could subsequently reduce dose in conventional and dedicated breast CT. Two methods have been proposed for optimal energy weighting: weighting the energy-bin data prior to log normalization (projection-based weighting) and weighting the energy-bin data after log normalization (image-based weighting). Previous studies suggested that optimal projection-based and image-based energy weighting provide similar CNR improvements for energy-resolved CT compared to photon-counting or conventional energy-integrating CT. This study experimentally investigated the improvement in CNR of projection-based and image-based weighted images relative to photon-counting for six different energy bin combinations using a benchtop system with a CZT detector. The results showed CNR values ranged between 0.37 and 0.59 for the projection-based weighted images and between 0.91 and 1.43 for the image-based weighted images, relative to the CNR for the photon-counting image. The range of CNR values demonstrates the effects of energy-bin selection on CNR for a particular energy-weighting scheme. The non-ideal spectral response of the CZT detector caused spectral tailing, which appears to reduce the CNR for the projection-based weighted images. Image-based weighting, however, increased CNR in five of the six bin combinations despite the non-ideal spectral effects.

8668-68, Session 13

Objective assessment of penalized maximum likelihood reconstruction with L1-penalty for low-count myocardial perfusion SPECT imaging

Joyeeta M. Mukherjee, Univ. of Massachusetts Medical School (United States)

Novel methods of reconstructing the tracer distribution in myocardial perfusion images are being considered for low-count scenarios. Few examples of low count scenarios are when the amount of radioisotope administered or the acquisition time is lowered, in gated studies where individual gates are reconstructed, or for patient motion correction where few angles are acquired at any given pose. The reconstruction methods are based on the assumption that the tracer distribution is sparse in some transform domain, which is enforced by a L1-penalty on the transform coefficients. In this work two transform domains are investigated: total variation (TV) which is commonly used in CT for sparse reconstruction and the proposed curvelet basis. The objective is to determine if myocardial perfusion images can be efficiently represented in any of these transform domains, which can then be exploited in a penalized maximum likelihood (PML) reconstruction scheme for improving defect detection in low-count scenarios. The performance of these PML-L1 type algorithms is compared to standard OSEM with post-smoothing using a Gaussian filter using the Channelized Hotelling Observer (CHO) for a defect detection task in a “signal-known-exactly” ROC study. Preliminary investigations indicate superior CHO performance with the proposed curvelet basis. However, further assessment using more complex tasks within LROC paradigm which better model the human observer will be performed for clinical significance.

8668-69, Session 13

Spectra optimization for dual-energy contrast-enhanced breast CT

Pablo Milioni de Carvalho, GE Healthcare France (France) and Univ. Paris Sud XI (France); Ann-Katherine Carton, Sylvie Saab-Puong, Razvan Iordache, Serge Muller, GE Healthcare France (France)

This work investigates a dual-energy subtraction technique for cone-beam breast CT combined with an iodinated contrast agent providing both iodine-enhancement and morphological information. Simulations were performed to obtain optimally enhanced iodine images; the optimal energy set of monochromatic beams and optimal average glandular dose (AGD) repartitioning between the low-energy (LE) and high-energy (HE) beams were investigated. Cylindrical phantoms with 10, 14 and 18 cm diameters and 50% fibroglandular breast tissue equivalent material were simulated. They contained spherical inserts with 0, 25, 75 and 100% fibro-glandular equivalent tissues, homogeneous mixtures of 50% glandular tissue and 0.5, 1.0, 2.5 and 5.0 mg per cm3 iodine, as well as a pure CaHA (calcium hydroxylapatite), emulating calcifications. Six hundred projections were acquired, considering primary-only photons and a perfect energy-integrating detector. LE and HE beams ranging from 20 keV to 80 keV were investigated as a function of AGD repartitioning. After reconstruction by filtered backprojection, the LE and HE volumes were recombined to produce iodine-equivalent images. Contrast-to-noise ratio (CNR) between iodine inserts and non-enhanced breast tissue normalized to the square root of the total AGD (CNRD) was used as figure-of-merit for the detectability of iodine in the iodine-equivalent images. When the depiction of microcalcifications and adipose tissues on fibroglandular background are also considered, optimal CNRD values are obtained for a 30keV-34keV pair at ~50/50% LE/HE AGD repartitioning for an average sized breast.

8668-70, Session 14

Measurement of breast-tissue x-ray attenuation by spectral mammography: First results on cyst fluid

Erik Fredenberg, Philips Women's Healthcare (Sweden); David R. Dance, The Royal Surrey County Hospital NHS Trust (United Kingdom) and Univ. of Surrey (United Kingdom); Paula Willsher, Cambridge Breast Unit and NIHR Cambridge Biomedical Research Ctr., Addenbrookes Hospital (United Kingdom); Miriam von Tiedemann, Philips Women's Healthcare (Sweden); Kenneth C. Young, The Royal Surrey County Hospital NHS Trust (United Kingdom) and Univ. of Surrey (United Kingdom); Matthew G. Wallis, Cambridge Breast Unit and NIHR Cambridge Biomedical Research Ctr., Addenbrookes Hospital (United Kingdom)

Knowledge of x-ray attenuation is essential for developing and evaluating x-ray imaging technologies. For instance, techniques to better characterize cysts at mammography screening would be highly desirable to reduce recalls, but the development is hampered by the lack of attenuation data for cysts. We have developed a method to measure x-ray attenuation of tissue samples using a prototype photon-counting spectral mammography unit. Spectral (energy-resolved) images of solid and liquid samples were acquired, and the image signal was mapped to two known reference materials, which were used to derive the x-ray attenuation as a function of energy. As a first step, we have measured the attenuation of 50 samples of breast cyst fluid, and the results indicate a possibility of improving both specificity and sensitivity of mammography by distinguishing cysts from tumors in screening with spectral imaging. Chemical analysis and elemental attenuation calculation was used as an independent method on a subset of the samples, and agreed within 1.4% compared to the spectral measurement. Further, spectral measurements of water samples agreed within 1.5%. The study will be extended to include measurements on tumor tissue, and test runs have been performed on turkey meat.

8668-71, Session 14

Model observer detectability as a substitute for contrast detail analysis in routine digital mammography quality control

Elena Salvagnini, UZ Gasthuisberg (Belgium) and SCK•CEN (Belgium); Kim Lemmens, Hilde Bosmans, UZ Gasthuisberg (Belgium); Lara Struelens, SCK•CEN (Belgium); Nicholas W. Marshall, UZ Gasthuisberg (Belgium)

This work investigated the substitution of CDMAM contrast detail (c-d) analysis with detectability (d') from a non-prewhitening eye filter model observer (NPWE) for routine quality control (QC). Routinely acquired QC data for 14 systems were analyzed: 3 computed radiography (CR) and 11 integrated detector (DR) systems. For a given system, threshold gold thickness from the c-d analysis (T) was calculated from 10 images and compared against d' calculated for 0.1 and 0.25 mm diameter discs. The d' data were calculated from the routine 50 mm PMMA AEC image and the measured modulation transfer function (MTF). T and d' were plotted as function of MGD and compared. The Fuji and the Agfa CR systems had the highest T values and MGD compared to the other systems. The Konica CR had the highest dose, but T values close to the other systems. The Hologic systems were found to have a low value of T for the 0.1 mm disc compared to the other systems, with MGD somewhat higher. The NPWE results reflected the performance seen for T data for the Konica, Fuji and Agfa systems in that these units had lower d' and higher MGD. The Hologic Selenia Dimensions was the only system that gave anomalous results: the d' index is unexpectedly low or the T value is unexpected low for this system. For all other systems, there was correspondence between the two quality indices.

8668-72, Session 14

Intensity standardization in breast MR images improves tissue quantification

Shandong Wu, Jayaram K. Udupa, Aikaterini Marinaki, Susan P. Weinstein, Despina Kontos, The Univ. of Pennsylvania Health System (United States)

Computerized algorithms are increasingly being developed for quantifying breast MRI features for facilitating lesion detection and breast tissue segmentation in various clinical applications. One of the current impediments is the intensity non-standardness of the breast tissue in the acquired MR images across different cases, scanners, and/or patients. This degrades the performance of quantitative image processing. In this work, we investigate the usefulness of post-hoc intensity standardization of breast MR images by using a landmark-based nonlinear intensity mapping algorithm. The standardization algorithm is applied after correction of the images for background bias field non-uniformity. We then quantitatively compare the percentage coefficient of variation (%CV) of image intensity in the fibroglandular (e.g., dense) tissue region before and after the standardization to evaluate the standardization procedure. In our experiments, we use 9 representative 3D bilateral breast MRI scans/cases constituting 18 breasts (a total of 504 tomographic breast MR slices), in which we observe a significant decrease of the %CV in the standardized images, indicating that the standardization significantly reduces the intensity variation for the fibroglandular tissue across these cases. Furthermore, we demonstrate for two segmentation methods that the standardization leads to improved segmentation of the fibroglandular tissue. Our work suggests that intensity standardization following bias field correction may serve as an effective preprocessing step to support improved quantitative breast MR image processing and analysis, particularly for breast density quantification.

8668-73, Session 14

Conventional mammographic image generation in dual-energy digital mammography

Xi Chen, Xi'an Jiaotong Univ. (China); Robert M. Nishikawa, The Univ. of Chicago (United States); Xuanqin Mou, Xi'an Jiaotong Univ. (China)

Dual-energy digital mammography (DEDM) can generate tissue-subtracted calcification image for improving the detectability of breast calcifications. However, the masses, if present, are missing in the tissue-subtracted calcification image. This paper proposes an algorithm to generate conventional mammographic image by DEDM images based on a multi-scale decomposition and reconstruction architecture with Gaussian filters. Firstly, calibration coefficients are measured at different kVp to correct the original LE and HE. Secondly, the LE and HE images are decomposed into multi-scale components. Thirdly, the components at different scale of the two images are weighted based on a similarity measure to generate new components. Finally, the conventional mammographic image is reconstructed by these new components using noise suppression technique. The proposed method was validated on two commercially available full-field digital mammography systems. Results show that the method is effective and the reconstructed image has similar gray value, contrast and noise level to the corresponding conventional mammogram. Therefore, both the calcification image and conventional mammogram-like image can be generated, the patient will not need more exposure to get the conventional mammogram in DEDM.

8668-74, Session 14

Testing realism of software breast phantoms: texture analysis of synthetic mammograms

Predrag R. Bakic, Brad M. Keller, Yuanjie Zheng, Yan Wang, James C. Gee, Despina Kontos, Andrew D. A. Maidment, The Univ. of Pennsylvania Health System (United States)

Software breast phantoms have been developed for pre-clinical validation of breast imaging systems. Phantom realism may be assessed directly or indirectly. Direct assessment is performed by comparing phantoms and tissue properties using anatomical or pathological slices; this approach is limited by the available clinical material. Alternatively, indirect realism assessment includes comparison of clinical and simulated phantom images. Analysis of image texture properties is of interest since it reflects the spatial tissue distribution, which is known to correlate with breast cancer risk. In this work, we compared texture properties of synthetic mammograms generated using software breast phantoms with clinical data. Sixty-seven synthetic mammograms were generated using software phantoms developed at the University of Pennsylvania. The phantoms simulated 450ml breasts, with voxel size of 500 microns. The synthetic images were generated assuming clinically used acquisition geometry and monoenergetic (20 kVp) x-ray beam with no scatter. The texture analysis was performed using fully automated software, which extracts a battery of features from analyzed images. The extracted texture properties of phantom images were compared with those from clinical mammograms. The clinical data included 60 anonymized mammograms acquired in a previous IRB approved study. The same postprocessing was applied to clinical and phantom images. The preliminary comparison yielded good agreement in 11 out of 26 features averaged over the breast tissue region, with partial agreement observed for additional 8 features.

8668-75, Session 15

Estimation of patient dose with standard and low-dose MDCT fluoroscopy protocols for lung biopsy

Federica Zanca, Annelies Jacobs, Walter De Wever, Wouter Crijns, Raymond Oyen, Hilde Bosmans, UZ Leuven (Belgium)

Purpose: This study aimed at assessing patient dose with standard and low-dose MDCT fluoroscopy protocols for lung biopsy. Materials and Methods: The low-dose protocol used lower tube potential (80 kV) respect to the standard protocol (120 kV); all other scanning parameters were left unchanged. Data from sixty-nine (69) CT fluoroscopy (CTF) lung interventions were prospectively collected and included in the study. Effective patient dose was calculated using the dose-length product information, while peak entrance skin dose was measured with EBT2 gafchromic films. Results: The median effective patient dose was 5.4 mSv (minimum 2.4 mSv, maximum 18.8 mSv; 19 procedures) for the standard protocol and 1.1 mSv (minimum 0.4 mSv, maximum 4.5 mSv; 50 procedures) for the low-dose protocol ($p<0.01$). The median peak entrance skin dose was 268 mGy (95-899 mGy) and 141 mGy (38-410 mGy) for the standard and low-dose protocol respectively ($p<0.01$). Conclusions: High patient entrance skin dose (up to 899 mGy) and high effective patient dose (up to 18.8 mSv) can occur for standard CTF lung biopsy protocol. Simple means, like lowering the kV, allow reducing patient dose significantly, with skin doses now far below the 2 Gy level of deterministic effects. Occupational doses, occasionally of concern in high work load regimes, are expected to follow the same trend.

8668-76, Session 15

Radiation dose reduction in dual-energy CT using prior image constrained compressed sensing: image quality evaluation in virtual monochromatic imaging

Stephen Brunner, Yinsheng Li, Jie Tang, Kari Pulfer, Univ. of Wisconsin-Madison (United States); Jiang Hsieh, GE Healthcare (United States); Howard Rowley, Univ. of Wisconsin-Madison (United States); Guang-Hong Chen, Univ. of Wisconsin School of Medicine and Public Health (United States)

Dual-energy CT has the potential to overcome many of the limitations of routine single-energy CT scanning, such as the potential to provide quantitative imaging via electron density, effective atomic number, and virtual monochromatic imaging and the potential to completely eliminate beam-hardening artifacts via projection space decomposition. While the potential clinical benefit is strong, a main barrier to more frequent clinical use of dual-energy CT scanning is radiation dose for high quality images, which is still a concern for state-of-the art dual-energy CT scanners. One of the main methods of performance evaluation is to compare the image quality of virtual monochromatic images generated from a dual-energy CT scan with that of routine single-energy CT images for the same radiation dose. The rationale is that if virtual monochromatic images do not exhibit inferior image quality to single-energy CT scans, then virtual monochromatic images could be used as substitutes for single-energy CT scans. In this abstract, this approach is used to investigate the application of Prior Image Constrained Compressed Sensing (PICCS) to reduce radiation dose. Virtual monochromatic images are generated using PICCS reconstructed images, and image quality is compared to that of single-energy CT images at 120 kV. The additional quantitative images, such as electron density and effective atomic number, which in essence are generated alongside virtual monochromatic images for free (that is to say, without additional radiation dose) are also evaluated.

8668-77, Session 15

Dependence of area and volumetric mammographic breast density estimation on radiation dose

Hao Jing, Brad M. Keller, R Crescenzi, Emily F. Conant, Andrew D. A. Maidment, Despina Kontos, Univ. of Pennsylvania (United States)

Mammographic breast density is a strong risk factor for breast cancer. Studies on imaging dose in mammography have primarily focused on imaging quality and diagnostic accuracy, while little work has been done on understanding its effect on the estimation of breast density. Studies on the effect of dose on mammographic density estimation can be useful in dose reduction for the purpose of density estimation and monitoring. We investigate the dependence of percent area (PD%) and volumetric (VD%) breast density estimation on the imaging dose using an anthropomorphic breast phantom (Rachel, Gammex). A set of digital mammograms were obtained with a GE Senographe 2000D FFDM system, using 220 unique combinations of different imaging physics, namely target/filter, kVp and mAs. Specifically, 8 mAs settings were defined corresponding to 10%, 20%, 40%, 70%, 100%, 150%, 200% and 300% of 1.8 mGy reference average glandular dose (AGD) for standard phototimed exposure. Breast density was estimated using fully-automated FDA-cleared software (Quantra v.2.0, Hologic Inc.). The obtained estimates were analyzed to study the effect of the imaging dose, using ANOVA and linear regression. Results show that there is a statistically significant dependence of density estimation on imaging dose (p-value=0.014 and <0.001 for PD% and VD% respectively), while the actual variation of the estimation across different levels of dose is relatively low (standard deviation of 2.87% and 0.66% for PD% and VD% respectively), considering the range of commonly used intervals (e.g., Boyd scale) for breast density categorization.

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8668-78, Session 15

A real-time radiation dose monitoring system for patients and staff during interventional fluoroscopy using a GPU-accelerated Monte Carlo simulator and an automatic 3D localization system based on a Kinect depth camera

Andreu Badal, U.S. Food and Drug Administration (United States); Fahad Zafar, Han Dong, U.S. Food and Drug Administration (United States) and Univ. of Maryland Baltimore County (United States); Aldo Badano, U.S. Food and Drug Administration (United States)

Radiation monitoring systems able to accurately track the radiation dose received by the patient and medical staff during interventional fluoroscopy can be used to minimize the likelihood and severity of radiation-induced skin injuries and estimate the accumulated organ doses. We describe a method to monitor doses in real time using automatic sensors in the imaging room and a computer simulator in a remote location. A GPU cluster running the Monte Carlo simulation code MC-GPU is used to estimate patient and staff doses due to primary and scattered radiation and the associated statistical uncertainties. The geometrical configuration of the irradiation is automatically determined and updated using data from a Kinect depth camera that tracks the location and posture of each person in the imaging room. A dose-area product sensor is used to trigger the simulations and convert the simulated doses (per x ray) to absolute dose units (Gy). A preliminary validation of the implemented geometrical model is presented. The Kinect module can reliably measure the size and location of the operators in the room with an error below 5 cm. For a typical image acquisition, a patient skin dose map can be displayed at the operator's monitor within 10 seconds with an average error below 5%. Accurate dosimetric results can be obtained in less than a minute with an error below 1%. We demonstrate that a dose monitoring system based on accurate Monte Carlo simulations can provide timely information regarding possible overdoses while allowing for the estimation of accumulated organ doses.

8668-79, Session 15

Projection-based dose metric: accuracy testing and applications for CT design

Xiaoyu Tian, CT Systems and Applications Lab., GE Global Research (United States); Zhye Yin, CT Systems and Applications Lab., GE Global Research (United States); Bruno De Man, CT Systems and Applications Lab., GE Global Research (United States); Ehsan Samei, Carl E. Ravin Advanced Imaging Labs., Duke Univ. (United States)

Purpose

The as low as reasonably achievable (ALARA) principle has been widely accepted by the clinical community, leading to increasing efforts to reduce radiation dose and optimize CT protocols. These efforts can greatly benefit from a dose estimation method associated with each specific patient and each CT scan. Monte Carlo simulation is usually adopted for patient-specific dose estimation. However, Monte Carlo simulation is usually computationally expensive, limiting its applicability when quick and real-time dose estimation is required. The purpose of this study was to develop and validate a projection based dose metric serving two purposes: (a) achieving computationally efficient dose estimation; (b) developing a metric that accounts for patient specificity.

Results

The average dose of one cross section was estimated for each phantom using projection-based dose estimation and Monte Carlo-based estimation. For four sets of simulation, the transfer functions between the two methods were derived using regression fitting. The results for water phantom, HBP phantom, kVp testing, and nCat phantom testing was illustrated in Figure 3-6 respectively. Strong linear relationship was found between projection based dose metric and Monte Carlo based dose metric for all four phantom testing. As tabulated in Table I, the linear correlation coefficients R2 for all phantom testing were above 0.96 and percentage residual were below 15%.

IV.New work

Previous work related to CT dose estimation is usually performed through Monte Carlo simulation. The computational expense of Monte Carlo simulation limits its applicability when quick and real-time dose estimation is required. The projection-based dose metric is a first step towards real-time and patient-specific dose estimation. When applied during patient scanning, it is feasible to provide real-time dose information as guideline for patient-specific scanning parameter and protocol optimization. It also could be used as criteria to quantify the dose saving for various dose reduction strategies.

Conclusions

The proposed projection-based dose metric predicts consistent results with Monte Carlo-based dose results. Consistent transfer function was found for different phantoms sizes, materials, kVp settings, and a realistic phantom. This study demonstrated the feasibility of real-time and patient-specificity dose estimation requiring only the projection data.

8668-80, Session 15

Organ dose in chest CT: effect of modulation scheme on estimation accuracy

Xiang Li, William P. Segars, Ehsan Samei, Duke Univ. Medical Ctr. (United States)

The purpose of our study was two-fold: (1) to evaluate how the different implementations of the tube current modulation (TCM) technology affect organ dose conversion factors in chest CT and (2) to improve the accuracy of organ dose estimation across modulation schemes. Computational phantom of a normal-weight female patient was used. A method was developed to generate tube current (mA) modulation profiles based on the attenuation of the phantom, taking into account the geometry of the CT system as well as the x-ray energy spectrum and bowtie filtration in a CT scan. The mA for a given projection angle was calculated as a log-linear function of the attenuation along this projection. The slope of this function, termed modulation control strength, was varied from 0 to 1 to emulate the effects of different TCM schemes. Organ dose was estimated for a chest scan for each modulation scheme and was subsequently normalized by volume-weighted CT dose index (CTDIvol) to obtain conversion factors. The results showed that the conversion factors are polynomial functions of the modulation control strength. The conversion factors established for a fixed-mA scan may be used to estimate organ dose in a TCM scan. For organs on the periphery of the scan coverage, the best accuracy is achieved when using CTDIvol computed from the average mA of the entire scan. For organs inside the scan coverage, the best accuracy is achieved when using CTDIvol computed from the volume-averaged mA values of all the axial slices containing the organ.

8668-81, Session PSWed

Task based assessment of a motion compensation algorithm via simulation of a moving stenotic vessel

Brian E. Nett, GE Healthcare (United States); Jed D. Pack, GE Global Research (United States); Darin Okerlund, GE Healthcare (United States)

An analysis of a task based simulation study of coronary artery imaging via computed tomography (CT). Evaluation of standard filtered backprojection (FBP) reconstruction and motion compensated

reconstruction of a moving cylindrical vessel that contains a hyper-intense lesion.

Multiple conditions are simulated including: varying rest times of the vessel and varying motion orientations.

A reference image with no motion was used for all comparisons. The images were segmented and quantitative metrics for accurate segmentation were compared.

The motion compensated images have consistent error metrics with respect to the static case for all rest times. The FBP reconstructions were visually inferior for shorter rest times and had significantly inferior metrics. This is the first demonstration of equivalent performance for a given task when the rest times are reduced well below the temporal aperture of the acquisition, using either advanced algorithms or different data acquisition such as multi-source geometries.

8668-82, Session PSWed

Grid artifact reduction based on homomorphic filtering in digital radiography imaging

Dong Sik Kim, Hankuk Univ. of Foreign Studies (Korea, Republic of); Sanggyun Lee, Jung Kee Yoon, DRTECH Corp. (Korea, Republic of)

In digital radiography imaging, the x-ray images are formed based on a multiplicative model, in which the projected image of an object is multiplied by the antiscatter grid shadow. Hence, the formed image is amplitude-modulated by the grid shadow and the resultant modulated terms appear as the grid artifacts. Since the bandwidths of the modulated terms are as wide as that of the projected image, we should employ relatively wide-bandwidth band-reject filters (BRFs) to reduce the grid artifacts. When we apply such BRFs, the object to be recovered is prone to distortion due to the wide filter bandwidth. In this paper, to reduce the signal bandwidth of the grid shadow images in reduction of the grid artifacts, applying BRFs within a homomorphic system is proposed by employing the logarithmic function. By taking the logarithm of the formed image, we can separate the grid component from both projected image and the exposure amount of x-rays. Hence, by employing a relatively narrow and fixed-bandwidth BRFs, we can efficiently alleviate the grid artifacts independently of the strength of the grid artifacts comparing to the conventional approaches. For real x-ray images, the superior performance of the proposed approach is compared in this paper.

8668-83, Session PSWed

Atlas-based linear volume-of-interest (ABL-VOI) image correction

Andreas K. Maier, Siemens AG (Germany); Zhenzhen Jiang, Johannes Jordan, Christian Riess, Hannes G. Hofmann, Joachim Hornegger, Friedrich-Alexander-Univ. Erlangen-Nürnberg (Germany)

In the recent years the use of small implanted devices in neurological angiographic interventions has increased [1]. For the treatment of aneurysms, for example, flow diverters and pipeline stents are on the rise. While they are easy to deploy, they are barely visible in a fluoroscopic view. Using 3D reconstruction technologies, flow diverters can be visualized at a good image quality, as 3D reconstructions allow for low to medium contrast imaging. In terms of dose, however, 3D imaging protocols often impose a higher burden on the patient [2]. Thus, there is a new demand for low-dose 3D imaging of small devices.

Volume-of-interest (VOI) imaging offers a possible solution to this problem, as scanning of smaller volumes also reduces the dose delivered to the patient. However, this also imposes the constraint that the scan of the object of interest is incomplete with respect to its spatial extent. In reconstruction theory, this problem is known as the so-called interior problem. For an exact solution, either the extent of the object has to be known from a prior scan [3], or at least a tiny part of the object has to be known a priori [4].

In cases where no prior knowledge is available, the problem can also be solved by using heuristics. The better the heuristic is fulfilled, the better the outcome of these methods. These methods are often called truncation correction in the literature. Some of these are based on the extrapolation of the field-of-view that was not measured [5] [6] [7], while others extrapolate the view only implicitly [1][8]. Truncation correction approaches deliver a satisfying image quality; the solution however, is only approximate. Correct reconstruction is only guaranteed if the heuristic matches the imaged object exactly. If the heuristic assumption is violated, the reconstructions still suffer from low frequency artifacts. Figure 1 displays a difference image between a full scan reconstruction and a reconstruction based on a heuristic method comparable to [6]. The main difference in this case is an offset of about 150 HU. Furthermore, there is a slight intensity increase in the VOI reconstruction towards the boundary of the field-of-view. This kind of residual artifact is typical for most heuristic truncation correction methods.

In an interventional setting, this difference is often negligible as the imaged objects are medium to high contrast. In most cases, the physician wants to see high contrast details at high spatial resolution (as the bony structures in Figure 1). A correct scaling of the HU values in the reconstruction is still desirable, as they allow conclusions on the type of material and may be of further diagnostic interest. In addition, some correction steps that are applied in image domain rely on a correct scaling, e.g. noise reduction and ring correction algorithms [9].

In this paper, we estimate the missing offset of truncation correction methods by using image retrieval methods. In this way, we are able to include prior knowledge into the reconstruction process without having to rely on information of a specific patient. We detect patch-based features and search for similar features in a database. Then we use the matched patches to estimate the correct scaling of the images. In order to limit the amount of prior information that is included in this process, we only allow a global linear scaling to correct the image.

8668-84, Session PSWed

Design and analysis of a calibration-method for stereo-optical motion tracking in MRI using a virtual calibration phantom

Martin Hoßbach, Fraunhofer-Institut für Graphische Datenverarbeitung (Germany); Johannes Gregori, Fraunhofer MEVIS (Germany); Stefan Wesarg, Fraunhofer-Institut für Graphische Datenverarbeitung (Germany); Matthias Günther, Fraunhofer MEVIS (Germany)

Motion tracking for head motion compensation in MRI has been a research topic for several years. However, literature is not giving much attention to the calibration of such setups. We present a method to calibrate the coordinate systems of a stereo-optical camera setup mounted to the MRI head coil. Though using a simple setup and visible instead of infrared light for tracking, it is possible to achieve a sub-millimeter tracking precision.

Blue water-filled spheres are positioned throughout the whole MRI imaging volume and detected in images of the tracking cameras as well as MRI scans. In order to register the coordinate systems of both camera system and MRI scanner, a heuristic-enhanced brute-force approach is used to match detected spheres in the different images. Then, a rigid transformation is calculated and applied to the cameras' external parameters to align the coordinate systems.

The precision of our setup was evaluated using leave-one-out cross validation both for the camera calibration and the scanner coordinate system registration. We found that the cameras' locations and orientations are correct within 0.1mm and 0.01 degrees, using at least 18 spheres. Evaluation of the MRI coordinate system registration showed an average reprojection error of 0.37mm. The resulting calibration

transformation is correct within 0.05mm and 0.05 degrees.

Influence of a feature point jitter of 0.5px is 0.03mm for a point close to the cameras and 0.3mm for a point close to the back of the patient's head. Tracked poses are correct within 0.17mm and 0.001 degrees.

8668-85, Session PSWed

Truncation correction for VOI C-arm CT using scattered radiation

Bastian Bier, Friedrich-Alexander-Univ. Erlangen-Nürnberg (Germany); Andreas K. Maier, Siemens AG (Germany); Hannes G. Hofmann, Chris Schwemmer, Yan Xia, Friedrich-Alexander-Univ. Erlangen-Nürnberg (Germany); Tobias Struffert, Univ. Erlangen (Germany); Joachim Hornegger, Friedrich-Alexander-Univ. Erlangen-Nürnberg (Germany)

In this paper, we presented a new method of truncation correction using scattered radiation. First tests showed that the method works as well as other state-of-the-art correction methods, like the Water-Cylinder Correction, which are already in clinical use. Our method has advantages if bones are truncated. Dense objects can be reconstructed in the area outside the FOV, and no cupping occurred in our method.

ACKNOWLEDGMENT

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8668-86, Session PSWed

A papillary muscle guided motion estimation method for gated cardiac imaging

Jizhe Wang, George S. K. Fung, Tao Feng, Benjamin Tsui, Johns Hopkins Univ. (United States)

This research aims to develop a new feature guided motion estimation method for the left ventricular wall in gated cardiac imaging. The guiding feature is the "footprint" of the papillary muscle, which is the attachment of the papillary muscle on the endocardium. Since the footprint can be tracked accurately, this feature guided approach will significantly improve the accuracy and robustness of traditional optical flow based motion estimation method. First, the 4-D XCAT phantom, with papillary muscles, cardiac motion and motion vector field (MVF), was used to simulate typical gated myocardial PET images. The 4-D MVF of the heart model of the phantom was generated as a reference. Second, for each gated cardiac image, the 3-D "footprint" surface of the papillary muscle was extracted and its centroid was calculated. Third, the motion of the centroid of the "footprint" throughout a cardiac cycle was tracked and analyzed in 4-D. This motion was extrapolated to build a papillary muscle guided initial estimation of the 4-D MVF of the left ventricular wall according to the relationship between the magnitude of the longitudinal motion and the longitudinal height of the myocardium reported in the literature. Last, we applied our previously developed motion estimation algorithms with three different initial MVF estimates, including zero initial (0-initial), papillary muscle guided initial (P-initial), and true MVF from phantom (T-initial) on the simulated gated myocardial PET images. Qualitative and quantitative comparison between the estimated MVFs and the true MVF has shown that P-initial always achieves more accurate motion estimation than 0-initial with 25% to 75% improvement and comparable estimation with T-initial in longitudinal motion.

8668-87, Session PSWed

Noise reduction of low-dose computed tomography by using the multi-resolution total variation minimization algorithm

Cheng-Ting Shih, National Tsing Hua Univ. (Taiwan); Shu-Jun Chang, Institute of Nuclear Energy Research (Taiwan); Yan-lin Liu, National Tsing Hua Univ. (Taiwan); Jay Wu, China Medical Univ. (Taiwan)

Computed tomography (CT) has become a popular tool in radiologic diagnosis due to the ability of obtaining high-resolution anatomical images. However, radiation doses to patients are substantial and can increase the risk of cancer incidence. Although lowering the tube current is a direct way to reduce absorbed doses, insufficient photon numbers can cause severe quantum mottle and subsequently degrade the diagnostic value of CT images. In this study, we proposed an algorithm for noise reduction of low-dose computed tomography (LDCT) based on the multiresolution total variation minimization (MRTV) method. The discrete wavelet transform was used to decompose the CT image into high- and low-frequency wavelet coefficients. The total variation minimization with suitable tuning parameters was then applied to reduce the variance among the wavelet coefficients. The noise-reduced image was reconstructed by the inverse wavelet transform. The results of the Shepp-Logan phantom added with Gaussian white noise showed that the noise was eliminated effectively and the SNR was increased by a factor of 9. In the clinical head CT scan with a tube current of 9.12 mA, the MRTV successfully removed the severe noise in the parenchyma region, and SNR was increased by 3 to 4 times. In addition, the details of the septal structure of the sinus cavity were maintained. We conclude that the MRTV approach can effectively reduce the image noise caused by tube current insufficiency, and thereby could improve the diagnostic value of LDCT images.

8668-88, Session PSWed

Monte Carlo modeling of field angle-dependent spectra for x-ray imaging systems

Edward B. Gindele, Carestream Health, Inc. (United States)

The photon spectrum for x-ray capture systems is a function of field angle. The spectrum variability is most pronounced for cone beam CT systems with wide field angles operating close to the anode angle limit. Filtration devices also contribute to the change in photon spectrum with field angle especially for variable-thickness filters, e.g., bow-tie filters. The change in photon spectrum is primarily due to the distance traversed through anode and filtration materials with field angle. Although Monte Carlo x-ray simulations can include the materials and geometries for these source assembly elements, the computational requirements can be prohibitive. As a consequence, most x-ray Monte Carlo simulation implementations ignore field angle spectral effects. Our uses a probabilistic rejection scheme to model the field angle spectral effects within the context of a Monte Carlo simulation tool. A bounding spectrum is constructed that supercedes all possible spectrums for all field angles. Photons are generated with the bounding spectrum and rejected or accepted based on the probability of transmission through the cascade of anode and filtration materials relative to a pre-calculated maximum probability of transmission. The resultant photon spectrum properly models the intensity and spectral shape of emitted photons as a function of field angle. For a wide field angle CBCT system, approximately 20% of the generated photons are rejected, with less than a 10% additional computation cost.

8668-89, Session PSWed

Fast iterative beam hardening correction based on frequency splitting in computed tomography

Qiao Yang, Friedrich-Alexander-Univ. Erlangen-Nürnberg (Germany); Matthias Elter, Siemens AG (Germany); Ingo Schasiepen, Friedrich-Alexander-Univ. Erlangen-Nürnberg (Germany) and Siemens AG, H CP CV ME (Germany); Nicole Maass, Siemens AG (Germany); Joachim Hornegger, Friedrich-Alexander-Univ. Erlangen-Nürnberg (Germany)

In computed tomography (CT), the nonlinear characteristics of beam hardening are caused by the polychromaticity of x-rays, which severely degrade the CT image quality and diagnostic accuracy. The correction of beam hardening has been an active area since the early years of CT, and various techniques have been developed. State-of-the-art works on multi-material beam hardening correction (BHC) are mainly based on segmenting datasets into different materials, and correcting the non-linearity with correction images iteratively. Those techniques are limited in correction effectiveness due to inaccurate segmentation. Furthermore, most of them are computationally intensive. In this study, we introduce a fast BHC scheme based on frequency splitting, which incorporates the artifact properties. Our approach assumes that beam hardening artifacts are primarily contained in the lower frequency components, and it will be sufficient to apply BHC only to those. After low-pass filtering and correcting artifacts at low resolution projections, an artifact reduced high resolution reconstruction will be obtained by incorporating the original edge information from the high frequency components. Evaluations in terms of correction accuracy and computational efficiency are performed using simulated and real CT datasets. In comparison to the BHC algorithm without frequency splitting, the proposed accelerated algorithm yields comparable reduction of cupping and streak artifacts with tremendously reduced computational effort. The presented framework can achieve a speedup of 76% while still obtaining excellent artifact reduction. This is a significant practical advantage for clinical as well as industrial data.

8668-90, Session PSWed

Removing intra plane blurring in dental panoramas

Christian Hofmann, Institut für Medizinische Physik (Germany); Michael Knaup, Friedrich-Alexander-Univ. Erlangen-Nürnberg (Germany); Marc Kachelrieß, Deutsches Krebsforschungszentrum (Germany)

Dental x-ray imaging today covers several modalities. Intraoral radiography and extraoral radiography (which includes two--dimensional cephalometry, the art of performing dimensional measurements in the head of living individuals) are rather conventional imaging methods on the one hand. Tomographic techniques such as digital panoramic imaging and digital volume tomography (DVT) are more sophisticated methods on the other hand. While digital volume tomography is nothing but a different term for cone-beam computed tomography (CBCT) panoramic imaging deserves more explanation. Nowadays, more and more DVT systems are installed. Some of them rather use a single flat detector for panoramic radiography and cone-beam CT. For those systems one may combine the advantages of both acquisition modes to reduce the intra plane blurring. One possible approach to reduce the intra plane blurring combines a standard panoramic image with a panoramic image taken with a wider fan-beam collimation. In this work we want to propose a method that uses a form filter to simultaneously acquire the data for a typical orthopantomogram and data with a significantly increased fan-angle, sufficient to perform a low dose FDK reconstruction.

8668-91, Session PSWed

Cascaded-systems analysis of the DQE of double-Z x-ray detectors including photoelectric, coherent and incoherent interactions

Seungman Yun, Robarts Research Institute (Canada) and Pusan National Univ. (Korea, Republic of); Jesse Tanguay, Robarts Research Institute (Canada); Ho Kyung Kim, Pusan National Univ. (Korea, Republic of); Ian A. Cunningham, Robarts Research Institute (Canada)

Image quality in diagnostic x-ray detectors is limited by the statistical properties governing how, and where, x-ray energy is deposited in a detector. This in turn depends on the physics of the underlying x-ray interactions. For high atomic-number (Z) detector materials and energies in the diagnostic energy range (10-100 keV), most of the energy deposited in the detector is through photoelectric interactions. However, for low-Z detectors, such as silicon-based photoconductors, energy deposited from Compton interactions becomes important. We present a theoretical model of energy deposition within an x-ray detector material that addresses the nature of energy absorption following photoelectric and Compton interactions. The model also includes the effects of Coherent scatter prior to energy deposition by photoelectric interactions. A cascaded systems approach is used to describe the transfer of signal and noise in terms of the modulation transfer function (MTF), Wiener noise power spectrum (NPS), and detective quantum efficiency (DQE). The model was validated by comparing Monte Carlo simulation results with various detector materials. Excellent agreement is obtained for each metric over the entire diagnostic energy range up to 10 cycles/mm. We believe that this study will be useful for the optimal design of conventional radiography detectors and the estimation of x-ray imaging performance of the novel photoconductor materials as well.

8668-92, Session PSWed

Hybrid EID algorithm for PCD/EID-CT systems

Katsuyuki Taguchi, George S. K. Fung, Qiulin Tang, Jochen Cammin, Johns Hopkins Univ. (United States)

One of the major obstacles toward photon counting detector (PCD)-based clinical x-ray CT systems is the large count rates, because when operated under too intense x-rays, pulse pileup effects (PPEs) due to coincident photons distort the spectrum recorded by PCDs. In this paper we discuss a strategy using a hybrid detector, which consists of PCDs for the central part of the detector [which corresponds to a central small field-of-view (FOV) of the object] and energy integrating detectors (EIDs) for the peripheral part, to achieve the following three goals: 1) to minimize the PPEs; 2) to produce accurate spectral images for the small FOV; and 3) to provide conventional CT images for the entire FOV. The third goal requires a solution to exterior problem, because the central part of EID data is missing. The spectral data obtained by PCDs carry richer information than the intensity data obtained by EIDs; however, performing a simple weighted summation of counts from multi-energy windows of PCD would not produce realistic EID data, as the spectrum recorded by PCD could be skewed by spectral response effects (SREs) and PPEs. We propose a unique approach for the hybrid PCD/EID-CT system in this paper.

8668-93, Session PSWed

Cardiac deformation indices derived from motion estimated x-ray computed tomography

Liwei Jiang, Qiulin Tang, Katsuyuki Taguchi, Johns Hopkins Univ. (United States)

Cardiac deformation indices such as strain, strain rate, and time to peak strain have tremendous prognostic value in assessing patients recovering from heart failure. These indices have been previously measured in modalities such as Doppler ultrasound and magnetic resonance imaging (MRI). However, cardiac deformation has not been well characterized in X-ray computed tomography (CT), a modality whose balance of high acquisition speed and good temporal and spatial resolution makes it highly desirable in the clinical setting. The current work, an extension of our group's cardiac motion estimation algorithm, calculates deformation indices such as strain, strain rate, maximum strain, and time to maximal strain from motion vector field data. Along each dimension, calculations are made between every adjacent pair of grid points, yielding an increase in spatial resolution over approaches that divide the heart into a number of segments. Results are visualized as semi-transparent color maps superimposed on CT image slices in the short-axis view and the two long-axis views. Early results agree with the expected behavior of myocardial contraction, but new findings have also been uncovered. Further refinements of the present work may yield rich yet easily accessible information for clinicians in diagnostic assessments.

8668-94, Session PSWed

Metal artifact reduction based on beam hardening correction and statistical iterative reconstruction for X-ray computed tomography

Yanbo Zhang, Xuanqin Mou, Xi'an Jiaotong Univ. (China)

Metal artifact is a main cause to degrade CT image quality, but there is still no standard solution to this issue. The cause of introducing metal artifact is due to multiple effects, among which beam hardening and low counts due to photon starvation are two main factors. Accordingly, in this paper these two factors are alleviated by beam hardening correction based on polynomial fitting and statistical iterative reconstruction based on Poisson log-likelihood approach. Unlike reducing metal artifact by iterative polychromatic reconstruction, the proposed method in this work do not need a priori knowledge about the X-ray spectrum and the materials to be reconstructed. Experiment shows that the proposed method can suppress metal artifact greatly and restore low contrast tissues.

8668-95, Session PSWed

A model-based volume restoration approach for Monte Carlo scatter correction in image reconstruction of cone beam CT with limited field of view

Guozhi Zhang, Reinhilde Jacobs, KU Leuven (Belgium); Hilde Bosmans, UZ Leuven (Belgium)

Scatter remains a major cause of image artefacts in cone beam CT (CBCT). In multi - slice CT, Monte Carlo simulation of scatter has been useful to estimate the scatter distribution for improved image reconstruction purpose. This technique, however, requires a 3D model of the full patient and is typically obtained from the reconstructed 3D image. This is not available for CBCT scans with limited field of view. This study proposes a novel approach to restore the patient information in such cases by use of a standard patient model and image registration techniques. As demonstrated for a 6 ? 6 cm oral CBCT scan, a full-field image of a standard model could be registered to the truncated patient image from the CBCT acquisition and was then successfully imported to Monte Carlo simulation for scatter estimation. Scatter correction was achieved by subtracting the Monte Carlo scatter data from the raw data on a projection-by-projection basis. Compared to the original data, the reconstructed image with scatter correction showed reduced streak artefacts and an improved contrast resolution of up to 15% between the soft and bony tissue. This volume restoration approach in the scatter correction technique for CBCT was efficiently implemented by exploiting the low-frequency characteristic of the scatter distribution It can be further optimized and implemented in practice.

8668-96, Session PSWed

A method to characterize the radiation output from a cone beam O-arm using a device for dose and dose profile scanning measurement

Lars Herrnsdorf, Marcus Söderberg, Lund Univ. (Sweden)

The O-arm system is a mobile intraoperative imaging system that is comprised of fluoroscopy and cone-beam CT. The configuration of the O-arm system with no patient table and broad beam width (150 mm in isocenter) brings new practical and physical requirements on how to perform dose measurements. The purpose of this study was to describe a method that overcomes this using an external vertical hanging holder mover and characterize the radiation output from the O-arm system.

A holder with a clamp and a flexible ball joint that can orientate the measuring tube and the Mover that can be adjusted to hold the dose detector in a vertical position was used. Evaluation of the dose response for three different dose detectors of different active length (0.3, 23.1 and 100 mm) was made for three different beam qualities. Furthermore the dose profile free in air to control the possible heel effect and width of the x-ray field during rotation was measured and the dose rate waveform was analyzed.

The FWHM of the dose profile was 163 mm. The dose response of the three detectors is reported.

The average dose response was lower for the detector with longer active length due to the influence of the dose profile shape. From dynamic measurement total exposure time, pulse width, and the number of pulses were verified.

In conclusion, an external vertical hanging holder with mover option helps to assist to make dose measurement easier and enables characterize the radiation output from the O-arm system.

8668-97, Session PSWed

Volume of interest CT implemented with a dynamic bowtie filter

Timothy P. Szczykutowicz, Charles A. Mistretta, Univ. of Wisconsin-Madison (United States)

Often in clinical CT imaging situations, a clinician only requires a small volume of interest (VOI) within a CT slice to be imaged. Unfortunately, due to some fundamental constraints in CT image reconstruction, the entire slice must be irradiated even when a small VOI is all that is clinically required. This produces excess dose for the patient, excess scatter which degrades image quality and increases clinician dose, and may effect patient care because clinicians may limit their use of CT in the interventional setting due to the previous two factors. This paper shows experimental results in which a dynamic bowtie filter (DBA) is used to modulate the patient dose as a function of view and gantry angle to enhance the SNR in a small VOI relative to the surrounding areas.

A VOI image with a difference in pixel standard deviation of 2.1 times (from inside the VOI to outside) was generated. The results suggest DBA enabled VOI is possible with a dose savings of 3.4 times compared to an unmodulated CT acquisition.

8668-100, Session PSWed

Radiation dose reduction and CNR enhancement in C-arm cone beam CT

Kai Niu, Univ. of Wisconsin-Madison (United States); Jie Tang, Univ. of Wisconsin-Madison (United States); Kevin Royalty, Siemens Medical Solutions USA, Inc. (United States); Orhan Ozkan, Charles M. Strother, Beverly Aagaard-Kienitz, Kari Pulfer, Univ. of Wisconsin-Madison (United States); Guang-Hong Chen, Univ. of Wisconsin School of Medicine and Public Health (United States)

In this work we applied dose reduction using the prior image constrained compress sensing (DR-PICCS) method on a C-arm cone beam CT system. DR-PICCS uses a smoothed image as the prior image. After applying DR-PICCS, the final image will have noise variance inherited from the prior image and spatial resolution from the projection data. In order to investigate the dose reduction of DR-PICCS, three different dose levels were used in C-arm scans of animal subjects using a Siemens Zeego C-arm system under an IACUC protocol. Image volumes were reconstructed using the standard FBP and DR-PICCS algorithms. These images were randomly mixed and presented for three experienced interventional radiologists to review and score using a five-point scale. Meanwhile, 10 clinical human head scans were studied to assess noise reduction and spatial resolution preservation. In each human subject study, we selected six ROIs (two gray matter, two white matter and two ventricle) in corresponding FBP and DR-PICCS images. The noise reduction factor and CT number change can be calculated from these measurements. Spatial resolution was qualitatively tested by simple subtraction of DR-PICCS and FBP images and quantitatively tested using a pseudo point spread function. Animal studies show that DR-PICCS can achieve more than a 60% dose reduction while maintaining the same image quality, indicating that both patients and doctors can benefit from lower radiation dose during the intervention procedure. Human studies indicate that at the same dose level DR-PICCS can achieve two times CNR enhancement without compromising spatial resolution. This may allow for diagnosable images to be generated on C-arm systems which would effectively take conventional CT out of the work flow for some protocols.

8668-101, Session PSWed

Motion detection in cone-beam computed tomography incorporating a geometric calibration approach

Rizza D. Pua, Boyeol Yoo, KAIST (Korea, Republic of); Chang Hwan Kim, KAIST (Korea, Republic of) and KAIST (Korea, Republic of); Seungryong Cho, KAIST (Korea, Republic of)

This work proposed a motion detection method for cone-beam computed tomography (CBCT) that utilizes a calibration phantom of known geometry as the motion detector and an established geometric calibration protocol to provide the motion information. An initial numerical study regarding the consequences of motion and its correction was conducted with a Shepp-Logan and an XCAT phantom. Motion artifacts were induced by acquiring the projections in a simple saddle trajectory scan. Since the scanning trajectory is set, the magnitude of motion for each projection view is already known, the correction of motion can then be efficiently implemented. Motion correction was done prior to the backprojection process of the filtered backprojection (FBP) image reconstruction algorithm. Results showed that motion correction improved the image quality of the reconstructed images. For a known or unknown scanning trajectory, the geometric calibration method can define the geometric information of a scanning system. In the current work, projections of a calibration phantom of known geometry were acquired from a saddle trajectory scan, and geometric parameters for selected projection views were successfully computed from the projection matrix provided by the geometric calibration method. Further studies will involve an experimental investigation wherein a calibration phantom is attached to a randomly moving object and scanned in a circular trajectory. Utilizing the parameters extracted from the geometric calibration, an accurate description of the object motion can be used and adapted for motion correction.

8668-102, Session PSWed

Infinite impulse response filtering for cone beam tomography

Karl Barth, Frank Dennerlein, Thomas Brunner, Andreas Fieselmann, Rainer Graumann, Siemens AG (Germany)

Filtered backprojection (FBP) is an efficient way for reconstructing CT or cone beam tomography (CBT) volumes. FBP involves convolution-based filtering to compensate for the systematic blurring in backprojection, characterized by a radial 1/r decay in the spatial and in the frequency domain which has been known from Fourier reconstruction theory. This blurring is compensated e.g. by the Shepp-Logan filter. Theoretically an infinite continuation of signals and filters should be regarded. Practically a limitation to e.g. n=1024 data elements in a convolution kernel is sufficient. This can be classified as finite impulse response (FIR) filtering and leads to a complexity of O(n?) operations for nxn data in every projection, a critical issue for high-resolution detectors.

From discrete system theory, another filter type with infinite impulse response (IIR) has been known. Because such a filter recursively uses backward components, it needs very view coefficients. In the presented work, IIR filters have systematically been designed and tested, first by investigating their frequency response in z-space. Secondly, image quality has carefully been inspected by (re-) reconstruction of phantom data and clinical conebeam cases.

It has been shown that the filtering step in FBP/CBT can be realized as a recursive filter only, i.e. in closed IIR-notation. Adaptions like e.g. apodisation can directly be designed and realized without additional effort. The number of FBP filtering operations is reduced to O(n?) with IIR filters while the long-range filter effect is preserved. So with IIR filtering an alternative for FBP filtering is available.

8668-103, Session PSWed

ML reconstruction of cone-beam projections acquired by a flat-panel rotational x-ray device

Tim Pfeiffer, Robert Frysch, Sebastian Gugel, Georg Rose, Otto-von-Guericke-Univ. Magdeburg (Germany)

The steadily growing computational power of modern hardware allows use of more sophisticated reconstruction methods. We present an implementation of the maximum likelihood (ML) method, a previously studied method, for the case of a flat-panel rotational X-ray device. Contrary to the related principle of algebraic reconstruction (ART), the physical properties of X-radiation, especially the corpuscular character and the associated Poisson distribution of the measured number of photons are considered. The basic principle is the maximization of the joint probability of all measured projections with respect to the attenuation coefficients of all voxels of the object. The application of the ML optimization procedure finally generates an iterative scheme for the update of the attenuation coefficients. For this, in each step an accurate estimation of the forward projections (FP) is mandatory. We use an approximate calculation of the footprints of single voxels based on separable trapezoids. The resulting enormous computational effort is handled by an efficient implementation on GPGPU (General-purpose computing on graphics processing units). As a first look, using data from 133 projections of a sheep head acquired by means of a flat-panel rotational angiography system, we compare the reconstructions by the ML based method with the gold standard - the Feldkamp filtered back projection (FBP) procedure. The results reveal a clearly reduced amount of streak artifacts as well as less blurring of the statistical reconstruction method.

8668-104, Session PSWed

A new approach for prospective gated cardiac rotational angiography

Stijn De Buck, Dieter Dauwe, Jean-Yves Wielandts, Piet Claus, Stefan Janssens, Heidbuchel Hein, Dieter Nuyens, KU Leuven (Belgium)

Cardiac rotational angiography (RA) is well suited for 3D cardiac imaging during catheter based interventions but remained limited to static images or was characterized by high dose. We present a new prospective imaging technique that is capable of imaging the dynamics of the cardiac cavities in a single C-arm run during the intervention with a relatively low dose.

By applying slow atrial pacing a stable heart rhythm can be obtained and C-arm imaging can be performed in a single C-arm rotation at a regular imaging interval. Pacing interval and imaging framerate can be adapted such that a single cardiac phase is imaged multiple times and a motion free state is imaged from different equiangular positions.

A practical implementation of this technique was realized in which the cardiac cavities are imaged while pacing at 105 bpm (574msec) and imaging at approximately 15fps. A number of animal experiments were conducted in which the technique was applied and MR imaging was performed subsequently. Quantitative comparison was made by manual contouring of the left ventricle in the RA and MR images of both end-systolic and end-diastolic phases.

Reconstructed images of the individual cardiac phases showed all four chambers and important vessels in spite of substantial image noise. RA and MR absolute surface distance errors amounted to 3.0±0.3mm which is acceptable. Further, no systematic difference could be identified. Finally, it is expected that the effective dose of a clinical protocol with 381 images will be lower than the current retrospective gated RA protocols.

8668-105, Session PSWed

Simulation study of cone beam CT for visualizing cell clusters in breast biopsies

Curtis Laamanen, Robert J. LeClair, Laurentian Univ. (Canada)

The feasibility of cone beam CT (CBCT) for differentiating normal epithelium from invasive carcinoma is investigated via a simulation study. The phantom consisted of a 5 mm long 5mm diameter cylinder of a 50:50 mixture of fibrous and fatty tissue. Normal epithelium and invasive carcinoma ROIs were each modeled as epithelium and connective tissue compartments with respective cross-sectional dimensions of 158 by 161 microns and 131 by 161 microns. For normal epithelium, 125 cells in total were placed in the compartments with a higher concentration in the basal layer. For the invasive carcinoma, 314 cells were spread out sporadically. Cells were modeled as 5.67 micron diameter spheres of water. The attenuation coefficients used in the simulation were those of fat for epithelium, 80:20 mixture of fibrous and fat for the connective tissue and water for cells. Imaging parameters were chosen to emulate a CCD digital specimen radiography system. The 25 micron focal spot was assumed a point source. Detector pixel sizes at the phosphor plane were 50 microns. Projections were acquired at magnification 5 using 26 kV, 1.14mAs beams. Scatter is negligible and therefore was neglected. ADU values were obtained via a calibration curve. Consider signals consisting of the sum of pixels within four identical ROIs and noise estimated using 10 images. Using 50 projections for reconstruction yielded a SNR= 4.9, suggesting that our CBCT method for visualizing clustering of cells for the purpose of diagnosing cancer in breast biopsies is borderline.

8668-106, Session PSWed

Cone-beam reconstruction for tilted detector plane and arbitrary detector surface

Zhengmin Li, Rensselaer Polytechnic Institute (United States)

In the standard setting of the cone-beam imaging geometry, the detector cells are usually mounted on a flat or curved panel with the same cell size, and the detector plane is perpendicular to the line crossing X-ray source and center of the object to be imaged. Moreover, the source trajectory is set to be circular or helical. Nearly all the analytic or iterative reconstruction methods are designed based on the this standard setting. With the rapidly increasing applications of cone-beam computerized tomography (CT), it is desirable to design reconstruction methods beyond the standard imaging geometry, for example, the detector plane can be rotated along local coordinates to avoid radiation of some region, and the detector surface can be designed to be arbitrary to fit the imaging object.

In this work, we present a new FBP-type reconstruction method to incorporate the non-standard Cone-beam imaging geometry. Specifically, we introduce new analytic forward models and the associated FBP-type inversion methods for X-ray CT image reconstruction from cone-beam projection data, when the detector plane is tilted and has arbitrary surface function. Firstly, we extend the forward model derived in our previous work to incorporate the non-standard cone-beam imaging geometry, specifically, when the detector plane is rotated around the local coordinates in any direction, and when the detector surface is arbitrarily defined, rather than a flat plane. Then, the filter in the filtered backprojection step is adjusted properly for the two cases. Finally, numerical simulations are conducted to demonstrate the effectiveness and correctness of our extended forward models and the associated inversion methods for the two cases.

8668-107, Session PSWed

Single-scan energy-selective imaging on cone-beam CT system: a preliminary study

Xue Dong, Tianye Niu, Lei Zhu, Georgia Institute of Technology (United States)

On an onboard cone-beam CT (CBCT) system, the poly-energetic beam generated by current commercial x-ray tubes hardens as it penetrates the object. The energy dependence of the object linear attenuation coefficients makes line integral measurements inaccurate, leading to beam-hardening artifacts in CT images of more than 100 HU, especially around dense objects (e.g. bones). We propose to insert a half-field beam filter between the x-ray source and the object, such that any ray passing through the object is filtered once from one of the opposite directions in a single full scan. Projection measurements therefore are acquired with two different x-ray spectra without changing the tube kVp energy. The data processing of dual energy imaging is then applied to obtain material decomposition as well as CT images free of beam-hardening artifacts. The proposed method is evaluated using simulation studies. On the head phantom, our approach significantly suppresses beam-hardening artifacts, and the synthesized mono-energetic image matches well with the ground truth image with an average error of below 5 HU. The method also successfully decomposes bone and soft tissue, a feature not achievable by conventional beam hardening correction. These preliminary studies demonstrate promise on a new energy-selective CBCT imaging method with significantly improved image quality and extra material information.

8668-108, Session PSWed

Development of an integrated x-ray/optical tomography system for the pre-clinical radiation research

Sohrab Eslami, Yidong Yang, John Wong, Johns Hopkins Univ. (United States); Michael Patterson, McMaster Univ. (Canada); Iulian Iordachita, Johns Hopkins Univ. (United States)

The current Small Animal Radiation Research Platform (SARRP) is poor for localizing small soft tissues targets for irradiation or tumor models growing in a soft tissue environment. Therefore, a complementary and on-board imaging method to x-ray CT is required to localize the soft tissue target's Center of Mass (CoM) to within 1 mm. In this paper, we have designed and built an integrated x-ray/bioluminescent tomography (BLT) system to provide the pre-clinical, high resolution irradiation system to investigate the influences of the radiation in small animals under the cone-beam computed tomography (CBCT) imaging guidance by adding the bioluminescent imaging system (BLI) as a stand-alone system and on-board the SARRP. The proposed system integrates two portable robotic rotational stages and a PXS10-65W x-ray source model rated at maximum 130 kV having a small variable focal spot. A high performance, low noise, CCD camera mounted on a light-tight housing along with an optical filter assembly to allow multi-spectral imaging is used for the aim of the BL imaging and tomography. A three-mirror arrangement is implemented to eliminate the need to rotate the CCD camera for acquiring images. This mirror system is attached to a motorized stage to capture images in angles between 0-90 deg (for stand-alone system). The camera calibration procedure is accomplished and the CBCT calibration is currently under evaluation. The animal test workflow and validation of the BLT algorithm are ongoing and will be completed subsequently. The clinical tests on animals will be followed as the final stage of this research.

8668-109, Session PSWed

Image reconstruction of arc cone-beam CT with reprojection: a preliminary study and its potential applications

Shih-Chung B. Lo, Georgetown Univ. Medical Ctr. (United States)

A reprojection reconstruction is proposed for limited angle cone-beam CT. This approach can be used as an improved method for any non-reprojection method such as total vibration (TV) minimization based and/or projection onto convex sets (POCS) methods in cone-beam CT reconstruction [1,2]. Since the reprojection and backprojection are mutually inversed operations, the reprojection as line integral can be implemented with backprojector currently used in most CT systems. In this study, we focused on the effect of reprojection reconstruction with a small arc cone-beam CT scan. 3D Shepp-Logan mathematic model and a human head phantom were used for the study with 15 projections spanning 45 degrees of the scan. The results showed that the ringing artifacts and edge unsharpness are greatly improved by the reprojection reconstruction method. We also found that an arc scan covering larger projection areas of the object would result in a much greater reconstruction result than a scan covering smaller projection areas with and without reprojection reconstruction method.

8668-110, Session PSWed

A novel image restoration method for on-board CBCT with deformed prior CT guidelines

Yuchuan Jian, Duke Univ. (United States)

Based on the compressed sensing theorem, a total-variation based image restoration algorithm is proposed for applying prior planning CT information and free-form deformation fields for image-guided therapy. The core algorithm we developed solves the image restoration problem for handling missing structures in one image set with prior information, and it enhances the quality of the image and the anatomical information of the volume of the on-board computed tomographic (CT) with limited-angle projections. Through the use of the algorithm, prior anatomical CT scans were used to provide additional information to help reduce radiation doses associated with the improved quality of the image volume produced by on-board Cone-Beam CT, thus reducing the total radiation doses that patients receive and removing distortion artifacts in 3D Digital Tomosynthesis (DTS) .

The performance of the algorithm was determined and evaluated by two built-in parameters in the algorithm, i.e., B-spline resolution and the regularization factor. These parameters can be adjusted to meet different requirements in different imaging applications. Adjustments also can determine the flexibility and accuracy during the restoration of images. Preliminary results have been generated to evaluate the image similarity and deformation effect for phantoms and real patient's case using shifting deformation window.

We incorporated a graphics processing unit (GPU) and visualization interface into the calculation platform as the acceleration tools for medical image processing and analysis. By combining the imaging algorithm with a GPU implementation, we can make the restoration calculation within a reasonable time to enable rapid on-board visualization, and the platform potentially can be applied to solve complicated, clinical-imaging algorithms.

8668-111, Session PSWed

Evaluation of adaptation strengths of CARE Dose 4D in pediatric CT

Marcus Söderberg, Lund Univ. (Sweden) and Skåne Univ. Hospital (Sweden); Sonny La, Skåne Univ. Hospital (Sweden)

The motivation of this study is the general lack of knowledge regarding the efficiency and the appropriate use of the adaptation strengths of Siemens automatic exposure control system CARE Dose 4D. The purpose was to evaluate the effect on radiation absorbed dose using different adaptation strengths of CARE Dose 4D in three routine pediatric CT protocols. A pediatric anthropomorphic whole body phantom was used to simulate a 4 year old patient. CT scans were performed with a Siemens SOMATOM Definition Flash using three different pediatric protocols: neck, thorax, and abdomen. The characteristic of the tube current modulation was similar for all adaptation strengths. The difference is the extent of decrease in tube current. The degree of dose reduction using CARE Dose 4D and CARE kV compared using a fix effective mAs was 34-57%, 51-88%, and 56-91% for neck, thorax, and abdomen protocol, respectively. Accordingly, there is a large difference in radiation dose dependent on the adaptation strength: a factor of 1.5, 4.5, and 4.6 for neck, thorax, and abdomen protocol, respectively. The adaptation strengths can be used to obtain user-specified modifications of image quality or radiation dose to the patient. Radiologists and medical physicists need to be aware of the large differences between the adaptation strengths, and such differences are useful when attempting strategies to optimize CT radiation dose.

8668-112, Session PSWed

Investigation of accurate image reconstruction from truncated, diagnostic-CT data

Zheng Zhang, Xiao Han, Junguo Bian, The Univ. of Chicago Medical Ctr. (United States); Alexander A. Zamyatin, Toshiba Medical Research Institute USA (United States); Emil Y. Sidky, Xiaochuan Pan, The Univ. of Chicago Medical Ctr. (United States)

Analytic-based algorithms are used for image reconstruction advanced diagnostic CT scanners, and they may not be suited for handling data truncation. In this work, we investigate the potential of optimization-based algorithms for image reconstruction of practical utility from truncated data. Specifically, we focus on image reconstruction within region of interest (ROI) by using the adaptive-steepest-descent-projection-onto-convex-sets (ASD-POCS) algorithm from cadaver data collected with a Toshiba 320-slice diagnostic CT scanner. The original data set is non-truncated and we artificially cut the sinogram to generate truncated data sets. Results of our study show that the ASD-POCS algorithm can yield accurate images within an ROI, with greatly reduced reconstruction artifacts such as the “cupping artifacts” observed in FBP reconstructions.

8668-113, Session PSWed

Alternative noise map estimation methods for CT images

Daxin Shi, Toshiba Medical Research Institute USA (United States)

In this work, we propose three alternative methods to estimate noise map for CT images. Our methods are generalizations to the existing even and odd views method proposed by Hsieh and Thibault. Method one in this work estimates noise map from images reconstructed from three sets of independent views. Method two deals with images reconstructed by using two sets of correlated views. Our method three generates the noise map from two images reconstructed from two sets of independent views while the number of views in each set is unequal. Physical phantom data were employed to validate our proposed noise map estimation methods. In comparison to the existing method, our alternative methods yield reasonably accurate noise map estimation.

8668-114, Session PSWed

FPGA-based Forward and Back-Projection Operators for Tomographic Reconstruction

Kyungchan Jin, Korea Institute of Industrial Technology (Korea, Republic of); Sangyup Song, MDS Technology (Korea, Republic of)

Many kinds of CT artifact such as noise, beam hardening, scatter and motion, are mostly encountered in tomographic reconstruction. These artifacts can also be reduced using iterative reconstruction, whereas the current clinical approaches, filtered back projections, are not sufficient for artifact free reconstruction. The primary computational bottleneck in iterative reconstruction methods is forward and back projection operations. Frequently, high-speed computations can overwhelm the primary CPU-based microprocessor. Generally, while the host processor performs useful functions such as the user and memory interface, with increasing demand for higher computational performance, there are many promising coprocessor, such as graphics processing unit (GPU) technologies. However, for computation that requires acceleration, a well designed ASIC or FPGA will provide the best performance. Thus, FPGA-based forward and back projection methods can reduce computation in iterative tomographic image reconstruction. Recently, an optimized reconstruction approach was shown to yield forward-backward splitting method. In this paper, we describe a FPGA-based forward and back projection operators for iterative reconstruction. Simulation and experimental results showed that FPGA-based operators can reduce computation for iterative reconstruction while still providing accuracy comparable to CPU and GPU-based parallel processing.

8668-115, Session PSWed

Modelling and simulation of a respiratory motion monitor using a continuous wave Doppler radar in near field

Florian Pfanner, Friedrich-Alexander-Univ. Erlangen-Nürnberg (Germany) and Siemens AG, Healthcare Sector (Germany); Thomas Allmendinger, Thomas G. Flohr, Siemens AG, Healthcare Sector (Germany); Marc Kachelrieß, Friedrich-Alexander-Univ. Erlangen-Nürnberg (Germany) and German Cancer Research Center (DKFZ) (Germany)

To avoid motion artifacts in medical imaging or to minimize exposure of healthy tissues in radiation therapy medical devices are often synchronized with the patient’s respiration. Today’s respiratory motion monitors require additional effort in preparing the patient, such as mounting of a motion belt or the placement of an optical reflector on the patient breast, and they are not able to measure internal organ motion without implanting markers. An interesting alternative to assess the person’s respiratory motion is a continuous wave Doppler radar. By placing the antennas close to the body, the radar waves propagate into the body and are reflected on boundaries between body tissues, for example between muscle and adipose tissue or on the outline of organs.

For further evaluations of the radar system, a macroscopic simulation model is created to study the radar measurement process of human beings. To check the theoretical considerations of the model, measurements performed by a robot are used. Simulation of human respiratory motion is done by using computed tomography (CT) datasets, reconstructed at different respiratory phases.

8668-116, Session PSWed

Feasibility study on multiple fan-beam data acquisition for low-dose helical CT

Taewon Lee, Miran Park, Yunjeong Lee, Seungryong Cho, KAIST (Korea, Republic of); Insoo Kim, Bumsoo Han, Ebtech (Korea, Republic of)

In computed tomography (CT) imaging, radiation dose delivered to the patient is one of the major concerns. Many CT developers and researchers have been making efforts to reduce radiation dose. Sparse-view CT takes projections at sparser view-angles and provides a viable option to reducing radiation dose. However, a fast power switching of an x-ray tube, which is needed for the sparse-view sampling, can be challenging in many CT systems. We have recently proposed a novel alternative approach to sparse-view circular CT that can be readily incorporated in the existing CT systems. Instead of switching the x-ray tube power, we proposed to use a multi-slit collimator placed between the x-ray source and the patient to partially block the x-ray beam thereby reducing the radiation. In this study, we performed a simulation study based on numerically acquired projection data to demonstrate a feasibility of a for helical CT. The XCAT phantom was used and a numerical collimator has been made to apply on the projection data. Numerical multi-slit collimators have equal size of slit-openings and radio-opaque rectangular areas, and the length dimension of the slits is perpendicular to the rotation axis. For image reconstruction, we used a total-variation minimization (TV) algorithm which has shown its out-performance in many sparse-view CT applications. We demonstrated that the proposed multiple fan-beam helical CT can provide a low-dose scanning option.

8668-118, Session PSWed

Statistical CT noise reduction with multi-scale decomposition and penalized weighted least square for incomplete data

Shaojie Tang, Xiangyang Tang, Emory Univ. (United States)

Tremendous effort has been devoted to decreasing x-ray radiation dose in diagnostic CT imaging while maintaining image quality. The iterative noise reduction in the projection domain has been a hot research topic recently. Previously, we have proposed a statistical noise reduction with unique multi-scale decomposition and penalized weighted least square (PWLS) in projection domain, in which the Markov Random Field (MRF) penalty function was employed. In this paper, we extend the method to deal with the situation wherein the projection data is incomplete. Using the projection data simulated by a computer, we evaluate and verify the performance and computational efficiency of the proposed method.

8668-119, Session PSWed

Bregman regularized statistical image reconstruction method and application to prior image constrained compressed sensing (PICCS)

Yinsheng Li, Univ. of Wisconsin-Madison (United States); Pascal Theriault Lauzier, Univ. of Wisconsin School of Medicine and Public Health (United States); Jie Tang, Univ. of Wisconsin-Madison (United States); Guang-Hong Chen, Univ. of Wisconsin School of Medicine and Public Health (United States)

Recently, the Statistical Image Reconstruction (SIR) framework has shown promise in the x-ray computed tomography (CT) community, as it has the potential to provide clinically acceptable CT reconstructions from high-noise projection data, which are often generated in ultra-low radiation dose CT exams. Mathematically speaking, this type of SIR reconstruction is accomplished by solving an unconstrained optimization problem. In recent years, another type of iterative image reconstruction algorithm, compressed sensing (CS), has also shown promise in the CT community since it has been able to accurately reconstruct an image from projection data acquired from fewer view angles. This type of iterative reconstruction was initially formulated as a constrained optimization problem. However, it is unclear whether images reconstructed with SIR and images reconstructed with the CS framework are equivalent. Thus, the question at hand is the following: Is it possible to formulate the CS reconstruction technique as an equivalent unconstrained optimization and to explicitly incorporate the noise model into the reconstruction process? In this paper, we propose to establish an equivalence between the unconstrained optimization problem, such as the technique commonly employed in SIR, and a constrained optimization with explicit data consistency term. The immediate consequence of the equivalence is to enable one to use the well-developed optimization method to solve the constrained optimization problem appearing in the CS reconstruction framework. As an application of this equivalence, the method was used to develop a convergent and numerically efficient implementation method for the prior image constrained compressed sensing (PICCS) .

8668-120, Session PSWed

A new padding scheme for local tomograpy in tomographic microscopy

Yongsheng Pan, Francesco De Carlo, Argonne National Lab. (United States)

Tomographic microscopy using synchrotron radiation provides high-resolution structure details on the scale of microns. The field of view (FOV) of the microscopy system, however, is usually limited by the detector size. For example, a typical CCD camera used for data acquisition is of size 2048 by 2048. In many cases this CCD camera is not large enough to provide complete information required for accurate reconstruction, and the local tomography problem hereby arises. On the other hand, the huge dataset generated by tomographic microscopy asks for a highly efficient solution with no a priori information necessary. A new padding scheme is therefore proposed for the local tomography issue. It first pads the projection data using the boundary value inside the FOV, which is specified by the detector size, followed by a zero-value padding to 1.5 times the FOV length. The boundary-value padding removes the energy deposition and cupping artifact in reconstruction results from local tomography, while the zero-value padding reduces the drift of the intensity values caused by fully boundary padding. The combination of two padding schemes keeps advantages of fully zero-value padding and fully boundary-value padding, while avoiding their disadvantages. Quantitative analysis using synthetic data shows that the proposed method outperforms fully zero-value padding and fully boundary-value padding in terms of accuracy and ease for post processing. Experimental results for real data are also provided to demonstrate the effectiveness of the proposed method.

8668-121, Session PSWed

Influence of metal segmentation on the quality of metal artifact reduction methods

Maik Stille, Bärbel Kratz, Jan Müller, Univ. zu Lübeck (Germany); Nicole Maaß, Ingo Schasiepen, Matthias Elter, Siemens AG (Germany); Imke Weyers, Thorsten M. Buzug, Univ. zu Lübeck (Germany)

In computed tomography, star shape artifacts are introduced by metal objects inside a patient's body. The quality of the reconstructed image can be enhanced by applying a metal artifact reduction method. Unfortunately, a method that removes all such artifacts remains to be found. In this study, the influence of metal segmentation is investigated. A thresholding technique, which is the state of the art in the field, is compared with a manual segmentation. A qualitative and quantitative evaluation is performed using the well-known Dice coefficient and a reference free image quality metric for CT. Results indicate that a more accurate segmentation can lead to a preservation of important anatomical details, which are of high value for medical diagnosis.

8668-122, Session PSWed

TV-Stokes strategy for sparse-view CT image reconstruction

Yan Liu, Lin Chen, Hao Zhang, Ke Wang, Stony Brook Univ. (United States); Jianhua Ma, Southern Medical Univ. (China); Zhengrong Liang, Stony Brook Univ. (United States)

This paper introduced a new strategy to reconstruct computed tomography (CT) images from sparse-view projection data based on total variance-stokes (TVS) strategy. Previous works have shown that CT images can be reconstructed from sparse-view data by minimizing the constrained TV of the to-be-estimated image. Considering the incompressible velocity field of the voxels along the isophote directions, a tangent vector of the gradient is consolidated in this newly-proposed algorithm for normal vector estimation. After estimating the normal vector, a minimization problem based on this estimated normal vector is then addressed and resolved in computation. The to-be-estimated image is iteratively solved with constraints from the sparse-view projection data fidelity. By introducing this normal vector estimation, the edges of the image are well preserved and the artifacts are efficiently inhibited. In addition, the new proposed algorithm can mitigate the over-smooth and block-image problems which are usually observed in resulting image by using the conventional TV model. The proposed method was evaluated

by physical phantom simulation, where the anthropomorphic head phantom was used. In this simulation we observed that the proposed TVS strategy can accurately reconstruct the head phantom images and generate comparable results with TV-projection onto convex sets (TV-POCS) methods from 211 projection views data. In addition, an improvement was observed when using only 126 projection-view data for image reconstruction by TVS method compared to TV-POCS method. Further evaluations between the reconstructed results by TVS and the TV-POCS strategy using more realistic data are under progress.

8668-123, Session PSWed

A comparison study of sinogram- and image-domain penalized re-weighted least-squares approaches to noise reduction for low-dose cone-beam CT

Hao Zhang, Yan Liu, Hao Han, Stony Brook Univ. (United States); Jing Wang, The Univ. of Texas Southwestern Medical Ctr. at Dallas (United States); Jianhua Ma, Southern Medical Univ. (China); Lihong Li, City University of New York (United States); Zhengrong Liang, Stony Brook Univ. (United States)

Reducing X-ray exposure to the patients is one of the major research efforts in the CT field. In general, it could be simply achieved by lowering the X-ray tube current and/or shortening the exposure time (mAs) or lowering the tube voltage in currently available CT scanners. However, the image quality from low mAs acquisition is severely degraded due to excessive quantum noise. Statistical reconstruction algorithms model the statistical property of the noise using a cost function and minimizing the cost function for an optimal solution in statistical sense. The algorithms have shown to be feasible and effective in both projection and image domain. In our previous researches, we proposed penalized re-weighted least-squares (PRWLS) approach to sinogram noise reduction and image reconstruction for low-dose CT imaging, which are in this statistical category. This work is a continuation of the research along this direction and aims to compare the reconstruction quality of two different PRWLS implementations: (1) PRWLS sinogram restoration followed by analytical Feldkamp-Davis-Kress (FDK) reconstruction, (2) fully iterative PRWLS image reconstruction. Experiments using the CatPhan600® phantom were carried to study the spatial resolution of image reconstructions by these two PRWLS implementations. Quantitative measures consistently revealed that the implementation (2) could better preserve edges and have higher resolution than implementation (1) at the same noise level. However, this gain is offset by the cost of increased computational time. Thus, further examination of real patient data is necessary to show the clinical significance of the iterative PRWLS image reconstruction over the PRWLS sinogram restoration.

8668-124, Session PSWed

Background filtering for accuracy improvement in computed tomography with iterative region-of-interest reconstruction

Keisuke Yamakawa, Shinichi Kojima, Hitachi, Ltd. (Japan)

The iterative reconstruction method has drawn attention since it can reduce irradiation doses while maintaining image qualities. In this method, a CT image needs to be reconstructed by using full-coverage measured data, which include data in and outside Regions-of-Interest (ROI). Thus, to reconstruct ROI in high-spatial resolution, outside-ROI must also be reconstructed in high-spatial resolution. A method with iteration only in ROI is needed because unnecessary outside-ROI computation time ruins the practical usage. A method has been proposed that subtracts projected data outside ROI from full-coverage measured data. This method's major drawback is it degrades the accuracy of confined measured data in ROI depending on errors (artifact, discrete errors) outside ROI. In this paper, we propose two techniques for preventing the accuracy deteriorating in the subtraction method. Approaches studied were applying filters to the whole outside-ROI, 1) without distinguishing objects (Method-1), and 2) only to air and patient table while masking other objects outside ROI (Method-2). The evaluated effectiveness of Method-1 and -2 compared with the conventional method is discussed with simulated CT-values by using two different kinds of phantoms. Method-1 and -2 reduce the artifacts by 40% more than the conventional method. In the case of high absorption coefficients in an object, with Method-2, the artifacts are decreased and CT image is correctly uniform compared with Method-1. Therefore, Method-2 improved accuracy without deterioration by the filters and decreased errors easily without increasing computation time.

8668-125, Session PSWed

Co-registered image quality comparison in hybrid iterative reconstruction techniques: SAFIRE and SafeCT

Seungwan Lee, Aran Shima, Sarabjeet Singh, Mannudeep K. Kalra, Massachusetts General Hospital (United States); Hee-Joung Kim, Yonsei Univ. (Korea, Republic of); Synho Do, Massachusetts General Hospital (United States)

Iterative reconstruction techniques (IRTs) are used to reduce the radiation dose significantly in the medical field. However, the images from different IRTs are very hard to distinguish and correlate to the human visual system due to the presence of outlier, non-Gaussian noise structure, edge enhancing effect etc. The traditional mean and standard deviation are limited to provide the information of noise characteristics of an image comprehensively when the undesirable colored noise arises and the iterative edge enhancement effect results on the image. In this study, the images reconstructed by using the image-based IRTs (SAFIRE and SafeCT) were compared with high-order noise statistics and modulation transfer function (MTF). Two sets of images (SAFIRE and SafeCT) are reconstructed from a single raw data. The result showed that the reconstructed images from SafeCT had favorable noise characteristics than those from SAFIRE. In contrast, SAFIRE showed higher 10% MTF measurement compared to that of SafeCT in the phantom scan. This study will be able to contribute to the development of a figure-of-merit (FOM), which combines all the conventional image quality measurement, and to provide a direction with image quality improvement in new IRT algorithm development.

8668-126, Session PSWed

Iterative CT reconstruction using continuous model

Yongsheng Pan, Daxin Shi, Alexander A. Zamyatin, Toshiba Medical Research Institute USA, Inc. (United States)

A typical iterative CT reconstruction using SART involves ray-driven forward projection and voxel-driven backward projection. Bilinear interpolation is usually applied on image data for forward projection, and linear interpolation is usually applied on projection data for backward projection, when both data are represented using discrete samples in 2D fan-beam geometry. The applied interpolations, however, may affect the bias and noise properties of the reconstruction. A basis function (such as blob and spline) is therefore applied to formulate a continuous model for the image data to reduce bias. In this paper we propose to apply the blob representation on the projection data and explore its effectiveness. In this way we use continuous model for projection data during backward projection, and we avoid the linear interpolation in this process. Preliminary results show that the proposed scheme seems to introduce more local variations in the reconstruction. However, the aliasing artifacts in the reconstruction are largely reduced with the combination of total variation (TV) minimization.

This scheme will be further examined, with the combination of the

continuous model during forward projection if necessary, in the full manuscript.

8668-127, Session PSWed

Image reconstruction from limited-angle range projections

Nan Du, Yusheng Feng, Artyom M. Grigoryan, The Univ. of Texas at San Antonio (United States)

Problem of image reconstruction from a finite number of projections and with a limited angular range is important in computed tomography and electron microscopy. Different algorithms were developed and many of them work well under the assumption that objects in images have structures represented by very sparse matrices. We apply a new approach for reconstructing images from a finite number of projections. The ray-integrals of the image f(x,y) are transformed uniquely into the ray-sums of the image f(n,m) on the Cartesian lattice. This transformation allows for calculating the tensor representation of the discrete image, when the image is considered as the sum of direction images, or splitting-signals carrying the spectral information of the image at frequency-points of different subsets that cover the Cartesian lattice. These subsets are intersected and this property of redundancy can be used effectively to reduce the angular range of projections. The proposed approach is presented for parallel projections and the continuous model; the image f(x,y) is on the unite square [0,1]?[0,1] and consists of N2 cells on the Cartesian lattice N?N, and the intensity of the image on each such cell is constant. Preliminary results show very good results of image reconstruction when the angular range scanned is 27° and down to 10°. The proposed method was implemented on MATLAB and C+, and the experimental results of image reconstruction from a finite number of projections with a limited range of angles are illustrated for images of size up to 512?512.

8668-128, Session PSWed

Impact of noise level and edge sharpness of a prior image on the performance of prior image constrained compressed sensing (PICCS)

Yinghua Tao, Jie Tang, Michael A. Speidel, Univ. of Wisconsin-Madison (United States); Guang-Hong Chen, Univ. of Wisconsin School of Medicine and Public Health (United States)

Dose-reduced prior image constrained compressed sensing (DR-PICCS) is a method of CT reconstruction which utilizes prior image information in a compressed sensing framework to significantly reduce the noise in images acquired at low dose. We investigated the impact of edge sharpness and noise level in the prior image data on the resulting DR-PICCS images. Bilateral, anisotropic diffusion, and mean filters were used to generate prior images. Although the filters produced prior images with significantly different spatial resolution characteristics at similar noise levels, these differences were mitigated in DR-PICCS images and the DR-PICCS had improved fidelity in comparison to the priors.

8668-129, Session PSWed

Evaluation of reconstructed images from sparse data on the micro-CT system

Dae-Hong Kim, Hee-Joung Kim, Pil-Hyun Jeon, Yonsei Univ. (Korea, Republic of)

The quantitative evaluation is required in micro-CT imaging for total variation (TV) minimization methods at few-view scan data. We acquired the phantom and mouse image using the micro-CT system (DRGem, Harmony 80H, Republic of Korea) and demonstrated the contrast, noise, and similarity of the images.

To verify the contrast-to-noise ratio (CNR), sparse data were acquired using phantom and mouse and filtered-backprojection (FBP) images of phantom and mouse data were used as a reference image reconstructed with 400 projection data. Universal quality index (UQI) was used as a image-similarity metric for comparison between TV algorithm and FBP algorithm for both phantom and mouse image.

CNR value for image obtained from TV minimization algorithm with 80-view was approximately 45 % higher than FBP with 400-view up to 10% iodine solution material. UQI value for phantom and mouse were measured with 0.974 and 0.999, respectively.

TV minimization algorithm was proved to be advantageous for micro-CT system. Contrast and Noise properties on image from TV minimization at few-view were higher than FBP 80-view and full-view scan. However, CNR from 15% iodine solution to 20% iodine solution were lower than FBP due to the lower-intensity of the x-rays. Reconstructed images for both phantom and mouse from TV minimization were well matched to FBP-reference images.

8668-130, Session PSWed

Low-dose CT reconstruction based on multiscale dictionary

Ti Bai, Xuanqin Mou, Qiong Xu, Yanbo Zhang, Xi'an Jiaotong Univ. (China)

Statistical CT reconstruction using penalized weighted least-squares(PWLS) criteria can improve image-quality in low-dose CT reconstruction. A suitable design of regularization term can benefit it very much. Recently, sparse representation based on dictionary has been treated as the regularization term and results in a high-quality reconstruction. In this paper, we incorporate a multiscale dictionary into statistical CT reconstruction, which can keep more details compared with the reconstruction based on singlescale dictionary. Further more, we exploit reweigted l1 norm minimization for sparse coding, which performs better than l1 norm minimization.

Experiments show that combine multiscale dictionary and reweighted l1 norm minimization can result in a reconstruction superior to that bases on singlescale dictionary.

8668-131, Session PSWed

Detection of low-dose CT reconstruction artifacts using a bi-modal approach

Salman Mahmood, Klaus Mueller, Stony Brook Univ. (United States)

Low-dose Computed Tomography (CT) has the benefit of exposing patients to less radiation. However, low dose CT requires special reconstruction techniques to improve the clarity of the image. Unfortunately, these special reconstruction techniques often cannot remove all of the low-dose artifacts. It is important to recognize these artifacts else we run the risk of obscuring important detail or adding false features. In this work, we present a simple scheme which allows us to detect these artifacts. Our technique applies to the specific low-dose CT strategy in which the number of X-ray views taken from the patient is reduced. The first step uses directional interpolation in the low dose sinogram to add more views. While the image created from this interpolated sinogram does not have any artifacts it lacks significantly in clarity due to blurring. Our scheme then compares this image with the image created with a low-dose CT reconstruction technique which has better detail but also some remaining artifacts. The comparison reveals these artifacts which we then remove by simple pixel replacement.

8668-132, Session PSWed

Truncation artifact correction by support recovery

Scott S. Hsieh, Stanford Univ. (United States); Guangzhi Cao, Brian E. Nett, GE Healthcare (United States); Norbert J. Pelc, Stanford Univ. (United States)

Truncation artifacts arise when the object being imaged extends past the scanner field of view (SFOV). The line integrals which lie beyond the scanner field of view are subsequently unmeasured, and reconstruction with traditional FBP produces bright streaks at the edge of the SFOV and little useful information outside the SFOV. A variety of techniques have been proposed to correct for truncation artifacts by estimating the unmeasured rays. We explore an alternative, iterative correction technique that recovers the support (or outline) of the object that is consistent with the measured rays. We assume that the support is filled uniformly with soft tissue. In general, a proposed support will not be consistent with the measured rays, because the forward projection of the image containing support will not match the measured rays. We begin with an estimate of the object support using the water cylinder extrapolation algorithm, an existing truncation artifact correction technique. The estimate of the object support is then iteratively deformed to reduce the inconsistency with the measured rays. After several iterations, forward projection is used to estimate the missing rays. Preliminary results indicate that this iterative, support recovery technique is able to produce superior reconstructions in the case of significant truncation compared to water cylinder extrapolation.

8668-133, Session PSWed

Single CPU Monte Carlo simulation of DQE(f) for scintillating x-ray detectors

Eric Abel, Mingshan Sun, Josh M. Star-Lack, Varian Medical Systems, Inc. (United States); Dragos Constanin, Rebecca Fahrig, Stanford Univ. (United States)

The optimization of scintillating x-ray detector design is complicated by the high costs and long lead times required for manufacturing. Where most engineering disciplines turn to software simulation to overcome such limitations, the corresponding tool, Monte Carlo (MC) has proven impractical due to the computational overhead. Specifically, the large number of particles required to generate the uniform flood fields used to determine the NPS in the conventional DQE(f) calculation is prohibitive. The approach presented in this work exploits the theoretical concepts of Lubberts by averaging the individual NPS' derived from autocorrelation functions resulting from single x-ray photon interactions, thereby greatly reducing the number of required simulated x-rays. We show furthermore, that the autocorrelation function is fully characterized by a minimum number of optical photons, which can be much lower than that of real materials. The combination of these optimizations results in a single CPU execution time on the order of minutes for an accurate scintillating detector DQE(f).

8668-134, Session PSWed

Achieving sub-pixel resolution using CZT-based photon counting detectors for dedicated breast CT

Andrey V. Makeev, Stephen J. Glick, Univ. of Massachusetts Medical School (United States); John McGrath, Kromek (United Kingdom); Martin Clajus, Scott Snyder, Nova R&D, Inc. (United States)

Our group is investigating dedicated CT imaging of the breast using a direct conversion CZT semiconductor detector that operates in photon counting mode. For clinical applications, such as visualizing microcalcifications or assessing tumor microvasculature, breast CT requires high spatial resolution. A straightforward approach for improving spatial resolution is to reduce the size of the detector pixel. Two problems arise when designing a CZT-based detector with very small pixels: 1) expense of fabricating the circuitry becomes prohibitive, 2) inter-pixel charge sharing can obviate any improvement in spatial resolution. To address these issues, we investigate a detector design with a physical pixel pitch of 200 microns that explicitly takes advantage of the charge sharing to achieve sub-pixel spatial resolution on an event-by-event basis. Our aim is to identify the quadrant of the central pixel in which the X-ray interaction occurred, resulting in an effective pixel size of 100 microns. To test this approach, computer simulations are performed using the COMSOL package to model charge transport within the detector. Two algorithms for estimating X-ray interaction position were analyzed: maximum likelihood and a more simplistic method that can be practically implemented in an application specific integrated circuit, without excessive limitations on count-rate. Our simulations show that, as good as, 20 micron uncertainty on the X-ray interaction location is achievable, using the method of maximum likelihood, for a CZT detector with a 200 micron pixel pitch. Another technique, employing pixel sub-division into quadrants, allows for 50 micron uncertainty position measurements and offers a far superior speed performance.

8668-135, Session PSWed

Application of organic semiconductors in amorphous selenium based photodetectors for high performance X-ray imaging

Shiva Abbaszadeh, Zhechen Du, Nicholas Allec, Karim S. Karim, Univ. of Waterloo (Canada)

Previously organic materials have found use in amorphous selenium (a-Se) detectors by improving their stability and spectral response. Fuji used fullerene (C60)-doped polymer layer to improve the lag characteristics and durability in high ambient temperature. Another research group used zinc hexadecafluoro phthalocyanine (F16 -ZnPc) to extend the long wavelength spectral response of a-Se devices.

The good interface quality of a-Se and organic material makes organic material a good candidate to be used as a blocking layer for a-Se detectors. A proper hole blocking contact should have either a large potential barrier for holes between the positively biased metal contact and the a-Se layer or a large number of hole traps and a very low hole mobility. In addition, electrons should be able to flow freely through this hole-blocking layer. Most importantly, the layer should be compatible with the large area electronics semiconductor fabrication process. There are numerous organic materials that have attractive properties that satisfy the requirements of a good hole-blocking layer.

In this study we investigate different organic materials with high ionization potential and good electron mobility as hole-blocking layers for a-Se based photodetectors for indirect medical imaging applications. The effect of the thickness of organic layers (50-300 nm) on the dark current performance of the device will be examined.

8668-136, Session PSWed

Spatial resolution characteristics of a-Se imaging detectors using Monte Carlo methods with detailed spatiotemporal transport of x rays, electrons, and electron-hole pairs under applied bias

Yuan Fang, Univ. of Waterloo (Canada) and FDA/CDRH/OSEL/DIAM (United States); Andreu Badal, U.S. Food and Drug Administration (United States); Karim S. Karim, Univ. of Waterloo (Canada); Aldo Badano, U.S. Food and Drug Administration

(United States)

Detectability of microcalcifications and small lesions in mammography has driven the development of high spatial resolution imagers with small pixel pitch. In this work, we study the detector resolution limits of amorphous selenium (a-Se) with a detailed Monte Carlo transport code for simulation of direct x-ray detectors. The model takes into account generation and re-absorption of characteristic x rays, spreading due to Compton scattering and high-energy secondary electron transport, and drift and diffusion of electron-hole pairs under the applied external electric field. The transport of electron-hole pairs is achieved with a spatiotemporal model that accounts for recombination and trapping of carriers and Coulombic effects of 3D spatial charge distribution. The location information for each detected electron and hole over millions of simulation histories are used to build the detector point response. A range of incident x-ray energies are simulated from 10 to 100 keV. The simulated detector point response can be used to study the spatial resolution characteristics of detectors at different energies ranges and for calculation of the modulation transfer function and image quality metrics.

8668-137, Session PSWed

Fabrication and characterization of a novel x-ray silicon detector

Kyung-Wook Shin, Karim S. Karim, Univ. of Waterloo (Canada)

As the protein crystallography being a crucial method of protein structure investigation in modern medicine science, the requirement of X-ray diffraction detectors has been studied continuously. We have introduced the silicon detector, based on active-pixel readout of hydrogenated amorphous silicon(a-Si:H) thin film transistors(TFTs). In this work, we will present the fabrication process of the detector array, performance of the first batch of TFT array, and the performance of the TFTs in terms of field-effect mobility, gate material quality, and stability under long stress under Fe-55 (50 uCi)gamma ray, which has around 6 to 10 keV photon energy range, presence. The fabrication process was mainly performed in the in-house facility, Giga-to-Nano microfabrication facility, in University of Waterloo, involving plasma enhanced chemical vapor deposition(PECVD) and wet and dry etch techniques involving simple two mask process. The TFT test results promise higher field effect mobility of 16.49 cm2/V•s due to the presence of silicon substrate contacting the a-Si:H channel layer with a compromise of leakage current, yielding 104 of on/off ratio. Meanwhile, the threshold voltage shift can be cured rather easily by applying negative voltage less than 1/10 of the duty cycle. From the detector leakage test, the leakage current through TFT gate was acceptable range while the photo-generated current needs to be suppressed with positive voltage bias at the gate electrode. Thus, minimizing the negative gate bias in readout operation is crucial. Finally, TFT readout current under the same Fe-55 X-ray source shows the optimal operation range can be determined when bulk bias is higher than TFT operation biases.

8668-138, Session PSWed

High performance microstructured Lu2O3:Eu thin film scintillator for X-ray computed tomography

Zsolt Marton, Harish B. Bhandari, Charles Brecher, Stuart R. Miller, Bipin Singh, Vivek V. Nagarkar, Radiation Monitoring Devices, Inc. (United States)

Large penetration depth and weak interaction of high energy (hard) X-rays in living organisms provide a non-destructive way to study entire volumes of organs without the need for sophisticated preparation (injection of contrast material, radiotracer labels etc.). X-ray computed tomography (CT) is a powerful diagnostic tool allowing 3D image reconstruction of the complete structure. Using hard X-rays in medical imaging leads to reduced dose received by the patient. At higher energies, however, the conventional scintillators quickly become the limiting factor. They must be thin in order to provide reasonable spatial resolution and preserve image quality. Nevertheless, insufficient thickness introduces the need for long acquisition times due to low stopping power. To address these issues, we synthesized a new structured scintillator to be integrated into CCD- or photodiode-based CT systems. Europium-doped Lu2O3 (Lu2O3:Eu) has the highest density among all known scintillators, very high absorption coefficient for X-rays and a bright red emission matching well to the quantum efficiency of the underlying CCD- and photodiode arrays. When coupled to a suitable detector, this microcolumnar scintillator significantly improves the overall detective quantum efficiency of detector. For the first time ever, structured and scintillating film of Lu2O3:Eu was grown by electron-beam physical vapor deposition. A prototype sensor was produced and evaluated using both laboratory X-ray sources as well as synchrotron radiation. Comparative performance evaluations of the newly developed sensor versus commercial grade scintillators were conducted. Such synthesis of high density, micro-structured, scintillating coatings enables the development of high sensitivity X-ray detectors for CT applications.

8668-139, Session PSWed

Low dark current and high dynamic range a-Si:H MSM photodetector for large area medical imaging

Sina Ghanbarzadeh, Shiva Abbaszadeh, Michael Adachi, Karim S. Karim, Univ. of Waterloo (Canada)

Previously a-Si:H metal-semiconductor-metal (MSM) lateral detectors for indirect medical imaging applications had been proposed by our research group. These lateral detectors are attractive due to their ease of fabrication primarily because there is no p+ doped semiconductor layer, thus making it compatible with industry standard amorphous silicon thin film transistor electronics processing. However the earlier devices exhibited high dark current which is problematic for integration mode imaging. In the other words, they were limited in term of dynamic range. In this study, we demonstrate an a-Si:H MSM lateral structure with low dark current, high dynamic range and comparable sensitivity and quantum efficiency to conventional p-i-n photodiodes. These improvements are achieved by the introduction of a thin polymer layer as a blocking contact. The fabricated amorphous silicon based MSM detector exhibits a photo-response of more than 3 orders of magnitude to a green light source (λ = 525nm). In comparison to vertical p-i-n structures, the reported MSM lateral devices show gains in terms of dynamic range, ease of fabrication (no p+ layer), faster speed at the cost of a slightly reduced quantum efficiency. The experimental results of dark and photocurrent measurements as well as the responsivity for two in-house fabricated MSM structures at different bias voltages and light intensity are presented. This results are promising and encourage the development of a-Si:H lateral MSM devices for indirect conversion large area medical imaging applications and especially low cost flat panel computed tomography.

8668-224, Session PSWed

Investigating the optical diffusion capabilities of nanophosphors for use in medical imaging

P. F. Liaparinos, I. S. Kandarakis, Technological Educational Institute (Greece)

For several decades, micro powder phosphors have been employed in indirect detectors of many diagnostic medical imaging systems. Within this application it is of interest to investigate whether nanophosphors could replace existing micro phosphors for next generation high-performance displays and imaging devices. For this reason sophisticated quantitative and qualitative research on nanophosphors is still required. The purposes of the present investigation was: (i) to provide a detailed analysis of the optimum structural and optical properties of

nanophosphors, within the framework of Mie scattering theory, using Monte Carlo simulation and (ii) trace possibilities for further image signal modulation improvement. A variety of structural and optical properties were examined and corresponding optimum optical parameters were predicted (e.g. light extinction coefficient , probability of light absorption, light anisotropy factor). Thereafter, Monte Carlo techniques were employed to simulate optical diffusion within nanophosphors of different structural parameters (Regions of grain sizes: (i) 200 - 600 nm, (ii) 600 - 800 nm and (iii) 800 - 1000 nm) and estimate modulation transfer curves. Results showed that the spatial frequency was found higher in case of low grain size nanophosphors. In particular, the spatial frequency was found approximately: 38 cycles/cm (case i), 42.5 cycles/cm (case ii) and 47 cycles/cm (case iii). For a specific thickness of nanophosphor layer (200 ?m), high signal (optical) modulation was accomplished employing nanograins of high refractive index and size close to 200 nm.

8668-225, Session PSWed

Light emission efficiency of Lu_2O_3:Eu nanophosphor scintillating screen under x-ray radiographic conditions

I. E. Seferis, Univ. of Patras Medical School (Greece); N. I. Kalyvas, I. G. Valais, C. M. Michail, P. F. Liaparinos, G. P. Fountos, Technological Educational Institute of Athens (Greece); E. Zych, Wroclaw Univ. (Poland); I. S. Kandarakis, Technological Educational Institute of Athens (Greece); George Panayiotakis, Univ. of Patras Medical School (Greece)

Phosphors are used in indirect digital radiography as x-ray to light converters coupled to electronic optical sensors (photodiodes, CCDs, CMOS). Recently, nanophosphors have been reported to have enhanced luminescence efficiency. The purpose of the present study was to evaluate Lu2O3:Eu nanophosphor as a candidate for medical imaging applications. Lu2O3:Eu was employed in the form of a 30.2 mg/cm2 powder screen of 50 nm grain size and 5% Eu concentration. Both the nanophosphor material and the screen were prepared in our laboratories. Parameters such as the Absolute Efficiency-AE (light energy flux over exposure rate), the Luminescence Efficiency-XLE (Light energy flux over incident x-ray energy flux), Detector Quantum Gain-DQG (optical quanta emitted per incident x-ray quantum) and the light spectral compatibility to electronic optical sensors (Effective Efficiency) were investigated under X-ray excitation in the radiographic energy range. Results were compared with previously published data for a 33.1 mg/cm2 Gd2O2S:Eu conventional phosphor screen. It was found that Lu2O3:Eu nanophosphor has higher AE and XLE by a factor of 1.32 and 1.37 on average, respectively, in whole radiographic energy range. DQG was also found higher in the energy range from 50 kVp to 100 kVp and comparable thereafter. Effective efficiency was found with high values for electronic optical sensors such as CCDs and CMOS, due to the high spectral compatibility with the red light wavelength range. These results indicate that Lu2O3:Eu nanophosphor could potentially be considered for applications in digital X-ray radiography detectors.

8668-141, Session PSWed

Expanded analysis of occupational dose in interventional and diagnostic fluoroscopy with the use of active dosimeters

Robert Bujila, Charlotta Palmgren, Karolinska Univ. Hospital (Sweden); Artur Omar, Annette Fransson, Karolinska Univ Hospital (Sweden)

Due to the relatively high occupational doses associated with interventional and diagnostic fluoroscopy procedures it is important to create awareness about and to quantify the radiation environment that medical staff are exposed to. A computer program was developed to analyze dose data collected from a dosimetry system that uses active dosimeters to monitor staff dose in real-time, to obtain an expanded analysis of the radiation environment that clinical staff are exposed to on a procedural basis. The analyses that are made per procedure and staff member include: accumulated dose μSv, maximum and median dose rate μSv/h, the amount of time a staff member has been exposed to radiation compared to the total fluoroscopy time and the percentage of accumulated dose from 3 different dose rate intervals, including < 0.3 mSv/h, 0.3 - 2.6 mSv/h, and > 2.6 mSv/h. The developed computer program was used to analyze dose data collected from the dosimetry system at the Karolinska University Hospital to study the radiation environment that different categories of staff are exposed to during interventional aorta aneurysm treatment procedures. The analyses have provided the ability to know where to concentrate radiation safety training in interventional and diagnostic fluoroscopy and to ensure that operating rooms are equipped with adequate radiation protection (e.g., radiation protection barriers etc.). The developed computer program and dose data collected from the dosimetry system can be appropriated for other radiation environmental studies in diagnostic x-ray imaging.

8668-142, Session PSWed

Dose reduction in fluoroscopic interventions using a combination of a region of interest (ROI) x-ray attenuator and spatially different, temporally variable temporal filtering

Setlur Nagesh Swetadri Vasan, Liza Pope, Ciprian N. Ionita, Toshiba Stroke and Vascular Research Ctr. (United States); Albert H. Titus, Univ. at Buffalo (United States); Daniel R. Bednarek, Stephen Rudin, Toshiba Stroke and Vascular Research Ctr. (United States)

A novel dose reduction technique for fluoroscopic interventions involving a combination of a material x-ray region of interest (ROI) attenuator and spatially different, temporally variable ROI temporal recursive filter, was used to guide the catheter to the ROI during two animal studies. In the first case presented in a rabbit, a catheter was guided to the entrance of the carotid artery. With the added ROI attenuator the image under the high attenuation region is very noisy. By using temporal filtering with a filter weight of 0.6 on previous frames, the noise is reduced. In the second study the catheter was guided to the descending aorta of a sheep. The sheep offered a relatively higher attenuation to the incident x-rays and thus a higher temporal filter weight of 0.8 on previous frames was used during the procedure to reduce the noise to levels acceptable by the interventionalist.

The image sequences from both studies show that significant dose reduction of 5-6 times can be achieved with acceptable image quality outside the ROI by using the above mentioned technique. Even though the temporal filter weighting outside the ROI is higher, the consequent lag does not prevent perception of catheter movement.

8668-143, Session PSWed

Updates in the real-time Dose Tracking System (DTS) to improve the accuracy in calculating the radiation dose to the patient's skin during fluoroscopic procedures

Vijay Rana, Stephen Rudin, Daniel R. Bednarek, Toshiba Stroke Research Ctr. (United States)

We have developed a dose- tracking system (DTS) to manage the risk of deterministic skin effects to the patient during fluoroscopic image-guided interventional procedures. The DTS calculates the radiation dose to the patient's skin in real-time by acquiring exposure parameters and imaging-system geometry from the digital bus on a Toshiba C-arm unit, and displays the cumulative dose values as a color map on a 3D graphic of the patient for immediate feedback to the interventionalist.

Several recent updates have been made to the software to improve its function and performance. Whereas the older system needed manual input of pulse rate for dose-rate calculation and used the CPU clock with its potential latency to monitor exposure duration, each x-ray pulse is now individually processed to determine the skin-dose increment and to automatically measure the pulse rate. In addition, since the presence of attenuating materials such as the patient table and pad beneath the patient affect the skin dose for under-table projections, both table and pad must be considered. Whereas the previous software only included the table, we recently added a correction for the pad which was found to reduce the beam intensity to the patient by an additional 5-11% over that of the table alone, for 0-50° beam angulation and all x-ray filters at 80 kVp. A technique for correcting table and pad attenuation as a function of beam angulation has been further introduced. These changes provide more accurate estimation of the skin-dose which is critical for managing patient radiation risk.

8668-144, Session PSWed

Extraction of coronary angiographic information from low tube current HYPR-CT myocardial perfusion scans

Yinghua Tao, Michael A. Speidel, Michael S. Van Lysel, Univ. of Wisconsin-Madison (United States); Guang-Hong Chen, Univ. of Wisconsin School of Medicine and Public Health (United States)

Low tube current scanning in combination with HYPR (HighlY constrained backPRojection) noise reduction is a proposed method for low-dose time-resolved CT myocardial perfusion imaging. We report animal studies and simulations investigating the coronary angiographic information available in these scans. Four pigs were scanned at 100 mA and 500 mA. Image noise was matched between 100-mA HYPR and 500-mA FBP images. Vessel cross sectional area and intensity in HYPR images were less than 6% different on average compared to FBP images for vessels larger than 2 mm^2. Vessel visibility in 100-mA HYPR images was improved relative to 100-mA FBP, in cross sectional and multiplanar reformatted images.

8668-145, Session PSWed

Image extrapolation for patient specific CT dose determination based on Scout images

Qing Liang, Larry A. DeWerd, Univ. of Wisconsin-Madison (United States)

Monte Carlo (MC) simulation based on patient CT images is a promising way to determine patient-specific dose. It is well-known that interactions between the x-ray photons and patient start beyond the scan region, and cannot be taken into account when using only the CT images during MC simulations of dose. However, the interactions outside the scan region also contribute to dose to the patient, and dose underestimation (especially at the scan edge) will appear without enough scatter from the region beyond the scan region. In this work, the dose underestimation without any additional scatter in the scan region is demonstrated and the size of the scatter region required for providing accurate results was determined with mathematical phantom studies. Without any additional scatter, a 25% underestimation in dose was observed. It was found that at least 40 mm of scatter is required for both the 40 mm and 5 mm collimation sizes. Different image extrapolation methods based on the existing CT images and Scout images were proposed based on a chest CT scan. The dose calculation with the chest images only and chest images plus four different types of extrapolated images were compared with the dose calculated using the whole body images. The image extrapolation methods especially the ones based on Scout images were shown to improve the dose calculation accuracy under both step-shoot scan mode and helical scan mode.

8668-146, Session PSWed

An approach to correlate the CTDIvol to organ dose for thorax and abdomen CT taking tube current modulation and patient size into account

Xochitl Lopez Rendon, Univ. Katholieke Leuven (Belgium); Federica Zanca, UZ Leuven (Belgium); Raymond Oyen, Hilde Bosmans, UZ Leuven (Belgium)

Purpose: To estimate conversion factors for calculating effective dose (E) and organ dose taking tube current modulation (TCM) and patient size into account in adult thorax and abdomen CT examinations.

Method: 99 consecutive adult patients were included in this study. All examinations were performed with TCM (CareDose 4D, Siemens Definition Flash) at 120 kVp and 110 (thorax) and 200 (abdomen) reference mAs. E and organ dose were estimated with PCXMC 2.0 (STUK, Helsinki, Finland), using an extension of the software from a planar geometry to spiral acquisitions of a CT scanner. This software accounts for patient size by rescaling the anthropomorphic phantom to actual patient weights and heights.

E and organ doses were normalized to the CTDIvol as reported in the patient's report. These conversion factors (dE and dorgan) were studied as a function of different patient metrics: lateral and anterior-posterior (AP) diameter, sum of the lateral and AP diameter, area of a cross section image and effective diameter.

Results:. For a thorax examination, the average dE was 0.57 ± 0.14 mSv/mGy, dlungs was 1.26 ± 0.28 and dbreasts was 1.29 ± 0.40. For an abdomen scan dE was 0.82 ± 0.18, mSv/mGy, dstomach was 1.42 ± 0.26, dliver was 1.42 ± 0.30. No trend was found for any of the metrics neither for E nor for the organs investigated (lungs, breasts, stomach and liver).

Conclusion:. For the scanner studied, average conversion factors, which account for TCM and patient size, were proposed. This is a first step towards patient-specific dosimetry.

8668-147, Session PSWed

Longitudinal study of radiation exposure in computed tomography with an in-house developed dose monitoring system

Bernhard Renger, Ernst J. Rummeny, Technische Univ. München (Germany); Peter B. Noël, Technische Univ. München (Germany)

The reduction of radiation exposure in CT in one of the most explored topics. In the same time, it seems challenging to quantify the clinical dose reduction with regard to new dose reduction strategies. To overcome this challenge, we developed a Dose-Monitoring-System, which collects information from PACS, RIS, MPPS and structured reports. We investigated the dose reduction in CTA examination when employing a noise-suppressing reconstruction. For this examination a significant long-term reduction in dose is reported. In summary our DMS enables to track radiation exposure on daily bases as well as long-term effects of new dose saving strategies.

8668-148, Session PSWed

Comparison of organ and effective dose between chest radiography, tomosynthesis, and CT

Yakun Zhang, Xiang Li, William P. Segars, Ehsan Samei, Duke Univ. (United States)

There are three main x-ray based modalities for imaging the thorax:

radiography, tomosynthesis, and CT. CT perhaps provides the highest level of feature resolution but at notably higher radiation dose. To identify the best imaging modality for patients, the American College of Radiology published the guiding principle of "The right exam, for the right reason, at the right time". To implement this principle in making an appropriate choice between standard chest projection imaging, tomosynthesis, and CT, the organ and effective dose for each modality should be accurately known. In this study, we used identical computational anthropomorphic male and female extended cardiac-torso (XCAT) reference phantoms and Monte Carlo dose estimation methods to assess organ dose and effective dose across the three modalities. A clinical X-ray radiography system with the capability of conducting tomosynthesis and a clinical 64-slice CT system was modeled by a Monte Carlo package (PENELOPE). The modalities were simulated using common clinical technique (120 kVp, 25 and 75 mR ESE for PA and lateral radiography, 250 mR ESE for tomosynthesis, 12.02 mGy CTDIvol for chest CT). Organ doses were obtained from the simulation and used for the calculation of effective dose. The effective dose for the chest tomosysthesis was about three times of the conventional two view chest X-ray and around 4% of the chest CT examination.

8668-149, Session PSWed

Comparison of photon counting and conventional scintillation detectors in pinhole SPECT system for small animal imaging

Young-Jin Lee, Hee-Joung Kim, Hyun-Ju Ryu, Su-Jin Park, Yonsei Univ. (Korea, Republic of)

The photon counting detector based on cadmium telluride (CdTe) or cadmium zinc telluride (CZT) is a promising imaging modality and provides many benefits compared to conventional scintillation detectors. When using the pinhole collimator with the photon counting detector, we are able to improve both spatial resolution and sensitivity. The purpose of this study was to evaluate the photon counting and conventional scintillation detectors in the pinhole SPECT system. We designed five pinhole SPECT systems of two types. One was the CdTe photon counting detector, and the other was the conventional NaI(Tl) scintillation detector. We conducted simulations studies and evaluated the image performances. The results showed that the spatial resolution of CdTe photon counting detector was 0.38 mm and the sensitivity in this detector was 1.40 times higher than conventional NaI(Tl) scintillation detector in the same detector thickness condition. Also, the averages of scatter fraction of the CdTe photon counting and the conventional NaI(Tl) scintillation detectors were 1.93% and 2.44%, respectively. In conclusion, we successfully evaluated various pinhole SPECT systems for small animal imaging.

8668-150, Session PSWed

Non-invasive high-resolution tracking of human neuronal pathways: diffusion tensor Imaging at 7T with 1.2 mm isotropic voxel size

Ralf Lützkendorf, Otto-von-Guericke-Univ. Magdeburg (Germany); Frank Hertel, Otto-von-Guericke-Univ. Magdeburg (Germany); Robin M. Heidemann, Siemens Healthcare Sector (Germany); Andreas Thiel, OFFIS e.V. (Germany); Michael Luchtmann, Otto-von-Guericke-Univ. Magdeburg (Germany); Markus Plaumann, Otto-von-Guericke-Univ. Magdeburg (Germany); Jörg Stadler, Leibniz Institute for Neurobiology (Germany); Johannes Bernarding, Otto-von-Guericke-Univ. Magdeburg (Germany)

Diffusion tensor imaging (DTI) allows characterizing and exploiting diffusion anisotropy effects, thereby providing important details about tissue microstructure. A major application in neuroimaging is the so-called fiber tracking where neuronal connections between brain regions are determined non-invasively by DTI. Combining these neural pathways within the human brain with the localization of activated brain areas provided by functional MRI offers important information about functional connectivity of brain regions. However, DTI suffers from severe signal reduction due to the diffusion-weighting. Ultra-high field (UHF) Magnetic resonance imaging (MRI) should therefore be advantageous to increase the intrinsic signal-to-noise ratio. This in turn enables to acquire high quality data with increased resolution which is the prerequisite to perform optimum data processing as necessary for tracking small or bent fibers. But UHF MRI imposes difficult problems mainly due to the larger B1 inhomogeneity as compared to 3T MRI. We therefore optimized the parameters to perform DTI at a 7 Tesla whole body Magnetic Resonance Tomograph equipped with a 70 mT/m gradient coil and a 32 channel head coil. A Stesjkal Tanner spin-echo EPI sequence was used, to acquire 110 slices with an isotropic voxel size of 1.2 mm covering the whole brain. 60 directions were scanned which enabled to calculate the principal direction components of the diffusion vector in each voxel. The results prove that DTI can be performed with high quality under UHF conditions. Combining UHF fMRI data with UHF DTI results will therefore be a major step towards better neuroimaging methods.

8668-151, Session PSWed

Motion correction of rodent thoracic PET image using radioactive bead and MRI image

Jung Woo Yu, Korea Institute of Radiological & Medical Sciences (Korea, Republic of) and Yonsei Univ. (Korea, Republic of); Sang-Keun Woo, Yong Jin Lee, In Ok Ko, Ran Ji Yoo, Joo Hyun Kang, Byung Il Kim, Korea Institute of Radiological & Medical Sciences (Korea, Republic of); Yong Hyun Chung, Yonsei Univ. (Korea, Republic of); Sang-Moo Lim, Korea Institute of Radiological & Medical Sciences (Korea, Republic of); Kyeong Min Kim, Korea Institute of Radiological & Medical Sciences (Korea, Republic of)

PET image of tumor located in thoracic region was affected by various organ motions such as respiration and heartbeat. Thoracic motion is difficult to estimate and correct accurately using external measurement or anatomical image solely. The aim of this study was to correct the thoracic motion in rodent PET image using radioactive bead and MRI image.

The bead for motion tracking was realized from molecular sieve (MS) contained 0.37 MBq F-18 and placed in thoracic region. PET study was performed using a small animal PET scanner after IV injection of FDG. MRI study was performed using 3-T clinical MRI system with T1-VIBE (TR/TE=5.67/1.42 ms) sequence. Motion corrected PET image was created by mutual information registration with B-Spline interpolation to the mean image after first realignment.

The estimated variation of MS PET image was 2.98, 0.71, 1.42 mm and 0.02, 0.05, 0.13, translations and rotation degree, respectively. The estimated variation of MRI image was 0.33, 0.17, 1.01 mm and 0.004, 0.005, 0.005, translations and rotation degree, respectively. The evaluated horizontal and vertical FWHM(mm) of MS was 2.01±0.42, 3.06±0.57 before correction, and 1.89±0.02, 2.89±0.03 after correction. The improvement of resolution was observed by proper correction method.

We approved motion correction was performed well by reduced variation of translations and rotations. In case of MRI image, the motion compensation range was smaller than the reduced variation of MS PET image. These results suggest motion correction would be possible without external device using MRI motion data if pre-calculate factor regarding difference with real motion.

8668-152, Session PSWed

Optimal interpolation algorithm for quantitative estimation of tumor in the thoracic region using small animal PET/MRI image registration

Ji-Min Kim, Korea Institute of Radiological & Medical Sciences (Korea, Republic of) and Konkuk Univ. (Korea, Republic of); Sang-Keun Woo, Jung Woo Yu, Yong Jin Lee, Jong Guk Kim, Ji-Ae Park, Joo Hyun Kang, Byung Il Kim, Korea Institute of Radiological & Medical Sciences (Korea, Republic of); Sang-Moo Lim, Kyeong-Min Kim, Korea Institute of Radiological & Medical Sciences (Korea, Republic of)

Small animal image registration is necessary to accurately evaluate diagnostic and monitoring of therapeutic response in preclinical phases. Intramodality and intermodlity registration can be considered the image characteristics and quality from multimodal imaging by the optimal transformation. The aim of this study was to estimate the optimal interpolation algorithm in PET/MRI image registration. Listmode small animal PET data was obtained from dedicated small animal PET scanner (InveonTM, Siemens) during 20 min. FDG PET images were acquired with OSEM 2D algorithm. The MRI images were obtained with the diagnostic 3T-MRI (MAGNETOM) followed by T1-weighted VIBE sequence (TR=11.6 ms, TE=3.1 ms, FA=10 degree). Registration framework was performed by metric, optimizer, transform and interpolator. We used 4 metrics (Mean squares difference [MSD], normalized cross correlation [NCC], Mattes mutual information [MMI], mean reciprocal squared difference [MRSD]) and 3 interpolators (Nearest neighbor [NI], Linear [LI], B-Spline [BSI]). We use mean squared error and peak signal-to-noise ratio (PSNR) value to compare algorithm performance. In case of PET/PET registration, the highest PSNR was showed 50.663 in MSD with NI. In MRI/MRI registration, the highest PSNR was showed 30.426 in MMI with NI. In PET/MRI multimodal registration, the highest PSNR was showed 10.647, 11.539, 11.403, and 11.331 in MSD with LI, NCC with BSI, MMI with LI, and MRSD with BSI, respectively. In this case, LI was showed proper performance in all of metrics. We confirmed that LI method is widely adaptable in various PET/MRI registration methods. Multimodal image registration method should be optimized with proper interpolation algorithm.

8668-153, Session PSWed

LASCA and PPG imaging for non-contact assessment of skin blood supply

Dainis Jakovels, Uldis Rubins, Janis Spigulis, Univ. of Latvia (Latvia)

Laser speckle contrast analysis (LASCA) offers a non-contact, full-field, and real-time mapping of capillary blood flow and can be considered as an alternative method to Laser Doppler perfusion imaging (LDPI). Photoplethysmography (PPG) is well known technique for assessment of skin blood pulsations that can be related to blood flow. In recent years several studies are done in development of non-contact PPG imaging.

LASCA and PPG technique is simpler and cheaper compared with LDPI. LASCA technique has been implemented in several commercial instruments. However, these systems are still too expensive and bulky to be widely available. Several optical techniques have found new implementations as connection kits for mobile phones thus offering low cost screening device.

In this work we demonstrate simple implementation of LASCA and PPG imaging technique for first and low-cost assessment of skin blood flow. Both devices consist of widely available 1.3 mega pixel CMOS camera. 650 nm laser diode module is used for LASCA illumination and white LEDs for PPG imaging device.

An arterial occlusion test was performed to test LASCA and PPGI imaging devices. An example of scratch image and corresponding blood flow map also was demonstrated. The results showed that both techniques can be used for fast monitoring and mapping of skin blood flow and implemented as connection kits for smartphone.

8668-154, Session PSWed

Multispectral imaging for early diagnosis of melanoma

Anna Pelagotti, Pasquale Ferrara, Leonardo Pescitelli, Chiara Delfino, Istituto Nazionale di Ottica (Italy); Gianni Gerlini, Lorenzo Borgognoni, Regional Melanoma Referral Ctr., Santa Maria Annunziata Hospital (Italy); Alessandro Piva, Univ. degli Studi di Firenze (Italy)

Melanoma is a very aggressive cutaneous neoplasm, incidence and mortality of which are rapidly increasing. Mortality increases in advanced stages, where neoplastic cells reach deeper dermal layers. However, identification of early melanoma may be difficult because its clinical aspects are not so “dramatic” as in advanced melanoma, and it could look like a nevus. Currently, definitive diagnosis is made only by histopathological observation of the excised lesion. Several tools have been developed to help detecting malignant lesions. Dermoscopy highlights numerous characteristic features of the lesion and of the pigmented network. The method we propose exploits a multispectral imaging device to acquire a set of images in the visible and NIR range. Thanks to the fact that light propagates into the skin and reaches different depths depending on its wavelength, such a system is capable of imaging layers of structures placed at increasing depths. Therefore a new semeiotics is proposed to describe the content of such images. Dermoscopic criteria can be easily applied to describe each image in the set, however inter-images correlation needs new suitable descriptors. The first group of new parameters describes how the dermoscopic ones, vary across the set of images. More features are then introduces. E.g. the longest wavelength where structures can be detected gives an estimate of the maximum depth reached by the pigmented lesion. While the presence of a bright-to-dark transition between the wavebands in the violet to blue range, reveals the presence of blue-whitish veil, and is a further malignancy marker.

8668-155, Session PSWed

An optical 3D surface measurement system for medical imaging

Arezoo Movaghar, Reza Safabakhsh, Khosro Madanipour, Amirkabir Univ. of Technology (Iran, Islamic Republic of)

3D imaging and visualization play an increasingly important role for the diagnosis. Recently, a verity of techniques has been developed to produce 3D images. Some of the current methods alter the environment of the body (physically or chemically) in order to obtain data. Development of accurate, real time, non-contact methods of acquiring data with the ability to visualize important structures in great detail is one of the most important purposes of medical imaging research activities. Optical topography is a simple and inexpensive method to reconstruct a 3D model of different parts of human body in order to use for clinical purposes.

In this paper we are proposing a new configuration for fringe projection system in order to acquire highly-detailed images of human body. We used a collimated laser beam as the light source. By combination of a lens as Fourier transformer, a 2-hole plane for selection of +1 and -1 components and an inverse Fourier transform, we produced a complete sinusoidal pattern. This pattern is projected on the object’s surface and the deformed pattern of the projected beam is used for analyzing three dimensional profile of the reference object. Less noise, simpler analysis and faster processes will be eventuated. Difference in the size of the target object is a concern in medical imaging. This method has the lowest-order aberration, highest contrast ratio as well as being applicable to all objects regardless of their size and complexity.

8668-156, Session PSWed

Improved DOT reconstruction by estimating the inclusion location using artificial neural network

Rusha Patra, Pranab K. Dutta, Indian Institute of Technology Kharagpur (India)

Diffuse optical tomography (DOT), a noninvasive imaging modality, uses near infrared light to illuminate the tissue and reconstruct the optical parameters of the tissue from the boundary intensity measurements. Here continuous wave measurements have been performed to make the overall instrument inexpensive. Due to the non-unique solution of the inverse problem, prior information improves the resolution of the reconstructed image. An artificial neural network (ANN) based approach has been developed to obtain the location of the inclusion. The peak amplitude, 50% and 10% bandwidth and their corresponding source-detector angles of the difference intensity plot with and without the inclusion are taken as the input. The offset distance between the source and centre of inclusion, the angle with x-axis, sample and inclusion radii are the output of the 2 layered error back propagation neural network. Least square optimization with regularization term is used to minimize the mean squared error for image reconstruction. The optical parameters are updated using the prior information from the ANN. The parameters present in double the region of detected area are updated only. The performance of the proposed method has been assessed quantitatively by computing the mean square error, object centroid error and misclassification ratio. The use of prior improves the convergence and reduces the presence of ghost or noise. Hence the proposed method shows potential to improve DOT reconstruction.

8668-157, Session PSWed

Single-shot phase-shifting digital holography

Jing Zhang, Univ. of Central Florida (United States); Yu Xie, University of Electronic Science & Technology of China (China); Guifang Li, Univ. of Central Florida (United States); Yutang Ye, Univ. of Electronic Science and Technology of China (China); Bahaa Saleh, Univ. of Central Florida (United States)

No Abstract Available

8668-158, Session PSWed

Pressure distribution on mammography compression of breasts containing breast cancer

Daniel Förnvik, Magnus Dustler, Ingvar Andersson, Håkan Brorson, Pontus A. Timberg, Sophia Zackrisson, Anders Tingberg, Lund Univ. (Sweden)

The pressure distribution over a compressed breast is in general heterogeneous. In this study we investigated the pressure distribution over compressed breasts in the presence of tumor masses. Sixteen women either recalled for work up of findings suspicious for breast cancer in our screening program or with clinically suspected findings were included in the study. Fifteen lesions turned out to be malignant and one benign. The distribution of compression pressure was measured using thin FSR (Force Sensing Resistor) pressure sensors attached to the compression plate. The pressure over the breast was ascertained by acquiring an x-ray image of the compressed breast with the pressure sensors present. The pressure data and the mammogram were used to create a composite image with pressure data displayed as a color overlay. The malignant tumor area generally matched an elevated pressure area and this pressure was generally higher than the pressure over surrounding parenchyma. In 9 out of 16 (56%) subjects the maximum pressure over the breast was located over the tumor. Only 3 out of 16 masses had a lower mean pressure compared to the mean pressure over the breast (including one small < 10 mm tumor and one benign structure). The results suggest that tumors are stiffer, thus, absorbing more pressure compared to the surrounding parenchyma. Refined pressure techniques could possibly be used to demonstrate the relative stiffness distribution in breast tissue, which might provide valuable differential diagnostic information.

8668-159, Session PSWed

Optimizing the acquisition parameters of a newly developed digital breast tomosynthesis system

Hye-Suk Park, Ye-Seul Kim, Yonsei Univ. (Korea, Republic of); JaeGu Choi, Young-Wook Choi, Korea Electrotechnology Research Institute(KERI), (Korea, Republic of); Hee-Joung Kim, Yonsei Univ. (Korea, Republic of)

The purpose of the present work was to investigate the effect of variable acquisition parameters and to characterize their relationships in order to improve the detection of microcalcifications using digital breast tomosynthesis (DBT). DBT acquisition parameters were optimized using 32 different acquisition sets with various angular ranges and projection views (PVs). To investigate the effects of variable angular dose distribution, the acquisition sets were evaluated with delivering more dose toward the central views. To investigate the effect of different distribution for PVs, two PV distributions (the dense distribution of central and peripheral site) were selected from the 21 acquired PVs over ±25° angular range. The contrast-to-noise ratio for in-focus plane quality and the full width at half maximum of artifact spread function for resolution in the z-direction were used. Our results show that a wide angular range improved the reconstructed image quality in the Z-direction. If large PVs are acquired, then electronic noise may dominate the CNR due to reduced radiation dose per projection. The non-uniform acquisition configurations with more PVs or dose on central site distribution yielded the higher image quality than others. Although it was found that increasing concentration of PV or angular dose distributions in central site improved the reconstructed image quality, it was also found that excessive concentration in central site did not improve by increasing noise in the peripheral views. Therefore, it is necessary to consider the potential trade-off of these physical imaging properties for optimizing the acquisition parameters of a DBT system.

8668-160, Session PSWed

Energy dispersive x-ray diffraction computed tomography of breast-mimicking test objects and breast tissue samples

Shyma Alkhateeb, Univ. of Surrey (United Kingdom) and King Abdulaziz Univ. (Saudi Arabia); Mohamed Abdelkader, David Bradley, Silvia Pani, Univ. of Surrey (United Kingdom)

Breast lesions and normal tissue have different characteristics of density and molecular arrangement that affect their diffraction patterns. X-ray diffraction can be used to determine the spatial structure of such tissues at the atomic and molecular level. Energy Dispersive X-Ray Diffraction Computed Tomography (EDXRDCT) can be used to produce 2-dimensional images of cross sections of the samples. The purpose of this work is to use an EDXRDCT system to find the limiting visibility for details that simulate breast lesions. Results are presented for EDXRDCT images of samples of different materials simulating breast tissue contrast and shapes.

For simple circular details, the contrast between details and background in the images was measured with the goal of simulating the contrast between real breast tissue components. The limiting visible diameter was measured as a function of detail diameter in order to find the

limit visibility for different combinations of scanning and geometrical parameter. Images of more complex test objects were assessed in terms of both contrast and accuracy of shape reproduction in order to evaluate the feasibility of using shape analysis as an additional parameter for lesion identification. The optimum combination of parameters will be applied for the scanning of waxed breast tissue blocks.

8668-161, Session PSWed

Mask collimation meets high-efficient data acquisition: a novel design of a low-dose-CT-scanner for breast-imaging

Claudia Braun, Oleg Tischenko, Helmholtz Zentrum München GmbH (Germany); Roswitha Giedl-Wagner, GFH GmbH (Germany); Helmut Schlattl, Christoph Hoeschen, Helmholtz Zentrum München GmbH (Germany)

A novel designed X-ray CT scanning geometry is proposed. Composed of a specially designed tungsten collimation mask and a flat panel detector, which is placed inside the mask, this scanning geometry provides high efficient data acquisition allowing dose reduction potential by factor of two.

In recent years a first prototype of Dual Optimal Reading (CTDOR) geometry has been evaluated. It consisted of a discontinuous ring of detectors fixated on X-Ray absorbing material. The source and an outer detector were mounted on a gantry rotating around the inner static detector and thus the patient. Despite many drawbacks of that set-up, resulting images have shown promising potential of dual reading. This work presents further development and improvement of the preliminary recommended scanner geometry. The main idea consists of collimating the X-ray beam through a specially designed shielding mask thereby reducing radiation dose and structuring data without compromising image quality. An especially developed high precision laser-beam cutting process assures an accurate mask crafting with tungsten shielding and window sizes of 300µm. Surface and edge quality as well as precision-engineered tolerances are essential factors for implementation of good collimation performance and high resolution achievement.

Simulation and phantom data were first obtained to test the scanning device. Retaining advantages of the CTDOR geometry such as dose reduction, scatter correction potential and radiation structuring, the CT-Scanner, proposed in this work, yields high resolution images for breast-imaging in low energy ranges.

8668-162, Session PSWed

The influence of position within the breast on microcalcification detectability in continuous tube motion digital breast tomosynthesis

Eman Shaheen, KU Leuven (Belgium); Nicholas W. Marshall, Hilde Bosmans, UZ Leuven (Belgium)

For digital breast tomosynthesis (DBT), the detectability and characterization of all lesions especially microcalcifications is still an issue under investigation. When the DBT system is equipped with a tube that moves continuously during exposure, theory predicts an impact of the focal spot motion blur on detectability and diagnosis of small lesions, such as microcalcifications. The x-ray tube motion blur experienced by a lesion at some position in the breast is known to depend on the height of the lesion above the table within the breast. In this study, we investigated the influence of position above the table on microcalcification contrast (and detectability), by means of a hybrid simulation method. Microcalcifications, represented by spheres of calcium 400 µm in diameter, were simulated into projection images of homogeneous objects and into anatomical backgrounds. The influence of system sharpness was included via a modulation transfer function (MTF) model that included detector, focus size, tube motion and x-ray oblique entry components. Preliminary results show a contrast reduction of 42% and 32% for a sphere inserted at 69 mm height compared to an insertion 1 mm above the table surface for homogeneous and anatomical backgrounds, respectively.

8668-163, Session PSWed

Breast image registration by using non-linear local affine transformation

Feiyu Chen, Peng Zheng, Penglong Xu, David D. Pokrajac, Delaware State Univ. (United States); Predrag R. Bakic, Andrew D. A. Maidment, Univ. of Pennsylvania (United States); Fengshan Liu, Xiquan Shi, Delaware State Univ. (United States)

A novel breast image registration method is proposed to obtain a composite mammogram from several images with partial breast coverage, for the purpose of accurate breast density estimation. The breast percent density estimated as a fractional area occupied by fibroglandular tissue has been shown to be correlated with breast cancer risk. Some mammograms, however, do not cover the whole breast area, which makes the interpretation of breast density estimates ambiguous. One solution is to register and merge mammograms, yielding complete breast coverage. Due to elastic properties of breast tissue and differences in breast positioning and deformation during the acquisition of individual mammograms, the use of linear transformations does not seem appropriate for mammogram registration. Non-linear transformations are limited by the changes in the mammographic projections pixel intensity with different positions of the focal spot. We propose a novel method based upon non-linear local affine transformations. Initially, pairs of feature points are manually selected and used to compute the best fit affine transformation in their small neighborhood. Finally, Shepherd interpolation is employed to compute affine transformations for the rest of the image area. The pixel values in the composite image are assigned using bilinear interpolation. Preliminary results with clinical images show a good match of breast boundaries, providing an increased coverage of breast tissue. The proposed transformation is continued and can be controlled locally. Moreover, the method is converging to the ground truth deformation if the paired feature points are evenly distributed and its number large enough.

8668-164, Session PSWed

Reduction of patient dose in digital mammography: simulation of low-dose image using computed radiography system and flat panel detector system

Yuki Saito, Nagoya Univ. (Japan); Maki Yamada, Nagoya Daini Red Cross Hospital (Japan); Naotoshi Fujita, Nagoya Univ. Hospital (Japan); Yoshie Kodera, Nagoya Univ. (Japan)

To reduce the patients' exposure, several low-dose images are necessary to obtain an image that can be used for diagnosis. However, it is clinically undesirable to expose a patient to multiple exposures in order to obtain an optimal image. The purpose of this study was to simulate a low-dose image from the image generated by a routine dose. Images of acrylic steps were obtained using multiple doses in digital mammography to generate additional noise. This study used the digital mammography system with different detectors. It is computed radiography (CR) system and flat panel detector (FPD) system. This noise was added to take into account the resolution of the X-ray detector using the following filters. The filters were designed based on the presampled modulation transfer function (MTF), digital MTF containing aliasing, and measured value of the Wiener spectrum (WS). The image simulated using the filter based on the WS was similar to an actual low-dose image by both systems. The image simulated using the presampled MTF filter was less similar to an actual low-dose image by CR system. But the image simulated using the presampled MTF filter of FPD system was similar to an actual low-dose image. The image simulated using the digital MTF filter was closer to

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an actual low-dose image compared to the image simulated using the presampled MTF filter by CR system. By using the proposed method, we were able to obtain a simulated low-dose image from an image generated by a routine dose.

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Estimating breast density with dual energy mammography: a simple model based on calibration phantoms

Hyunkoo Chung, Lynda Ikejimba, Nooshin Kiarashi, Ehsan Samei, Duke Univ. (United States); Mathias Hoernig, Siemens Healthcare (Germany); Joseph Y. Lo, Duke Univ. (United States)

Dual energy digital mammography has been used to suppress specific breast tissue, primarily for the purpose of iodine contrast-enhanced imaging. Another application of dual energy digital mammography is to estimate breast density, as defined by the fraction of glandular tissue, by suppressing adipose tissue. Adipose equivalent phantoms were used to derive the weighting factor for dual energy subtraction at 2, 4, and 6 cm thickness, then linearly fit to derive weights for 1, 3, and 5 cm. For all 6 thicknesses, measurements were taken over a range of densities (0-100% for even thicknesses, 30-70% for odd thicknesses) and used for calibration measurements to model a density map. For the various thickness and densities, the maximum error for calibration density estimates of the uniform phantoms was 4.3, mean error was 2.8, and RMS error was 2.9. Once the density map was verified with uniform slabs, the density map was evaluated with a 50/50 CIRS 020 phantom and demonstrated the feasibility of using dual energy subtraction to estimate breast density on complex phantoms.

8668-166, Session PSWed

Are uniform phantoms sufficient to characterize the performance of iterative reconstruction in CT?

Justin B. Solomon, Ehsan Samei, Duke Univ. Medical Ctr. (United States)

research in CT. The non-linearity of IR algorithms poses challenges to using traditional image quality metrics. Past attempts to evaluate iterative algorithms have relied on measurements taken from uniform background phantoms. In this study, noise is measured in CT images with gross texture (acrylic spheres + water), fine texture (sponge + water), and no texture (water). Images were reconstructed with a commercially available IR algorithm (SAFIRE) and filtered back projection (FBP). Noise was characterized in terms of pixel standard deviation, noise power spectrum (NPS), and stationarity for IR and FBP images of all background types using an image subtraction technique. For textured (uniform) backgrounds, pixel standard deviation was 34-14% (27%) lower for IR images compared to FBP. The peak frequency of the NPS of the IR images was slightly shifted towards low frequencies by as much as 0.02 mm-1 for textured backgrounds and 0.01 mm-1 for uniform background. The stationarity of noise in IR images was comparable to FBP. For IR images with gross texture, pixel noise was 20% lower in acrylic sphere regions compared to water regions in the same slice. For FBP images, there were negligible differences between acrylic sphere and water regions in terms of pixel noise. The background dependency of noise is a feature of SAFIRE reconstruction that has not been previously reported.

8668-167, Session PSWed

Noise power spectrum and modulation transfer function analysis of breast tomosynthesis imaging

Weihua Zhou, Linlin Cong, Southern Illinois Univ. Carbondale (United States); Xin Qian, The Univ. of North Carolina at Chapel Hill (United States); Ying Chen, Southern Illinois Univ. Carbondale (United States); Yueh Z. Lee, The Univ. of North Carolina at Chapel Hill (United States); Jianping Lu, Otto Z. Zhou, The Univ. of North Carolina at Chapel Hill (United States)

The recent commercialization of digital breast tomosynthesis systems realizes the clinical applications of this new three-dimensional imaging technology. The total dosage of breast tomosynthesis for single patient is comparable to that of the traditional mammography. The incomplete sampling of tomosynthesis imaging requires understanding of physical fundamentals of tomosynthesis and image reconstruction. This paper presents our continuous work on image quality analysis for the optimization of a new multi-beam breast tomosynthesis system based on carbon nanotube X-ray emission technology. Several tomosynthesis reconstruction algorithms were implemented to reconstruct the phantom data. Noise power spectrum and modulation transfer function were investigated to evaluate the image quality.

8668-168, Session PSWed

System sharpness (STF) analysis of HD-OCT in 3D space using standard MTF methods

Horst Scherer, Rainer Nebosis, Malte Schulz, Marc A. Weber, Agfa-Gevaert HealthCare GmbH (Germany)

For many applications of optical coherence tomography systems (OCT) optical resolution is a key feature. We present a method to determine the system transfer function (STF) of a full field high definition OCT (HD-OCT) in the three-dimensional space.

The measurement of the system sharpness is performed using structured glass phantoms, with a reflectivity adapted to the system dynamic range.

After aligning the phantom within the field of view, a 3D image is recorded.

A polynomial fit is applied to the 3D cube to extract the surface of the edge in space. In that way the image field curvature as well as the orientation of the surface in space are obtained.

In a second step the intensity distribution of that surface is projected onto a plane using the polynomial fit parameters.

Such a reconstructed planar phantom image allows a true 3D sharpness evaluation using standard MTF analysis. In this way the technical image quality during production can be ensured.

This procedure - to our knowledge - was applied for the first time to a full 3D OCT (SKINTELL). Such a HD-OCT is capable to produce a full 3D image with more than 325k parallel A-scans in only one fast sweep.

The optimum sharpness in every depth position is ensured during the sweep by focus tracking.

The devices showed typical STF values larger than 25% @ 170 lp/mm, which is in accordance to dermatological surveys.

8668-169, Session PSWed

Evaluation of Nonlinear Pre-sampled Modulation Transfer Function in Iterative Reconstruction CT

Hyeong-min Jin, Jong Hyo Kim, Seoul National Univ. (Korea, Republic of)

Iterative reconstruction (IR) technique is growingly used in clinical CT imaging due to improved image quality at lower patient doses. However, the nonlinear frequency response in different noise level and object contrast is less explored. In this paper, we evaluate noise level and contrast dependent behavior of modulation transfer function in iterative reconstruction computed tomography imaging with an in-house phantom. We created multi-contrast edge phantom, which consists of acrylic panel and has iodine concentration of different contrast. Images were acquired on multi-detector CT (Discovery CT750 HD: GE) at four dose levels (25, 50, 100 and 200mAs), and were reconstructed using FBP and two IR technique (ASIR50 and VEO). Edge spread functions were extracted across angled edges on image, and were differentiated to yield line spread function. LSF were Fourier transformed to evaluate the presampled MTFs of IR and FBP reconstruction techniques. At same dose level (200mAs), the MTFs with higher contrast showed marginally higher response than that of lower contrast in VEO. A MTF50 of 200mAs showed clearly higher responses up to 19% than that of 25mAs scan with VEO reconstruction at Contrast 6. Our study revealed that MTF of IR technique degrades depending on noise level at low dose scan. Therefore, we recommend that its characteristic should be considered in quantitative analysis such as lesion size measurement.

8668-170, Session PSWed

An experimental study on the shift-variant MTF of CT systems using a simple cylindrical phantom

Hosang Jeon, Pusan National Univ. Yangsan Hospital (Korea, Republic of); Hanbean Youn, Ho Kyung Kim, Soohwa Kam, Pusan National Univ. (Korea, Republic of)

The spatial resolution of computed radiography (CT) is one of key parameters to evaluate CT performances. The typical factor to represent spatial resolution of imaging systems is modulation transfer function (MTF). Recently, a novel method to measure object-based MTF of CT using a conventional quality assurance (QA) phantom was introduced by Richard, etc. For the clinical usefulness, we design a novel acrylic disk phantom with the diameter of 40cm. There are many holes forming the shape of two spiral patterns in our phantom, so any three holes are not on a straight line. Because each hole has different axis-to-hole distance (r) in a spiral pattern, the shift-variant MTF(r) can be acquired by single scan. In the preliminary result, we obtained four MTFs. The best MTF is presented at center, and worst MTF is found at outermost area. For example, MTF(0) is 0.62, and MTF(150) is 0.42 at 0.6 lp/mm. We expect that the sufficient data will be acquired to assess shift-variant MTF(r) function of CT systems by scanning our spiral disk phantom, and the object-based MTF assessment can be done by inserting different materials into the holes of the phantom. Finally, we will present a simple and effective object-based MTF assessment method by the single scan of a novel spiral disk phantom.

8668-171, Session PSWed

Characterization of a breast tomosynthesis unit to simulate images

Alistair Mackenzie, The Royal Surrey County Hospital NHS Trust (United Kingdom); Nicholas W. Marshall, Univ. Hospitals Leuven (Belgium); David R. Dance, The Royal Surrey County Hospital NHS Trust (United Kingdom); Hilde Bosmans, Univ. Hospitals Leuven (Belgium); Kenneth C. Young, The Royal Surrey County Hospital NHS Trust (United Kingdom)

The aim of this work is to characterise the image quality of a mammography system in both planar and tomosynthesis imaging mode for the purpose of realistic image simulation. The technique will be applied to projected images from voxelised breast phantoms to investigate the imaging properties of different configurations of tomosynthesis systems. Methods: A Hologic Dimensions was characterised in terms of noise, sharpness and lag in both planar and tomosynthesis modes. To validate the image simulation, a PMMA block was imaged in planar and tomosynthesis modes, then images were created to simulate these real images. The noise power spectra (NPS) were measured for both sets of images. Results: The MTF was shown to be affected by focus size and movement of the X-ray tube, these effects will be modelled in the projection images using an extended source. The combined effect of lag and ghosting caused the signal in the last projection of a tomosynthesis run to be between 2 and 4% higher than the first projection. The measured NPS of the simulated images of a PMMA block were about 8% lower than the NNPS measured on the real images for both tomosynthesis and planar images. Conclusions: We have characterised the imaging noise and resolution properties of a Hologic Dimensions tomosynthesis system and shown some preliminary results of image simulation for tomosynthesis. Future work may expand the model to include detector lag and ghosting and the influence of oblique X-ray incidence on the detector.

8668-174, Session PSWed

Characterization of spectral x-ray imaging for dental cone-beam computed tomography

Radin Adi Aizudin Bin Radin Nasirudin, Technische Univ. München (Germany); Petar Penchev, Institut für Medizinische Physik und Strahlenschutz, Technische Hochschule Mittelhessen (Germany); Kai Mei, Ernst J. Rummeny, Technische Univ. München (Germany); Martin Fiebich, Institut für Medizinische Physik und Strahlenschutz, Technische Hochschule Mittelhessen (Germany); Peter B. Noël, Technische Univ. München (Germany)

The recent advancement in detector technology contributed toward the development of photon counting detectors with the ability to discriminate photons according to their energy on reaching the detector. This provides spectral information about the acquired object; thus, giving additional data on the type of material as well as its density. In this paper, we investigate possible advantages of such spectral information for dental cone-beam CT. Especially for the reduction of artifacts caused by dental implements. For this investigation we used a virtual jaw phantom, which replicates components of a real jaw such as soft-tissue, bone, teeth and gold crowns. We generated spectral projection images by simulating a dental cone-beam setup with a Monte-Carlo CT simulator. The Monte-Carlo setup simulated a scan on an energy-resolving photon counting detector with six energy threshold levels. Next a maximum-likelihood basis-component decomposition technique was used to single out sinograms of the individual materials. The decomposition revealed the spatial information of the dental implant. By using the knowledge gained for the spectral imaging, we jointly reconstruct tomographic slices via the SPS algorithm. The subjective image assessment of the resulting reconstructions showed significant reduced streaking artifacts, which are primarily caused by the presence of dental implants. The overall image quality is improved such that the contrast-to-noise ratio increased compared to the conventional FBP reconstruction. In this work we illustrated the potential of Spectral CT for improve diagnostic quality, especially in performing metal artifacts reduction in dental cone-beam CT.

8668-175, Session PSWed

The effect of cross-scatter correction on the performance of dual energy micro-CT

Darin P. Clark, Samuel M. Johnston, G. Allan Johnson, Cristian T. Badea, Ctr. for In Vivo Microscopy (United States)

Dual energy (DE) CT imaging is expected to play a major role in the diagnostic arena as it provides a quantitative decomposition of basis materials, opening the door for new clinical applications without significantly increasing dose to the patient. DE-CT provides a particularly unique opportunity in preclinical CT where new elemental contrast agents are providing novel approaches for quantitative tissue characterization. We have implemented DE CT imaging with a unique preclinical dual source micro-CT scanner. When one x-ray tube is fired to acquire a projection image, the signal from scattered radiation at the detector that is not in line with the tube is significant, introducing errors into the resultant material decomposition. The purpose of this work is to investigate the effect of cross-scatter correction on the accuracy of a post-reconstruction iodine and calcium decomposition. Cross-scatter has been estimated using a lead beam stop approach. Our scatter correction has been quantitatively validated using phantom experiments. Our results indicate that cross-scatter correction of dual energy micro-CT data reduces the presence of cupping effects and increases both the accuracy and precision of dual energy decompositions of calcium and iodine.

8668-176, Session PSWed

Resonance-frequency based electrical impedance spectroscopy and its detection sensitivity to breast lesions

Sreeram Dhurjaty, Dhurjaty Electronics Consulting LLC (United States); Bin Zheng, David Gur, Univ. of Pittsburgh (United States)

Electrical impedance spectroscopy (EIS) has been investigated and emerged as a potential non-invasive, low cost, and easy to use tool for prescreening and detecting breast abnormalities that may lead to the cancer. However, the performance of conventional EIS is unacceptable in the clinical practice. In our laboratory we developed a new EIS approach based on the resonance frequency measurements. This system relies on parameters generated by resonating breast capacitance with a fixed inductor at 6 different directions using the nipple as a reference electrode. The system detects breast tissue abnormalities due to the capacitance change caused by the growth of angiogenesis. Although the preliminary testing results from a prospective clinical study were encouraging, we also found that the detection results were not robust. One of the primary reasons is that the measured EIS signals in particular the resonance frequencies vary as the change of lesion depth. Based on the circuit theory we in this study investigated and derived the analytical expressions between the sensitivity of capacitance change and parallel resistance to the pathologies and the distance of the lesions from the nipple electrode. The resistor tends to short out the measured EIS signal and has a tendency to decrease the amplitude of the waveforms at resonance frequency. The theoretical analysis is consistent with our experimental observation, which provides the new guideline for us to develop and assemble the next generation resonance-frequency based EIS system with an optimal electrical circuit design and the computerized EIS signal processing and classification schemes.

8668-177, Session PSWed

TestDose: a SPECT image generator for clinical dosimetry studies

Marie-Paule Garcia, Institut de Recherche en Informatique de Toulouse (France); Henri Der Sarkissian, Erin McKay, Ludovic Ferrer, ICO René Gauducheau (France); Manuel Bardiès, Daphné Villoing, UMR 1037 INSERM/UPS (France); Hadj Batatia, Adrian Basarab, Jean-Yves Tourneret, Denis Kouamé, Institut de Recherche en Informatique de Toulouse (France)

Patient-specific dosimetry in nuclear medicine relies on activity quantification in volumes of interest from scintigraphic imaging. Clinical dosimetry protocols have to be benchmarked against results computed from test phantoms. The design of an adequate model is a crucial step for the validation of image-based activity quantification. We propose a computing platform to automatically generate simulated SPECT images from a dynamic phantom for arbitrary scintigraphic image protocols. As regards the image generation, we first use the open-source NCAT phantom code to generate an anatomical model and 3D activity maps for different source compartments. This information is used as input for an image simulator and each source is modelled separately. Then, a compartmental model is designed, which describes interactions between different functional compartments. As a result, we can derive time-activity curves for each compartment with sampling time determined from real image acquisition protocols. Finally, to get an image at a given time after radionuclide injection, the resulting projections are aggregated by scaling the compartment contribution using the specific pharmacokinetics and corrupted by Poisson noise. Our platform consists of many software packages, either in-house developments or open-source codes. In particular, an important part of our work has been to integrate the GATE simulator in our platform, in order to generate automatically the command files needed to run a simulation. Furthermore, some developments were added in the GATE code, to optimize the generation of projections with multiple energy windows in a minimum computation time.

8668-178, Session PSWed

Comparison of correction methods for bronchial lumen and wall thickness measurement using a physical tube array phantom

Rafael Wiemker, Udo van Stevendaal, Holger Schmitt, Philips Research (Germany); Amnon Steinberg, Philips Healthcare CT (Israel); Ekta Dharaiya, Philips Healthcare CT (United States); Mark Rabotnikov, Philips Healthcare CT (Israel); Tobias Klinder, Philips Research (Germany)

Three different methods to correct for partial volume effect and scanner blur were tested on simulated phantoms as well as on CT-scanned physical phantoms. The correction methods were variants of the physically motivated method suggested by Weinheimer which integrates the HU densities in a certain wall area, and derives the corrected values assuming a characteristic true HU-density of the bronchial wall.

For validation, an acrylic plastic phantom has been designed with an array of cylindrical tubes varying lumen diameter and wall thickness in a systematic way, which has been manufactured by inexpensive 3D-printing.

Analysis showed high agreement and good noise robustness of all correction methods, but significant dependency on the choice of the CT reconstruction filter. Thus, optimal accuracy and inter-study comparability of bronchial lumen and wall measurements can be achieved if the unobtrusive array phantom is scanned simultaneously with the patient for each exam. This allows automated calibration for each specific scan.

8668-179, Session PSWed

Dependency of the darkfield signal on the sample thickness in interferometric x-ray imaging

Karl C. Gödel, Florian Bayer, Wilhelm Haas, Florian Horn, Georg Pelzer, Jens Rieger, André Ritter, Thomas Weber, Andrea Zang, Jürgen Durst, Thilo Michel, Gisela Anton, Friedrich-Alexander-Univ. Erlangen-Nürnberg (Germany)

Grating-based interferometric X-ray imaging is becoming increasingly important in medical and non-destructive testing applications. Contrary to the conventional approach of radiologic imaging, the phase-contrast technique not only provides the absorption image of X-rays, but also supplies information about differential phase-shift and about unresolved structures in the so-called darkfield. Using a Talbot-Lau interferometer, it is possible to obtain these three different images with a conventional X-ray tube. The information about granular structures which are supplied by the darkfield image is of special interest, e.g. in the early detection of breast cancer. The reduction of the darkfield signal is dependent on the sample thickness. This relation is, inter alia, important for the reconstruction in darkfield tomography. So far, a simple exponential relation between thickness and darkfield was suggested.

In this contribution we show that an exponential decrease of the darkfield signal with increasing thickness of granular samples is an insufficient description. Our results are confirmed by wave field simulations and corresponding experiments.

8668-180, Session PSWed

A statistical image reconstruction method to reduce small angle scattering induced streaking artifacts in differential phase contrast CT

Kai Niu, Univ. of Wisconsin-Madison (United States); Ke Li, Zhihua Qi, Univ. of Wisconsin School of Medicine and Public Health (United States); Nicholas B. Bevins, Univ. of Wisconsin-Madison (United States); Joseph N. Zambelli, Guang-Hong Chen, Univ. of Wisconsin School of Medicine and Public Health (United States)

Statistical iterative reconstruction methods have come to the forefront of CT research in recent years, as they have the ability to incorporate the statistical fluctuations in CT measurements into the image reconstruction process. Such methods have been shown to reduce streaking artifacts induced by metal objects, which is a major problem in CT imaging. While statistical iterative reconstruction methods have been found to be beneficial in CT imaging, they have not been extensively investigated or applied in other new and promising CT imaging techniques, such as x-ray differential phase contrast computed tomography (DPC-CT). In DPC-CT, three sets of tomographic images, including absorption contrast, differential phase contrast, and small angle scattering (SAS), can be simultaneously generated from a single DPC-CT acquisition. Most DPC-CT image reconstruction methods have employed filtered backprojection (FBP) for image reconstruction. However, image objects with strong SAS signals can lead to an increase in noise in the DPC projection data. Therefore, DPC-CT images often contain streak artifacts, which significantly degrade image quality. Therefore, the purpose of this study is two-fold: (1) How can statistical iterative reconstruction be extended and applied to fan-beam DPC-CT using experimental data from a benchtop system? (2) Can statistical iterative reconstruction reduce the SAS induced streaking artifacts? In this study, a physical phantom containing object with strong small angle scatters was used to evaluate the application of statistical iterative image reconstruction to DPC-CT. Results demonstrate that statistical iterative image reconstruction can indeed be used to strongly mitigate streaking artifacts in DPC-CT.

8668-181, Session PSWed

Feasibility study of spectral imaging for differential phase contrast cone beam CT

Weixing Cai, Ruola Ning, Jiangkun Liu, Univ. of Rochester Medical Ctr. (United States)

In principle, differential phase contrast (DPC) imaging allows the use of a hospital grade x-ray tube that has a large focal spot size and a wide polychromatic spectrum. It should be noted that due to the integration of interference patterns over the entire spectrum, the fringe contrast in the final intensity image is lower than that from a monochromatic spectrum. Therefore better image quality can be potentially obtained if the energy-dependent interference patterns can be analyzed separately. The key idea of the proposed spectral DPC imaging approach is to acquire DPC images for each photon energy level, which is named spectral DPC images. The final DPC image can be computed by summing up these spectral DPC images. This research is a feasibility study based on computer simulations to investigate how the spectral DPC method works for a DPC-based cone beam CT (DPC-CBCT) system. The spectral DPC imaging approach is applied to an x-ray spectral centered at 30keV, which is divided into five energy levels in simulation. A simple numerical phantom with low contrast inserts is used and the entire imaging process is simulated using Fresnel diffraction theory. Phase stepping approach is used to manifest and retrieve phase information. The phantom is scanned over a full circular trajectory and the Hilbert filter-based FBP algorithm is used to compute the DPC-CBCT reconstruction. The reconstruction from the proposed spectral DPC-CBCT is compared to that from the conventional DPC-CBCT that only takes detector images for the integrated polychromatic spectrum. The uniformity, noise level and contrast of the inserts in the reconstruction are measured and compared. Simulation results indicate that the spectral DPC imaging approach can improve object contrast and reduce noise for DPC-CBCT.

8668-182, Session PSWed

Phantom study for volume-of-interest breast imaging using differential phase contrast cone beam CT (DPC-CBCT)

Jiangkun Liu, Ruola Ning, Weixing Cai, Univ. of Rochester Medical Ctr. (United States)

Differential phase contrast (DPC) imaging is reported to be able to deliver much higher contrast and spatial resolution compared to attenuation-based modalities. Due to the nature of attenuation contrast, the conventional cone beam breast CT technology have limitations in characterizing breast tissues with a higher spatial resolution and contrast resolution. As an alternative, the grating based DPC technology is potentially a powerful tool for breast imaging. However, limited by current grating fabrication techniques, a full field of view to cover the whole breast is not practical at present. Previously by our group, a volume-of-interest (VOI) imaging method, which incorporates DPC CBCT into a dedicated attenuation-based breast imaging CBCT system, was presented. The CBCT scan is used to localize suspicious volumes and DPC CBCT scan characterizes the suspicious volume with a higher resolution. In this work, we will investigate the performance of DPC CBCT VOI imaging using breast phantoms. The breast phantom includes mass and micro-calcifications, which will respectively be centered and scanned by our DPC CBCT system. The reconstructed images will be investigated according to several concerns: 1. Thick project could reduce the spatial coherence of X-rays and thus degrade the image quality. 2. The background trend may affect the image quality. 3. Truncation artifact may occur. In addition, the result will be evaluated with regard to CNR, noise level, mass and calcification detectability.

8668-183, Session PSWed

Energy-resolved interferometric x-ray imaging

Georg Pelzer, Andrea Zang, Florian Bayer, Karl C. Gödel, Wilhelm Haas, Florian Horn, Jens Rieger, André Ritter, Peter Sievers, Thomas Weber, Jürgen Durst, Thilo Michel, Gisela Anton, Friedrich-Alexander-Univ. Erlangen-Nürnberg (Germany)

Interferometric X-ray imaging becomes more and more attractive for applications such as medical imaging or non-destructive testing, where a compact setup is needed. Therefore a so-called Talbot-Lau interferometer in combination with a conventional X-ray tube is used. Thereby, three different kinds of images can be obtained. An absorption image like in conventional X-ray imaging, an image of the differential phase-shift caused by the object and the so-called darkfield image. The darkfield image shows information about the object's granularity even in sub-pixel dimensions what especially seems very promising for applications like e.g. mammography.

As this setup has a complex energy-dependent response and it works best for only one energy, the design- energy, other energies in a continuous X-ray spectrum reduce the setup's performance. By evaluating the interferometers complex energy-dependent response and using the information obtained by a energy-resolving detector, the performance can be increased again. So, with respect to optimizing this output of interferometric X-ray imaging in any application, it is inevitable to know the energy response of the interferometer as well as the energy dependence of the interactions of X-rays with matter.

In this contribution, simulations and corresponding measurements using a Timepix detector are presented. The behavior of the darkfield image has been evaluated on a large energy range for the first time.

8668-184, Session PSWed

Enhancement of sensitivity for calcifications through x-ray darkfield imaging

Andrea Zang, Florian Bayer, Karl C. Gödel, Wilhelm Haas, Florian Horn, Georg Pelzer, Jens Rieger, André Ritter, Thomas Weber, Jürgen Durst, Thilo Michel, Gisela Anton, Friedrich-Alexander-Univ. Erlangen-Nürnberg (Germany)

Screening mammography is an important tool in early detection of breast carcinoma. One significant feature here is the presence of microcalcifications. Recent investigations show that using a Talbot-Lau X-ray interferometer might enhance the detection significantly. This interferometric setup uses the Talbot effect. By illuminating a periodic structure with a coherent light source a repetitive intensity pattern is generated in certain distances, the Talbot distances. The positioning of an object within the optical path leads to a distortion of this pat- tern and by using an analyzer grating to detect those distortions three different imaging information can be derived. An attenuation image, a differential phase image and the so-called darkfield image. In particular the darkfield signal with its high sensitivity for granularities yields promising results for mammographic applications.

In this study we examine the sensitivity of the darkfield signal as well as the attenuation signal with the fraction of volume occupied by chalk particles, expected to occur in breast carcinoma. We therefore prepare gelatin gels with varying concentrations of two types of calcium salts (Calcium phosphate and Calcium oxalate) and measure both signals. Furthermore, we investigate the possibility of discrimination between these different types of calcifications. That may be an indicator for the malignancy of the lesion.

Our results confirm the much higher sensitivity of the darkfield signal compared to the attenuation signal. We can also show that in principle it is possible to discriminate between the different particle types.

8668-185, Session PSWed

Preliminary study on phase-contrast digital tomosynthesis: development and evaluation of experimental system

Ai Ikeya, Atsushi Teramoto, Fujita Health Univ. (Japan); Kenji Noguchi, Nagoya Electric Works Co., Ltd. (Japan); Hiroshi Fujita, Gifu Univ. of Medical Science (Japan)

The advantage of X-ray phase imaging is its ability to obtain information on soft tissues, which is difficult using conventional X-ray imaging. Moreover, a sharp X-ray image can be obtained from the edge effect resulting from phase contrast. Digital tomosynthesis is an imaging technique used to reconstruct multiple planes in a single scan. In this study, we developed an experimental system that combines the phase-contrast and digital tomosynthesis techniques. Our experimental system consists of a transmission-type micro-focus X-ray source (minimum focus size: 1 ?m). We also introduced an indirect conversion-type flat panel detector (pixel pitch: 50 ?m, matrix size: 2366 ? 2368) as an imaging device. The sample is placed on a computer-controlled rotation table, and projection images are captured from various angles. The images are then reconstructed using the filtered back projection method. In the experiments, a tomosynthesis image of an acrylic phantom was obtained at a tube voltage of 40 kV and at a maximum projection angle of ±25°. To evaluate the edge enhancement effect by phase contrast, the resolution, degree of edge enhancement, and image contrast were measured using the acrylic phantom. A good edge enhancement effect was confirmed under the specified conditions. Furthermore, we compared to the shape between the projection image and the tomosynthesis image and found that the tomosynthesis image showed high shape reproducibility compared to the conventional projection image. These results indicate that phase-contrast digital tomosynthesis may be useful for the three-dimensional imaging of low-contrast material.

8668-186, Session PSWed

The signal-to-noise property in differential phase contrast CT compared with its counterpart in conventional CT

Xiangyang Tang, Yi Yang, Shaojie Tang, Emory Univ. (United States)

The x-ray differential phase contrast (DPC) CT is emerging as a new technology with the potential for extensive preclinical and clinical applications. Based on theoretical derivation and experimental verification, we have characterized the noise power spectrum NPS(k) and the spectrum of noise equivalent quanta NEQ(k) of DPC-CT in our previous publication. In this work, via system analysis, modeling and simulation study, we continue to investigate the signal-to-noise properties of DPC-CT and compare it with the conventional CT. It is believed that, through an investigation into its signal and noise properties jointly, the imaging performance of the DPC-CT and its advantages over the conventional attenuation-based CT can be thoroughly and insightfully understood.

8668-187, Session PSWed

Artifacts in thickness-dependent x-ray darkfield measurements

Florian Horn, Florian Bayer, Karl C. Gödel, Wilhelm Haas, Georg Pelzer, Jens Rieger, André Ritter, Thomas Weber, Andrea Zang, Jürgen Durst, Thilo Michel, Gisela Anton, Friedrich-Alexander-Univ. Erlangen-Nürnberg (Germany)

Grating-based X-ray phase-contrast imaging is a promising method to increase soft tissue contrast and gain additional information

in comparison to attenuation-based imaging using a Talbot-Lau interferometer. It provides an absorption image similar to attenuation-based imaging, a phase shift image and a darkfield image with a single measurement. A convential polychromatic X-ray tube is used together with a Talbot-Lau interferometer consisting of a phase grating and an absorption grating. Sufficient spatial coherence is ensured by a source grating serving as absorption mask.

The darkfield image shows information about the sub-pixel size granularity of the measured object. This supplemental information is supposed to be suitable in a large scale of medical applications, such as mammogra- phy.

In this contribution we present recent results of measurements investigating the thickness-dependent behavior of darkfield imaging. This is done by measuring wedge-shaped, granular objects with our X-ray phase-contrast imaging device and calculating the darkfield image signal.

Measurements show a resurgence of darkfield signal with increasing thickness of the object after passing a minimum contrary to theoretical considerations, which claim an exponential decrease. This is interpreted as artifacts caused by absorption effects within the object.

Understandig the thickness-dependent X-ray darkfield behavior advances the comprehension of the formation of the darkfield image, which is helpful in finding new applications and ameliorating the ones recently investigated.

8668-188, Session PSWed

Experimental measurement of the modulation transfer function of differential phase contrast CT Systems

Ke Li, Joseph N. Zambelli, Univ. of Wisconsin School of Medicine and Public Health (United States); Nicholas B. Bevins, Univ. of Wisconsin-Madison (United States); Guang-Hong Chen, Univ. of Wisconsin School of Medicine and Public Health (United States)

By introducing a Talbot-Lau interferometer, an absorption CT can be modified to simultaneously generate DPC-CT and absorption CT images. It has been postulated that DPC-CT has the same or even better spatial resolution compared to the associate absorption CT due to the observed edge enhancement in projection data. However, this hypothesis has never been experimentally investigated. This paper concerns such an experimental method to determine the MTF of DPC-CT. Note that there are new challenges in this measurement, as conventional metal wire-based phantoms are no longer applicable for this purpose, because high density wires generate refraction signals that are out of the dynamic range of measurements, and DPC-CT is not sensitive to objects finer than a detector pixel. These challenges were overcome by carefully choosing experimental materials and using a method to fully exploit the intrinsic relationship between the MTF of a DPC-CT and that of the associated absorption CT. The proposed method was used to measure the MTFs of an experimental DPC-CT system with 96 micron detector pixel size. The results demonstrate appreciable differences in MTFs of DPC-CT and the associated absorption CT. At the 10% MTF level, the MTFs of DPC-CT and absorption CT are 4.7 c/mm and 5.2 c/mm, respectively. This suggests that the interferometer has a frequency-dependent response. The MTF results add further insight in understanding the signal properties of DPC-CT and will benefit this emerging modality's potential application in medical imaging.

8668-189, Session PSWed

Single-step phase contrast x-ray imaging using photon counting detectors

Doga Gursoy, Mini Das, Univ. of Houston (United States)

Current phase contrast imaging (PCI) techniques involve multiple precise measurements and/or elaborate x-ray optics. Unless a significant improvement in lesion detection is observed, these methods are unlikely to replace mammography. A predicted three orders of magnitude of phase change in comparison to attenuation changes in soft tissue has driven much of the efforts in this area, however there have been not many elaborate studies to understand or demonstrate the detectability aspects in an optimized PCI system. In this abstract we propose and demonstrate a new single-step in-line phase retrieval method when spectral data is obtained using a photon-counting x-ray detector. Two spectrally distinct intensity measurements (that combines absorption and phase changes) are used to solve the transport of intensity equations to obtain a phase image and a differential phase contrast image . A rigorous computer simulation which evaluates various design and acquisition parameters for a practical clinical utility and best dose efficiency for this newly proposed single-step in-line phase contrast imaging method will be evaluated. Finally, we believe that lesion and microcalcification (MC) detectability of phase-contrast images should be evaluated to predict their true utility for breast imaging. To this end, the complete paper will also use realistic computer simulations, breast phantoms, lesion and MC models in a using a human observer localization ROC study. Due to its simplicity, it is straightforward to extend the proposed technique to tomographic PCI.

8668-190, Session PSWed

A compendium of publicly available Monte Carlo transport codes for the simulation of radiation imaging detectors

Diksha Sharma, Han Dong, Yuan Fang, Aldo Badano, U.S. Food and Drug Administration (United States)

Simulations play a vital role in the understanding and analysis of existing and emerging medical imaging technologies. Over the last years, Monte Carlo simulations have become increasingly necessary tools for studying the fundamental limitations and for the design and optimization of medical imaging systems. We compare available open-source software packages from the Division of Imaging and Applied Mathematics at the FDA for modeling scintillator- and semiconductor-based radiation imaging detectors for applications in x-ray and nuclear imaging including MANTIS, hybridMANTIS, cartesianDETECT2, and ARTEMIS. We describe the significant features of these packages and discuss their advantages or disadvantages. We also introduce a graphical user interface which greatly facilitates the set up of simple experiments involving scintillator structures with columnar geometries.

8668-191, Session PSWed

Evaluating radiation damage to scintillating plastic fibers with Monte Carlo simulations

Aimee L. McNamara, Samuel J. Blake, The Univ. of Sydney (Australia); Philip Vial, Liverpool and Macarthur Cancer Therapy Ctrs. (Australia) and The Univ. of Sydney (Australia); Lois Holloway, Liverpool and Macarthur Cancer Therapy Ctrs. (Australia) and The Univ. of Sydney (Australia) and Univ. of Wollongong (Australia); Peter B. Greer, Calvary Mater Newcastle Hospital (Australia) and Univ. of Newcastle (Australia); Zdenka Kuncic, The Univ. of Sydney (Australia)

Current electronic portal imaging devices (EPIDs) use a thin Cu plate/phosphor screen to convert x-ray energies into optical photons. In order to achieve a high spatial resolution, thinner screens are used which subsequently results in low x-ray absorption and thus a low detector quantum efficiency (DQE) for megavoltage (MV) x-rays. To increase the detector efficiency, thicker segmented screens would increase the x-ray conversion volume while preventing a large spread of optical photons. In particular, EPIDs using plastic scintillator fibers have been proposed. These types of fibers may however be susceptible to radiation damage under high doses. Damage is mostly caused by the low energy secondary electrons formed through the interaction of x-rays with the material. Here we used Monte Carlo simulations to investigate the

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ionization formation within a single plastic fiber to assess the radiation sensitivity of the material. In this preliminary study, we find a large number of ionizations can be formed along the fiber length, which over repeated exposures could lead to breaks within the plastic polymer molecules. Polymer breaks have the potential to change the optical photon absorption properties of the fiber, which may have an effect on the imaging performance of the detector.

8668-192, Session PSWed

A 2.5 dimensional vein imaging system for venipuncture

Xiaoming Hu, Ya Zhou, Zhaoguo Wu, Beijing Institute of Technology (China)

Imaging of subcutaneous veins is important in many applications, such as gaining venous access and vascular surgery. However, there are a lot of venipuncture failures in actual operation. So a new kind of the venipuncture auxiliary equipment is needed to improve the success rate of venipuncture. Traditional vein imaging system can only obtain the two dimensional information of the vein which loses the depth information of the vein. It may cause the errors of judgment and the venipuncture failure.

On the basis of previous research, a new system was proposed to acquire the three dimensional of the vein. In this paper, the infrared absorption characteristics of the vein and the principle of binocular vision were combined to obtain infrared images of subcutaneous veins and recovery the three dimensional information. The binocular vision system was consists of the 850 nm near-infrared LEDs used as the source to illuminate the back of the hand and two near-infrared CCD devices to obtain the transmission IR image.

The couple of CCDs will get IR images of the hand which contain the disparity information. So we use the principle of the stereo visions to recover the three dimensional structure. The algorithm processes includes camera calibration, image preprocessing, epipolar rectification, stereo correspondence and three dimensional information recovery. Experimental result shows that it can reach a good three dimensional structure. Since the new system can recover the depth of the vein, it can be applied as the venipuncture auxiliary equipment to improve the success rate of venipuncture.

8668-193, Session PSWed

Imagistic evaluation of bone regeneration: optical coherence tomography versus microCT methods

Meda-Lavinia Negrutiu, Cosmin Sinescu, Univ. of Medicine and Pharmacy Victor Babes Timisoara (Romania); Adrian Manescu, Univ. Politecnica delle Marche (Italy); Florin-Ionel Topala, Bogdan Hoinoiu, Mihai Rominu, Univ. of Medicine and Pharmacy Victor Babes Timisoara (Romania); Adrian Gh. Podoleanu, Univ. of Kent (United Kingdom)

Bone grafting is a commonly performed surgical procedure to augment bone regeneration in a variety of orthopaedic and maxillofacial procedures, with autologous bone being considered as the “gold standard” bone-grafting material, as it combines all properties required in a bone-graft material: osteoinduction (bone morphogenetic proteins – BMPs - and other growth factors), osteogenesis (osteoprogenitor cells) and osteoconduction (scaffold).]

An osteoconductive bone substitute promotes bone growth in periodontal and maxillofacial osseous defects. It provides the body with a matrix for bone cell migration and is integrated into the natural physiologic remodelling process.

The problematic elements of bone regenerative materials are represented by their quality control methods, the adjustment of the initial bone regenerative material, the monitoring (noninvasive, if possible) during their osteoconduction and osteointegration period and biomedical evaluation of the new regenerated bone.

One of the research directions was the interface investigation of the regenerative bone materials and their behavior at different time periods on the normal femoral rat bone. 12 rat femurs were used for this investigation. In each ones a 1 mm diameter hole were drilled and a bone grafting material was inserted in the artificial defect. The femurs were removed after one, three and six months. The defects repaired by bone grafting material were evaluated by optical coherence tomography working in Time Domain Mode at 1300 nm. Three dimensional reconstructions of the interfaces were generated. The validations of the results were evaluated by microCT. Synchrotron Radiation allows achieving high spatial resolution images to be generated with high signal-to-noise ratio. In addition, Synchrotron Radiation allows acquisition of volumes at different energies and volume subtraction to enhance contrast.

Evaluation of the bone grafting material/bone interface with noninvasive methods such as optical coherence tomography could act as a valuable procedure that can be use in the future in the usual clinical techniques. The results were confirmed by microCT. Optical coherence tomography can be performed in vivo and can provide a qualitative and quantitative evaluation of the bone augmentation procedure.

8668-194, Session PSWed

Noise reduction for cone-beam SPECT by penalized reweighted least-squares projection restoration

Hao Zhang, Stony Brook Univ. (United States) and Beijing Institute of Technology (China); Junhai Wen, Donghao Shi, Rui Yang, Beijing Institute of Technology (China); Jing Wang, The Univ. of Texas Southwestern Medical Ctr. at Dallas (United States); Zhengrong Liang, Stony Brook Univ. (United States)

In single photon emission computed tomography(SPECT), the non-stationary Poisson noise in the projection data is one of the major degrading factors that jeopardize the quality of reconstructed images. In our previous researches for low-dose CT reconstruction, based on the noise properties of the projection data, a penalized weighted least-squares (PWLS) cost function was constructed and the ideal projection data was then estimated by minimizing the PWLS cost function. The experimental results showed the method could effectively suppress the noise without noticeable sacrifice of the spatial resolution for both fan- and cone-beam low-dose CT reconstruction. However, noise in X-ray CT projection data after logarithm transform follows approximately Gaussian distribution with a nonlinear signal-dependent variance, while noise in SPECT projection data follows Poisson distribution. In this work, we tried to extend this PWLS projection restoration method to SPECT by utilizing corresponding Poisson noise properties to redefine the weighting term in PWLS cost function. The iterative Gauss-Seidel algorithm was used to minimize the cost function and the weighting was updated in each iteration, therefore, we refer our implementation as penalized reweighted least-squares(PRWLS) approach. The noise-treated projection data was then reconstructed by an analytical cone-beam SPECT reconstruction algorithm with compensation for non-uniform attenuation. Both high and low level Poisson noise was simulated in the cone-beam SPECT projection data, and the reconstruction results showed feasibility and efficacy of our proposed method on SPECT.

8668-195, Session PSWed

Respiratory motion correction in positron emission tomography with clustering short time binning raw data

Byung-Kwan Park, Taeyong Song, JaeMock Lee , SeongDeok Lee, Samsung Advanced Institute of Technology (Korea, Republic of)

Respiratory motion in positron emission tomography (PET) can lead to the motion artifacts like resolution degradation and underestimate of standardized uptake value (SUV). Due to low sensitivity characteristic of PET system the average scan time per one bed takes 1~2 minutes. However the normal patient takes about 5 seconds respiratory cycle. To overcome such a problem the common methods depend on the external motion tracking systems like pressure sensors or optical markers to estimate respiratory cycle. Based on this estimation similar phases are summed together independently which is so-called gating to get motion-free images. The disadvantage of this kind of methods is the low sensitivity due to discarding dissimilar phase data. On the other hand after summation of similar phase data different gated phases are registered to reference phase to get not only motion-free but also a high sensitivity image. In this work we propose new respiratory motion correction method which doesn't use any kind of external tracking systems which can cause inconvenient to patients and motion estimation error due to mismatch between internal and external motion. Based on the very short time binning raw data or Sinogram, the features are extracted and clustered into some phases which we call as image based pseudo gating. After pseudo gating we apply 3D motion estimation from the Sinogram and modified system matrix for the reconstruction process. Compared to existing methods we estimate the internal motion in Sinogram and apply it to reconstruction just one time, it is very efficient in process.

8668-196, Session PSWed

Iterative image reconstruction for sparse-view CT using normal-dose image induced total variation prior

Yunwan Zhang, Southern Medical Univ. (China); Jianhua Ma, Jing Huang, Hua Zhang, Zhaoying Bian, Dong Zeng, Qianjin Feng, School of Biomedical Engineering, Southern Medical University (China); Zhengrong Liang, Department of Radiology, State University of New York, Stony Brook (United States); Wufan Chen, School of Biomedical Engineering, Southern Medical University (China)

As a direct method for realizing the low-dose CT imaging, low-mAs related scanning protocols have been extensively used in clinic. However, due to the noisy measurement low-dose scan with low-mAs will cause the degradation of image. The associative iterative image reconstruction approaches have been widely studied for achieving high-quality image. It is known that the cost-function of iterative image reconstruction mainly contains two parts: one is the fidelity term which is developed by incorporating the physical measure model; another is the prior term which is usually designed in the the objective image itself. In this paper, in the scheme of penalized weighed least-square (PWLS) for low-dose CT image reconstruction, the weights of weighed least-square term (i.e., fidelity term) were estimated by considering the relationship between the variance and mean of the projection data, and then a normal-dose image induced total variation prior (i.e., prior term) was also proposed. For simplicity, the proposed approach was named as "PWLS-ndiTV". Qualitative and quantitative evaluations were carried out on the present PWLS-ndiTV approach. The results show that the present PWLS-ndiTV approach can achieve significant gains than the existing similar methods in noise and artifacts suppression.

8668-197, Session PSWed

Semi-dynamic preconditioned alternating projection MAP ECT reconstruction from low-dose ECT

Andrzej Krol, SUNY Upstate Medical Univ. (United States); Si Li, Guangdong Province Key Lab of Computational Science, School of Mathematics and Computational Science (China); Lixin Shen, Yuesheng Xu, Syracuse Univ. (United States)

Purpose: To achieve good quality ECT reconstruction from low-dose ECT scan.

Method: We developed a preconditioned alternating projection algorithm (PAPA) for solving the maximum a posteriori (MAP) ECT reconstruction problem. We expressed the reconstruction problem as a constrained convex optimization problem with the total variation (TV) regularization. We showed that the solution satisfies a system of fixed-point equations defined in terms of two proximity operators stemming from the convex functions that define the TV-norm and the constrain involved in the problem. It leads to an alternating projection algorithm. We proved theoretically that the algorithm converges with fixed preconditioner. We introduced a semi-dynamic preconditioner for PAPA that accelerates its convergence. The preconditioner matrix (PM) was allowed to dynamically change for the first n iterations. We showed that PM converges to a fixed matrix. After n iterations, we run the reconstruction with the fixed PM.

We created a digital cylindrical emission phantom with uniform mean background activity distribution and hot spheres. We simulated SPECT data (120 views in 128x64 matrix, pixel size 3.56 mm) with Poisson probability distribution (total number of detector counts: 1:947x10E7, 15% noise level). We applied PAPA with semi-dynamic preconditioner and conventional EM algorithm with TV for comparison.

Results: We observe significant improvement in image quality for PAPA, as compared to EM-TV.

Conclusions: The PAPA with the semi-dynamic PM outperforms significantly the conventional EM-TV in terms of the noise in the reconstructed images and the image quality. It might permit ECT scans with lower radiation dose to patients.

8668-198, Session PSWed

A new imaging method for real-time 3D x-ray reconstruction

Murat Tahtali, Sajib K. Saha, Andrew J. Lambert, Mark R. Pickering, UNSW@ADFA (Australia)

Existing Computed Tomography (CT) systems are vulnerable to internal organ movements. This drawback is compensated by extra exposures and digital processing. CT being a radiation dose intensive modality, it is imperative to limit the patient's exposure to X-ray radiation, if only by removing the necessity to take extra exposures. A multiple pinhole camera, akin to optical lightfield imaging, to acquire simultaneously multiple X-ray projections is presented. This new method allows a single snapshot acquisition of all necessary projections for 3D reconstruction. It will also allow the real-time dynamic 3D X-ray reconstruction of moving organs, as it requires no scanning and no moving parts in its final implementation. A proof-of-concept apparatus that simulates the intended process was built and parallaxed images were obtained with minor processing. Synthetic 3D reconstruction tests are also presented.

8668-199, Session PSWed

Characterization of a digital x-ray detector for region of interest tuberculosis screening

Ryan Mann, Univ. of Waterloo (Canada); Ian A. Cunningham, Imaging Research Labs., Robarts Research Institute (Canada) and Western Univ. (Canada); Karim S. Karim, Univ. of Waterloo (Canada)

Cost and accessibility are major barriers to x-ray medical diagnostic screening in low- to mid-income countries. The cost of traditional medical-grade x-ray imaging systems is prohibitively large except to major hospitals in urban centers, preventing the early diagnosis of many curable diseases. Sputum, blood and urine tests are slower, and difficult to administer in remote locations, having high associated transportation and storage costs. A low-cost, tuberculosis-specific, teleradiology-enabled, digital x-ray imaging system is proposed that will make diagnosis fast, accessible and inexpensive. A system of this type would

ideally cost below $10,000 and is achievable today using a combination of commodity and industrial products, region-of-interest imaging, and an optimization of resolution and sensitivity requirements for the task of screening pulmonary tuberculosis.

In this research, we report preliminary investigations we have carried out on the x-ray detector, a PerkinElmer (XRD 0820) industrial-grade, 8”x8” flat-panel, amorphous silicon array with 200 micron pixels. Detective quantum efficiency (DQE), modulation transfer function (MTF) and noise power spectrum (NPS) measurements are taken over a range of typical chest radiography exposures that allow a direct comparison with high-end chest x-ray detectors and existing CR systems.

8668-200, Session PSWed

Compact gamma camera for prostate cancer imaging

Yonggang Cui, Giuseppe Camarda, Gianluigi De Geronimo, Anwar Hossain, Ki Hyun Kim, George Mahler, George Meinken, Paul O’Connor, Paul Vaska, Ge Yang, Ralph B. James, Brookhaven National Lab. (United States); Terry Lall, Hybridyne Imaging Technologies, Inc. (United States); Youngho Seo, Univ. of California, San Francisco (United States); Benjamin Franc, Tammie Johnson, Radiological Associates at Sacramento (United States); Andrew Rittenbach, Benjamin Tsui, Marty Pomper, Steve Cho, Johns Hopkins Univ. (United States); Ken Weisman, MidState Medical Ctr. (United States)

In this presentation, we will report on a compact trans-rectal imaging probe for prostate cancer imaging. The probe works as a nuclear medical imaging device – a gamma camera to sense the distribution of radiopharmaceutical within the prostate gland. The device images the foci through the rectal wall. The short working distance enables better spatial resolution and higher sensitivity than the traditional positron emission tomography (PET) or single photon emission computed tomography (SPECT) methods. The camera uses Cadmium Zinc Telluride (CdZnTe or CZT) semiconductor radiation detectors to measure the gamma rays emitted from a radioisotope. Comparing to the scintillator detectors that are found in traditional PET or SPECT systems, CZT provides higher energy resolution, higher detection efficiency, and higher spatial resolution. In addition, because the material works in a mode of photon-electron direction conversion, it eliminates the use of photon sensing devices found between the scintillator detectors and the readout electronics. Thus, the fully assembled detector modules are very compact.

The camera has been tested in the lab, and the phase-I clinical trials have been done at two medical institutions. In this presentation, we will discuss the system design of this gamma camera and report on the results of the lab tests and the clinical trials.

8668-201, Session PSWed

Image acquisition, geometric correction and display of images from a 2x2 x-ray detector array based on electron multiplying charge coupled device (EMCCD) technology

Setlur Nagesh Swetadri Vasan, Prateek Sharma, Ciprian N. Ionita, Toshiba Stroke and Vascular Research Ctr. (United States); Albert H. Titus, Alexander N. Cartwright, Daniel R. Bednarek, Univ. at Buffalo (United States); Stephen Rudin, Toshiba Stroke and Vascular Research Ctr. (United States)

A high resolution (up to 11.2 lp/mm) and large field of view (8.5cmx8.5cm) x-ray detector has been developed. The detector is a 2x2 array of individual imaging modules based on EMCCD technology. Each module outputs a frame of size 1088 x 1037 pixels, each 12 bits. The frames from the 4 modules are acquired into the processing computer using one of two techniques. The first uses 2 camera link communication channels with each carrying information from two modules, the second uses custom integrated circuits, the Multiple Module Multiplexer Integrated Circuit (MMMIC), 3 of which are used to multiplex the data from 4 modules into one camera link channel. Once the data is acquired using either of the above mentioned techniques, it is decoded in the graphics processing unit (GPU) to form one single frame of size 2176x2074 pixels each 16 bits. Each imaging module uses a fiber optic taper coupled to the EMCCD sensor. Due to mechanical misalignment between the sensors and the fiber optic tapers, the image in each module may be rotated and translated slightly in the x-y plane with respect to each other. To correct this and to produce a seamless image, geometric corrections are performed.

To evaluate the detector acquisition and correction techniques, an aneurysm model was placed over an anthropomorphic head phantom and a coil was guided into the aneurysm under fluoroscopic guidance using the detector array. Image sequences before and after correction are presented.

8668-202, Session PSWed

Rectangular computed tomography using a stationary array of CNT emitters: initial experimental results

Brian Gonzales, XinRay Systems (United States)

XinRay Systems Inc has a rectangular x-ray computed tomography (CT) imaging setup using multibeam cold cathode x-ray tubes. XinRay has carbon nanotube (CNT) based x-ray emitters which emit electrons without heat using field emission. Due to their unique design, a CNT x-ray tube can contain a dense array of independently controlled electron emitters which generate a linear array of x-ray focal spots. We use a set of linear CNT x-ray tubes to design and construct a stationary CT setup which achieves sufficient CT coverage from a fixed set of views. The CT system has no moving gantry, enabling it to be enclosed in a compact rectangular tunnel. The fixed locations of the x-ray focal spots were optimized through simulations. The rectangular shape creates significant variation in path length from the focal spots to the detector for different x-ray views. The shape also results in unequal x-ray coverage in the imaged space. We discuss the impact of this variation on the reconstruction. We use an iterative reconstruction algorithm to account for this unique geometry. The iterative algorithm is implemented on a graphics processing unit (GPU). The fixed focal spots prohibit the use of an anti-scatter grid. Quantitative measure of the scatter and its impact on the reconstruction will be discussed. We also discuss the variation in path lengths affect on beam hardening. This result represents the first known implementation of a completely stationary CT setup using CNT x-ray emitter arrays.

8668-203, Session PSWed

Multi-resolution analysis of scatter in digital breast tomosynthesis imaging

Da Zhang, Xinhua Li, Bob Liu, Massachusetts General Hospital (United States)

The influence of large x-ray scatter components in projection images remains a problem for digital breast tomosynthesis, especially when anti-scatter grids may not be used due to dose limitation and possible source/detector geometric limitation. Software based methods, such as Monte-Carlo simulation of scatter, seem appropriate in this situation, but the heavy computational cost hinders their clinical application. One characteristic of scatter that is commonly exploited to relieve this problem is the smoothness. However, scatter is not spatial invariant across a projection image, and where and to what degree the smoothness could be claimed and utilized is unclear. We studied this question via multi-resolution analysis. We conducted two sets of

experiments: one with direct measurements of scatter profiles in the projection images of an anthropomorphic breast phantom; the other with scatter map obtained from a Monte-Carlo simulation using a voxelized breast model as input. We applied 1D and 2D wavelet based multi-resolution analyses to the scatter profiles and scatter maps. The results from the first experiment indicated that a reduced number of points might be extracted from the densely sampled but noisy scatter profiles: a data reduction rate of 64-128 was achieved at the inner region of the phantom, suggesting that the slowly changing scatter might be obtained at a lower sampling distance of 9.0~17.9 mm. Near the edge of the phantom a data reduction rate of 8 was achieved, corresponding to a sampling distance of 1.1mm. Similar observations were made from the results based on the simulated scatter maps.

8668-204, Session PSWed

Metal artifact reduction in tomosynthesis by metal extraction and ordered subset-expectation maximization (OS-EM) reconstruction

Tomonori Sakimoto, Kazuyoshi Nishino, Shimadzu Corp. (Japan)

Tomosynthesis is a useful imaging tool for breast, lung and orthopedic diagnostics. Compared to computed tomography (CT), fewer artifacts are caused by metal components (metal artifacts). This advantage makes tomosynthesis particularly useful for orthopedics. Implementing filtered back projection (FBP) with a modified kernel leads to an increase in the low-frequency components of reconstructed images and reduces metal artifacts in tomosynthesis. However, even using this reconstruction method, metal artifacts are present in the region very close to any piece of metal. Due to the modified kernel, the observation of fine structures is difficult. We developed a new reconstruction algorithm to provide fewer metal artifacts in tomosynthesis images than in conventional images without filtering. Our new algorithm consists of four steps: 1) automatically extracting metal components from projection images using a novel method that we developed; 2) dividing projection images into metal-free projection images and metal-only projection images; 3) reconstructing these two projection images using the ordered subset-expectation maximization (OS-EM) method to create metal-free tomosynthesis images and metal-only tomosynthesis images; 4) combining the tomosynthesis images and thereby obtaining metal artifact-reduced tomosynthesis images. Our new metal extraction method in step 1 is based on the graph cuts algorithm. We compared four image reconstruction algorithms: (a) FBP, (b) FBP with a modified kernel, (c) simple OS-EM and (d) the proposed method. The results demonstrate that the proposed method significantly reduces metal artifacts when compared to the other methods.

8668-205, Session PSWed

Feasibility of stationary digital breast tomosynthesis as an effective screening tool for patients with augmentation mammoplasty

Andrew W. Tucker, Cherie M. Kuzmiak M.D., Christy R. Inscoe, Yueh Z. Lee M.D., Jianping Lu, The Univ. of North Carolina at Chapel Hill (United States); Otto Z. Zhou, The Univ. of North Carolina at Chapel Hill (United States)

Conventional mammography techniques used for imaging patients that have undergone augmentation mammoplasty produce substandard images, incomplete evaluation of breast tissue, and can cause discomfort to the patient. Typically, four images of each breast are acquired (double the amount of a patient without implants), two with the implant in view and two “pushback” views, which moves the implant posteriorly out of the field of view. The “pushback” view can be difficult to perform when there is encapsulation of the breast tissue around the implant. In severe cases, performing the technique can cause unwarranted pain to the patient. This technique can also result in up to a three times increase in procedure time which leads to lower patient throughput. Using 2D mammography, it is difficult to interpret tissue above and below implants due to the overlap of breast tissue and implant. Recently, Digital Breast Tomosynthesis (DBT) has been shown to aid in the localization and diagnosis of breast masses by removing underlying and overlying tissue from the plane of interest in 3D space. However, commercial DBT systems have motion blurring of the projection images associated with x-ray source motion. To overcome this limitation, stationary DBT (s-DBT) has been developed. Here we report the feasibility of using s-DBT as an effective screening tool for patients who have undergone augmentation mammoplasty. Qualitative image analysis is completed on reconstruction images of tomosynthesis phantoms combined with implants. Reconstruction images show that it is possible to locate lesions above and below the implant using a clinically relevant entrance dose.

8668-206, Session PSWed

Impact of subtraction and reconstruction strategies on dual-energy contrast enhanced breast tomosynthesis with interleaved acquisition

Lin Chen, Yihuan Lu, Yue-Houng Hu, Wei Zhao, Gene Gindi, Stony Brook Univ. (United States)

Contrast enhanced digital breast tomosynthesis can yield superior visualization of tumors relative to conventional tomosynthesis and can provide the contrast uptake kinetics available in breast MR while maintaining a higher image spatial resolution. Dual-energy (DE) acquisition protocols for contrast enhancement often involve two separate continuous motion sweeps of the X-ray tube (one per energy) followed by weighted subtraction of the HE (high energy)and LE (low energy) projection data. However, there are advantages in using a single-sweep interleaved acquisition in which HE and LE projections alternate. Relative to two-sweep acquisition, interleaved acquisition suffers from a lesser degree of motion artifacts and entails less time spent under breast compression. The HE and LE acquisitions during interleave each see an iodine spatial distribution that is relatively unchanged compared to that seen in the two-sweep method. These advantages for DE interleaved acquisition are reduced by subtraction artifacts due to the fact that each HE, LE acquisition pair is offset in angle for the usual case of continuous tube motion. These subtraction artifacts propagate into the reconstruction and are present even in the absence of patient motion. To reduce these artifacts, we advocate a strategy in which the HE and LE projection data are separately reconstructed then undergo weighted subtraction in the reconstruction domain. We compare the SDNR of tumors in a phantom for the subtract-then-reconstruct vs. reconstruct-then-subtract strategies and evaluate each strategy for two algorithms, FBP and SART. For a given algorithm, the reconstruct-then-subtract strategy has a higher SDNR than the subtract-then-reconstruct strategy.

8668-207, Session PSWed

An simulation based image reconstruction strategy with predictable image quality in limited-angle x-ray tomography

Shiyu Xu, Ying Chen, Southern Illinois Univ. Carbondale (United States)

This paper presents a penalized-likelihood method for limited-angle X-ray tomography. According to the theory of resolution properties of regularized image reconstruction conducted by Dr. Fessler, a basic penalty could not take consistent effect on the image quality of reconstructed image due to data dependence of the method.Through a modification over a quadratic penalty, linearized impulse response is obtained from reconstructed image, therefore resolution properties can be predicted. Based on the theoretical knowledge, we present

a simplified version of the modified quadratic penalty to reduce the computational intensity. By applying the derivation presented in the theory1 on the X-ray system and the simplified version of the modified penalty, the effectiveness of the penalized-likelihood on resolution properties of reconstructed image can be quantified by the one of basic penalized-likelihood on projections with unit background. Next we provide the iterative solutions for both basic quadratic and modified quadratic penalized-likelihood. Then a simulation based two step routine is proposed. It reconstructs image with a desired quality by selecting the corresponding smoothing parameter in the tables, which are generated by system simulations and represent the relationships between smoothing parameter and image quality of the system.The experiments validate the efficiency of the procedure.

8668-208, Session PSWed

Comparison of the diagnostic accuracy of stationary digital breast tomosynthesis to digital mammography with respect to lesion characterization in breast tissue biopsy specimens: a preliminary study

Andrew W. Tucker, The Univ. of North Carolina at Chapel Hill (United States); Yueh Z. Lee M.D., Cherie M. Kuzmiak M.D., Emily Gidcumb, Jianping Lu, Otto Z. Zhou, The Univ. of North Carolina at Chapel Hill (United States)

Current practice for imaging surgical breast specimens is a single 2D magnification view on a mammography system, but 2D imaging overlaps the tissue in different planes causing distortion of lesion margins. Digital breast tomosynthesis (DBT) could be used as an alternative imaging modality for imaging breast specimens. DBT systems acquire multiple low dose projection images, over a small angular span, which are then reconstructed into a partial 3D volume. The reconstructed images can be used to increase visualization of lesion margins and extent of microcalcifications (MCs). Current commercial DBT systems use a single rotating X-ray source, the movement of which produces motion blur. Motion blur reduces visualization of small objects such as MCs. MCs, depending on size and structure, can be implicative of breast cancer. We have developed a stationary DBT (s-DBT) system using a linearly distributed, CNT X-ray source array. S-DBT allows for rapid acquisition of projection images with no image degradation from X-ray source motion. Full tomosynthesis datasets can be acquired, allowing visualize of both masses and microcalcifications. Here we report the preliminary results of a reader study comparing breast specimen images from a 2D commercial mammography system and an s-DBT system. Preliminary results show that s-DBT is capable of producing equivalent image quality to 2D mammography, and in some cases is superior.

8668-209, Session PSWed

Preliminary evaluation of transmission x-ray tube system with a flat-detector DR system: image quality and dose reduction

Leonard Berliner M.D., New York Methodist Hospital (United States); Kui-Ming Chen, Shenq-Rong Hwang, GAMC Biotech Development Co., Ltd. (Taiwan); Alfonso Buffa, New York Univ. - Bellevue Hospital Ctr. (United States); Martin Darms, Andrew Jeffries, Swissray Medical AG (Switzerland)

Ionizing radiation from medical imaging now accounts for over 95% of all man-made radiation exposures and is the single largest radiation source after natural background radiation. As a result, new techniques are under development for reducing radiation exposure incurred in diagnostic radiography.

Preliminary phantom studies with a transmission X-ray tube and generator system utilizing conventional X-ray film showed that there was potential for the production of radiographic images of diagnostic image quality at reduced radiation dose.

It was the purpose of this study to determine if a system using transmission tube technology in conjunction with a flat-panel detector is capable of achieving diagnostic quality radiographic images at reduced radiation doses.

The results have shown that the transmission tube and generator system, in combination with a flat-detector system, is capable of producing radiographic images of sufficient quality for diagnostic medical imaging within certain parameters. We can postulate at this time that when low mAs is required, as in imaging of neonatal and young pediatric patients, the transmission tube may prove to be very effective in obtaining diagnostic images at reduced radiation dose.

Further investigation of this technology is therefore warranted, and may be combined with other technologies to further reduce patient dose, such as adult imaging. These studies may provide information concerning the suitability of this technology for specific types of clinical applications, especially in neonatal and pediatric imaging. Additional studies could also focus on the impact of different target materials and their characteristic X-ray spectra in specific imaging applications, such as mammography.

8668-210, Session PSWed

X-ray tube focal spot size, digital detectors, imaging system aperture and spatial resolution

Edward L. Nickoloff, Columbia Univ. (United States)

The goal is the examine the effects of focal spot size and digital detector size on the effective aperture and resulting spatial resolution. In addition, a method to measure focal spot size (without film) on systems with digital detectors is presented.

METHOD AND MATERIALS: Calculations of the effective aperture using typical x-ray focal spot sizes and digital image receptor DEL sizes are utilized to examine the effect of geometrical magnification upon the spatial resolution. These calculations are compared to measurements on several digital systems by imaging line pair and star patterns at various magnifications. The measurement of focal spot size is difficult without film. The star pattern can be directly imaged on the digital receptor and a new equation utilized to determine the focal spot size.

RESULTS: Even though the DEL size limits resolution with digital image receptors, the image blur attributed to the focal spot is still important a for most clinical geometry. The focal spot size can be determined using the star pattern with a different formula for determining its size. With typical 0.6 mm focal spot size and 153-200 micron detectors, spatial resolutions of 3 - 4 LP/mm can be achieved. However, usage of a large focal spot can degrade the spatial resolution less than 2.0 LP/mm at clinically used geometry.

CONCLUSION: Although the size of the DEL on digital image receptors is important, focal spot blur is still a major limitation to spatial resolution at clinically used geometries. It is important to assess the x-ray tube focal spot size with digital imaging systems.

8668-211, Session PSWed

Physical model-based metal artifact reduction (MAR) scheme for a 3D cone-beam CT extremity imaging system

Dong Yang, Robert A. Senn, Nathan Packard, Samuel Richard, John Yorkston, Carestream Health Technology and Innovation Ctr. (United States)

Metallic and other dense objects, such as implantable orthopedic appliances, surgical clips and staples, and dental fillings, are often placed into the human body. These high-density objects with high atomic numbers attenuate X-rays in the diagnostic energy range much more strongly than soft tissue or bone, resulting in far fewer photons reaching the detector. In addition, measurements in the vicinity of the metal shadow and within the metal shadow show stronger physical effects, such as high levels of quantum noise, scattered radiation, and beam hardening. All of these effects combined create the resulting nonlinearities, which are amplified by conventional filtered back-projection (FBP) reconstruction algorithms, and they produce strong artifacts in the form of dark bands and light streaks that spread across the entire reconstructed image. They reduce image quality by masking soft tissue structures, not just in the immediate vicinity of the dense object, but also throughout the entire image volume. A novel, physical-model-based, metal-artifact reduction scheme (MAR) is proposed to mitigate the metal-induced artifacts.

8668-212, Session PSWed

Theoretical performance analysis for CMOS based high resolution detectors

Amit Jain, Daniel R. Bednarek, Stephen Rudin, Toshiba Stroke and Vascular Research Ctr. (United States)

High resolution imaging capabilities are essential for guiding successful endovascular interventional procedures. Present x-ray imaging detectors are not adequate due to their inherent limitations. The newly-developed high-resolution micro-angiographic fluoroscope (MAF) detector has demonstrated excellent clinical image quality; however, further improvement in performance and physical design may be possible using CMOS sensors. We have thus calculated the theoretical performance of two proposed CMOS detectors which may be used as a successor to the MAF.

The proposed detectors have a 300 μm thick HL-type CsI phosphor, a 50 μm-pixel CMOS sensor with and without a variable gain light image intensifier (LII), designated MAF-CMOS-LII and MAF-CMOS, respectively. For the performance evaluation, linear cascade modeling was used. The detector imaging chains were divided into individual stages characterized by one of the basic processes (gain blurring, additive noise). Ranges of readout noise and exposure were used to calculate the detectors' MTF and DQE.

The MAF-CMOS showed slightly better MTF than the MAF-CMOS-LII, but the MAF-CMOS-LII showed far better DQE, especially for lower exposures.

The proposed detectors can have improved MTF and DQE compared with the present high resolution MAF detector. The performance of the MAF-CMOS is excellent for the angiography exposure range; however it is limited at fluoroscopic levels due to additive instrumentation noise. The MAF-CMOS-LII, having the advantage of the variable LII gain, can overcome the noise limitation and hence may perform exceptionally for the full range of required exposures.

8668-213, Session PSWed

A novel a-Se mammography flat panel detector with high sensitivity and low image artifacts

Takaaki Ito, FUJIFILM Corp. (Japan); Keiichiro Sato, Yoshihiro Okada, FUJIFILM Corp. (Japan)

We developed a new amorphous selenium (a-Se)-based flat panel detector (FPD) for digital mammography. This detector was designed to achieve high sensitivity and low image artifacts. The pixel size of the detector is less than 70um and the active area is approximately 24 cm ? 30 cm.

We investigated an optimal pixel pattern for 2D and 3D image detection. In this paper, the dependence of an a-Se-based FPD performance on the pixel pattern was showed for the first time. In general, a collection efficiency of electrons on an a-Se-based FPD dose not only depend on a fill-factor of a pixel electrode but also on a distribution of electric field. We prepared detectors with different pixel patterns and evaluated the dependence of their detective quantum efficiency (DQE), modulation transfer function (MTF), and image lag performance on electric field.

As a result, a newly developed detector with new pixels achieved high DQE and low image lag compared with conventional detectors with simple square pixels. The DQE value of the new detector is the highest at presents to our knowledge.

8668-214, Session PSWed

Monte Carlo simulation of bowtie filter scatter on a wide-cone low-dose CT system

Xin Liu, Anjali Srivastava, Hyoung-Koo Lee, Missouri Univ. of Science and Technology (United States); Jiang Hsieh, GE Healthcare (United States)

Knowledge of scattering generated by bowtie filter is crucial for providing artifact free images by the wide cone low dose CT scanner. We investigate and determine the scatter level and artifact generated by the widely used bowtie filter in a wide cone low dose CT system. Our approach is to use Monte Carlo simulation to estimate the scatter level generated by the bowtie filter. First, major components of CT systems, such as pre-patient collimator, flat filter, bowtie filter, and an optional post patient collimator (antiscatter grid), are built into a 3D model. The scatter to primary ratio (SPR) is determined by the MCNP5 – a Monte Carlo simulation toolkit. With the increased interests in the low dose and wide coverage CT technology, a tube potential of 80 kVp with more then 10 degree of cone angle is selected. Finally, simulated water images are generated by superimposing the scatter generated by the bowtie filter onto the primary x-ray beam. Scatter generated by the bowtie filter is significant and affects the image quality in a modern CT scanner with wide x-ray cone angle, and low x-ray tube potentials.

8668-215, Session PSWed

Quantifying cross scatter in biplane fluoroscopy motion analysis systems

Janelle A. Cross, Taly G. Schmidt, Ben McHenry, Marquette Univ. (United States)

Biplane fluoroscopy is currently used for dynamic, in vivo three-dimensional motion analysis of various joints of the body. The benefits of fluoroscopy compared to conventional optical marker tracking methods are the elimination of marker skin motion artifacts, and the ability to directly quantify in vivo skeletal motion that is not optically accessible while wearing orthotic devices and footwear. One potential drawback for biplane fluoroscopy is the cross-scatter contamination between two gantries, as the acquisitions are typically synchronized to facilitate motion tracking. The purpose of this study was to experimentally measure the magnitude and effects of cross-scatter in biplane fluoroscopy images acquired over a range of gantry angles (45-90 degrees) and kV settings (60-110 kV). Four cylindrical water phantoms of 4, 6, 8, and 10-in diameter were imaged, each containing a 1-in-diameter Teflon sphere. The cross-scatter fraction and the relative change in contrast-to-noise ratio due to cross scatter were calculated. Results demonstrated that the cross-scatter fraction varied from 0.051 for the 4-in cylinder to 1.326 for the 10-in cylinder at 60 kV, and from 0.010 to 0.832 at 110 kV. The reduction in CNR ranged from 0.974 (110 kV, 75°) for the 4-in cylinder to 0.618 (60 kV, 60°) for the 10-in cylinder. The results suggest that cross-scatter contamination during biplane fluoroscopy is relatively low when imaging distal extremities, and would not likely require antiscatter grids or asynchronous timing circuits. Analyzing joints with more soft tissue may introduce cross scatter that could reduce accuracy and may require additional scatter reduction hardware.

8668-216, Session PSWed

Full-field digital mammography with grid-less acquisition and software-based scatter correction: investigation of dose saving and image quality

Andreas Fieselmann, Daniel Fischer, Siemens AG (Germany); Ghani Hilal, Univ. of Düsseldorf (Germany); Frank Dennerlein, Thomas Mertelmeier, Siemens AG (Germany); Detlev Uhlenbrock, St. Josefs Hospital (Germany) and Ruhr-Univ. Bochum (Germany)

Anti-scatter grids in full-field digital mammography not only attenuate scattered radiation but also attenuate primary radiation. Dose saving could be realized if the effect of scattered radiation is compensated with a software-based scatter correction not attenuating the primary radiation. In this work, we have carried out phantom studies in order to investigate dose saving and image quality of grid-less acquisition in combination with software-based scatter correction. The results show that similar image quality (contrast-to-noise ratio and contrast-detail curves) can be obtained with this alternative acquisition and post-processing scheme at reduced dose. The dose reduction factor is breast thickness dependent and is >20% for typical breast thicknesses.

8668-217, Session PSWed

Characterization of Varian on-board imaging systems for use in automatic exposure control software

Daniel R. Morton, Rasika Rajapakshe, Cynthia Araujo, BC Cancer Agency (Canada)

Modern image guided radiation therapy involves the use of an isocentrically mounted On-Board Imager (OBI) to take kV images of a patient's position. Orthogonal OBI images are used with 2D-2D match software to determine the treatment couch shifts required for ideal alignment based on digitally reconstructed radiographs created in treatment planning. The lack of an automatic exposure control (AEC) on Varian OBI systems requires x-ray techniques to be selected manually which may result in over or under exposed images and compromise the accuracy of the image matching. A software based AEC system is being developed in order to predict the optimal, patient specific exposure factors. This software requires that each OBI system be uniquely characterized for both the x-ray tube output (mR/mAs) and the detector response (pixel value/mR) for a clinical range of energies (kVp). Characteristic curves show that the detector is highly energy dependent at low kVp and increasingly energy independent with increasing kVp for open field images (no phantom material). A Beam Quality Index (BQI) was defined as the half value later measured for the beam including scatter effects for each kVp value. The detector response (per mR) was determined as a function of the BQI. Subsequent measurements using phantom material to "harden" the beams showed that the BQI can be modelled based on patient thickness, and the level of detector saturation per unit exposure can be accurately predicted based on this beam quality. Using this model, the optimal exposure (mAs) can be determined to produce the highest quality image.

8668-218, Session PSWed

Carbon nanotube field emission x-ray system for high resolution computed tomography

Jehwang Ryu, Wan Sun Kim, Seung Ho Lee, Jung Su Kang, Jae Gon Kim, Soo Yeol Lee, Kyu Chang Park, Hun Kuk Park, Kyung Hee Univ. (Korea, Republic of)

We developed a carbon nanotube field emission x-ray system for computed tomography imaging. The obtained x-ray images were reconstructed to tomography image using back projection and filtered back projection algorithm. The resulting reconstructed x-ray image clearly shows micrometer scale.

In this paper, we demonstrated the CNT FE x-ray system for CT imaging. The x-ray images show micrometer scale resolution with stable and repeatable measurements. The demonstrated CNT x-ray system and their imaging processing are discussed.

8668-219, Session PSWed

A digital compact x-ray tube with carbon nanotube field emitters for advanced imaging systems

Jae-woo Kim, Univ. of Science and Technology (Korea, Republic of); Jin-woo Jeong, Jun-tae Kang, Sungyoul Choi, Kyoung Eun Choi, Seungjoon Ahn, Yoon-ho Song, Electronics and Telecommunications Research Institute (Korea, Republic of)

Although there have been many reports on the carbon nanotube (CNT) emitter-based x-ray source, most of them have been built in a large vacuum chamber with a turbo-molecular and/or ion pump, which strongly limits its application to medical imaging systems. Furthermore, even several reported vacuum-sealed CNT x-ray tubes were achieved in a simple diode or triode configuration without a focusing structure, not showing a good controllability and a small focal spot.

We have successfully developed a fully vacuum-sealed CNT x-ray source in a very compact tube without any active vacuum pump. The brazing process was specially designed and adopted for the vacuum sealing of the x-ray tube at an elevated temperature. This method enables us to obtain and maintain a desired vacuum level for the reliable electron emission from the CNT emitters after the vacuum packaging. The CNT x-ray tube also had a novel focusing electrode to effectively focus electron beams from the CNT emitters on a small area of the anode target, giving a small focal spot of below 0.3 mm with a large tube current of above 50 mA. The active-current control modulated the CNT x-ray source digitally with a low voltage of below 5 V and enhanced its stability further. Also, the pull-up circuit positioned at the cathode node of the x-ray tube shortened the response time down to several micro second. The developed CNT x-ray tube can open up new applications in medical imaging like a stationary tomosynthesis or pulsed fluoroscopy over conventional hot-cathode x-ray sources.

8668-220, Session PSWed

Quantification of a silver contrast agent in dual-energy breast x-ray imaging

Roshan Karunamuni, Andrew D. A. Maidment, Univ. of Pennsylvania (United States)

Dual-energy (DE) breast x-ray imaging involves acquiring images using a low- and high-energy x-ray spectral pair. These images are then subtracted using a weighting factor that eliminates the soft-tissue signal variation present in the breast leaving only image contrast that is attributed to an exogenous imaging agent. We have previously demonstrated the potential for silver (Ag) as a contrast material for DE breast imaging. Theoretical analysis shows that silver can provide better contrast to clinically-used iodine. Here, we present the subtraction method developed to eliminate the contrast between adipose and glandular tissue; the two major component materials in the breast. The weighting factor is calculated from the attenuation coefficients of the two tissue types and varies between values of 0 and 1 for the energy combinations studied. A spectral search was performed to identify the set of clinically-feasible imaging parameters that will optimize the contrast of silver using our subtraction technique. The subtraction methodology was tested experimentally using step-phantoms and demonstrated that we are able to a) nullify the soft-tissue contrast that

arises from differences in glandularity, and b) preserve an image contrast for silver that is independent of the underlying soft-tissue composition. Work is currently underway to test the Ag-optimized spectral pair on physical phantoms.

8668-221, Session PSWed

Exploring the relationship between SDNR and detectability in dual-energy breast x-ray imaging

Roshan Karunamuni, Univ. of Pennsylvania (United States); Swathiu Kanamaluru, Drexel Univ. (United States); Kristen Lau, Sara Gavenonis, Predrag R. Bakic, Univ. of Pennsylvania (United States); Andrew D. A. Maidment, Univ. of Pennsylvania Health System (United States)

Contrast-enhanced dual-energy (DE) breast x-ray tomosynthesis provides a technique to increase the contrast of radiographic imaging agents by suppressing soft-tissue signal variation. By reducing the effect of the soft-tissue contrast, it is then possible to quantify the signal from an iodinated contrast agent. The combination of dual-energy and tomographic acquisitions allows for both the accurate quantification and localization of an iodinated lesion. Here, we present our findings demonstrating the relationship that exists between the signal difference to noise ratio (SDNR) and reader detectability of iodinated lesions in a physical anthropomorphic phantom. The observer study was conducted using a ViewDEX software platform with a total of nine readers. The readers were asked to score each of the iodinated lesions on a scale from 1 (entire boundary and area are visible) to 5 (not visible). The SDNR was found to be vary more with the concentration of the iodinated lesion than the overall thickness of the breast tissue. The observer ratings of detectability increased with increasing areal concentrations of iodine and decreasing thickness of tissue. Our results demonstrated that the observer ratings correlated well with the SDNR calculated for the lesions. As expected from the Rose criterion, lesions whose SDNR fell below 5 were difficult to distinguish from the background and were in general not visible. Lesions that were rated entirely visible corresponded to those with SDNR values above 15. These results will be used in future studies to help optimize the imaging acquisition parameters of lesions in contrast-enhanced DE clinical studies.

8668-222, Session PSWed

Rat coronary microangiography system for preclinical imaging using synchrotron radiation

Keiji Umetani, Japan Synchrotron Radiation Research Institute (Japan); James T. Pearson, Monash Univ. (Australia); Daryl O. Schwenke, Univ. of Otago (New Zealand); Mikiyasu Shirai, National Cerebral and Cardiovascular Ctr. Research Institute (Japan)

A rat microangiography system was developed for in vivo visualization of the coronary, cerebral, and pulmonary arteries without exposure of organs and with spatial resolution in the micrometer range and temporal resolution in the millisecond range. We refined the system continuously in terms of spatial resolution and exposure time using synchrotron radiation at SPring-8. The spatial resolution has improved to 7 μm, yielding sharp images of small arteries. Exposure time has been shortened to around 2 ms using a new rotating-disk X-ray shutter, enabling imaging of beating hearts.

Quantitative evaluations of the rat coronary microangiography system were extracted from measurements of the smallest-detectable vessel size and detection of vessel function. The smallest-diameter vessel viewed for measurements is determined primarily by the concentration of iodinated contrast material. The iodine concentration depends on the injection technique. It is extremely difficult to inject contrast agent directly into small rat coronary arteries. Instead, the contrast agent was injected into the aorta close to the origin of the coronary arteries in the rat coronary angiography.

The vascular internal diameter response of coronary arterial circulation was analyzed to evaluate the vessel function. Small blood vessels of around 50-μm diameter or above were visualized clearly at heart rates of 300–360 per minute. Vasodilation compared to the control was observed quantitatively using drug manipulation. The technique can enable direct investigation of the mechanisms of vascular dysfunction. It is expected to be useful to evaluate the severity of damage to arterial inner walls resulting from diseases.

8668-223, Session PSWed

Development of a line electron focusing lens for carbon nanotube field emission based microbeam radiation device

Jian Zhang, Shanghai Advanced Research Institute (China) and United Imaging Healthcare (China) and Univ. of North Carolina at Chapel Hill (United States); Michael Hadsell, University of North Carolina at Chapel Hill (United States); Jianping Lu, Otto Z. Zhou, The Univ. of North Carolina at Chapel Hill (United States); Sha Chang, University of North Carolina at Chapel Hill (United States)

Microbeam radiation therapy (MRT) is an experimental and preclinical technique with demonstrated capability of eradicating brain tumors while sparing normal tissues from radiation damage. We have proposed the design of a microbeam radiation source using a carbon nanotube (CNT) field emission x-ray source. The key enabling technology here is the CNT based spatially distributed x-ray technology. The proposed MRT system has a circular system geometry with the radiations shining on the targeting tumor positioned at the center of the circle. A high microbeam dose rate is achieved by distributing the electron energy over multiple long circular focal tracks with a significantly larger area and therefore higher heat capacity compared to a conventional x-ray source with a point focal spot. Meanwhile the efficiency of the x-ray photons going through the narrow microbeam collimator, thus the dose rate, is greatly increased by making the effective width of the focal track comparable to that of the microbeam collimator opening. In order to achieve the desired focal track on the anode, a commercial software package (Opera 3D, Cobham plc) was used to simulate and design the optimal line focusing lens. The finalized design was based on a two-electrode Einzel focusing lens configuration. The simulation shows the two-stage electrostatic focusing lens is able to provide the 100μm effective focal spot size required for the proposed microbeam x-ray with 100um beam width. The recent focal spot size measurement performed using a testing x-ray chamber has also verified the simulation results.

8669-1, Session 1

Efficient convex optimization-based curvature dependent contour evolution approach for medical image segmentation

Eranga Ukwatta, Jing Yuan, Wu Qiu, Martin Rajchl, Aaron Fenster, Robarts Research Institute (Canada)

Markov random field (MRF) based approaches are extensively used in image segmentation applications, which often produce segmentation results with a boundary of minimal length/surface and tending to pass along image edges, yet affected by boundary shrinkage or bias in the absence of proper image edge information to drive the segmentation. In this paper, we propose a novel curvature re-weighted boundary smoothing term and introduce a new convex optimization-based contour/surface evolution method for medical image segmentation. The proposed curvature-based term generates the optimal solution with low curvatures and helps to avoid boundary shrinkage and bias. This is particularly useful for segmenting medical images, in which noisy and poor image quality widely exists and the shapes of anatomical objects are often smooth and even convex. Moreover, a new convex optimization-based contour evolution method is applied to propagate the initial contour to the object of interest efficiently and robustly. Distinct from the traditional methods for contour evolution, it provides a fully time-implicit contour evolution scheme, which allows a large evolution step-size to significantly speed up convergence. It also propagates the contour to its globally optimal position during each discrete time-frame, which improves the algorithmic robustness to noise and poor initialization. The fast continuous max-flow-based algorithm for contour evolution is implemented on GPU to achieve a high computational performance. Experimental results for both synthetic and 2D/3D medical images showed that the proposed approach generated segmentation results efficiently and increased the accuracy and robustness of segmentation by avoiding segmentation shrinkage and bias.

8669-2, Session 1

An automated algorithm for cell-level FISH dot counting

Yousef Al-Kofahi, GE Global Research (United States) and GE Global Research (United States); Dirk R. Padfield, Antti Seppo, GE Global Research (United States)

FISH (fluorescent in-situ hybridization) dot counting is the process of enumeration of chromosomal abnormalities in interphase cell nuclei. This process is widely used in many areas of biomedical research and diagnosis. We present a generic and fully automatic algorithm for cell-level counting of FISH dots in 2-D fluorescent images. Our proposed algorithm starts by segmenting cell nuclei in DAPI stained images using a 2-D wavelet based segmentation algorithm. Nuclei segmentation is followed by FISH dot detection and counting, which consists of three main steps. First, image pre-processing where median and top-hat filters are used to clean image noise, subtract background and enhance the contrast of the FISH dots. Second, FISH dots detection where a multi-level h-minima transform based image binarization method is used to account for varying image contrast. Third, FISH dots counting, which starts by separating clusters of FISH dots using a local maxima detection-based method followed by FISH dot size-based constraint to account for large connected components of tightly-clustered dots.

In order to quantitatively assess the performance of our proposed FISH dot counting algorithm, automatic counting results were compared to manual counts of 880 cells selected from 19 invasive ductal breast carcinoma samples exhibiting varying degrees of Her2 expression. Cell-level dot counting accuracy was assessed using two metrics: cell classification agreement and dot-counting match. Our automatic results gave an overall cell-by-cell classification agreement of 88% and an overall accuracy of 81%.

8669-3, Session 1

Automatic cell segmentation in fluorescence images of confluent cell monolayers using multi-object geometric deformable model

Zhen Yang, John A. Bogovic, Aaron Carass, Mao Ye, Peter C. Searson, Jerry L. Prince, Johns Hopkins Univ. (United States)

With the rapid development of microscopy for cell imaging, there is a strong and growing demand for image analysis software to quantitatively study cell morphology. Automatic cell segmentation is an important step in image analysis. Despite substantial progress, there is still a need to improve the accuracy, efficiency, and adaptability to different cell morphologies. In this paper, we propose a fully automatic method for segmenting whole cells in fluorescence images of confluent cell monolayers. This method addresses several challenges through a combination of ideas: 1) It realizes a fully automatic segmentation process by first detecting the cell nuclei as initial seeds and then using a multi-object geometric deformable model (MGDM) for final segmentation. 2) To deal with different defects in the fluorescence images, the cell border is enhanced by applying an order-statistic filter and principal curvature based image operator. 3) The final segmentation using MGDM promotes robust and accurate segmentation results, and guarantees no overlaps and gaps between neighboring cells. The automatic segmentation results are compared against manually delineated cells, and the average Dice coefficient over all distinguishable cells is 0.88.

8669-4, Session 1

Robust local appearance features for MRI brain structure segmentation across scanning protocols

Hakim C. Achterberg, Dirk H. J. Poot, Fedde van der Lijn, Meike W. Vernooij M.D., M Arfan Ikram M.D., Erasmus MC (Netherlands); Wiro J. Niessen, Erasmus MC (Netherlands) and Delft Univ. of Technology (Netherlands); Marleen de Bruijne, Erasmus MC (Netherlands) and Univ. of Copenhagen (Denmark)

Segmentation of brain structures in magnetic resonance images is an important task in neuro image analysis. Several papers on this topic have shown the benefit of supervised classification based on local appearance features, often combined with atlas-based approaches. These methods require a representative annotated training set and therefore often do not perform well if the target image is acquired on a different scanner or with a different acquisition protocol than the training images. Assuming that the simpler task of brain tissue classification can be performed more robustly for images obtained with different protocols, we propose to derive appearance features from brain-tissue density maps instead of directly from the MR images. We evaluated this approach on hippocampus segmentation in two sets of images acquired with substantially different imaging protocols and on different scanners. While a combination of conventional appearance features trained on data from a different scanner with multi-atlas segmentation performed poorly with an average Dice overlap of 0.698, the local appearance model based on the new acquisition-independent features significantly improved (0.783) over atlas-based segmentation alone (0.728).

8669-150, Session 1

Region-based graph cut using hierarchical structure with application to ground-glass opacity pulmonary nodules segmentation

Chi-Hsuan Tsou, Kuo-Lung Lor, Institute of Biomedical

Engineering, National Taiwan Univ. (Taiwan); Yeun-Chung Chang, National Taiwan Univ. Hospital (Taiwan); Chung-Ming Chen, Institute of Biomedical Engineering, National Taiwan Univ. (Taiwan)

Image segmentation for the demarcation of pulmonary nodules in CT images is intrinsically an arduous task. The difficulty can be summarized into two aspects. Firstly, lung tumor can be various in terms of physical densities in pulmonary regions, implying the different interpretation as a mixture of GGO and solid nodules. Hence, processing of lung CT images may generally encounter tissue inhomogeneous problem. The second factor that complicates the task of nodule demarcation is the irregular shapes that most nodules are directly connected to other structures sharing the similar density profile. In this paper, an image segmentation framework is proposed by unifying the techniques of statistical region merging and conditional random field (CRF) with graph cut optimization to address the difficult problem of GGO nodules quantification in CT images. Different from traditional segmentation methods that use pixel-based approach such as region growing and morphological constraints, we employ a hierarchical segmentation tree to alleviate the effect of inhomogeneous attenuation. In addition to building perceptual prominent regions, we perform inference in CRF model based on restricting the pool of segmented regions. Following that, an inference CRF model is carried out to detect and localize individual object instances in CT images. The proposed algorithm is evaluated with four sets of manual delineations on 77 lung CT images. Incorporating with the efficiency and accuracy of pulmonary nodules segmentation method proposed in this paper, a computer aided system is hence feasible to develop related clinical application.

8669-6, Session 2

Fiber feature map based landmark initialization for highly deformable DTI registration

Aditya Gupta, The Univ. of North Carolina at Chapel Hill (United States) and Univ. of Pittsburg (United States); Matthew Toews, Harvard Medical School (United States); Ravikiran Janardhana, The Univ. of North Carolina at Chapel Hill (United States); Yogesh Rathi, Harvard Medical School (United States); John Gilmore, The Univ. of North Carolina at Chapel Hill (United States); Maria Escolar, Univ.of Pittsburgh (United States); Martin A. Styner, The Univ. of North Carolina at Chapel Hill (United States)

This paper presents a novel pipeline for the registration of diffusion tensor images (DTI) with large pathological variations to normal controls based on the use of a novel feature map derived from white matter (WM) fiber tracts. The research presented aims towards an atlas based DTI analysis of subjects with considerable brain pathologies such as tumors or hydrocephalus. In this paper, we propose a novel feature map that is robust against variations in WM fiber tract integrity and use these feature maps to determine a landmark correspondence using a 3D point correspondence algorithm. This correspondence drives a deformation field computed using Gaussian radial basis functions(RBF). This field is employed as an initialization to a standard deformable registration method like demons. We present early preliminary results on the registration of a normal control dataset to a dataset with abnormally enlarged lateral ventricles affected by fatal demyelinating Krabbe disease. The results are analyzed based on a regional tensor matching criterion and a visual assessment of overlap of major WM fiber tracts. While further evaluation and improvements are necessary, the results presented in this paper highlight the potential of our method in handling registration of subjects with severe WM pathology.

8669-7, Session 2

Morphological changes in the corpus callosum: A study using joint Riemannian feature spaces

Meena Mani, Univ. of Minnesota (United States); Anuj Srivastava, Florida State Univ. (United States); Christian Barillot, INRIA (France)

Shape, scale, orientation and position, the physical features associated with white matter fibers, can, either individually or in combination, be used to define feature spaces.

Recent work by Mani et al. describes a Riemannian framework in which these joint feature spaces are considered.

In this paper, we use the tools and metrics defined within this mathematical framework to study morphological changes due to disease progression. We look at sections of the anterior corpus callosum, which describes a deep arc along the mid-sagittal plane, and show how multiple sclerosis and normal control populations have different joint shape-orientation signatures.

8669-8, Session 2

Parcellation of the thalamus using diffusion tensor images and a multi-object geometric deformable model

Chuyang Ye, John A. Bogovic, Sarah H. Ying, Jerry L. Prince, Johns Hopkins Univ. (United States)

The thalamus is a sub-cortical gray matter structure that relays signals between the cerebral cortex and midbrain. It can be parcellated into the thalamic nuclei which project to different cortical regions. The ability to automatically parcellate the thalamic nuclei could lead to enhanced diagnosis or prognosis in patients with some brain disease. Previous works have used diffusion tensor images (DTI) to parcellate the thalamus, using either tensor similarity or cortical connectivity as information driving the parcellation. In this paper, we propose a method that uses the diffusion tensors in a different way than previous works to guide a multiple object geometric deformable model (MGDM) for parcellation. The primary eigenvector (PEV) is used to indicate the homogeneity of fiber orientations. To remove the ambiguity due to the fact that the PEV is an orientation, we map the PEV into a 5D Knutsson space. An edge map is then generated from the 5D vector to show divisions between regions of aligned PEV's. The generalized gradient vector flow (GGVF) calculated from the edge map drives the evolution of the boundary of each nucleus. Region based force, balloon force, and curvature force are also employed to refine the boundaries. Experiments have been carried out on five real subjects. Quantitative measures show that the automated parcellation agrees with the manual delineation of an expert under a published protocol.

8669-9, Session 2

Effects of DTI spatial normalization on white matter tract reconstructions

Nagesh Adluru, Univ. of Wisconsin-Madison (United States); Hui Zhang, Univ. College London (United Kingdom); Do P. M. Tromp, Andrew L. Alexander, Univ. of Wisconsin-Madison (United States)

Major white matter (WM) pathways in the brain can be reconstructed in vivo using tractography on diffusion tensor imaging (DTI) data. Performing tractography using the native DTI data is often considered to produce more faithful results than performing it using the spatially normalized DTI obtained using highly non-linear transformations. However, tractography in the normalized DTI is playing an increasingly

important role in population analyses of the WM. In particular, the emerging tract specific analyses (TSA) can benefit from tractography in the normalized DTI for statistical parametric mapping in specific WM pathways. It is well known that the preservation of tensor orientations at the individual voxel level is enforced in tensor based registrations. Small reorientation errors at individual voxel level can accumulate and could potentially affect the tractography results adversely. To our knowledge, there has been no study investigating the effects of normalization on consistency of tractography that demands non-local preservation of tensor orientations which is not explicitly enforced in typical DTI spatial normalization routines. This study aims to evaluate and compare tract reconstructions obtained using normalized DTI against those obtained using native DTI. Although tractography results have been used to measure and influence the quality of spatial normalization, the presented study addresses a distinct question: whether non-linear spatial normalization preserves even long-range anatomical connections obtained using tractography for accurate reconstructions of pathways. Our results demonstrate that spatial normalization of DTI data does preserve tract reconstructions of major WM pathways and does not alter the variance (individual differences) of their macro and microstructural properties. This suggests one can extract quantitative and shape properties efficiently from the tractography data in the normalized DTI for performing population statistics on major WM pathways.

8669-10, Session 2

Susceptibility artefact correction by combining B0 field maps and non-rigid registration using graph cuts

Pankaj Daga, Marc Modat, Univ. College London (United Kingdom); Gavin Winston, Dept. of Clinical and Experimental Epilepsy (United Kingdom); Mark White, Laura Mancini, Andrew McEvoy, John Thornton, Tarek Yousry, Institute of Neurology, Univ. College London (United Kingdom); John Duncan, Dept. of Clinical and Experimental Epilepsy (United Kingdom); Sebastien Ourselin, Univ. College London (United Kingdom)

We present a novel method for correction of geometric distortions arising from susceptibility artefacts in echo planar MRI images that combines fieldmap and an image registration based correction technique in a unified framework. The geometric distortions arising from these artefacts lead to inaccurate alignment of images from different MRI techniques and hinders their joint analysis. A novel phase unwrapping algorithm is presented that can efficiently compute the B0 field inhomogeneity map as well as the confidence associated with the estimated solution. This information is used to adaptively drive a subsequent image registration step to further refine the results in low-confidence areas. The effectiveness of the proposed unified algorithm in correcting for geometric distortions due to susceptibility artefacts is demonstrated on interventional MRI EPI images.

8669-11, Session 2

Functional brain atlas construction for brain network analysis

Hongming Li, Yong Fan, Institute of Automation (China)

Brain network analysis is a promising tool in studies of the human brain function's organization and neuropsychiatric disorders. Network nodes are typically defined as distinct grey-matter regions delineated by anatomical brain atlases, random parcellation of the brain space, or image voxels for neuroimaging data based brain network analysis, resulting in brain network nodes with different spatial scales. As precise functional organization of the brain remains unclear, it is challenging to determine a proper spatial scale in practice. The brain network nodes defined anatomically or randomly do not necessarily possess desired properties of a good definition of the brain network nodes, i.e., functional homogeneity within individual nodes, functional distinctiveness across different nodes, and functional consistency across different subjects. To obtain a definition of brain network nodes with the desired properties, a brain parcellation method based on functional information is proposed to achieve a brain parcellation consistent across subjects and highly in agreement with the functional organization of the brain. Particularly, spatially contiguous voxel-wise functional information of the brain fMRI data recursively aggregate according to inter-voxel/region functional affinity from voxel level to coarser scales, resulting in a brain parcellation with a multi-level hierarchy. A trade-off between functional homogeneity and distinctiveness is determined by identifying the hierarchy level with network measures highly consistent across subjects. The proposed method has been validated on a resting-state fMRI dataset with 20 subjects for functional network analysis, and the result indicates that brain networks constructed with 200~500 nodes could achieve the highest inter-subject consistence.

8669-12, Session 3

Multi-object statistical analysis of late adolescent depression

Mahdi Ramezani, The Univ. of British Columbia (Canada); Abtin Rasoulian, Queen's Univ. (Canada); Purang Abolmaesumi, The Univ. of British Columbia (Canada); Tom Hollenstein, Ingrid Johnsrude, Kate Harkness, Queen's Univ. (Canada)

Shape deformations and volumetric changes in the hippocampus and amygdala have previously been noted in Major Depressive Disorder (MDD). Unfortunately, these analyses are limited because relative shape and pose (rigid+scale transformation) information of multiple objects in brain are generally disregarded. We hypothesize that this information might complement studies of limbic structural deformation in MDD. We focus on changes in temporal (e.g., superior, middle and inferior temporal gyrus) and limbic (e.g., hippocampus and amygdala) lobes. Here, we use a multi-object statistical pose+shape model to analyze imaging data from young people with and without a depressive disorder. Nineteen individuals with a depressive disorder (mean age: 17.85) and twenty six healthy controls (age: 18) were enrolled in the study. A segmented atlas in MNI space has been used to segment hippocampus, amygdala, parahippocampal gyri, putamen, and the superior, inferior and middle temporal gyri in both hemispheres of the brain. Points on the surface of each structure were extracted and warped to each subjects' structural MRI. These corresponding surface points were used within the analysis, to extract the pose and shape features. Pose and shape differences were detected between the two groups, such that second principal mode of pose variation ($p = 0.022$), and the first and forth principal modes of shape variation ($p = 0.005$ and $p = 0.017$, respectively) were found to differ significantly between the two groups.

8669-13, Session 3

Statistical shape representation with landmark clustering by solving the assignment problem

Bulat Ibragimov, Boštjan Likar, Franjo Pernuš, Tomaž Vrtovec, Univ. of Ljubljana (Slovenia)

Statistical shape modeling is considered as a backbone of image analysis, since shapes capture distinguishable geometrical properties and spatial relationships of depicted objects. In this paper, we present a novel statistical shape model based on landmark positions and spatial relationships among landmarks. A given training set of images is first annotated by a set of landmarks, which represents the shape of the object of interest. In contrast to active shape (ASM) and appearance models (AAM), where a shape is a single object characterized by a system of eigenvectors, we describe a shape as a combination of distances and angles between landmarks. Finding a suitable combination of distances and angles is achieved by optimizing the representativeness

of the model (i.e. the distances and angles must describe the shape and its plasticity) and complexity of the model (i.e. the number of distances and angles must be acceptable for practical applications). To generate a model that satisfies these conditions, the landmarks are first separated into clusters, which are then optimally connected. The optimal connections between clusters are generated by using the assignment problem. The obtained model combined with the existing game-theoretic framework was applied to segment lung fields from chest radiographs. The resulting symmetric mean boundary distance decreased on average for 0.05 mm, however, a 3.3-times acceleration in the computational time was on average observed when compared to segmentation without landmark clustering.

8669-14, Session 3

Quantitative vertebral morphometry in 3D

Darko ?tern, Univ. of Ljubljana (Slovenia); Vesna Njagulj, Klinicki Ctr. Vojvodine (Serbia); Boštjan Likar, Franjo Pernuš, Tomaž Vrtovec, Univ. of Ljubljana (Slovenia)

Identification of vertebral deformations in two dimensions (2D) is a challenging task due to the projective nature of radiographic images and natural anatomical variability of vertebrae. By generating detailed three-dimensional (3D) anatomical images, computed tomography (CT) enables accurate measurement of vertebral deformations. We present a novel approach to quantitative vertebral morphometry (QVM) based on parametric modeling of the vertebral body shape in 3D. A detailed 3D representation of the vertebral body shape is obtained by automatically aligning a parametric 3D model to vertebral bodies in CT images. The parameters of the 3D model describe clinically meaningful morphometric vertebral body features, and QVM in 3D is performed by comparing the parameters to their statistical values. By applying statistical classification analysis, thresholds and parameters that best discriminate between normal and fractured vertebral bodies are determined. The proposed QVM in 3D was applied to 454 normal and 228 fractured vertebral bodies, yielding classification sensitivity of 92.5% at 7.5% specificity, with corresponding accuracy of 92.5% and precision of 86.1%. The 3D shape parameters that provided the best separation between normal and fractured vertebral bodies were the vertebral body height, and the inclination and concavity of both vertebral endplates. The described QVM in 3D is able to efficiently discriminate between normal and fractured vertebral bodies, and identify morphological cases (wedge, (bi)concavity, crush) and grades (1, 2, 3) of vertebral body deformations. It may be therefore valuable for diagnosing and predicting vertebral fractures in patients who are at risk of osteoporosis.

8669-15, Session 3

Combining Active Appearance and Deformable Superquadric Models for LV Segmentation in Cardiac MRI

Sharath K. Gopal, Univ. of California, Los Angeles (United States) and Cedars-Sinai Medical Ctr. (United States); Yuka Otaki, Reza Arsanjani, Daniel S. Berman, Cedars-Sinai Medical Ctr. (United States); Demetri Terzopoulos, Univ. of California, Los Angeles (United States); Piotr Slomka, Cedars-Sinai Medical Ctr. (United States) and Univ. of California, Los Angeles (United States)

In this work we automatically segment the left ventricle(LV) in cardiac MR images in the end-diastole (ED) and end-systole (ES) phases using a novel approach that combines statistical and deformable models. A 3D Active Appearance Model (AAM) is used to segment the ED phase. The AAM texture model is trained on radial samples from gradient magnitude images to make the fitting process faster and more discriminative. A trained ED-to-ES shape correspondence model is used to map a given ED shape to an ES shape. Once the AAM model converges to a shape in ED, the correspondence model is used to get an approximate ES shape. We segment the LV in the ES phaseby first fitting a deformable superquadric to the AAM converged shape(in ED) using data range forces and then tracking the LV using image and data range forces(for the ES shape obtained from correspondence model). We test our approach by running leave-one-out training on a set of 35 patients. The set is composed of 19 normal patients and 16 patients having heart function abnormalities (cardiomyopathy and myocardial infarction). The composition makes it a challenging dataset with significant shape variation. The performance of our method is judged by measuring mismatch between automated and expert contours using the Mean Perpendicular Distance(MPD) and Dice metrics. The average MPD is 2.6mm for ED and 3.7mm for ES (error mostly towards apex and base). The average dice is 0.9 for ED and 0.8 for ES. These results show good potential for clinical use.

8669-16, Session 3

Parsing radiographs by integrating landmark set detection and multi-object active appearance models

Albert Montillo, Qi Song, Xiaoming Liu, GE Global Research (United States); James Miller, GE Research (United States)

This work addresses the challenging problem of parsing 2D radiographs into salient anatomical regions such as the left and right lungs and the heart. We propose the integration of an automatic detection of a constellation of landmarks via rejection cascade classifiers and learned geometric constellation model with a multi-object active appearance model (MO-AAM) initialized by detected landmarks. Our main contribution is twofold. First we propose to (1) recover missing (false negative) landmarks through the consensus of inferences from subsets of the detected landmarks, and (2) choose one from multiple false positives for the same landmark by learning multi-variate Gaussian distributions for the relative location of each landmark. False positive and negative recovery allows to handle extreme ranges of anatomical and pathological variability. Second, we train a MO-AAM using the true landmarks for the detectors and initialize the model using detected landmarks. The integration of these approaches reduces mean distance error of the detected landmarks from 20.0mm to 12.6mm. We assess our method using a database of scout CT scans from 80 subjects with varying pathology.

8669-17, Session 4

Multiple sclerosis lesions evolution in patients with clinically isolated syndrome

Alessandro Crimi, Olivier Commowick, INRIA/IRISA (France); Gilles Edan, Ctr. Hospitalier Univ. de Rennes (France); Christian Barillot, INRIA/IRISA (France); Adil Maarouf M.D., Neurology Department University hospital Reims (France) and CRMBM Aix-Marseille Universitz, CNRS (France); JeanChristoph Ferre M.D., CHU Rennes (France)

Multiple sclerosis (MS) is a disease with heterogeneous evolution among the patients. Some classifications have been carried out according to either the clinical course or the immunopathological profiles. Epidemiological data and imaging are showing that MS is a two-phase neurodegenerative inflammatory disease. At the early stage it is dominated by focal inflammation of the white matter (WM), and at a latter stage it is dominated by diffuse lesions of the grey matter and spinal cord. A Clinically Isolated Syndrome (CIS) is a first neurologic episode caused by inflammation/demyelination in the central nervous system which may lead to MS. Few studies have been carried out so far about this initial stage. Better understanding of the disease at its onset will lead to a better discovery of pathogenic mechanisms, allowing suitable therapies at an early stage. We propose a novel paradigm for discovering spatio-temporal patterns in MRI volumes of CIS patients using a new contrast agent called USPIO.

The method is based on a two layers unsupervised clustering. Initially, the spatio-temporal lesion patterns are classified using a tensor-like representation, the discovered lesion patterns are then used to identify group of patients and their correlation to total lesion loads by one year follow-up. The proposed framework can infer future lesion load which is relevant since it correlates with the relapse number and hence with the disease severity.

The predictive power is motivated by the observation that USPIO appears to give complementary information compared to the traditional Gd.

The proposed framework is based on a two layers unsupervised clustering. Initially lesion patterns are identified, then the discovered patterns are used to identify group of patients. These two steps are performed by the same unsupervised clustering algorithm using the output of the first layer as the input of the second, i.e. the detected lesion patterns are used as features for a second layer clustering at the patient level.

This final patient classification correlates with the future lesion load after one year, which might indicate an even further evolution. This finding could lead to early diagnosis and more suitable treatments.

The proposed approach involved 23 CIS patients from different centers, which were assessed RRMS by follow-up. The MRI volumes were acquired by different hospitals using either a Verio 3T Siemens or an Achieva 3T Philips scanner according to a multi-center protocol. The volumes are isotropic at millimetric scale on both scanners. For each patient, at m time points, we acquired different MRI volumes with an interval of three months: a T1 Gd-enhanced, a T1 USPIO-enhanced, and a T2. The USPIO-enhanced MRI were acquired after 24 hours delay to let the macrophages go in the inflammatory area. Gd and USPIO do not study the same phenomenon: Gd studies the blood brain barrier breakdown whereas USPIO studies the inflammatory process related to macrophages. The follow-up lesion loads are assessed on T2 volumes after 12 months from the last time point m . A trained technician performed the manual delineation of the lesions for both contrast agents on T1 and for all the lesions on T2 volumes. The lesion load is normalized with respect the brain volume per patient.

8669-18, Session 4

Landmark detection and coupled patch registration for cardiac motion tracking

Haiyan Wang, Wenzhe Shi, Biomedical Image Analysis Group, Imperial College London (United Kingdom); Xiahai Zhuang, Shanghai Advanced Research Institute, Chinese Academy of Sciences (China); Xianliang Wu, Imperial College London (United Kingdom); Kai-Pin Tung, Biomedical Image Analysis Group, Imperial College London (United Kingdom); Sebastien Ourselln, Ctr. for Medical Image Computing, Univ. College London (United Kingdom); Philip J. Edwards, Imperial College London (United Kingdom); Daniel Rueckert, Biomedical Image Analysis Group, Imperial College London (United Kingdom)

Increasing attention has been focused on the estimation of the deformation of the endocardium to aid the diagnosis of cardiac malfunction. Landmark tracking can provide sparse, anatomy-specific constraints to help establish correspondences between images being tracked or registered. However, landmarks on the endocardium are often characterized by ambiguous appearance in cardiac MR images which makes the extraction and tracking of landmarks problematic. Here we propose an automatic framework to select and track a sparse set of distinctive landmarks, with relatively large deformations, to capture the endocardial motion of cardiac MR sequences.

A sparse set of the landmarks is identified using an entropy-based approach. In particular we use singular value decomposition (SVD) to reduce the search space and localise the landmarks with relatively large deformation across the cardiac cycle. The tracking of the sparse set of landmarks is performed simultaneously by a multi-stage Markov Random Field (MRF). The tracking result is further used to initialise registration based dense motion tracking.

We used this framework to extract a set of landmarks at the endocardial border of the left ventricle for each of the 51 MR image sequences. Although the left ventricle undergoes a number of different deformations, we show how the radial, longitudinal motion and twisting of the endocardial surface can be captured by the multi-stage MRF. In our experiments we demonstrated that both the sparse and the dense motion tracking using sparse landmarks outperformed conventional motion tracking by a substantial amount, with improvements of 17.0% and 18.3% respectively.

8669-19, Session 4

Voxel-wise displacement as independent features in classification of multiple sclerosis

Min Chen, Aaron Carass, Johns Hopkins Univ. (United States); Daniel S. Reich, National Institute of Neurological Disorders and Stroke (United States); Peter Calabresi, Johns Hopkins School of Medicine (United States); Dzung Pham, Ctr. for Neuroscience and Regenerative Medicine (United States); Jerry L. Prince, Johns Hopkins Univ. (United States)

We present a method that utilizes registration displacement fields to perform accurate classification of magnetic resonance images (MRI) of the brain acquired from healthy individuals and patients diagnosed with multiple sclerosis (MS). Contrary to standard approaches, each voxel in the displacement field is treated as an independent feature that is classified individually. Results show that when used with a simple linear discriminant and majority voting, the approach is superior to using the displacement field with a single classifier, even when compared against more sophisticated classification methods such as adaptive boosting, random forests, and support vector machines. Leave-one-out cross-validation was used to evaluate this method for classifying images by disease, MS subtype (Acc: 77%--88%), and age (Acc: 96%--100%).

8669-20, Session 4

pCT derived arterial input function for improved pharmacokinetic analysis of longitudinal dceMRI for colorectal cancer

Monica Enescu, Manav Bhushan, Institute of Biomedical Engineering (United Kingdom); Esme J. Hill, Jamie Franklin, Ewan M. Anderson, Ricky A. Sharma, Oxford Univ. Hospitals NHS Trust (United Kingdom); Julia A. Schnabel, Institute of Biomedical Engineering (United Kingdom)

Dynamic contrast enhanced MRI is the modality of choice for outcome prediction in cancer patients.

Changes in tumour microvasculature are typically quantified by pharmacokinetic modelling of contrast up-take curves. Reliable pharmacokinetic parameter estimation depends on the measurement of the arterial input function. However, it has been shown that there are several problems with measuring it based on MRI intensities. We propose computing a perfusion CT based arterial input function which is used for dynamic contrast enhanced MRI pharmacokinetic parameter estimation. Parameter estimation is performed simultaneously with intra-sequence motion correction by registration. Ktrans maps obtained with this approach were compared with those obtained using a population averaged arterial input function, i.e. Orton. The dataset comprised of 5 colorectal cancer patients, who had been imaged with both perfusion CT and dynamic contrast enhanced MRI, before and after the administration of a radiosensitising drug. The Kolmogorov-Smirnov distance between Ktrans distributions pre and post therapy was computed using both the perfusion CT and the Orton arterial input function. When using the former, a separation gap of 0.09 between responders and non-responders was obtained. When using the latter, the separation gap was smaller,

namely 0.03. Perfusion CT derived arterial input functions can be used for pharmacokinetic modelling of dynamic contrast enhanced MRI data, when perfusion CT images of the same patients are available. Compared to the Orton model, perfusion CT functions give a more accurate separation between responders and non-responders.

8669-21, Session 4

Registration of multiple temporally related point sets using a novel variant of the coherent point drift algorithm: Application to coronary tree matching

Séverine Habert, Siemens Corporate Research (United States) and Ecole Polytechnique de Montréal (Canada); Parmeshwar Khurd, Christophe Chefdhotel, Siemens Corporate Research (United States)

We present a novel algorithm for the registration of multiple temporally related point sets. Although our algorithm is derived in a general setting, our primary motivating application is coronary tree matching in multi-phase cardiac spiral CT. Our algorithm builds upon the fast, outlier-resistant Coherent Point Drift (CPD) algorithm, but incorporates temporal consistency constraints between the point sets, resulting in spatiotemporally smooth displacement fields. We preserve the speed and robustness of the CPD algorithm by using the technique of separable surrogates within an EM (Expectation-Maximization) optimization framework, while still minimizing a global registration cost function employing both spatial and temporal regularization. We demonstrate the superiority of our novel temporally consistent group-wise CPD algorithm over a straightforward pair-wise approach employing the original CPD algorithm, using coronary trees derived from both simulated and real cardiac CT data. Both our group-wise and the pair-wise approach employ regularization and bandwidth parameters. We tested a variety of configurations for these parameters. Our method presents lower average error between tree landmarks compared to the pairwise method when an average over all parameter configurations is considered. Moreover, for the best parameter configuration with either approach, our groupwise method presents significantly lower error than the pairwise approach with the greatest improvement for a dataset with numerous outliers. In addition, with a fixed set of parameters which have been tuned automatically in either approach, our algorithm presents better results than the pairwise approach which shows the capacity to register without a priori information on a unknown dataset.

8669-22, Session 4

Contextual filtering in curvelet domain for fluoroscopic sequences

Carole Amiot, Jérémie Pescatore, Thales Electron Devices (France); Jocelyn Chanussot, Michel Desvignes, Gipsa-Lab (France)

X-ray exposure during image guided interventions can be important for the patient and also the medical staff. Therefore dose reduction is a major concern. Nevertheless decreasing the dose affects significantly the image quality. Indeed the noise is higher and the contrast is poor. Hence, we have proposed to develop an efficient method to reduce noise in low dose fluoroscopic sequences. Many studies in that domain have been proposed implementing either multi-scales approaches using wavelet with its derivatives or using filters in the direct space. Our work is based on a spatio-temporal denoising filter using the curvelet transform. Indeed, this sparse transform represents well smooth images with edges and can be applied to fluoroscopic images in order to achieve robust denoising performances. Therefore, we propose to combine a temporal recursive filter with a spatial curvelet filter. Our work focus on the use of the statistical dependencies between the curvelet coefficients in order to optimize the threshold function. Determining the correlation among coefficients allow to detect which coefficients represent the relevant signal. Thus, our method allows to diminish or even to erase curvelet-like artefacts. We demonstrated our work on synthetic and real low dose sequences (ie: 20 nGy/frame).

8669-23, Session 5

Multimodal segmentation of optic disc and cup from stereo fundus and SD-OCT Images

Mohammad Saleh Miri, Kyungmoo Lee, Meindert Niemeijer, The Univ. of Iowa (United States); Michael D. Abramoff, The Univ. of Iowa (United States) and U. S. Depart. of Veterans Affairs (United States); Young H. Kwon, The Univ. of Iowa (United States); Mona K. Garvin, The Univ. of Iowa (United States) and U. S. Depart. of Veterans Affairs (United States)

Glaucoma is one of the major causes of blindness worldwide. One important structural parameter for the diagnosis and management of glaucoma is the cup-to-disc ratio (CDR), which tends to become larger as glaucoma progresses. While approaches exist for segmenting the optic disc and cup within fundus photographs, and more recently, within spectral-domain optical coherence tomography (SD-OCT) volumes, no approaches have been reported for the simultaneous segmentation of these structures within both modalities combined. In this work, a multimodal pixel-classification approach for the segmentation of the optic disc and cup within fundus photographs and SD-OCT volumes is presented. In particular, after segmentation of other important structures (such as the retinal layers and retinal blood vessels) and fundus-to-SD-OCT image registration, features are extracted from both modalities and a k-nearest-neighbor classification approach is used to classify each pixel as cup, rim, or background. The approach is evaluated on 70 multimodal image pairs from 35 subjects in a leave-10%-out fashion (by subject). A significant improvement in classification accuracy is obtained using the multimodal approach over that obtained from the corresponding unimodal approach (97.8% versus 95.2%; $p < 0:05$; paired t-test).

8669-24, Session 5

Ultrasound image segmentation using feature asymmetry and shape guided Live Wire

Thomas M. Rackham, Sylvia Rueda, IBME, Univ. of Oxford (United Kingdom); Caroline L. Knight, Univ. of Oxford (United Kingdom); J. Alison Noble, IBME, Univ. of Oxford (United Kingdom)

Ultrasound is a versatile, low cost, real-time, widely available imaging modality. However, manual segmentation for volumetric measurements can be difficult and incredibly time consuming, requiring slice-by-slice segmentations. Besides, automatic segmentation of ultrasound images can prove challenging due to the presence of speckle, attenuation, missing boundaries, signal dropouts and artefacts. Semi-automatic segmentation techniques can improve the speed and accuracy of such measurements, taking advantage of clinical expertise. Furthermore, the interaction between the clinician and the images they are analysing is preserved, making the task of manual segmentation easier. This paper presents a novel solution for interactive image segmentation on B-mode ultrasound images. The proposed method builds on the Live Wire framework and introduces two new sets of Live Wire costs, namely Feature Asymmetry (FA) cost to localise edges and a weak shape constraint cost to aid the selection of appropriate boundaries in the presence of missing information or artefacts. The resulting semi-automatic segmentation method follows edges based on structural relevance rather than intensity gradients, adapting the method to ultrasound images, where the object boundaries are normally fuzzy. The new method is applied in the context of fetal arm adipose tissue measurements, the adipose tissue being an indicator of the fetal

nutritional state. A quantitative and qualitative evaluation is performed with respect to related segmentation techniques. The method was tested on 48 manually segmented ultrasound images of the fetal arm, showing similar accuracy to the intensity-based Live Wire approach but superior repeatability while requiring significantly less time and user interaction.

8669-25, Session 5

Automatic ultrasound image segmentation for right ventricle using sparse matrix transform and level set

Xulei Qin, Zhibin Cong, Luma V. Halig, Baowei Fei, Emory Univ. (United States)

An automatic framework is proposed to segment right ventricle on ultrasound images. This method can automatically segment both epicardial and endocardial boundaries from a continuous echocardiography series by combining sparse matrix transform, a training model, and localized region based level set. First, the sparse matrix transform extracts main motion regions of myocardium as eigenimages by analyzing statistical information of these images. Second, a training model of right ventricle is registered to the extracted eigenimages to automatically detect the main location of the right ventricle and the corresponding transform relationship in the series. Third, the training model is then varied as an adapted initialization for the segmentation of each image in the series. Finally, based on the adapted initializations, a localized region based level set algorithm is applied to segment both epicardial and endocardial boundaries of the right ventricle from the whole series. Experimental results from real subject data validated the performance of the proposed framework in segmenting right ventricle from echocardiography. The mean Dice scores for both epicardial and endocardial boundaries are 89.1%±2.3% and 83.6±7.3%, respectively. The automatic segmentation method based on sparse matrix transform and level set can provide a useful tool for quantitative cardiac imaging.

8669-26, Session 5

Segmentation of retinal OCT images using a random forest classifier

Andrew Lang, Jerry L. Prince, Aaron Carass, Johns Hopkins Univ. (United States); Elias Sotirchos, Peter Calabresi, Johns Hopkins Univ. School of Medicine (United States)

Optical coherence tomography (OCT) has become one of the most common tools for diagnosis of retinal abnormalities. Both retinal morphology and layer thickness can provide important information to aid in differential diagnosis. Automatic segmentation methods are essential to provide these thickness measurements. Manual delineation of each layer is cumbersome given the sheer amount of data within each OCT scan. In this work, we propose a new method for retinal layer segmentation using a random forest classifier. A total of seven features are extracted from the OCT data and used to simultaneously classify nine layer boundaries. Taking advantage of the probabilistic nature of random forests, probability maps for each boundary are extracted and used to help refine the classification. We are able to accurately segment eight retinal layers with an average Dice coefficient of 0.79 and a mean absolute error of 1.21 pixels for the layer boundaries.

8669-27, Session 5

Classification of atorvastatin effect based on shape and texture features in ultrasound images

Xin Yang, Huazhong Univ. of Science and Technology (China); Rui Wang, Huazhong Univ of Science and Technology (China); Liu Li, Huazhong Univ. of Science and Technology (China); Aaron Fenster, The Univ. of Western Ontario (Canada); Mingyue Ding, Huazhong Univ. of Science and Technology (China)

Carotid atherosclerosis is the major cause of ischemic stroke, a leading cause of mortality and disability. Various researches have been conducted on how to quantitatively evaluate local arterial effects for potential carotid disease treatments. In this paper, the atorvastatin effect evaluation on atherosclerosis plaques are classified with different shape and texture features extracted in ultrasound images. First, the images of atherosclerotic lesions were extracted manually from ultrasound images by an expert. After analysis, 26 shape and 85 texture characteristics, and vessel wall volume (VWV) percent of change, were extracted from the atherosclerotic lesions. Among these, 13 features, including 6 shape, 6 texture features and VWV percent of change, were selected by physicians' evaluation from the 112 features. Finally support vector machine (SVM) was utilized to classify atherosclerosis plaques to atorvastatin or placebo group. The leave-one-case-out protocol was utilized on a database of 768 carotid ultrasound images of 12 patients (5 subjects of placebo group and 7 subjects atorvastatin group) for evaluation. Experiments showed an overall accuracy 91.67%, sensitivity 95.56%, specificity 86.16%; positive predictive value 90.72%, negative predictive value 93.20%, Matthew's correlation coefficient 82.81%, and Youden's index 81.72% were obtained. The results also demonstrated that the classification using 13 combined selected features has higher accuracy than that using shape/texture feature or VWV percent of change only. The proposed method can be used for the statins effect evaluation especially with the patients treated with drugs and further developed to a beneficial tool for facilitating the diagnosis of atherosclerosis.

8669-28, Session 6

Real time motion analysis in 4D medical imaging using conditional density propagation

Johannes Lotz, Bernd Fischer, Janine Olesch, Matthias Günther, Fraunhofer MEVIS (Germany)

Motion, like tumor movement due to respiration, constitutes a major problem in radiotherapy and/or diagnostics. A common idea, to compensate for the motion in 4D imaging, is to invoke a registration strategy, which aligns the images over time. This approach is especially challenging if real time processing of the data and robustness with respect to noise and acquisition errors is required.

To this end, we present a novel method which is based only on selected image features and uses a probabilistic approach to compute the wanted transformations of the 3D images. Moreover, we restrict the search space to rotation, translation and scaling.

In an initial phase, landmarks in the first image of the series have to be identified, which are in the course of the scheme automatically transferred to the next image.

To find the associated transformation parameters, a probabilistic approach, based on factored sampling, is invoked. We start from a state set containing a fixed number of different candidate parameters whose probabilities are approximated based on the image information at the landmark positions. Subsequent time frames are analyzed by factored sampling from this state set and by superimposing a stochastic diffusion term on the parameters.

The algorithm is successfully applied to clinical 4D CT data. Landmarks have been placed manually to mark the tumor in the initial image whose position is then tracked over time. We achieve a processing rate of two images per second. The accuracy of the tracking after five time steps is measured based on expert placed landmarks. We achieve a mean landmark error of less than 3 mm in a 5 cm cubic region around the tumor.

8669-29, Session 6

Population based modeling of respiratory lung motion and prediction from partial information

Dirk Boye, Ctr. for Proton Therapy, Paul Scherrer Institut (Switzerland) and Computer Vision Lab., ETH Zurich (Switzerland); Golnoosh Samei, Computer Vision Lab., ETH Zurich (Switzerland); Johannes Schmidt, Institute for Biomedical Engineering, Univ. and ETH (Switzerland); Gabor Szekely, Christine Tanner, Computer Vision Lab., ETH Zurich (Switzerland)

Treatment of tumor sites affected by respiratory motion requires knowledge of the position and the shape of the tumor and the surrounding organs during breathing. As not all structures of interest can be observed in real-time, their position needs to be predicted from partial information (so-called surrogates) like motion of diaphragm, internal markers or patient's surface. Here, we present an approach to model respiratory lung motion and predict the position and shape of the lungs from surrogates. 4D-MRI lung data of 10 healthy subjects was acquired and used to create a model based on Principal Component Analysis. The mean RMS motion ranged from 1.88 mm to 9.66 mm. Prediction was done using a Bayesian approach and an average RMSE of 1.44 mm was achieved.

8669-30, Session 6

A derivative of stick filter for pulmonary fissure detection in CT images

Changyan Xiao, Hunan Univ. (China); Marius Staring, Leids Univ. Medisch Ctr. (Netherlands); Juan Wang, Hunan Univ. (China); Denis P. Shamonin, Berend C. Stoel, Leids Univ. Medisch Ctr. (Netherlands)

Pulmonary fissures are important landmarks for automated recognition of lung anatomy. We propose a derivative of stick (DoS) filter for fissure detection in CT scans by considering the thin linear shape across multiple transverse planes. Based on a stick decomposition of a rectangle neighborhood, our main contribution is to define a nonlinear derivative vertical to the stick orientation. Then, combining with a standard deviation of intensity along the stick, the composed likelihood function will take a strong response to fissure-like bright lines, and tends to suppress undesired structures including large vessels, step edges and blobs. Applying the 2D filter sequentially to the sagittal, coronal and axial planes, an approximate 3D co-planar constraint is implicitly exerted through the cascaded pipeline, which helps to further remove the non-fissure tissues. To generate a clear segmentation, we adopt a connected component based post-processing scheme, and a branch-point finding algorithm is introduced to disconnect the residual adjacent clutters from the fissures, after binarizing the filter response with a relatively low threshold. The performance of our filter has been verified in experiments with a 23 patients dataset, where pathological deformations to different extents are included. It compared favorably with prior algorithms.

8669-31, Session 6

Globally optimal lung tumor co-segmentation of 4D CT and PET images

Junjie Bai, The Univ. of Iowa (United States); Qi Song, GE Global Research (United States); Sudershan Bhatia, The Univ. of Iowa (United States); Xiaodong Wu, The Univ. of Iowa (United States) and The Univ. of Iowa (United States)

Four-dimensional CT scans provides valuable motion information of patient throughout different phases of breathing. PET, on the other hand, provides functional information about tumor, which differentiate tumor from normal tissue effectively. However, manually contouring structures of interest on 4D CT is prohibitively tedious due to the large amount of data, although PET data can assist in identify rough tumor location quickly.

In this paper, we propose an automatic method to segment lung tumor simultaneously in all 4D CT scan phases and PET scan. We model the problem as an optimization problem based on Markov Random Fields (MRF) which involves region, boundary terms and a regularization term between PET and CT scans. The problem is solved optimally by computing a single max flow in a properly constructed graph. As far as the authors know, this is the first work in simultaneously segmenting tumor in 4D CT while incorporating PET information. Experiments on 3 lung cancer patients are conducted. The average Dice coefficient is improved from 0.553 to 0.691, which shows that the proposed method improves the tumor segmentation accuracy compared to segment 4D CT scans phase by phase without incorporating PET information.

Our method is efficient in terms of running time since the method only requires computing a max flow for which efficient algorithm exists. The memory consumption is linearly scalable with respect to number of 4D CT phases, which enables our method to handle multiple 4D CT phases with reasonable memory consumption.

8669-32, Session 6

Pulmonary lobe segmentation using the thin plate spline (TPS) with the help of the fissure localization areas

Benjamin L. Odry, Siemens Corporate Research (United States); Pauline Steininger, Univ. de Technologie de Compiegne (France) and Siemens Corporate Research (United States); Li Zhang, Atilla P. Kiraly, Siemens Corporate Research (United States); Alexander Mahnke M.D., Friedrich-Alexander-Univ. Erlangen-Nürnberg (Germany); Sandra Sudarsky, Carol L. Novak, Bernhard Geiger, Shuping Qing, Siemens Corporate Research (United States); Hendrik Ditt, Siemens AG - Healthcare (Germany)

Lung lobe segmentation is clinically important for disease classification, treatment and follow-up of pulmonary diseases. Some diseases such as tuberculosis and silicolis typically present in specific lobes i.e. almost exclusively the upper ones. However, the fissures separating different lobes are often difficult to detect because of their variable shape, appearance and low contrast in computed tomography images. In addition, a substantial fraction of patients have missing or incomplete fissures. To solve this problem, several methods have been employed to interpolate incomplete or missed fissures. For example, Pu et al. [1] used an implicit surface fitting with different radial basis functions; Ukil et al. [2] apply fast marching methods; and Ross et al. [3] used an interactive thin plate spline (TPS) interpolation where the user selects the points that will be used to compute the fissure interpolation via TPS. In our study, results of an automated fissure detection method based on a plate-filter as well points derived from vessels were fed into an a robust TPS interpolation that ultimately defined the lobes. To improve the selection of detected points, we statistically determined the areas where fissures are localized from 19 data-sets. These areas were also used to constrain TPS fitting so it reflected the expected shape and orientation of the fissures, hence improving result accuracy. Regions were the detection step provided low response were replaced by points derived from a distance-to-vessels map . The error, defined as the Euclidian mean distance between ground truth points and the TPS fitted fissures, was computed for each dataset to validate our results. Ground truth points were defined for both exact fissure locations and approximate fissure locations (when the fissures were not clearly visible). The mean error was 5.64 ± 4.83 mm for the exact ground truth points, and 10.01 ± 8.23 mm for the approximate ground truth points.

8669-33, Session 6

Highly accurate fast lung CT registration

Jan Ruehaak, Stefan Heldmann, Till Kipshagen, Bernd Fischer, Fraunhofer MEVIS (Germany)

Lung registration in thoracic CT scans has received much attention in the medical imaging community. Possible applications range from follow-up analysis, motion correction for radiation therapy, monitoring of airflow and pulmonary function to lung elasticity analysis.

In a clinical environment, runtime is always a critical issue, ruling out quite a few excellent registration approaches. In this paper, a highly efficient variational lung registration method based on minimizing the normalized gradient fields distance measure with curvature regularization is presented. The method ensures diffeomorphic deformations by an additional volume regularization. Supplemental user knowledge, like a segmentation of the lungs, may be incorporated as well.

The accuracy of our method was evaluated on 40 test cases from clinical routine. In the EMPIRE10 lung registration challenge, our scheme ranks third, with respect to various validation criteria, out of 27 algorithms with an average landmark distance of 0.72 mm. The average runtime is about 1:50 min on a standard PC, making it by far the fastest approach of the top-ranking algorithms. Additionally, the ten publicly available DIR-Lab inhale-exhale scan pairs were registered to subvoxel accuracy at computation times of only 20 seconds. Our method thus combines very attractive runtimes with state-of-the-art accuracy.

8669-34, Session 7

Assessing accuracy of non-linear registration in 4D image data using automatically detected landmark correspondences

René Werner, Univ. Medical Ctr. Hamburg-Eppendorf (Germany); Christine Duscha, Alexander Schmidt-Richberg, Jan Ehrhardt, Heinz Handels, Univ. zu Lübeck (Germany)

4D medical imaging becomes increasingly important in different areas of application. Their use for diagnostics and therapy planning usually requires the application of non-linear registration techniques. The reliability of extracted numbers is therefore directly dependent on the registration accuracy. Ideally, this accuracy should be evaluated on a patient- and data-specific level – which, however, requires appropriate measures and procedures. A standard criterion for evaluation of non-linear registration accuracy is the target registration error (TRE), computed using manually detected landmark correspondences in the images to register. Manual landmark detection is, however, time-consuming and error-prone. Thus, in this contribution different operators for automatic landmark detection and a template matching-based strategy for landmark propagation in 4D image sequences (here: 4D lung CT and 4D liver MRT data) are proposed and evaluated. It turns out that the so-called Förstner-Rohr-type operators perform best for landmark detection and that the propagation strategy ensures a robust landmark transfer between the patient's images. The automatically detected landmark correspondences are then used to evaluate the accuracy of different registration approaches (in total 48 variants) applied for registering 4D lung CT data. The resulting TRE values are compared to values obtained by manually detected landmark pairs. It is shown that statements concerning differences in accuracy of the registration approaches considered are identical for both the TRE values computed using manually and automatically detected landmark sets.

8669-35, Session 7

Deformable image registration by multi-objective optimization using a dual-dynamic transformation model to account for large anatomical differences

Tanja Alderliesten, Jan-Jakob Sonke, Netherlands Cancer Institute (Netherlands); Peter Bosman, Centrum Wiskunde & Informatica (Netherlands)

Some of the hardest problems in deformable image registration are problems where large anatomical differences occur between image acquisitions (e.g. large deformations due to images acquired in prone and supine positions and (dis)appearing structures between image acquisitions due to surgery). In this work we developed and studied, within a previously introduced multi-objective optimization framework, a dual-dynamic transformation model to be able to tackle such hard problems. This model consists of two non-fixed grids: one for the source image and one for the target image. By not requiring a fixed, i.e. pre-determined, association of the grid with the source image, we can accommodate for both large deformations and (dis)appearing structures. To find the transformation that aligns the source with the target image we used an advanced, powerful model-based evolutionary algorithm that exploits features of a problem's structure in a principled manner via probabilistic modeling. The actual transformation is given by the association of coordinates with each point in the two grids. Linear interpolation inside a simplex was used to extend the correspondence (i.e. transformation) as found for the grid to the rest of the volume. As a proof of concept we performed tests on both artificial and real data with disappearing structures. Furthermore, the case of prone-supine image registration for 2D axial slices of breast MRI scans was evaluated. Results demonstrate strong potential of the proposed approach to account for large deformations and (dis)appearing structures in deformable image registration.

8669-36, Session 7

Multimodal rigid-body registration of 3D brain images using bilateral symmetry

Sylvain Prima, INRIA Rennes - Bretagne Atlantique (France); Olivier Commowick, IRISA / INRIA Rennes (France)

In this paper we show how to use the approximate bilateral symmetry of the brain with respect to its interhemispheric fissure for intra-subject (rigid-body) mono- and multimodal 3D image registration. We propose to define and compute an approximate symmetry plane in the two images to register and to use these two planes as constraints in the registration problem. This 6-parameter problem is thus turned into three successive 3-parameter problems. Our hope is that the lower dimension of the parameter space makes these three subproblems easier and faster to solve than the initial one. We implement two algorithms to solve these three subproblems in the exact same way, within a common intensity-based framework using mutual information as the similarity measure. We compare this symmetry-based strategy with the standard approach (i.e. direct estimation of a 6-parameter rigid-body transformation), also implemented within the same framework, using synthetic and real datasets. We show our symmetry-based method to achieve subvoxel accuracy with better robustness and larger capture range than the standard approach, while being slightly less accurate and slower. Our method also succeeds in registering clinical MR and PET images with a much better accuracy than the standard approach. Finally, we propose a third strategy to decrease the run time of the symmetry-based approach and we give some ideas, to be tested in future works, on how to improve its accuracy.

8669-37, Session 7

CT colonography: inverse-consistent symmetric registration of prone and supine inner colon surfaces

Holger R. Roth, Jamie R. McClelland, Marc Modat, Thomas E. Hampshire, Ctr. for Medical Image Computing, Univ. College London (United Kingdom); Darren J. Boone, Ctr. for Medical Imaging, Univ. College Hospital (United Kingdom); Emma Helbren, Andrew Plumb, Centre for Medical Imaging, University College London (United Kingdom); Mingxing Hu, Sebastien Ourselin, Ctr. for Medical Image Computing, Univ. College London (United Kingdom); Steve Halligan, Ctr. for Medical Imaging, Univ. College Hospital (United Kingdom); David J. Hawkes, Ctr. for Medical Image Computing, Univ. College London (United Kingdom)

CT colonography interpretation is difficult and time-consuming because fecal residue or fluid can mimic or obscure polyps, leading to errors in diagnosis. To compensate for this, it is normal practice to obtain CT data with the patient in prone and supine positions. Repositioning redistributes fecal residue and colonic gas; fecal residue tends to move, while fixed mural pathology does not.

The cornerstone of competent interpretation is the matching of corresponding endoluminal locations between prone and supine acquisitions. Robust and accurate automated registration between acquisitions should lead to faster and more accurate detection of colorectal cancer and polyps.

Any directional bias when registering the colonic surfaces could lead to incorrect anatomical correspondence resulting in reader error. We aim to reduce directional bias and so increase robustness by adapting a cylindrical registration algorithm to penalize inverse-consistency error, using a symmetric optimization.

Using 17 validation cases, the mean inverse-consistency error was significantly reduced by 86% from 3.3mm to 0.45mm. We furthermore show an improved alignment of the prone and supine colonic surfaces, visible in a reduction in the mean sum-of-squared-differences in all cases by 43%. Mean registration error, measured at a sparse set of manually selected reference points, stayed at the same level as with the non-symmetric method (no significant differences). Our results suggest that the inverse-consistent symmetric algorithm performs more robustly than non-symmetric implementation of B-spline registration. Registration error is comparable with the observer error in establishing the reference standard. Work is in progress to produce a more accurate reference standard.

8669-38, Session 7

Statistical 3D prostate imaging atlas construction via anatomically constrained registration

Mirabela Rusu, Rutgers, The State Univ. of New Jersey (United States); B. Nicolas Bloch, C. Carl Jaffe, Boston Univ. School of Medicine (United States); Neil M. Rofsky, The Univ. of Texas Southwestern Medical Ctr. at Dallas (United States); Elizabeth M. Genega, Beth Israel Deaconess Medical Ctr. (United States); Robert E. Lenkinski, The Univ. of Texas Southwestern Medical Ctr. at Dallas (United States); Anant Madabhushi, Rutgers, The State Univ. of New Jersey (United States)

Statistical imaging atlases integrate multiple patient information collected across scales and modalities, such as multi-parametric(MP) MRI and histology, providing population statistics in a single canonical representation. Such atlases are particularly valuable in the identification and validation of meaningful imaging signatures for disease characterization in vivo within a population. Despite the high incidence of prostate cancer, an imaging atlas focused on different anatomic structures of the prostate, i.e. an anatomic atlas, has yet to be constructed.

We introduce a novel framework for MP-MRI atlas construction that uses an iterative, constrained registration (ACR) scheme to enable the proper alignment of the prostate (Pr) and central gland (CG) boundaries. Our current implementation uses endorectal T2-weighted MRI from 43 patients with biopsy confirmed cancer; however, the prostate atlas is seamlessly extensible to include additional MRI parameters. In our cohort, radical prostatectomy is performed following MP-MR image acquisition, thus ground truth annotations for prostate cancer are available from the histological specimens. Once mapped on MP-MRI, such annotations are utilized by the ACR framework to characterize the 3D statistical distribution of cancer per anatomic structure. Such distributions are useful for guiding biopsies toward regions of higher cancer likelihood and understanding imaging profiles for disease extent in vivo. We evaluate our approach via the Dice similarity coefficient (DSC) for different anatomic structures (delineated by expert radiologists): Pr, CG, peripheral zone, seminal vesicles and neurovascular bundles. The ACR-based atlas had a CG DSC of 89.31%, and Pr DSC of 92.66%.

8669-39, Session 7

Mouse lung volume reconstruction from efficient groupwise registration of individual histological slices with natural gradient

Haibo Wang, Mirabela Rusu, Thea Golden, Andrew Gow, Anant Madabhushi, Rutgers, The State Univ. of New Jersey (United States)

Mouse lung models facilitate the study of the pathogenesis of various pulmonary diseases such as infections and inflammatory diseases. The co-registration of histological data and magnetic resonance imaging (MRI) would allow for determination and validation of imaging signatures for different pathobiologies within the lung. While slice-based co-registration could be used, finding slice correspondences often requires the intervention of an expert and is time consuming. A more practical approach is to first reconstruct 3D histological volume from individual slices, then perform 3D registration with the MR volume. Before the histological reconstruction, image registrations are required to compensate for geometric differences between slices. Pairwise algorithms are usually used by registering pairs of successive slices. However, even if successive slices are registered reasonably well, the propagation of registration errors over slices can yield a volumetric reconstruction distorted from the shape of the true specimen. Groupwise registration can reduce the error propagation by considering more than two successive images during the registration, but existing algorithms are computationally expensive. In this paper, we present an efficient groupwise registration approach, which yields consistent volumetric reconstruction yet runs even faster than the pairwise registration. The achievements are based on 1) natural gradient speedup across transform warping iterations and 2) incremental computational component update across slices. The strength of the natural gradient technique lies in reducing the impact of the uncertainties of the gradients of multiple template slices. Experiments on two mouse lung datasets show that compared to pairwise registration, our groupwise approach runs faster in terms of registration convergence, and yields globally more consistent reconstruction.

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8669-40, Session 7

Surrogate-based diffeomorphic motion estimation for radiation therapy: comparison of multivariate regression approaches

Matthias Wilms, René Werner, Jan Ehrhardt, Alexander Schmidt-Richberg, Maximilian Blendowski, Heinz Handels, Univ. zu Lübeck (Germany)

Respiratoy motion is a major source of error in radiation treatment of thoracic and abdominal tumors. State-of-the-art motion-adaptive radiation therapy techniques are usually guided by external breathing signals acting as surrogates for the internal motion of organs and tumors. Assuming a relationship between the surrogate measurements and the internal motion patterns, which are usually described by non-linear transformations, correspondence models can be defined and used for surrogate-based motion estimation. In this contribution, a diffeomorphic estimation framework based on standard multivariate linear regression is extended by subspace-based approaches like principal component analysis, partial least squares, and canonical correlation analysis. These methods aim at exploiting the hidden structure of the training data to improve the use of the information provided by high-dimensional surrogate and internal motion representations. A quantitative evaluation carried out on 4D CT data sets of 10 lung tumor patients shows that subspace-based approaches are able to significantly improve the mean estimation accuracy when compared to standard multivariate linear regression.

8669-41, Session 8

Probabilistic model-based detection and localization of calibration phantoms in CT Images

Mingna Zheng, Yaorong Ge, Virginia Tech-Wake Forest Univ. School of Biomedical Engineering and Sciences (United States) and Wake Forest Univ. School of Medicine (United States); Jeffrey Carr, Wake Forest Univ. School of Medicine (United States)

As medical imaging moves from qualitative assessment to quantitative bio-markers, calibration of imaging data becomes critically important. Even in computed tomography (CT) images, in which image values are scaled to Hounsfield units, the measurements can vary due to differences in machine-level calibration and patient size. One way to ensure proper calibration at the image level is to include a phantom in each scan so that each image can be calibrated individually by the values measured from the phantom regions within the image. This introduces a need to extract phantom measurements from each image. Given a reasonable starting point manually or heuristically, this is a straightforward problem because the phantom regions are well defined and the values are relatively uniform. Many image segmentation algorithms will effectively find the phantom boundaries. However, the problem becomes challenging if the requirement is a fully automated method that is robust across variations of phantoms and that can exclude images without phantoms. In this paper, we describe a probabilistic model-based approach to tackling this problem. We use the constellation model framework first proposed by Burt el al. to represent a phantom as composed of a number of parts and determine the existence and localization of the phantom in a probabilistic sense based on the detection of candidate parts. This model based approach allows us to formally describe variations in phantom design and handle missing parts caused by phantom regions similar to the background. Initial results on 100 CT studies from a longitudinal cardiovascular study are encouraging.

8669-42, Session 8

Coarse-to-fine localization of anatomical landmarks in CT images based on multi-scale local appearance and rotation-invariant spatial landmark distribution model

Mitsutaka Nemoto, Yoshitaka Masutani, Shouhei Hanaoka, Yukihiro Nomura, Takeharu Yoshikawa, Naoto Hayashi, Kuni Ohtomo, The Univ. of Tokyo (Japan)

Purpose: Anatomical Landmarks (LM) often play a key role in medical image analysis. In our previous study, we reported an automatic detection method from CT images. Though the detection sensitivity was sufficiently high, the distance errors of the detection results for some LMs were relatively large as it sometimes exceeded 1 cm. Naturally, it is desirable that LM detection error is as small as possible, especially when the LM detection results are used by the following image analysis tasks such as image segmentation. In this study, we introduce a novel method for coarse-to-fine localizing the pre-detected LM positions to improve the accuracy of our LM detection method.

Method: The proposed LM position localization is performed by both the multi-scale local image pattern recognition and the likelihood estimation from prior knowledge on spatial distribution of multiple LMs. The classifier ensemble for recognizing local image pattern is trained by the cost sensitive MadaBoost. In the classifier training, the cost of each sample was altered depending on the distance from the correct LM position. Additionally, the spatial LM distribution likelihood, calculated by a statistical model of the inter-landmark distances between all LM pairs, is also used to determine the final LM position.

Results: The evaluation experiment was performed with 12 LM positions and 20 CT images. The average distance error of the LM position was decreased by 1.46 mm by the proposed localization process.

Conclusion: The proposed method was shown to be effective for reducing the LM detection errors.

8669-43, Session 8

Automated anatomical labeling of the cerebral arteries using belief propagation

Murat Bilgel, Snehashis Roy, Aaron Carass, Paul A. Nyquist, Jerry L. Prince, Johns Hopkins Univ. (United States)

Labeling of cerebral vasculature is important for characterization of anatomical variation, quantification of brain morphology with respect to specific vessels, and inter-subject comparisons of vessel properties and abnormalities. We propose an automated method to label the anterior portion of cerebral arteries using a statistical inference method on the Bayesian network representation of the vessel tree. Our approach combines the likelihoods obtained from a random forest classifier trained using vessel centerline features with a belief propagation method integrating the connection probabilities of the cerebral artery network. We evaluate our method on 30 subjects using a leave-one-out validation, and show that it achieves an average correct vessel labeling rate of over 92%.

8669-44, Session 8

A pattern recognition framework for vessel segmentation in 4D CT of the brain

Jan-Jurre Mordang, Marcel T. H. Oei, Rieneke van den Boom, Diagnostic Image Analysis Group, Dept. of Radiology, Radboud Univ. Nijmegen Medical Ctr. (Netherlands); Ewoud J. Smit, Univ. Medical Ctr. Utrecht (Netherlands); Mathias Prokop, Bram van Ginneken, Rashindra Manniesing, Diagnostic Image Analysis

Group, Dept. of Radiology, Radboud Univ. Nijmegen Medical Ctr. (Netherlands)

In this study, a framework is presented to automatically segment the complete cerebral vasculature from 4D Computed Tomography (CT) patient data. The following six image features are proposed: a subtraction image of a non-contrast CT from a timing-invariant CT Angiography, the area under the curve of a gamma variate function fitted to the tissue curves, three optimized parameter values of this gamma variate function, and a vessel likeliness function. These features are used in a linear discriminant voxel classifier to segment the 3D timing invariant CTA image into 4 different classes: blood vessel, soft tissue (consisting of white matter and grey matter), bone and background (consisting of air and equipment). 4D data sets of ten consecutive patients with a suspicion of ischemic stroke were obtained and feature images were constructed. Regions of interest were annotated in soft tissue and vessels and a leave-one-out training and testing scheme was applied to evaluate the framework. The resulting averaged accuracy was 0.985 ± 0.014 with a range of 0.957 to 0.999. To our knowledge, this is the first study in which a pattern recognition approach has been applied to 4D CT data for the purpose of cerebral vessel segmentation. Our preliminary results suggest that the proposed framework is a good foundation for the segmentation of cerebral blood vessels.

8669-45, Session 8

Hepatic vein segmentation using wavefront propagation and multiscale vessel enhancement

Klaus Drechsler, Cristina Oyarzun Laura, Stefan Wesarg, Fraunhofer-Institut für Graphische Datenverarbeitung (Germany)

Modern volumetric imaging techniques such as CT or MRI, aid in the understanding of a patient's anatomy and pathologies. Depending on the medical use case, various anatomical structures are of interest. Blood vessels play an important role in several applications, e.g. surgical planning. Manual delineation of blood vessels in volumetric images is error prone and time consuming. Automated vessel segmentation is a challenging problem due to acquisition-dependent problems such as noise, contrast, spatial resolution, and artifacts.

In this paper, a vessel segmentation method is presented that combines a wavefront propagation technique with Hessian-based vessel enhancement. The latter has proven its usefullness as a preprocessing step to detect tubular structures before the actual segmentation is carried out. The former allows for an ordered growing process, which enables topological analysis.

The contribution of this work is as follows. 1. A new vessel enhancement filter for tubular structures based on the Laplacian is proposed, 2. a wavefront propagation technique is proposed that prevents leaks by imposing a threshold on the maximum number of voxels that the propagating front must contain, and 3. a volumetric hole filling method is proposed to fill holes, bays, and tunnels which are caused at locations where the tubular structure assumption is violated.

The proposed method reduces approximately 50% of the necessary eigenvalue calculations for vessel enhancement and prevents leaks starting at small spots, which usually occur using standard region growing. Qualitative and quantitative evaluation based on several metrics (statistical measures, dice and symmetric average surface distance) is presented.

8669-46, Session 9

Biomedical imaging in personalized medicine *(Keynote Presentation)*

Dorin Comaniciu, Siemens Corporate Research (United States)

Personalized medicine's focus is to do more in advance, promote early detection of the disease, more efficient clinical workflows, and provide patient-centric health management. This talk will analyze three dimensions of biomedical imaging for personalized medicine: knowledge-based imaging, real-time analysis and guidance in the OR, and in-silico modeling of the body function and disease. We will underline the detailed quantification of volumetric data through its parsing into hundreds of semantic components. We will show that multimodal and real-time imaging are at the base of a new generation of minimally invasive procedures with increased degree of automation. Finally, we will present individualized cardiac models with predictive power, including patient's anatomy, dynamics, hemodynamics and biomechanics. By highlighting example applications that make today a difference in hospitals we will extrapolate on the imaging technology potential, expectations for the near future, and the increased demand for multidisciplinary projects and applications.

8669-47, Session 9

A flexible toolkit for rapid GPU-based generation of DRRs for 2D-3D registration

Grant Marchelli, Univ. of Washington (United States); David R. Haynor, Univ. of Washington (United States); Richard Tsai, William R. Ledoux, U.S. Dept. of Veterans Affairs (United States); Duane W. Storti, Univ. of Washington (United States)

This paper presents initial performance results for a software toolkit for GPU-based parallel computation of digitally reconstructed radiographs (DRRs) from volumetric imaging data for 2D-3D registration. The computational parallelism is achieved using NVIDIA's CUDA implementation of general purpose computing on graphics processing units (GPU). We have tested the toolkit using a segmented CT scan of a cadaveric foot, but the toolkit can be applied equally well to other volumetric imaging data. The CUDA parallelism model involves launching hundreds of simultaneous, independent computational threads, and computational efficiency depends on the threads being largely independent and having fast access to the memory where they need to read and write data. We implemented the DRR computation by launching a thread for each pixel in the image, and achieved efficient memory access using 3D texture memory to store the volumetric data and Thrust vectors to store and manipulate the output image data. Here we present our initial fast DRR computations to demonstrate that the toolkit can produce useful results for a full 160 x 339 x 439 stack of floating point density data in 10ms (or for any selected segmented object in the image stack in under 10ms) on a midlevel workstation with an Intel Core 2 Quad CPU @ 2.4 GHz and an NVidia Tesla 2050 graphics card with 448 parallel computing cores and 3 GB of memory.

8669-48, Session 9

Breast compression simulation using ICP-based B-spline deformation for correspondence analysis in mammography and MRI datasets

Julia Krüger, Jan Ehrhardt, Institute of Medical Informatics, Univ. of Lübeck (Germany); Arpad Bischof, Univ. Medical Ctr. Schleswig-Holstein (Germany); Heinz Handels, Institute of Medical Informatics, Univ. of Lübeck (Germany)

Mammography is the most commonly used imaging modality in breast cancer screening and diagnosis.

The analysis of 2D mammographic images can be difficult due to the projective nature of the imaging technique and a poor contrast between tumorous and healthy fibro-glandular tissue. Contrast-enhanced magnetic resonance imaging (MRI) can overcome this disadvantages by providing a 3D dataset of the breast. The detection of corresponding image structures is challenging due to large differences in breast deformation during the image acquisition.

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We present a method for analyzing 2D/3D intraindividual correspondences between mammography and MRI datasets. Therefore, an ICP-based B-spline registration is used to approximate the breast deformation differences.

The resulting deformed MR image is projected onto the 2D plane to enable a comparison with the 2D mammogram. A first evaluation shows an accuracy of 4.87 mm.

In contrast to previous FEM-based approaches, we propose a fast and easy to implement 3D/3D-registration, for simulating the mammographic breast compression.

8669-49, Session 9

Semi-automatic registration of 3D orthodontics models from photographs

Raphaël Destrez, UsefulProgress (France) and PRISME Lab. Univ. Orléans (France); Sylvie Treuillet, Yves Lucas, PRISME Lab. Univ. Orléans (France); Benjamin Albouy-Kissi, Univ. d'Auvergne Clermont-Ferrand I (France)

In orthodontics, a common practice used to diagnose and plan the treatment is the dental cast. After digitization by a CT-scan or a laser scanner, the obtained 3D surface models can feed orthodontics numerical tools for computer-aided diagnosis and treatment planning. One of the pre-processing critical steps is the 3D registration of dental arches to obtain the occlusion of these numerical models. For this task, we propose to use photos of patient mouth as reference of the real occlusion. From a set of matched points between photos and the dental 3D models, a projection matrix can be calculated. From this one, we registrate the mandible under the maxillary through a rigid transformation minimizing the reprojection errors. During a precedent study, we established the importance of the 2D/3D matching accuracy. This paper adresses the issue of automatic point detection, since the matching remains temporarily manual. Based on a priori knowledge, histogram thresholding and edge detection are used to extract specific points in 2D images. Concurrently, curvatures information detects 3D corresponding points. From this first matching, a sparse bundle adjustment is used to optimize the projection matrix and the 2D/3D point coordinates by minimizing reprojection errors. Tests on real data are carried out to check the efficiency of the technique. The aim of this research work is to validate method and criteria for 2D/3D point extraction and optimization for the final registration.

8669-50, Session 10

Bias correction of maximum likelihood estimation in quantitative MRI

Dirk H. Poot, Gyula Kotek, Erasmus MC (Netherlands); Wiro J. Niessen, Erasmus MC (Netherlands) and Delft Univ. of Technology (Netherlands); Stefan Klein, Erasmus MC (Netherlands)

For quantitative MRI techniques, such as T1, T2 mapping and Diffusion Tensor Imaging (DTI), a model has to be fit to several MR images that are acquired with suitably chosen different acquisition settings. The most efficient estimator to retrieve the parameters is the Maximum Likelihood (ML) estimator. However, the standard ML estimator is biased for finite sample sizes. In this paper we derive a bias correction formula for magnitude MR images. This correction is applied in two different simulation experiments, a T2 mapping experiment and a DTI experiment. We show that the correction formula successfully removes the bias. As the correction is performed as post-processing, it is possible to retrospectively correct the results of previous quantitative experiments. With this procedure more accurate quantitative values can be obtained from quantitative MR acquisitions.

8669-51, Session 10

Near-lossless compression of computed tomography images using predictive coding with distortion optimization

Andreas Weinlich, Friedrich-Alexander-Univ. Erlangen-Nürnberg (Germany) and Siemens AG (Germany); Peter Amon, Andreas Hutter, Siemens AG (Germany); André Kaup, Friedrich-Alexander-Univ. Erlangen-Nürnberg (Germany)

This paper presents a method for iterative minimization of combined residual and prediction error for near-lossless compression of medical computed tomography acquisitions using pixel-wise least-squares prediction. While most other lossy state-of-the-art image compression systems like JPEG 2000 make use of transform-based coding, in lossless coding higher compression ratios can be achieved with plain predictive algorithms like JPEG-LS because of their non-linear data adaptive energy reduction. Yet, applying these algorithms in lossy coding, simple quantization usually leads to error propagation and therefore serious quality loss or rate increase, as prediction accuracy of a pixel value and thus data rate depends on the previously reconstructed image region. The proposed minimization approach modifies the original image to be coded in a way such that the edge-directed prediction method from literature may achieve better predictions while introducing only a minimum amount of distortion. Compared to transform-based coding methods the distortion mostly consists in noise reduction instead of blurring or the introduction of artificial structures. The method also prevents error propagation due to a consideration of all pixel dependencies of the prediction. It is shown that, combined with a context-adaptive arithmetic coder, in high-fidelity coding (i. e., PSNR higher than 55 dB) the proposed method can achieve higher compression ratios than the transform-based approaches JPEG 2000, H.264/AVC, and HEVC intra coding.

8669-52, Session 10

Tumor segmentation in brain MRI by sparse optimization

Shandong Wu, The Univ. of Pennsylvania Health System (United States); David J. Rippe, Florida Hospital Zephyrhills (United States); Nicholas G. Avgeropoulos, M.D. Anderson Cancer Ctr. Orlando (United States)

In this work we propose a novel method for brain tumor segmentation in MRI by adapting the sparse optimization techniques. The core of the method lies in the subspace decomposition of the tissue feature space constituted by the brain MR images. The tumor-grown MRI slices can be viewed as a corrupted observation, which therefore can be decomposed into two components: the low-rank normal brain tissue structures and the sparse corruption/error that is due to the developed tumor. Through performing rank decomposition the corruption/error can be spotted out, thus giving rise to an initial segmentation of tumor. Our method requires no model learning. Experiments are performed on a data set of 12 subjects and the segmentation agreement is 0.86 in terms of the Dice's similarity coefficient in comparison with the manual segmentation that is performed by a 15-year experienced radiologist. The proposed method represents an efficient mode for brain tumor segmentation that may be potentially incorporated in automated or semi-automatic segmentation systems in the clinical workflow.

8669-53, Session 10

Three-dimensional synthetic blood vessel generation using stochastic L-systems

Miguel A. Galarreta-Valverde, Maysa M. G. Macedo, Univ. de São Paulo (Brazil); Choukri Mekkaoui, Harvard Medical School -

MGH, Athinoula A. Martinos Ctr. for Biomedical Imaging (United States); Marcel P. Jackowski, Univ. of São Paulo (Brazil)

Segmentation of blood vessels from magnetic resonance angiography (MRA) or computed tomography angiography (CTA) images has become a very complex processes usually requiring an abundance of computational resources. Also, most vascular segmentation and detection algorithms do not work properly due to the wide architectural variability of the blood vessels. Thus, the construction of convincing synthetic vascular trees makes it possible to validate new segmentation methodologies. In this work, an extension to the traditional Lindenmayer systems (L-systems) that generates synthetic 3D blood vessels by adding stochastic rules and parameters to the grammar is proposed. Towards this aim, we implement a parser and a generator of L-systems whose grammars simulate natural features of real vessels such as the bifurcation angle, average length and diameter, in addition to as vascular anomalies, such as aneurysms and stenoses. The resulting expressions are then used to create synthetic vessel images that mimic MRA and CTA images. In addition, this methodology allows for vessel growth to be limited by arbitrary 3D surfaces, and the vessel intensity profile can be tailored to match real angiographic intensities.

8669-54, Session 10

Longitudinal intensity normalization of magnetic resonance images using patches

Snehashis Roy, Aaron Carass, Jerry L. Prince, Johns Hopkins Univ. (United States)

This paper presents a patch based method to normalize temporal intensities from longitudinal brain magnetic resonance (MR) images. Longitudinal intensity normalization is relevant for subsequent processing, such as segmentation, so that rates of change of tissue volumes, cortical thickness, or shapes of brain structures can be estimated robustly. Instead of using intensities at each voxel, we use patches as image features as a patch encodes neighborhood information. Once all the time-points of a longitudinal dataset are registered, the longitudinal intensity change at each patch is assumed to follow an auto-regressive (AR(1)) process. An estimate of the normalized intensities of a patch at every time-point are generated from a hidden Markov model, where the hidden states are the unobserved normalized patches and the outputs are the observed patches. A validation study on a phantom dataset shows good segmentation overlap with the truth, and an experiment with real data shows more stable rates of change for tissue volumes with the temporal normalization than without.

8669-55, Session 11

Automatic neonatal brain tissue segmentation with MRI

Vedran Srhoj-Egekher, Univ. of Zagreb (Croatia); Manon J. N. L. Benders, Wilhelmina Children's Hospital, Univ. Medical Ctr. Utrecht (Netherlands); Max A. Viergever, Ivana Isgum, Image Sciences Institute, Univ. Medical Center Utrecht (Netherlands)

Volumetric measurements of neonatal brain tissue classes have been suggested as an indicator of long-term neurodevelopmental performance. To obtain these measurements, accurate brain tissue segmentation is needed.

We propose a novel method for segmentation of cortical grey matter (CoGM), unmyelinated white matter (UWM), myelinated white matter (MWM), basal ganglia and thalami, brainstem, cerebellum, ventricles, and cerebrospinal fluid in the extracerebral space (CSF) in preterm infants imaged at term equivalent age.

For this project, a set of seven images acquired with 3T MRI scanner axially were used. The segmentation was performed in three subsequent stages. First, a multi-atlas-based segmentation (MAS) was employed to obtain localized, subject specific spatial priors for each tissue. Next, based on these priors, two-class classification with k-nearest neighbor (kNN) classifier was performed for each tissue separately. Last, to achieve the final result, a multiclass Naive Bayes classifier was employed. The results were evaluated against the manually set reference standard and quantified in terms of Dice coefficient (DC) and modified Hausdorff distance (MHD)..

The method achieved the following DCs: 0.87 for CoGM, 0.91 for UWM, 0.60 for MWM, 0.93 for basal ganglia and thalami, 0.87 for brainstem, 0.94 for cerebellum, 0.86 for ventricles, 0.82 for CSF. The obtained MHDs were 0.48 mm, 0.44 mm, 3.09 mm, 0.39 mm, 0.62 mm, 0.35 mm, 1.75 mm, 1.13 mm, for each tissue, respectively.

The proposed methods achieved high segmentation accuracy for all tissues except for MWM. It may provide a tool for quantification of brain tissue volumes in preterm infants.

8669-56, Session 11

Robust non-local multi-atlas segmentation of the optic nerve

Andrew J. Asman, Michael P. DeLisi, Louise A. Mawn, Robert L Galloway, Bennett A. Landman, Vanderbilt Univ. (United States)

Labeling or segmentation of structures of interest on medical images plays an essential role in both clinical and scientific understanding of the biological etiology, progression, and recurrence of pathological disorders. Here, we focus on the optic nerve, a structure that plays a critical role in many devastating pathological conditions – including glaucoma, ischemic neuropathy, optic neuritis and multiple-sclerosis. Ideally, existing fully automated procedures would result in accurate and robust segmentation of the optic nerve anatomy. However, current segmentation procedures often require manual intervention due to anatomical and imaging variability. Herein, we propose a framework for robust and fully-automated segmentation of the optic nerve anatomy. First, we provide a robust registration procedure that results in consistent registrations, despite highly varying data in terms of voxel resolution and image field-of-view. Additionally, we demonstrate the efficacy of a recently proposed non-local label fusion algorithm that accounts for small scale errors in registration correspondence. On a dataset consisting of 31 highly varying computed tomography (CT) images of the human brain, we demonstrate that the proposed framework consistently results in accurate segmentations. In particular, we show (1) that the proposed registration procedure results in robust registrations of the optic nerve anatomy, and (2) that the non-local statistical fusion algorithm significantly outperforms several of the state-of-the-art label fusion algorithms.

8669-57, Session 11

Improving whole-brain segmentations through incorporating regional image intensity statistics

Christian Ledig, Imperial College London (United Kingdom); Rolf A. Heckemann, Fondation Neurodis (France); Alexander Hammers, The Neurodis Foundation (France); Daniel Rueckert, Imperial College London (United Kingdom)

Multi-atlas segmentation methods are among the most accurate approaches for the automatic labeling of magnetic resonance images. The segmentations obtained through multi-atlas propagation can be combined using simple, unweighted approaches. More sophisticated strategies weight the individual contributions locally, based on intensity information from the atlas and target images, thereby achieving better accuracy. A main drawback of these approaches is that knowledge about the statistical intensity characteristics, especially the characteristic intensity variance of a certain structure, is not considered. The potential of incorporating regional intensity characteristics of individual regions is currently unexplored. In this work we suggest to employ learned

intensity characteristics of different brain regions to achieve additional segmentation improvements. Based on the intensity profile within labels in a training set, we estimate for each structure a normalized variance error. We derive from this expected variance error, how the intensity profile of a segmented region should be modified in order to better match the estimated intensity characteristics and thus improve segmentation results. In particular, we enlarge the label of a structure based on its probabilistic segmentation until the intensity variance is corrected for the expected region-specific variance error. We confirm the improvements through intensity-based statistical correction by means of overlap metrics on 15 datasets of the OASIS database for which manual gold-standard segmentations were available using a leave-one-out strategy. We apply our novel correction approach to segmentations obtained through both a locally weighted fusion strategy and an EM-based method and present significantly increased Dice overlaps.

8669-58, Session 11

Patch-based label fusion using local confidence-measures and weak segmentations

Andre Mastmeyer, Dirk Fortmeier, Ehsan Maghsoudi, Institute of Medical Informatics, Univ. of Luebeck (Germany); Martin Simon, Clinic for Radiology and Nuclear Medicine, Univ. Medical Ctr. Schleswig-Holstein (Germany); Heinz Handels, Institute of Medical Informatics, Univ. of Luebeck (Germany)

A system for the fully automatic segmentation of important abdominal organs such as the liver is presented. In a multi-atlas based manner, several existing segmentations are deformed in parallel to image intensity based registrations targeting the unseen patient. A new locally adaptive label fusion method is presented as the core of this paper. In a patch comparison approach, the transformed segmentations are compared to a weak segmentation of the target organ in the unseen patient. The weak segmentation estimates the hidden truth, instead of just relying on the deformed expert segmentations only, which is the state of the art standard approach. The result of patch comparison is a confidence weight for a neighboring label in the atlas label images to contribute to the voxel under study. Fusion is finally carried out in a weighted averaging scheme. The new contribution is the incorporation of locally determined confidence features of the unseen patient into the fusion process. For a small experimental set-up consisting of 12 patients, the proposed method performs favorable to standard classifier label fusion methods. In leave-one-out experiments we obtain a mean Jaccard index of 0.82 for the liver.

8669-59, Session PSMon

Combined pixel classification and atlas-based segmentation of the ventricular system in brain CT Images

Pieter C. Vos, Image Sciences Institute, Univ. Medical Ctr. Utrecht (Netherlands); Ivana Isgum, J. Matthijs Biesbroek, Birgitta K. Velthuis, Univ. Medical Ctr. Utrecht (Netherlands); Max A. Viergever, Image Sciences Institute (Netherlands)

Accurate segmentation of the brain ventricular system in Computed Tomography (CT) images is useful in neurodiagnosis, providing quantitative measures on changes in ventricular size due to stroke. Manual segmentation, however, is a time-consuming, tedious task and is prone to large inter-observer variability.

This study presents an automatic ventricle system segmentation method by combining the results of supervised pixel classification based on intensities with spatial information obtained from a multi-atlas-based segmentation method.

The method is applied to follow-up brain CT images which were collected from a cohort of 20 patients with proven ischemic stroke.

The automatic segmentation performance was evaluated in a leave-one-out strategy by comparing with manual segmentations.

The results show that combining information obtained from pixel classification and multi-atlas-based segmentation significantly outperforms each method independently with a mean Dice coefficient index of 0.81 pm 0.07.

8669-60, Session PSMon

Constructing a 4D murine cardiac micro-CT atlas for automated segmentation and phenotyping applications

Darin P. Clark, Alexandra Badea, G. Allan Johnson, Cristian T. Badea, Ctr. for In Vivo Microscopy (United States)

Research on small animal models of human cardiovascular disease is critical to our understanding of the origin, progression, and treatment of the disease—a major cause of death worldwide. We have developed a dual source micro-CT system that provides integrated high-throughput morphological and functional imaging for small-animal cardiovascular research. Although our scanning times are very short (i.e. approximately 5 minutes/animal), the analysis of a single 4D micro-CT data requires up to 10 hours of segmentation by a trained operator. To improve throughput, we are developing a pipeline for registration-based segmentation and functional analysis of 4D cardiac micro-CT data in the mouse. This paper presents our first steps in developing a murine 4D cardiac atlas for automated segmentation and phenotyping. Our methods are based on a highly successful deformation model known as symmetric normalization. Preliminary atlas construction and segmentation results presented here using C57BL/6 mice (n =5) are highly promising, yielding an average blood pool Dice coefficient of 0.94 ± 0.01 and an average volume accuracy of 0.96 ± 0.02. Extending these results to individual cardiac chambers and the myocardium, we expect the proposed, fully automated segmentation pipeline to yield accurate functional and morphological information in a variety of cardiac applications.

8669-61, Session PSMon

Build 4-Dimensional Myocardial Model for Dynamic CT Images

Yixun Liu, Songtao Liu, National Institutes of Health (United States); Albert C. Lardo, Johns Hopkins Bayview Medical Ctr. (United States); Marcelo N. Nacif, David A. Bluemke, Ronald M. Summers, Jianhua Yao, National Institutes of Health (United States)

4-Dimensional (4D), i.e., 3D + time, model is valuable in comprehensive assessment of cardiac function, especially in myocardial infarction of left ventricle (LV). Usually, the generation of the 4D myocardial models involves myocardial segmentation, mesh generation and non-rigid registration (to build mesh node correspondence). In this paper, we present a method, which can simultaneously perform the above tasks. This method begins from a triangular surface model of the myocardium at the first phase of cardiac cycle. Then, the myocardium surface is simulated as a linear elastic membrane, and evolves towards the next phase governed by an energy function while maintaining the mesh quality. The preliminary experiments performed on low dose CT image of dogs demonstrate the effectiveness of this method on both segmentation and mesh generation. The minimum average surface distance between the segmentation results of the proposed method and the ground truth can reach 0.72±0.55 mm, and the mesh quality measured by the aspect ratio of the triangle is not larger than 11.57±1.18.

8669-62, Session PSMon

A new morphological tool to extract blood vessels in cross sectional MRI

Cédric Blanchard, Tadeusz Sliwa, Alain Lalande, Olivier Bouchot, Yvon Voisin, Univ. de Bourgogne (France)

In this paper, we propose a new method of mathematical morphology called Aurora transform. This is a geodesic reconstruction that only spreads in radial orientations from a center. Thanks to this method, star domains such as blood vessels in cross sectional planes are extracted even if these regions are often inhomogeneous or some parts of their edges are not drawn very well. This method has been successfully applied to extract the edges of the aortic root, the ascending and the descending aorta in cross sectional cine-MRI. It has been then compared to the use of some active contours.

8669-63, Session PSMon

Automatic vessel extraction of lower extremity CT angiography using multi-segmented volume and regional vessel tracking

Min Jin Lee, Helen Hong, Seoul Women's Univ. (Korea, Republic of); Jin Wook Chung, Seoul National Univ. Hospital (Korea, Republic of)

Computed tomography angiography (CTA) is currently considered noninvasive potential alternative to conventional digital subtraction angiography (DSA) for the evaluation of lower extremity arteries. For the diagnosis of peripheral arterial occlusive disease, lower extremity vessels in CTA images are extracted in advance. However, several difficulties include a significant overlapping of density distribution between enhanced vessels and adjacent bone structures and a large capture range. Thus, we propose an automatic vessel extraction method using multi-segmented volume and local vessel tracking in lower extremity CT angiography. To consider anatomical characteristics of each lower extremity bone structure, whole volume is automatically divided into five segments along z-axis of the lower extremities. The vessels and bones are extracted by three-dimensional region growing with multi-seeding and iterative multiple threshold estimation. To localize eroded horizontal vessels near to bones in pelvis, horizontal vessel areas are selected by searching a prominent anatomical change with cavernous vessel structure. Finally, to restore the eroded vessels near to bones and weak enhanced vessels in pelvis and foot, local vessel tracking considering density, size and direction is performed. Experimental results show that our method provides accurate results in occluded and stenosed vessels without loss of soft tissue and calcification. For visual scoring, two radiologists compared paired images obtained from proposed method and conventional angiography. The score was 4.99±0.02 for vessel extraction and 4.74±0.02 for bone elimination(1=worst, 5=best). Our method can be used in the diagnosis of peripheral arterial occlusive disease and the assessment of localization and severity of the disease.

8669-64, Session PSMon

Automatic detection of retinal vascular bifurcations and crossovers based on isotropy and anisotropy

Guodong Li, Dehui Xiang, Fei Yang, Xiaonan Wan, Jie Tian, Xin Yang, Institute of Automation (China)

The analysis of retinal blood vessels is very important in the detection of some diseases in early stages, such as hypertension, diabetes, arteriosclerosis, cardiovascular disease, and stroke. The bifurcations and crossovers are important feature points, which play important roles in the analysis of the retinal vessel tree. These feature points have been demonstrated to be important features in many visual tasks such as image registration, mosaicing, and segmentation. In this paper, a new method is proposed to detect vascular bifurcations and crossovers in fundus images. The Gaussian filter is applied to the green channel of the original color retinal images to suppress the central reflex and reduce the candidate points. The eigenvalues and eigenvectors of Hessian matrix are then obtained in multiple scales to provide the structural and directional information. By computing the anisotropy and isotropy of neighboring image segments for each pixel in a retinal image, we define a multi-scale vessel filter which combines the responses of tubular structures and the responses of bifurcations and crossovers. Finally, the proposed method has been tested with publicly available database DRIVE. The experimental results show that bifurcations, crossovers and tubular structures can be detected simultaneously. And the proposed method performs well in detecting the bifurcations and crossovers which are in thin vessels or low contrast vessels.

8669-65, Session PSMon

Automatic liver vessels segmentation using histogram modeling and vessel separation with multi-seeding points in abdominal contrast-enhanced CT images

Yujin Jang, Helen Hong, Seoul Women's Univ. (Korea, Republic of); Jin Wook Chung, Seoul National Univ. Hospital (Korea, Republic of)

For planning surgical operation such as oncological resection and living liver donation, we propose automatic liver vessels segmentation based on histogram modeling and vessel separation with multi-seeding points in abdominal contrast-enhanced CT images. Liver border is automatically segmented using multiplanar anatomic information and deformable surface model fitting. For removing noises and preserving vessel boundaries, anisotropic diffusion filtering is applied to the segmented liver volume. Major vessels with high contrast and large thickness are segmented by optimal thresholding and 3D region growing. The optimal threshold value is decided by Gaussian Mixture Modeling with two components such as liver parenchyma and enhanced vessels. Then, hepatic and portal veins in major vessels are separated by morphological opening with a circular mask and are labeled by 3D region growing with multi-seeding points. The seed points of hepatic veins are selected by generating axial thin-slab Maximum Intensity Projection (MIP) image in upper segmented liver volume. The seed points of portal veins are selected by generating sagittal thin-slab MIP image in right-most segmented liver volume. For extracting peripheral vessels, non-segmented enhanced vessels are classified into two classes (hepatic or portal veins) considering labels and orientation of segmented neighboring major vessels. Experimental results show that our segmentation method can well segment vessels with small thickness as well as large thickness and separate liver vessels to hepatic and portal veins.

8669-66, Session PSMon

A hardware implementation of a levelset algorithm for carotid lumen segmentation in CTA

Andre van der Avoird, Ning Lin, BIC Design B.V. (Netherlands); Bram van Ginneken, Rashindra Manniesing, Radboud Univ. Nijmegen Medical Ctr. (Netherlands)

This work presents a novel hardware implementation of a levelset algorithm for carotid lumen segmentation in computed tomography. We propose to use a field programmable gate array (FPGA) to iteratively solve the underlying finite difference scheme. A FPGA processor can be programmed to have a dedicated hardware architecture including specific data path and processor core design with different types

of parallelizations which is fully tailored and optimized toward its application. The method has been applied to ten carotid bifurcation of six stroke patients and the results have been compared to the results obtained from the same method implemented in C++. Visual inspections revealed similar segmentation results. The average computation time in software was 1663+-86 seconds, the computation time on the FPGA processor was 28 seconds yielding approximately a 60-fold speed-up which to our knowledge has been unmmatched before for this class of algorithms.

8669-67, Session PSMon

Automated artery and vein detection in dynamic CT data with an unsupervised classification algorithm of the time intensity curves

Hendrik O. A. Laue, Fraunhofer MEVIS (Germany); Marcel T. H. Oei, Diagnostic Image Analysis Group, Radboud Univ. Nijmegen Medical Ctr. (Netherlands); Longquan Chen, Ina N. Kompan, Horst K. Hahn, Fraunhofer MEVIS (Germany); Mathias Prokop, Radboud Univ. Nijmegen Medical Ctr. (Netherlands); Rashindra Mannesieng, Diagnostic Image Analysis Group, Radboud Univ. Medical Ctr. (Netherlands)

In this work a fully automated detection method for artery input function (AIF) and venous output function (VOF) in perfusion computer tomography data (PCT) based on the unsupervised classification using the time intensity curve (TIC) as input data. Bone and air voxels are filtered out using thresholding of the baseline measurement. The TICs for each remaining voxel are converted to time-concentration-curves (TCC). Afterwards, an unsupervised K-means classifier is applied to each TCC with an area under the curve (AUC) larger than 95% of the maximum AUC of all TCCs. The results are three clusters, which yield average TCCs for vein and artery voxels in the brain, respectively. A third cluster is generally represents a vessel outside the brain. The algorithm was applied on data of five patients under suspicion if ischemic stroke which were scanned over a period of 200 s after contrast agent injection. For all five patients, the algorithm yields reasonable classification maps of arteries and veins as well as reasonable and reproducible AIFs and VOF. To our knowledge, this is the first application of an unsupervised classification method to identify arteries and veins in PCT data automatically. Preliminary results show the feasibility of using K-means clustering for the purpose of artery-vein detection in 4DCT patient data.

8669-68, Session PSMon

3D multiscale vessel enhancement based centerline extraction of blood vessels

Rahul P. Kumar, Oslo Univ. Hospital (Norway) and Univ. of Oslo (Norway); Fritz Albregtsen, Martin Reimers, Univ. of Oslo (Norway); Thomas Langø, SINTEF (Norway); Bjørn Edwin, Oslo University Hospital (Norway); Ole Jakob Elle, Oslo Univ. Hospital (Norway) and Univ. of Oslo (Norway)

Extraction of blood vessel tree structure is important for improving planning, navigation and tracking in several interventional procedures. Centerline based registration methods have proven to be fast for clinical applications and an effective way of registering multi-modal images. Here, we present a novel blood vessel centerline extraction method in 3D. Our method consists of two parts, namely Multiscale Vessel Enhancement Filtering (MVEF) and Centerline Extraction using Vessel Direction (CEVD). Our proposed MVEF has an improved dampening of noise and better Gaussian profile at the vessel cross-sections compared to conventional MVEF. The CEVD is our novel method for tracing the peaks of the Gaussian profile of the local MVEF at the vessel cross-sections. The peak of the Gaussian profile provides the centre position of the blood vessels. The innovation of this method is in effectively finding only the connected centerlines of the blood vessels of interest. The proposed method was evaluated using both synthetic and medical images. On comparing with Frangi's vesselness combined with thinning, our method is shown to be approximately 5 times faster. The results also show that our method is customized to detect only the desired blood vessels, thereby eliminating the detection of unwanted vessel-like structures. The centerline accuracy was evaluated by comparing with ground truth data created by finding Hough circle centers at each cross-section of the vessel structure. The modified symmetric Hausdorff distance between our result and the ground truth was approximately only 1 pixel for both synthetic and medical images.

8669-69, Session PSMon

A method for automated anatomical labeling of abdominal veins extracted from 3D CT images

Tetsuro Matsuzaki, Masahiro Oda, Nagoya Univ. (Japan); Takayuki Kitasaka, Aichi Institute of Technology (Japan); Yuichiro Hayashi, Nagoya Univ. (Japan); Kazunari Misawa, Aichi Cancer Ctr. Hospital (Japan); Kensaku Mori, Nagoya Univ. (Japan)

In abdominal surgery, understanding of blood vessel structure is important because abdominal blood vessels have large individual differences between patients.

It is necessary for sergeons to support understanding of the blood vessel structures with computers.

This paper presents a method for automated anatomical labeling of abdominal veins.

A thinning process is applied to abdominal vein regions extracted from 3D CT images.

The result of the process is expressed as a tree structure.

Since PV is the most characteristic blood vessel in the portal system, it is assigned to branches in the tree structure by a rule-based method.

Other veins are assigned to the branches based on a machine learning.

In the machine learning, several likelihood functions are constructed for each vessel name.

Weighted sum of them is used as the likelihood of the vessel name.

Then, branches in the tree structure are labeled by searching the vessel name whose likelihood is the maximum.

In the experiment using 20 cases of abdominal CT images, recall rate, precision rate, and F-measure were 86.3%, 85.7%, and 86.0%, respectively.

8669-70, Session PSMon

Graph-based bifurcation detection in phase-contrast MR images

Yoo-Jin Jeong, Karlsruher Institut für Technologie (Germany); Sebastian Ley, Univ. Hospital Heidelberg (Germany) and Univ. of Toronto (Canada); Michael Delles, Rüdiger Dillmann, Roland Unterhinninghofen, Karlsruher Institut für Technologie (Germany)

Dealing with cardiovascular diseases the velocity-encoded magnetic resonance imaging (PC-MRI) is a well-known technique to acquire non-invasive measurements of the blood flow. However, the application of conventional vessel segmentation methods in PC-MR images often leads to problems due to the reduced quality of the morphology image. We proposed a robust centerline extraction method in PC-MR images to overcome those problems. The method yielded satisfying results for the centerline extraction of large vessels but not for branching segments. Therefore, in this paper we present an approach for the detection of bifurcations with minimal user interaction in PC-MR images. The

developed algorithm requires the centerline points of the main vessel as an input. For each point on the centerline it determines, if there exists a bifurcation in the cross-sectional plane at that position. This is accomplished by an a* path finding algorithm, which computes the path costs for a potential bifurcation point to its corresponding center point. By comparison of all path cost sums, bifurcations can be detected due to their low cost sums. For the summation of the path costs different features from morphology and flow information are combined. The algorithm, evaluated on 7 volunteer and 12 patient PC-MRI datasets, yielded satisfying results.

8669-71, Session PSMon

Optimal filter approach for the detection of vessel bifurcations in color fundus images

Qiao Hu, The Univ. of Iowa (United States); Mona K. Garvin, The Univ. of Iowa (United States) and Ctr. of Excellence for Prevention and Treatment of Visual Loss (United States); Mark A. Christopher, Xiayu Xu, The Univ. of Iowa (United States); Todd E. Scheetz, The Univ. of Iowa (United States); Michael D. Abramoff, The Univ. of Iowa (United States) and Institute for Vision Research, The Univ. of Iowa Hospitals and Clinics (United States)

The analysis of retinal vessel bifurcations is of great interest in ophthalmological clinics and for retinal image processing algorithms such as registration, segmentation and change detection. Most previous methods use geometrical and topological information of the vessel tree to detect bifurcations, which might suffer due to the quality of the vessel segmentation. In this paper, we develop a method for direct bifurcation detection based on the optimal filter framework. This approach generates a set of filters that could represent all cases of bifurcations from samples of bifurcation. These filters are used to generate a feature space for a classifier to distinguish bifurcations and non-bifurcations in the image domain. Feature selection is also applied to decrease the number of dimensions of the feature space. This approach is different from previous methods as it uses a minimal number of assumptions, essentially only requiring training images and expert annotations of bifurcations. The method is trained on 60 fundus images and tested on 20 fundus images, resulting in an AUC of 0.883 for ROC curve, comparing well to a human expert.

8669-72, Session PSMon

Data-specific feature point descriptor matching using dictionary learning and graphical models

Ricardo Guerrero, Daniel Rueckert, Imperial College London (United Kingdom)

The identification of anatomical landmarks in medical images is an important task in registration and morphometry. The manual identification and labeling of these landmarks is very time consuming and prone to observer errors, especially when large datasets must be analyzed. Matching landmarks in a pair of images is a challenging task, although off-the-shelf feature point descriptors are powerful at describing points in an image, they are generic by nature, as they are usually conceived to be used in a computer vision setting where there is little prior knowledge about the images. Leveraging on recent developments in the machine learning community, in this paper we aim to build feature point descriptors that are dataset-specific. The proposed approach describes landmarks as feature descriptors based on a sparse coding reconstruction of a patch surrounding the landmark (or any point of interest), using a data-specific learned dictionary. Since strong spatial constraints exist in medical images, we also combine spatial information of surrounding point descriptors in an online built graph-model. We show accurate results in matching one-to-one anatomical landmarks in brain MR images.

8669-73, Session PSMon

Automated temperature calculation method for DWI-thermometry: volunteer study

Koji Sakai, Kyoto Univ. (Japan); Kei Yamada, Kyoto Prefectural Univ. of Medicine (Japan); Naozo Sugimoto, Kyoto Univ. (Japan)

Background & Purpose: Diffusion-weight imaging (DWI) has already been incorporated as a regular sequence for patients in clinical situations. If DWI could indicate brain temperature without a complicated procedure, such information may greatly contribute to initial diagnosis. Temperature conversion from DWI requires segmentation of effective cerebrospinal fluid (CSF) regions and maintenance of acceptable accuracy for diagnosis. This paper aimed to develop a method of fully automated deep brain temperature computation from DWI data.

Methods: DWI data from 33 healthy volunteers (mean (± standard deviation) age, 51.6 ± 18.3 years; range, 22-85 years) were used for this study. The temperature was calculated using the following equation: T (degree Celsius) = 2256.74/ln (4.39221/D) - 273.15, where D is the diffusion coefficient. The CSF region for automated temperature computation was segmented by 2-dimensional region growing. To evaluate the proposed method, we compared results to temperatures calculated from manually segmented lateral ventricle area by a radiologist.

Results: No significant differences were seen between temperatures using the proposed method and the manually segmented method ($p = 0.55$).

Conclusion: The proposed method of fully automated deep brain temperature computation from DWI data may prove feasible for application in MRI consoles.

8669-74, Session PSMon

Colour and multispectral imaging for wound healing evaluation in the context of a comparative preclinical study

Dorra Nouri, Yves Lucas, Sylvie Treuillet, Univ. d'Orléans (France); Romuald Jolivot, Franck Marzani, Université de Bourgogne (France)

Accurate wound assessment is a critical task for patient care and health cost reduction at hospital but even still worse in the context of clinical studies in laboratory. This task, largely devoted to nurses, still relies in routine on manual and tedious practise. Wound shape is measured with rules, tracing on plastic sheets or rarely alginate castings and serum injection. The proportion of the tissues on the wound is also estimated by a qualitative visual assessment based on the red-yellow-black code. Further to our preceding works on wound 3D complete assessment using a simple freehanded digital camera, we examine here the adaptation of this tool to wounds artificially created for experimentation purposes. It appears that tissue uniformity and flatness induces a simplified approach but appeals to multispectral imaging for enhanced wound delineation. We demonstrate that, in this context, simple active contour methods can advantageously replace more complex tools such as SVM supervised classification, as no learning stage is required and that one shot is enough to deal with perspective projection errors. Moreover, involving all the spectral response of the tissue and not only RGB components provides unequalled discrimination power to separate young healed epithelial tissue from granulation tissue. This research work is part of a comparative clinical study on healing at the animal stage. It aims to compare the efficiency of specific medical honeys with classical pharmaceutical wound care products during the healing of surgical wounds on pigs. It revealed that medical honey compete with far more costly pharmaceutical products.

8669-75, Session PSMon

Wound image analysis system for diabetics

Lei Wang, Peder C. Pedersen, Emmanuel Agu, Diane M. Strong, Bengisu Tulu, Worcester Polytechnic Institute (United States)

Diabetic foot ulcers represent a significant health issue and good daily self-care of wounds is necessary for promoting healing process. The goal of this research is to create a smart phone based wound image analysis system for diabetics to track the healing process of ulcers and wounds. This system operates on an Android smart phone in collaboration with a PC (or embedded PC). The wound image is captured by the smart phone camera and transmitted to the PC via Wi-Fi for image processing. The PC decompresses the image and converts it to bitmap format, then segments the wound in the image by employing the distance regularized level set evolution (DRLSE) method, which has the advantages of the level set algorithms while eliminating the need for re-initialization of level set function. Next, color segmentation within wound boundaries is performed by applying the K-Mean color clustering algorithm based on red-yellow-black (RYB) evaluation model for wound healing. Finally, the results are re-formatted, transmitted back to the smart phone and displayed. To accelerate the segmentation, we implement the DRLSE method on the GPU & CPU cooperative hardware platform in data-parallel mode, which has improved the computational efficiency. Processing wound images acquired from UMASS Medical Center has demonstrated that the wound image analysis system provides accurate wounds area determination and color segmentation. For all wound images of size of 576*324, with complicated wound boundaries, the wound analysis consumed max 2s, which is 5 times faster than the same algorithm running on CPU alone.

8669-76, Session PSMon

Clustering of lung adenocarcinomas classes using automated texture analysis on CT images

Antonio Pires, Henry Rusinek, James Suh, M.D., David Naidich, M.D., Harvey Pass, M.D., Jane Ko, NYU School of Medicine (United States)

To assess whether automated texture analysis enables discrimination between pathologic classes of lung adenocarcinomas (AdCas) on chest CT, and thus serves as an in vivo biomarker of lung cancer prognosis and assist in determining those lesions to be more aggressively acted upon.

Texture parameters determined by triplet optimal subsets allows for the clustering of AdCa classes using CT images. These preliminary results suggest the potential use of CT to predict the invasive pathologic character of lung nodules. Surprisingly, 3D features appeared less reliable. This may be due to the effect of variable reconstructed slice thickness (0.8-1.25 mm) and less accurate nodule segmentation in a 3D approach.

Texture based classification approach overcomes the limitations (subjectivity, inter- and intra-observer variability, the effect of reader experience) of current radiologic interpretation. In this approach, a rich set of imaging features and the interaction among features are accounted for, which may yield additional information compared to analyzing individual features [2].

CLINICAL RELEVANCE/APPLICATION

Needle biopsy of subsolid nodules, which frequently represent AdCas, is of less utility given the heterogeneity of such lesions. The use of computer-aided analysis of CT texture features allows for the potential classification of these nodules. Such ability would aid in differentiating lesions of greater aggressiveness histopathologically and therefore worse prognosis from more indolent AdCas, for which more aggressive management would be indicated such as resection.

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8669-77, Session PSMon

Morphometric connectivity analysis to distinguish normal, mild cognitive impaired, and Alzheimer subjects based on brain MRI

Lene Lillemark, Lauge Sørensen, Univ. of Copenhagen (Denmark); Peter Mysling, University of Copenhagen, Department of Computer Science (Denmark); Akshay Pai, Univ. of Copenhagen (Denmark); Erik B. Dam, Biomediq (Denmark); Mads Nielsen, Univ. of Copenhagen (Denmark) and Biomediq AS (Denmark)

This work investigates a novel way of looking at the regions in the brain and their relationship as possible markers to classify normal control (NC), mild cognitive impaired (MCI), and Alzheimer Disease (AD) subjects. MRI scans from a subset of 101 subjects from the ADNI study at baseline and month 12 were analyzed. 40 regions in the brain including hippocampus, amygdala, thalamus, white, and gray matter were segmented using FreeSurfer. From this data, we calculated the distance between the center of mass of each region, the normalized number of voxels and the percentage volume and surface connectivity shared between the regions. These markers were used for classification using a linear discriminant analysis in a leave-one-out manner. We found that the percentage of surface and volume connectivity between regions gave a significant classification between NC and AD and borderline significant between MCI and AD even after correction for whole brain volume at baseline. The results show that the morphometric connectivity markers include more information than whole brain volume or distance markers. This suggests that one can gain additional information by combining morphometric connectivity markers with traditional volume and shape markers.

8669-78, Session PSMon

Deformation texture-based features for classification in Alzheimer's disease

Nhat Trung Doan, Leiden Univ. Medical Ctr. (Netherlands); Baldur van Lew, Leiden University Medical Center (Netherlands); Boudewijn P. F. Lelieveldt, Mark A. van Buchem, Johan H. C. Reiber, Julien Milles, Leiden Univ. Medical Ctr. (Netherlands)

Neurological pathologies are often reflected in brain MR images as abnormal global, or local, anatomical changes. Those variations can be computed using non-rigid registration and the Jacobian determinant of the obtained deformation field can be used to depict local volume changes. We propose a new approach which exploits the information contained in whole-brain Jacobian determinant maps in Alzheimer's disease classification by means of texture analysis. Textural features were derived from whole-brain Jacobian determinant based on 3D Grey Level Co-occurrence Matrix. The large number of features obtained depicts anatomical variations at different resolution levels, allowing retaining both local and global information. PCA was applied for feature reduction such that 90% of the data variance was retained. We evaluated our method using separate training and testing sets which consisted of 84 subjects in total. Classification was performed using a linear support vector machine. For comparison purposes, an approach based on dissimilarities computed from the logarithm of the Jacobian determinant was implemented. The proposed approach, compared to the dissimilarity-based approach, yielded better results on the training set: 68% accuracy (71% specificity, 64% sensitivity) versus 50% accuracy (43% specificity, 57% sensitivity), and comparable results on the testing set: 61% accuracy (61% specificity, 61% sensitivity, and area under curve (AUC) = 0.62) versus 61% accuracy (54% specificity, 68% sensitivity, and AUC

= 0.54). The results demonstrated the potential of texture analysis on the Jacobian determinant over the entire brain for diagnosis of AD subjects.

8669-79, Session PSMon

3D spatio-temporal analysis for compressive sensing in magnetic resonance imaging of the murine cardiac cycle

Brice Hirst, Yahong Zheng, Missouri Univ. of Science and Technology (United States); Ming Yang, Lixin Ma, Univ. of Missouri - Columbia (United States)

This paper explores a three-dimensional compressive sensing (CS) technique for reducing measurement time in MR imaging of the murine (mouse) cardiac cycle. By randomly undersampling a single 2D slice of a mouse heart at regular time intervals as it expands and contracts through the stages of a heartbeat, a CS reconstruction algorithm can be made to exploit transform sparsity in time as well as space. For the purposes of measuring the left ventricular volume in the mouse heart, this 3D approach offers significant advantages against classical 2D spatial compressive sensing.

8669-80, Session PSMon

Curvelets as a sparse basis for compressed sensing magnetic resonance imaging

David S. Smith, Vanderbilt Univ. (United States); Lori R Arlinghaus, Thomas E Yankeelov, Vanderbilt University (United States); Edward B. Welch, Vanderbilt Univ. (United States)

We present an example in magnetic resonance imaging (MRI) where curvelets provide a superior sparse basis for compressed sensing reconstruction. Curvelets are an extension of wavelets with additional degrees of freedom and have been used for MR image enhancement, registration, and denoising. We use curvelets as a sparse basis to retrospectively simulate the 4x compressed sensing acceleration of a chemical exchange saturation transfer (CEST) MRI protocol. Curvelets outperformed both Haar and CDF9/7 (JPEG2000) wavelets.

8669-82, Session PSMon

Software-based diffusion MR human brain phantom for evaluating fiber-tracking algorithms

Yundi Shi, The Univ. of North Carolina at Chapel Hill School of Medicine (United States); Gwendoline Roger, The Univ. of North Carolina at Chapel Hill (United States); Clement Vachet, The Univ. of North Carolina at Chapel Hill (United States); Francois Budin, Eric Maltbie, The Univ. of North Carolina at Chapel Hill School of Medicine (United States); Audrey Verde, Marion Hoogstoel, Jean-Baptiste Berger, Martin A. Styner, The Univ. of North Carolina at Chapel Hill (United States)

Fiber tracking provides insights into the brain white matter network and has become more and more popular in diffusion MR imaging. Hardware or software phantom provides an essential platform to investigate, validate and compare various tractography algorithms towards a ``gold standard". Software phantoms excel due to their flexibility in varying imaging parameters, such as tissue composition, SNR, as well as potential to model various anatomies and pathologies. This paper describes a novel method in generating diffusion MR images with various imaging parameters from realistically appearing, individually varying brain anatomy based on predefined fiber tracts within a high-resolution human brain atlas. Specifically, joint, high resolution DWI and structural MRI brain atlases were constructed with images acquired from 6 healthy subjects (age 22-26) for the DWI data and 56 healthy subject (age 18-59) for the structural MRI data. Full brain fiber tracking was performed with filtered, two-tensor tractography in atlas space. A deformation field based principal component model from the structural MRI as well as unbiased atlas building was then employed to generate synthetic structural brain MR images that are individually varying. Atlas fiber tracts were accordingly warped into each synthetic brain anatomy. Diffusion MR images were finally computed from these warped tracts via a composite hindered and restricted model of diffusion with various imaging parameters for gradient directions, image resolution and SNR. Furthermore, an open-source program was developed to evaluate the fiber tracking results both qualitatively and quantitatively based on various similarity measures.

8669-84, Session PSMon

Connectivity-based parcellation of the postcentral gyrus using a spectral approach

Tristan Moreau, Bernard Gibaud, Equipe INSERM MediCIS. Unité U1099 LTSI. (France)

Subdividing the cortex into structural elements, known as parcellation, is a key aspect to apprehend the link between structure and function in the brain. A very exciting idea to parcellate the cortex and thus to construct the human connectome is to suppose that all structural elements of the cortex share similar connectivity pattern : this process defines a connectivity-based parcellation. We address the problem of the connectivity-based parcellation without anatomical a priori using structural connectivity reconstructed from diffusion magnetic resonance imaging data.

A probabilistic tractography based on a model of diffusion which could take in account up to two fibers in each voxel was used to characterize the connectivity pattern of each structural elements.

The possibility to use the high efficient normalized cut algorithm to classify, in a reproducible way, a large data set of connectivity pattern seeded in the grey/white matter interface of the left postcentral gyrus of four different subjects was explored in this study.

The idea was to model the grey/white matter interface of the postcentral gyrus as a graph in which each node represents a seed voxel, the edges between two nodes represent the local neighborhood relationships of the seed voxel, and weights of the edges represent the similarity of the two connectional fingerprints of the seed voxels corresponding. A synthetic data set based on a two overlapping compartments was used to assess the validity of our spectral approach. Results are encouraging.

8669-85, Session PSMon

DTI quality control assessment via error estimation from Monte Carlo simulation

Mahshid Farzinfar, Yinpeng Li, Audrey Verde, Ipek Oguz, The Univ. of North Carolina at Chapel Hill (United States); Guido Gerig, Univ. of Utah (United States); Martin A. Styner, Univ. of North Carolina at Chapel Hill (United States)

Diffusion Tensor Imaging (DTI) is currently the state of the art method for characterizing microscopic tissue structure in the white matter in normal or diseased brain in vivo. DTI is estimated from a series of Diffusion Weighted Imaging (DWI) volumes. DWIs suffer from a number of artifacts which mandate stringent Quality Control (QC) schemes to eliminate lower quality images for optimal tensor estimation. Conventionally, QC procedures exclude artifact-affected DWIs from subsequent computations leading to a cleaned, reduced set of DWIs, called DWI-QC. Often, a rejection threshold is heuristically/empirically chosen above which the entire DWI-QC data is rendered unacceptable and thus no DTI is computed. In this work, we have devised a more sophisticated, Monte-

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Carlo simulation based method for the assessment of resulting tensor properties. This allows for a consistent, error-based threshold definition in order to reject/accept the DWI-QC data. Specifically, we propose the estimation of two error metrics related to directional distribution bias of Fractional Anisotropy (FA) and the Principal Direction (PD). The bias is modeled from the DWI-QC gradient information and a Rician noise model incorporating the loss of signal due to the DWI exclusions. Our simulations further show that the estimated bias can be substantially different with respect to magnitude and directional distribution depending on the degree of spatial clustering of the excluded DWIs. Thus, determination of diffusion properties with minimal error requires an evenly distributed sampling of the gradient directions before and after QC.

8669-86, Session PSMon

UNC-Utah NA-MIC DTI framework: atlas based fiber tract analysis with application to a study of nicotine smoking addiction

Audrey R. Verde, Jean-Baptiste Berger, The Univ. of North Carolina at Chapel Hill (United States); Aditya Gupta, The Univ. of North Carolina at Chapel Hill (United States) and Children's Hospital of Pittsburgh, Univ. of Pittsburgh (United States); Mahshid Farzinfar, Adrien Kaiser, Vicki W. Chanon, Charlotte A. Boettiger, The Univ. of North Carolina at Chapel Hill (United States); Hans Johnson, Joy Matsui, University of Iowa (United States); Anuja Sharma, Scientific Computing and Imaging Institute, Univ. of Utah (United States); Casey Goodlett, Kitware, Inc. (United States); Yundi Shi, The Univ. of North Carolina at Chapel Hill School of Medicine (United States); Guido Gerig, Sylvain Gouttard, Scientific Computing and Imaging Institute, Univ. of Utah (United States); Clement Vachet, The Univ. of North Carolina at Chapel Hill (United States) and Scientific Computing and Imaging Institute, Univ. of Utah (United States); Hongtu Zhu, Martin A. Styner, The Univ. of North Carolina at Chapel Hill (United States)

Purpose: The UNC-Utah NA-MIC DTI framework represents a coherent, open source, atlas fiber tract based DTI analysis framework that addresses the lack of a standardized fiber tract based DTI analysis workflow in the field. Most steps utilize graphical user interfaces (GUI) to simplify interaction and provide an extensive DTI analysis framework for non-technical researchers/investigators. Data: We illustrate the use of our framework on 54 directional DWI neuroimaging study contrasting 15 Smokers and 14 Controls. Method(s): At the heart of the framework is a set of tools anchored around the multi-purpose image analysis platform 3D-Slicer. Several workflow steps are handled via external modules called from Slicer in order to provide an integrated approach. Our workflow starts with conversion from DICOM, followed by thorough automatic and interactive quality control (QC), which is a must for a good DTI study. Our framework is centered around a DTI atlas that is either provided as a template or computed directly as an unbiased average atlas from the study data via deformable atlas building. Fiber tracts are defined via interactive tractography and clustering on that atlas. DTI fiber profiles are extracted automatically using the atlas mapping information. These profiles are then analyzed by a statistician using our analysis toolbox (FADTTS). The statistical results are mapped back to the fiber bundles and visualized. Results: This framework provides a coherent set of tools for DTI quality control and analysis. Conclusions: This framework will provide the field with a uniform process for DTI quality control and analysis.

8669-87, Session PSMon

Mapping longitudinal cerebral cortex development using diffusion tensor imaging

Yaping Wang, Northwestern Polytechnical Univ. (China) and Univ. of North Carolina at Chapel Hill (United States); Gang Li, Mihye Ahn, Jingxin Nie, Hongtu Zhu, The Univ. of North Carolina at Chapel Hill (United States); Lei Guo, Northwestern Polytechnical Univ. (China)

Diffusion tensor imaging (DTI) could provides convenience and crucial insights into underlying age-related biological maturation of human brains, including myelination, axonal density changes, fiber tract reorganization, and synaptic pruning processes. Fractional anisotropy (FA) derived from DTI has been commonly used to characterize cellular morphological changes associated with development of human brain, due to its sensitivity to microstructural changes. In this paper, we aim to discern the longitudinally neurodevelopmental patterns in typically maturing human brains using 200 healthy subjects from 5 to 22 years of age based on the FA in cortical gray matter (GM). Specifically, FA image is aligned with the corresponding T1 image, which has been parcellated into different cortical ROIs, and then the average FA in each ROI is computed. Mixed model is used to analyze the FA developmental pattern in each cortical GM ROI. The developmental trajectory of FA in each ROI across ages is delineated, and the best-fitting models of age-related changes in FA were linear for all ROIs. In addition, males and females follow the similar pattern, with the FA of females being generally lower than that of males in most ROIs. This provides us some insights into the process of synaptic pruning in the longitudinal cerebral cortex development.

8669-88, Session PSMon

3D image noise reduction and contrast enhancement in optical coherence tomography

Kuanhong Xu, Qiang Wang, Samsung Advanced Institute of Technology (China) (China); Wooyoung Jang, Samsung Advanced Institute of Technology (Korea) (Korea, Republic of); Zhihui Hao, Samsung Advanced Institute of Technology (China) (China); Haibing Ren, Ji-Yeun Kim, Samsung Advanced Institute of Technology (China)

A novel noise reduction algorithm is proposed for reducing the noise and enhancing the contrast in 3D Optical Coherence Tomography (OCT) images. First, the OCT image is filtered into two areas: the background area in which the additive noise is dominant; the foreground area in which the multiplicative noise is dominant. In the background, the noise is eliminated by the 2D linear filtering combined with the frame averaging. In the foreground, the noise is eliminated by the 3D linear filtering-an extension of the 2D linear filtering. Therefore, the denoised image is reconstructed according to the combination of the denoised background and foreground. The above procedure can be formulated with a bi-linear model which can be solved efficiently. The proposed bi-linear model can dramatically improve image quality in 3D images with heavy noise and the corresponding linear filter kernel in 2D can be performed in real time.

The filter kernel we used is introduced based on the linear noise model in OCT system. The noise model used in the filter kernel both considers the multiplicative (speckle) noise and the additive (incoherent) noise, where the latter is not considered in the most existing linear speckle filters and wavelet filters. The filter kernel can also be treated as a low pass filter and can be applied to frequency extraction. Therefore an image contrast enhancement method is introduced in the frequency domain based on the frequency decomposing and weighted combination. A set of experiments are carried out to prove the effectiveness and efficiency of the proposed algorithm.

8669-89, Session PSMon

Image denoising of low-radiation dose coronary CT angiography by an adaptive block-matching 3D algorithm

Dongwoo Kang, The Univ. of Southern California (United States); Piotr Slomka, Ryo Nakazato, Cedars-Sinai Medical Ctr. (United States); Jonghye Woo, Univ. of Maryland (United States); Daniel S. Berman, Cedars-Sinai Medical Ctr. (United States); C. -C. Jay Kuo, The Univ. of Southern California (United States); Damini Dey, Cedars-Sinai Medical Ctr. (United States)

Our aim in this study was to optimize and validate an adaptive denoising algorithm based on Block-Matching 3D, for reducing image noise and improving assessment of left ventricular function , from low-radiation dose coronary CTA. In this paper, we describe the denoising algorithm and its validation, with low-radiation dose coronary CTA datasets from 7 consecutive patients. We validated the algorithm using a novel method, with the myocardial mass from the low-noise cardiac phase as a reference standard, and objective measurement of image noise. After denoising, the myocardial mass were not statistically different by comparison of individual datapoints by the students' t-test (130.9±31.3g in low-noise 70% phase vs 142.1±48.8g in the denoised 40% phase, p= 0.23). Image noise improved significantly between the 40% phase and the denoised 40% phase by the students' t-test, both in the blood pool (p <0.0001) and myocardium (p <0.0001). In conclusion, we optimized and validated an adaptive BM3D denoising algorithm for coronary CTA. This new method reduces image noise and has the potential for improving assessment of left ventricular function from low-dose coronary CTA.

8669-90, Session PSMon

Pulse sequence based multi-acquisition MR intensity normalization

Amod Jog, Snehashis Roy, Aaron Carass, Jerry L. Prince, Johns Hopkins Univ. (United States)

Intensity normalization is an important preprocessing step in magnetic resonance (MR) image analysis. In MR images, the observed intensities are primarily dependent on (1)~the intrinsic MR properties of the tissues such as proton density (P_D), transverse and longitudinal relaxation times (T_2 and T_1 respectively), and (2)~the scanner imaging parameters like echo time (*TE*), repetition time (*TR*), and flip angle (α). We propose a normalization method which utilizes three co-registered subject images with different contrast mechanisms (P_D-w, T_2-w, and T_1-w) to first estimate the imaging parameters and then estimate the P_D, T_2, and T_1 values. We then normalize the subject intensities to the reference by simply applying the pulse sequence equations of the reference image to the subject P_D, T_1, and T_2 maps. Previous approaches to this problem have focused on matching the intensity histogram of the subject image to a reference histogram by different methods. The fundamental drawback of these methods is their failure to respect the underlying imaging physics and tissue biology. Our method is validated on phantoms and we show improved normalization on real images of human brains.

8669-91, Session PSMon

Difference in airway wall estimation with different reconstruction kernels using phantom

Suicheng Gu, Univ. of Pittsburgh (United States)

Whereas bronchial wall thickening is a sign of chronic obstructive bronchitis, there are a number of investigations that tried to rate and classify the severity of specific lung diseases by quantifying the airway wall thickness using high resolution computed tomography (CT). Because of the partial volume effect that may vary under different scanning conditions (e.g., different scanners or reconstruction kernels), a direct measurement based on CT images is usually not reliable. In this study, we assess the impact of different scanning conditions on CT-based airway thickness quantification by testing a novel computerized airway wall segmentation scheme using phantoms acquired under different conditions. The involved computerized airway wall identification scheme uses an activate surface model that evolves or deforms progressively in a deformation force field. The evolution stops at the high signed contrast border along a distance vector field where the outside intensity is smaller than the inside intensity. The phantoms were acquired on two different scanners (i.e., GE and Siemens) with different reconstruction kernels. Our experiments show that the tube (equal to airways) thickness are consistently overestimated. The estimation errors of the GE scanner are smaller than those of the Siemens scanner, and smaller airways have smaller estimation errors. The GE scanner with Bone kernel yield the smallest estimation error of less than 0.06 mm (or 1.5% radius) for all tubes. Whereas the in plane pixel size is 0.703 mm 0.703 mm, this error is smaller than 0.1 pixel size.

8669-92, Session PSMon

Noise reduction using nonadditive q-Gaussian filters in magnetic resonance images

Isaias Soares Soares, Luiz O. Murta Jr., Univ. de São Paulo (Brazil)

Spatial filtering is a ubiquitous used image processing approach to reduce noise, and frequently part of image processing pipelines. The most commonly used function is the Gaussian. Recently, a generalization of the Gaussian function consistent with nonadditive statistics was proposed inspired by multifractals, long range correlations and power laws. Although generalized Gaussian has been used for image filtering, no study assessed its performance for medical images. Here we present two classes of Q-Gaussian filters as noise reduction method using nonadditive Gaussian filter. We evaluated filter performance for magnetic resonance images (MRI) in cerebral, thoracic and abdominal planes. Fractal dimension estimations from images were paired with filter effectiveness. Results showed that Q-Gaussian filters have improved filtering effective gain, when compared to classical Gaussian filtering. Furthermore, it is observed filter gain dependence with fractal dimension. The obtained results suggest that the Q-Gaussian filters are better for noise reduction than classic Gaussian filter when dealing with fractal MRI or fractal noise.

8669-93, Session PSMon

Multiscale TV flow with applications to fast denoising and registration

Prashant Athavale, Robert Xu, Univ. of Toronto (Canada); Perry Radau, Sunnybrook Research Institute (Canada); Adrian Nachman, Univ. of Toronto (Canada); Graham Wright, Sunnybrook Research Institute (Canada)

Medical images consist of image structures of varying scales, with different scales representing different components. For example, in cardiac images, left ventricle, myocardium and blood pool are the large scale structures, whereas infarct and noise are represented by relatively small scale structures. Thus, extracting different scales in an image i.e. multiscale image representation, is a valuable tool in medical image processing. There are various multiscale representation techniques based on different image decomposition algorithms and denoising methods. Gaussian blurring with varying standard deviation can be considered as a multiscale representation, but it diffuses the image isotropically, thereby diffusing main edges. On the other hand, inverse scale representations based on variational formulations preserve edges; but they tend to be time consuming and thus unsuitable for real-time applications.

In the present work, we propose a fast multiscale representation

technique, motivated by successive decomposition of smooth parts based on total variation (TV) minimization. Thus, we smooth given image at an increasing scale, producing a multiscale TV representation. As noise is a small scale component of an image, we can effectively use the proposed method for denoising . We also prove that the denoising speed, up to the time-step, is determined by the user, making the algorithm well-suited for real-time applications. The proposed method inherits edge preserving property from total variation flow. Using this property, we propose a novel multiscale image registration algorithm, where we register corresponding scales in images, thereby registering images efficiently and accurately.

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8669-94, Session PSMon

Robust blind deconvolution for fluorescence microscopy using GEM algorithm

Boyoung Kim, The Univ. of Tokyo (Japan); Takeshi Naemura, The Univ. of Tokyo (Japan)

Fluorescence microscopies have been used as an essential tool in biomedical researches, because of better signal to noise ratio compared to other microscopies. Among the various kinds of fluorescence microscopies, wide field fluorescence microscopy (WFFM) and confocal fluorescence microscopy are generally most widely used. While confocal microscopy image has higher clarity than WFFM, it is not suitable for live cells because of a number of major drawbacks such as photobleaching and low image acquisition speed. The purpose of this paper is to obtain clearer live cell images by restoring degraded WFFM image. Many studies have been carried out for the purpose of obtaining clearer live cell images by restoring degraded WFFM images, while most of them are based on not regularized MLE (Maximum likelihood estimator) which restores the image by maximizing Poisson likelihood. However, the MLE method is not robust to noise because of ill posed problems. Actually, Gaussian as well as Poisson noise exists in the WFFM image. There are some approaches to improve noise robustness, but these methods cannot guarantee the convergence of likelihood. The purpose of this paper is to obtain clearer live cell images by restoring degraded WFFM images utilizing a robust deconvolution method for WFFM using generalized expectation maximization (GEM) algorithm that guarantees the convergence of a regularized likelihood. Moreover, we actualized a blind deconvolution which can restore the images and estimate point spread function (PSF) simultaneously, while most of other researches assume the PSF in known previously. We performed proposed algorithm on fluorescent bead and cell images. Our results show that the proposed method restores more accurate than existing methods.

8669-95, Session PSMon

Pre-processing of infrared thermal images for the detection of necrotizing enterocolitis

Ruqia M. Nur, Monique Frize, Carleton Univ. (Canada)

Necrotizing Enterocolitis (NEC) is a devastating intestinal disease associated with a high rate of mortality and long-term morbidity. Treatments can be successful if NEC is diagnosed early, but no reliable methods exist. Infrared imaging can detect tissue inflammation and thus has the potential to be an early diagnostic tool for NEC. Infants with no clinical or radiographic signs of NEC, and a group of infants with evidence of at least Bell's Stage 2 NEC were enrolled in our study. Infants underwent bedside infrared imaging for 60 seconds. The dataset consists of twenty normal infants and nine infants with NEC.

In early work, in infants with NEC, the upper-to-lower (UL) region temperatures differed significantly, where no significant difference in the UL region was found in normal infants. No significant difference was found in left-to-right (LR) region temperatures for both groups. The decision tree classifier produced good results in terms of specificity, sensitivity, and standard deviation for ten trials. Results for the medians were: 90%+/-12%; 78%+/-18%; and for the means they were: 88%+/-14%; 69%+/-12%. [1]

In this new work, we assessed the impact of pre-processing in discriminating between infants with NEC and those without. The approaches explored were: (i) noise reduction; (ii) contrast enhancement; and (iii) frame registration. Preliminary results show marked improvement in detecting infants with NEC.

Future work will automate the analysis and carry-out a prospective study to attempt detecting NEC at earlier stages. Other image analysis techniques will be tested to enhance the performance of our new diagnostic tool.

8669-96, Session PSMon

Sparse dictionary representation and propagation for MRI volume super-resolution

Xian-Hua Han, Yen-Wei Chen, Ritsumeikan Univ. (Japan)

This study addresses the problem of generating a high-resolution (HR) MRI volume from a single low-resolution (LR) MRI input volume. Recent works have proved that the lost high-frequency information (the HR data) within the LR data can be recovered with the help of other modalities' available HR data from the same subject (or patient). The basic idea is that a low-resolution data can be reconstructed with the information of an HR reference volume according to an expected degradation model and image priors. However, the premise for the strategy is that the HR data of other modality from the same subject is necessarily available. In this study, we investigate to recover the lost high-frequency information within the low-resolution data using available HR and LR data pair from different subject not necessarily the same one. As recent statistical analysis of image representation have shown, any local image structure can be represented by a sparse linear combination of prototype structure (atoms) taken from an over-complete dictionary. This study adapts the basic idea of sparse code-based super-resolution (SCSR) for MRI volume data, and then improve the dictionary learning strategy in the conventional SCSR for achieving the precise sparse representation of HR volume patches. In the proposed MRI super-resolution strategy, we only learn the dictionary of the HR MRI volume patches with sparse coding algorithm, and then propagate the HR dictionary to the LR dictionary by mathematical analysis for calculating the sparse representation (coefficients) of any LR local input volume patch. The unknown corresponding HR volume patch can be reconstructed with the sparse coefficients from the LR volume patch and the corresponding HR dictionary. We validate that the proposed SCSR strategy through dictionary propagation can recover much clearer and more accurate HR MRI volume than the conventional interpolated methods.

8669-97, Session PSMon

iSTAPLE: improved label fusion for segmentation by combining STAPLE with image intensity

Xiaofeng Liu, Albert Montillo, Ek Tsoon Tan, John F. Schenck, GE Global Research (United States)

Multi-atlas based methods have been a trend for robust and automated image segmentation. In general these methods first transfer prior manual segmentations, i.e., label maps, on a set of atlases to a given target

image through image registration. These multiple label maps are then fused together to produce segmentations of the target image through voting strategy or statistical fusing, e.g., STAPLE. STAPLE simultaneously estimates the true segmentation and the label map performance level, but has been shown inaccurate for multi-atlas segmentation because it is determined completely on the propagated label maps and not on the target image intensity. We develop a new method, called iSTAPLE, that combines target image intensity into a similar maximum likelihood estimate (MLE) framework as in STAPLE to take advantage of both intensity-based segmentation and statistical label fusion based on atlas consensus and performance level. The MLE framework is then solved using a modified EM algorithm to simultaneously estimate the region intensity profiles as well as the true segmentation and atlas performance level. Unlike other methods, iSTAPLE does not require the target image to have same image contrast and intensity range as the atlas images, which greatly extends the use of atlases. Experiments on whole brain segmentation showed that iSTAPLE performed consistently better than STAPLE.

8669-98, Session PSMon

Tracking multiple neurons on worm images

Toufiq Parag, Victoria Butler, Dmitri Chklovskii, Janelia Farm Research Campus- HHMI (United States)

Movement is the main output of the textit{C. Elegans} worm nervous system. We are interested in establishing the correspondence between the activity of a particular class (Class D) of neurons and body curvature during various movements of textit{C. Elegans} worms.

Given long sequences of images, specifically recorded to so that class D neurons glow when they are active, it is required to track all identifiable neurons in each frame.

Due to our image characteristics, the features and deviance measures exploited in the standard single object tracking algorithms fail to accurately predict neuron locations in the next frame. Utilizing the relative arrangement of neurons appropriately, we show that the more sophisticated techniques, e.g., Linear Programming or Bayesian Network, employed for target association in multi-target tracking are redundant in our scenario.

In our proposed framework, we rely more on modeling the shape of the worm than modeling the neuron appearance because of the ambiguous nature of the appearance. On each new frame, we detect several candidate locations within a search window for each neuron by invoking mean-shift mode seeking algorithm multiple times from different initial locations. The neurons are then assigned to the set of candidates that maximizes the shape similarity between the current and preceding frames. The assignment task is formulated as an asymmetric tensor maximization problem that can be solved efficiently. The results demonstrate how the proposed method can robustly track more neurons than several existing methods in long sequences of images.

8669-99, Session PSMon

Involuntary motion tracking for dynamic medical infrared thermography using template-based algorithm

Tze-Yuan Cheng, Cila Herman, Johns Hopkins Univ. (United States)

In the medical application, Dynamic Infrared (IR) Thermography is used to detect the temporal variation of the skin temperature. Dynamic Infrared Imaging first introduces a thermal challenge such as cooling on the human skin, and then a sequence of hundreds of consecutive frames is acquired after the removal of the thermal challenge. As a result, by analyzing the temporal variation of the skin temperature over the image sequence, the thermal signature of skin abnormality can be examined. Nevertheless, during the acquisition of dynamic IR imaging, the involuntary movements of patients are unavoidable, and such movements will undermine the accuracy of diagnosis. In this study, based on the template-based algorithm, a tracking approach is proposed to compensate the motion artifact. The affine warping model is adopted to estimate the motion parameter of the image template, and then the Lucas-Kanade algorithm (Lucas and Kanade, 1981) is applied to search for the optimized parameters of the warping function. In addition, the weighting mask is also incorporated in the computation to ensure the robustness of the algorithm (Hager and Belhumeur, 1998, Ishikawa et al., 2002). To evaluate the performance of the approach, two sets of IR image sequence of a subject's hand are experimented: the steady-state image sequence, in which the skin temperature is in equilibrium with the environment, and the recovery image sequence, which is acquired after cooling is applied on the skin for 60 seconds. By selecting the target region in the first frame as the template, satisfying tracking results were obtained in both experimental trials, and the robustness of the approach can be effectively ensured in the recovery trial.

8669-101, Session PSMon

Volume-preserving correction of non-rigid registrations for the investigation of pleural thickening growth

Peter Faltin, RWTH Aachen Univ. (Germany); Thomas Kraus, Univ. Hospital Aachen (Germany); Kraisorn Chaisaowong, RWTH Aachen (Germany)

Pleural thickenings can be assessed using 3D CT-image data. A precise registration in the thickening regions is required for a detailed investigation of the volumetric thickening growth and to algorithmically combine image information from two points in time. For this purpose, a non-rigid registration, utilizing B-spline based deformations, is applied. This kind of deformation is computationally efficient; however it might induce volumetric compression in the image domain. For the assessment of growth, it is inevitable to guarantee volume-preservation. In this paper we suggest a new method to enforce this preservation during the registration process in selected image regions. In contrast to other volume-preserving approaches, this correction is independent of the preliminary chosen method to estimate the non-rigid registration. To reduce complexity in large scale cases, we additionally present a method to approximate the global correction by successively solving smaller sub-tasks. Finally we show that both methods reduce the compression induced by the deformation and also enhance the registration quality in terms of image similarity.

8669-102, Session PSMon

A framework for automatic tuning of system parameters and its use in image registration

Ren-Hui Gong, Children's National Medical Ctr. (United States); Ziv R. Yaniv, Children's National Medical Ctr. (United States)

The setting of system or internal parameters has significant impact on the overall performance of a system. Traditionally, such parameters are most often obtained empirically, through trial-and-error, if intrinsic knowledge about the parameters is not available. In this paper, we present a more emph{intuitive} and emph{systematic} framework for this type of problems, and use it to refine the system parameters of a common registration problem. We formulate the performance of the registration problem as a function of its system parameters, and use optimization techniques to search for an optimal setting for the parameters. The performance of the problem is evaluated as the overall final alignment for a group of registrations that use a set of training images. Each training image includes a segmentation of the anatomy of interest, and the quality of a registration is judged by comparing the overlap between the segmentations as induced by the registration. As a very large number of expensive registrations are performed during the optimization, a cluster of MPI-enabled computers are used to solve the problem collaboratively such that implementation of such an approach is practical. We evaluated

the proposed method using a set of human abdominal CT images, and examined three different optimization algorithms. The results showed that, compared with the empirical values suggested in the published literature, our new technique was able to obtain improved system parameters that are tuned for particular applications. In addition, the proposed framework can be potentially extended to solve a large number of similar problems.

8669-103, Session PSMon

3D registration of histology and ultrasound data for validation of prostate cancer imaging

Stefan G. Schalk, Eindhoven Univ. of Technology (Netherlands); Hessel Wijkstra, Academic Medical Ctr. (Netherlands); Tamerlan A. Saidov, Massimo Mischi, Eindhoven Univ. of Technology (Netherlands)

Several ultrasound (US) prostate cancer localization methods are emerging, opening opportunities for targeted biopsies and focal therapy. However, before any of these methods, like elastography or contrast-enhanced US, can be introduced in clinical practice, accurate validation is required. The current gold standard for validation is histological assessment of the prostate after radical prostatectomy. Therefore, a 3D registration of histological and US data is required. This task is complicated by misalignment between histology slices and ultrasound imaging planes, pressure caused by the transrectal US probe, and deformation and volume change during fixation in formalin solution. In this abstract, we introduce a dedicated 3D algorithm, automatically registering histology and ultrasound data. Because there is no information available between histology slices, and internal landmarks are not consistently present in US, registration is based on outer-contours shape only. A 3D surface model of the prostate in constructed, based on correlation between the midlines of a transrectal sweep video and a longitudinal image. Also, a similar model is constructed from the histology slices, including cancerous areas marked by a pathologist. Registration of the models is then performed in three steps: affine registration, elastic surface registration, and internal registration. In vitro validation of the algorithm was performed by administering elastic bands into four prostate mimicking phantoms and applying probe pressure. The resulting registration accuracy was 1.6 mm, which is significantly smaller than the histology resolution (4 mm).

8669-104, Session PSMon

Automatic measurement of wrist synovitis from contrast-enhanced MRI: a registration-centered approach

Peter Mysling, Sune Darkner, Univ. of Copenhagen (Denmark); Jon Sporring, University of Copenhagen (Denmark); Erik B. Dam, Martin Lillholm, Biomediq (Denmark)

Recently, MRI-determined measurement of synovial inflammation (synovitis) from hand MRIs has gained considerable popularity as a secondary marker in rheumatoid arthritis (RA) clinical trials. The currently accepted scoring systems are, however, purely semi-quantitative and rely on assessment from a trained radiologist. We propose a novel, fully automatic technique for quantitative wrist synovitis measurement from two MRIs acquired before and after contrast agent injection. The technique estimates the volume of the synovial inflammation in three steps. First, the wrist synovial membrane is segmented using multi-atlas B-spline based freeform registration. Second, positioning differences between the pre- and post-contrast acquisitions are corrected by rigid registration. Finally, wrist synovitis is quantified from the difference between the pre- and post-contrast sequences in the region of the segmented synovium. We evaluate the proposed technique on a data set of nineteen patients with acquisitions at two time points in a leave-one-patient-out fashion. Our experiments show that we are able to perform synovitis measurement with good correlation to manual semi-quantitative RAMRIS scores for both static (r=0.84) and longitudinal (r=0.87) scoring.

8669-105, Session PSMon

2D registration guided models for semi-automatic T2 MRI prostate segmentation

Ruida Cheng, Baris Turkbey, Justin Senseney, National Institutes of Health (United States); Alexandra Bokinsky, Geometric Tools, Inc. (United States); William Gandler, Marcelino Bernardo, Peter Choyke, Thomas Pohida, Matthew J. McAuliffe, National Institutes of Health (United States)

Accurate segmentation of magnetic resonance (MR) prostate images is a challenging task due to the high variation of prostate anatomical structure. Artifacts such as noise and homogeneous tissues around the prostate boundary make the segmentation a hard problem. In this work, two semi-automatic techniques for segmentation of T2 MRI images of the prostate are developed. Both models are based on 2D registration that changes shape to fit the prostate boundary between adjacent slices. The first model relies entirely on registration to segment the prostate. The second model applies Fuzzy-C means and morphology filters on top of the registration in order to refine the prostate boundary. Key to the success of the two models is the careful initialization of the prostate contours, which requires the user to specify three Volume of Interest (VOI) contours to each axial, sagittal and coronal image. Then a fully automatic segmentation algorithm proceeds to the three images to generate the final results. The performance of the algorithm is evaluated with 45 MR image datasets. VOIs' volume, 3D surface volume and VOI boundary masks are used to quantify the segmentation accuracy between the semi-automatic and expert manual segmentations. Both models achieve an average segmentation accuracy of 90%. The proposed registration guided segmentation model has been generalized to segment a wide range of T2 MRI prostate images.

8669-106, Session PSMon

Monoplane stereoscopic imaging method for inverse geometry x-ray fluoroscopy

Michael T. Tomkowiak, Univ. of Wisconsin-Madison (United States); Michael S. Van Lysel, Michael A. Speidel, Univ. of Wisconsin-Madison (United States)

Scanning Beam Digital X-ray (SBDX) is a low-dose inverse geometry fluoroscopic system for cardiac interventional procedures. The system performs x-ray tomosynthesis at multiple planes in each frame period and then combines the planes into a projection-like composite image for fluoroscopic display. We present a novel method of stereoscopic imaging using SBDX, in which two slightly offset projection-like images are reconstructed from the same scan data by dividing detector data into two regions. This technique has been facilitated by a recently developed wider-area detector (10.6 cm x 5.3 cm). To verify the assumed geometry of the stereoscopic projections, a phantom of known geometry containing high contrast steel spheres was imaged, and the spheres were localized in 3D using a stereoscopic localization method. Average localization error ranged between 1.05 mm and 1.52 mm, depending on the reconstruction parameters. To demonstrate visualization capabilities, an interventional device was imaged when oriented towards the detector. When viewed as a stereoscopic red/blue anaglyph, the true orientation of the device could be resolved, whereas the orientation was ambiguous using conventional reconstruction. This stereoscopic imaging method could be implemented in real time to provide live 3D guidance for cardiovascular interventions using a single gantry and data acquired through normal, low-dose SBDX imaging.

8669-107, Session PSMon

Cortical correspondence via sulcal curve-constrained spherical registration with application to Macaque studies

Ilwoo Lyu, Sun Hyung Kim, The Univ. of North Carolina at Chapel Hill (United States); Joon-Kyung Seong, Soongsil Univ. (Korea, Republic of); Sang Wook Yoo, KAIST (Korea, Republic of); Alan Evans, Montreal Neurological Institute, McGill Univ. (Canada); Yundi Shi, The Univ. of North Carolina at Chapel Hill (United States); Mar Sanchez, Emory Univ. (United States); Marc Niethammer, Martin A. Styner, The Univ. of North Carolina at Chapel Hill (United States)

In this work, we present a novel cortical correspondence method with application to the macaque brain. The correspondence method is based on sulcal curve constraints on a spherical deformable registration using spherical harmonics to parameterize the spherical deformation. Starting from structural MR images, we first apply existing preprocessing steps: brain tissue segmentation using the Automatic Brain Classification tool (ABC), as well as cortical surface reconstruction and spherical parametrization of the cortical surface via Constrained Laplacian-based Automated Segmentation with Proximities (CLASP). Then, initial correspondence between two cortical surfaces is automatically determined by a curve labeling method using sulcal landmarks extracted along sulcal fundic regions. Since the initial correspondence is limited to sulcal regions, we use spherical harmonics to extrapolate and regularize this correspondence to the entire cortical surface. To further improve the correspondence, we compute a spherical registration that optimizes the spherical harmonic parameterized deformation using a metric that incorporates the error over the sulcal landmarks as well as the normalized cross correlation of sulcal depth maps over the whole cortical surface. For a preliminary evaluation, a normal 18-months-old macaque brain (for both left and right hemispheres) was matched to a prior macaque brain template with 6 manually labeled, major sulcal curves. The results show the potential of our method as successful registration using the proposed registration approach was achieved. Evaluation results for optimal parameter settings are presented as well.

8669-108, Session PSMon

Novel PET/CT image fusion via Gram-Schmidt spectral sharpening

Ronald Kneusel, Exelis Visual Information Solutions (United States); Peter Kneusel, Colorado School of Mines (United States)

PET/CT is a widely used dual-modality imaging technique that has been clearly shown to improve tumor localization and hence patient outcomes. The standard means by which PET/CT images are displayed for review is alpha-blending which results in a merge of the two images using a variable parameter, a, which selects the relative proportion of each image displayed. In this work, we present a new fusion technique based on Gram-Schmidt spectral sharpening to display the physiological information found in the PET image along with the anatomical details from the higher resolution CT image.

A selected color table is applied to the PET data to create a mult-channel (multiband) RGB image. This image, up-scaled to the resolution of the CT data, along with the original PET data which represents a lower resolution single-channel (panchromatic) image, is processed via Gram-Schmidt orthogonalization. Then, the higher resolution CT data, modified to more closely match the PET statistics, is substituted for the first vector of the new orthogonal set. Finally, an inverse Gram-Schmidt process restores the data and results in a new RGB image which is the fusion of the original PET/CT data.

We show that this new image provides a clear indication of PET activity while preserving the details of the CT image. We compare these images with alpha-blended images as well as color-based and PCA-based spectral sharpening results.

8669-110, Session PSMon

Characterisation of respiratory motion extracted from 4D MRI

Ashrani Aizzuddin Abdul Rahni, Univ. of Surrey (United Kingdom) and Univ. Kebangsaan Malaysia (Malaysia); Emma Lewis, Kevin Wells, Univ. of Surrey (United Kingdom)

Nuclear Medicine (NM) imaging is currently the most sensitive approach for functional imaging of the human body. However, in order to achieve high-resolution imaging, one of the factors degrading the detail or apparent resolution in the reconstructed image, namely respiratory motion, has to be overcome. All respiratory motion correction approaches depend on some assumption or estimate of respiratory motion. In this paper, the respiratory motion found from 4D MRI is analysed and characterised. The characteristics found are compared with previous studies and will be incorporated into the process of estimating respiratory motion.

8669-111, Session PSMon

Extracting respiratory motion from 4D MRI using organ-wise registration

Ashrani Aizzuddin Abdul Rahni, Univ. of Surrey (United Kingdom) and Univ. Kebangsaan Malaysia (Malaysia); Rhodri L. Smith, Emma Lewis, Kevin Wells, Univ. of Surrey (United Kingdom)

Nuclear Medicine (NM) imaging serves as a powerful diagnostic tool for imaging of biochemical and physiological processes in vivo. The degradation in spatial image resolution caused by the often irregular respiratory motion must be corrected to achieve high resolution imaging. In order to perform motion correction more accurately, it is proposed that patient motion obtained from 4D MRI can be used to analyse respiratory motion. To extract motion from the dynamic MRI dataset an organ wise intensity based affine registration framework is proposed and evaluated. Comparison of the resultant motion obtained within selected organs is made against an open source free form deformation algorithm. For validation, the correlation of the results of both techniques to a previous study of motion in 20 patients is found. Organwise affine registration correlates very well ($r \approx 0.9$) with a previous study whilst free form deformation shows little correlation ($r \approx 0.3$). This increases the confidence of the organ wise affine registration framework being an effective tool to extract motion from dynamic anatomical datasets.

8669-112, Session PSMon

Evaluation of 3D-2D registration methods for registration of 3D-DSA and 2D-DSA cerebral images

Uroš Mitrovic, Univ. of Ljubljana (Slovenia); Žiga Špiclin, University of Ljubljana (Slovenia); Boštjan Likar, Franjo Pernuš, Univ. of Ljubljana (Slovenia)

With the introduction of C-arm systems, three-dimensional (3D) images depicting the vascular morphology and dynamic two-dimensional (2D+t) images showing the current state of the intervention can be acquired in the same interventional suite. Spatial alignment of 3D and 2D+t images can facilitate endovascular procedures, by displaying the intra-interventional tools and blood flow in 3D+t images. Several 3D-2D registration methods were proposed in the past. Basically, a registration method is concerned with finding the extrinsic rigid-body parameters, while assuming that the C-arm system is calibrated, i.e. that the intrinsic parameters are known. In practice, the intrinsic parameters are not accurately known because the object of interest may not necessarily be in the isocenter. The solution to this problem is searching for the extrinsic as well as the intrinsic parameters. In this paper we applied three 3D-2D

registration methods to real 3D and 2D angiographic images of five patients. All registrations were initialized by using parameter values given in the DICOM header. The performance of each registration method was evaluated by using accurate “gold standard” registration data obtained by fiducial markers attached to the patients during image acquisition. The results indicate that the two intensity-based methods utilizing mutual information and gradient correlation similarity measures are highly accurate as they both yielded fiducial registration errors smaller than 0.21 mm.

8669-113, Session PSMon

Super-resolution in cardiac MRI using a Bayesian approach

Nelson Velasco, Univ. Nacional de Colombia (Colombia); Andrea Rueda Olarte, Eduardo Romero Castro, Univ. Nacional de Colombia (Colombia)

Acquisition of proper cardiac MR images is highly limited by continued heart motion and apnea periods. A typical acquisition results in volumes with inter-slice separations of up to 8 mm. This paper presents a super-resolution strategy that estimates a high-resolution image from a set of low-resolution image series acquired in different non-orthogonal orientations. The proposal is based on a Bayesian approach that implements a Maximum a Posteriori (MAP) estimator combined with a Wiener filter. A pre-processing stage was also included, to correct or eliminate differences in the image intensities and to transform the low-resolution images to a common spatial reference system. The MAP estimation includes an observation image model that represents the different contributions to the voxel intensities based on a 3D Gaussian function. A quantitative and qualitative assessment was performed using synthetic and real images, showing that the proposed approach produces a high-resolution image with significant improvements (about 3dB in PSNR) with respect to a simple trilinear interpolation. The Wiener filter shows little contribution to the final result, demonstrating that the MAP uniformity prior is able to filter out a large amount of the acquisition noise.

8669-114, Session PSMon

Stochastic image registration with user constraints

Ivan A. Kolesov, Jehoon Lee, Patricio Vela, Georgia Institute of Technology (United States); Allen Tannenbaum, Boston Univ. (United States)

This note describes a non-rigid image registration framework for incorporating user constraints. The user selects points that must remain stationary, chooses the spatial extent of the inputs’ effects, and an automatic step computes the deformable registration, respecting the constraints. Parametrization of the deformation field is by an additive composition of a rigid transformation and a set of Gaussian radial basis functions. The bases’ centers, variances, and weights are determined with a global optimization approach that is introduced. This approach is composed of simulated annealing with a particle filter based generator function to perform the optimization.The registration process is implicitly regularized by limiting the number of bases making up the deformation. Additionally, a constraint on the deformation is enforced whose role is to ensure physically meaningful fields

(i.e., invertible). Results on 2D synthetic images are presented.

8669-115, Session PSMon

A novel point-based nonrigid image registration scheme based on learning optimal landmark configurations

Tao Wan, Rutgers, The State Univ. of New Jersey (United States); B. Nicholas Bloch, Boston Univ. (United States); Anant Madabhushi, Rutgers, The State Univ. of New Jersey (United States)

Landmark-based registration schemes represent the most popular class of registration methods due to their simplicity and high accuracy. Identifying important landmarks to perform an accurate registration remains a very challenging task. Current landmark selection methods, such as feature-based approaches, focus on optimization of global transformation and may have poor performance on recovering local deformation, e.g. subtle tissue changes caused by tumor resection, making them inappropriate for registering pre- and post-surgery images as a small cancerous region will be deformed after removing a tumor. In this work, a novel method is introduced to estimate optimal landmark configurations. An important landmark configuration that will be used as a training landmark set was learned for an image pair with a known deformation. This landmark configuration can be considered as a collection of discrete points. A generic transformation matrix between a pair of training landmark sets with different deformation locations was computed via an iterative close point (ICP) alignment technique. A new landmark configuration was determined by simply transforming the training landmarks to the current displacement location meanwhile preserving the topological structure of the configuration of landmarks. Two assumptions are made: 1) In a new pair of images the deformation is approximately the same size and has only spatially relocated in the image, then by a simple affine transformation one can identify the optimal configuration on this new pair of images; and 2) The deformation is of similar size and shape on the original pair of images. These are reasonable assumptions in many cases where one seeks to register tumor images at multiple time points following application of therapy and to evaluate changes in tumor size. The estimated landmarks greatly improved the quality metrics compared to a uniform grid placement and a speeded up robust features (SURF) based method as well as a generic free-form deformation (FFD) approach. The quantitative results showed that the new landmark configuration achieved 95% improvement on recovering the local deformation compared to 86% for the uniform grid placement, 79% for the SURF-based approach, and 10% for the FFD.

8669-116, Session PSMon

Recursive Bayesian estimation of respiratory motion using a modified autoregressive transition model

Ashrani Aizuddin Abdul Rahni, Emma Lewis, Kevin Wells, Univ. of Surrey (United Kingdom)

Compensation of respiratory motion has been identified as a crucial factor in achieving high resolution Nuclear Medicine (NM) imaging. Many motion correction approaches have been studied and they are seen to have advantages over simpler motion compensation approaches such as respiratory gating. However, all motion correction approaches rely on an assumption or estimation of respiratory motion. This paper builds upon previous work in recursive Bayesian estimation of respiratory motion assuming stereo camera observation of external respiratory motion. This paper compares a modified autoregressive transition model against the largely linear transition model previously used in evaluations using the XCAT phantom.

8669-117, Session PSMon

Skeleton based refinement of multi-material volumetric meshes

Cristina Oyarzun Laura, Pablo Bueno Plaza, Klaus Drechsler, Stefan Wesarg, Fraunhofer-Institut für Graphische Datenverarbeitung (Germany)

Accurate multi-material mesh generation is necessary for many applications, e.g. image-guided surgery, in which precision is important. For this application, it is necessary to enhance conventional algorithms with physiological information that adds accuracy to the results. There are several approaches working on the generation of such meshes. However, state of the art approaches show inaccuracies in the areas in which thin structures are, e.g. liver vasculature. These algorithms are not able to detect the vessels in areas in which they are narrow and they assign their elements to wrong materials, e.g., parenchyma. We propose to extend two state of the art algorithms, namely that by Boltcheva et al. and that by Pons et al. and enhance them making use of the skeleton of these structures to solve this problem. By analyzing the mesh generated by the aforementioned algorithms one can find several intersections between the mesh belonging to the vessels and the skeleton, showing that some elements must be mismatched. We evaluate the proposed algorithm in 23 clinical datasets of the liver, in which we previously segmented parenchyma and vessels. For quantitative evaluation the meshes generated with and without skeleton information are compared. The improvements are shown by means of intersection number, volume and length differences of the vasculature mesh using the different methods. The results show an improvement of 65% for the number of intersections, 4% for the volume and 22% for the length.

8669-118, Session PSMon

Image segmentation using normalized cuts with multiple priors

Esmeralda Ruiz Pujadas, Marco Reisert, Univ. Hospital Freiburg (Germany)

We present a novel method to incorporate prior knowledge into normalized cuts. The prior is incorporated into the cost function by maximizing the similarity of the prior to one partition and the dissimilarity to the other. For that, we demand the relative overlap between the prior and the partition for background or foreground to be large, but not mutually. One way is to demand the squared difference to be large. This simple formulation can also be extended to multiple priors to allow the modeling of the shape variations. A shape model obtained by PCA on a training set can be easily integrated into the new framework by computing the sum of squared distances of the relative overlap for every prior which in this case it could be an eigenvector of the PCA shape model. This is in contrast to other methods which usually incorporate the prior knowledge by hard constraints during optimization. The eigenvalue problem inferred by spectral relaxation is not sparse, but can still be solved efficiently. Furthermore, depending on the application, the method does not require the inclusion of spatial relationships, because they are already in the prior term. We apply this method to phantom and real data and compare it with other normalized cut based segmentation algorithms as well as graph cuts and a MAP approach as baselines. We demonstrate that our method gives promising results and can still give a good segmentation even when the image is noisy with limited contrast or the prior is inaccurate.

8669-119, Session PSMon

Sparseness constrained nonnegative matrix factorization for unsupervised 3D segmentation of multichannel images: demonstration on multispectral magnetic resonance image of the brain

Ivica Kopriva, Ante Jukić, Institut Ruder Boškovic (Croatia); Xinjian Chen, Soochow Univ. (China)

A method is proposed for unsupervised 3D (volume) segmentation of registered multichannel medical images. To this end, multichannel image is treated as 4D tensor represented by a multilinear mixture model, i.e. the image is modeled as weighted linear combination of 3D intensity distributions of organs (tissues) present in the image. Interpretation of this model suggests that 3D segmentation of organs (tissues) can be implemented through sparseness constrained factorization of the nonnegative matrix obtained by mode-4 unfolding of the 4D image tensor. Sparseness constraint implies that only one organ (tissue) is dominantly present at each pixel or voxel element. The method is preliminary validated, in term of Dice's coefficient, on extraction of brain tumor from synthetic multispectral magnetic resonance image obtained from the TumorSim database.

8669-120, Session PSMon

Customized hybrid level sets for automatic lung segmentation in chest x-ray images

Sridharan Kamalakannan, Texas Tech Univ. (United States) and National Library of Medicine (United States); Sameer Antani, Rodney Long, George R. Thoma, National Library of Medicine (United States)

A chest x-ray screening system for pulmonary pathologies such as tuberculosis (TB) is of paramount importance due to the increasing mortality rate of patients with undiagnosed TB, especially in densely-populated developing countries. As a first step towards developing such a screening system, this paper presents a novel computer vision module that automatically segments the lungs from posteroanterior digital chest x-ray images. The segmentation task is non-trivial, due to poor image contrast and occlusion of the lung region by ribs, clavicle, heart, and other abnormalities that may be present due to pulmonary diseases. As a first step of the algorithmic procedure, we compute a lung shape model by employing a level set based technique for registration up to a homography. We subsequently, use this computed mean lung shape to initialize the level set that is based on a best fit measure obtained in a heuristically estimated search space for the projective transform parameters. Once the level set is initialized, a suite of customized lower level image features and higher level shape features up to a homography evolve the level set function at a lower resolution in order to achieve a coarse segmentation of the lungs. Finally, a fine segmentation step is performed by adding additional shape variation constraints and evolving the level set in a higher resolution. We processed the standard Japanese Society of Radiological Technology (JSRT) dataset, comprised of 247 images, using this scheme. The promising nature of the preliminary results (92% accuracy) justify the viability and efficacy of the proposed approach.

8669-121, Session PSMon

An automatic tumor segmentation framework of cervical cancer in T2-weighted and diffusion weighted magnetic resonance images

Yueying Kao, Institute of Automation (China); Wu Li, Chinese

Academy of Sciences (China); Huadan Xue, Cui Ren, Peking Union Medical College Hospital (China); Jie Tian, Chinese Academy of Sciences (China)

Cervical cancer is one of the common malignant tumors and is a major health threat for women. The accurate segmentation of the cervical cancer is of important clinical significant for prevention, diagnosis and treatment of cervical cancer. Due to the complexity of the structure of human abdomen, the images in a single imaging modality T2-weighted MR images can not sufficiently show the precise information of the cervical cancer. In this paper, we present an automatic segmentation framework of cervical cancer, making use of the information provided by both T2-weighted magnetic resonance (MR) images and diffusion weighted magnetic resonance (DW-MR) images of cervical cancer. This framework consists of two parts. Firstly, the DW-MR images are registered to T2-weighted MR images using mutual information method; then classification operation is executed in the registered DW-MR images. Secondly, T2-weighted MR images are filtered by P-M nonlinear anisotropic diffusion filtering technique; and then bladder and rectum are segmented and excluded, so the Region of Interest (ROI) containing tumor and normal tissue is extracted; finally the tumor is accurately segmented by Confederative Maximum a Posterior (CMAP) algorithm combining with the results of T2-weighted MR images and DW-MR images. We tested this framework on 5 different cervical cancer patients. Compared with the results outlined manually by the experienced radiologists, it is demonstrated effectiveness of our proposed segmentation framework.

8669-122, Session PSMon

False-positive reduction of liver tumor detection using ensemble learning method

Atsushi Miyamoto, Junichi Miyakoshi, Kazuki Matsuzaki, Central Research Lab., Hitachi, Ltd. (Japan); Toshiyuki Irie, Hitachi General Hospital, Hitachi, Ltd. (Japan)

We proposed a novel ensemble learning method which can be applied to false-positive reduction of liver tumor detection. In many cases of the liver tumor detection, training data has some issues due to characteristics of liver tumors, and the conventional ensemble learning methods such as Bagging and AdaBoost tend to degrade sensitivity. The proposed method generates various weak classifiers based on adaptive sampling in order to enhance an ensemble effect against such issues, and can achieve accuracy satisfying requirements of liver tumor detection. We applied the method to 48 CT images and evaluated the accuracy. Results showed that the proposed method succeeded in reducing false positives greatly (from 3.96 to 1.10/image) while maintaining the required sensitivity.

8669-123, Session PSMon

Lobar fissure detection using line enhancing filters

Tobias Klinder, Rafael Wiemker, Philips Research Europe (Germany)

Automatic segmentation of lung lobes from CT data is becoming clinically relevant as an enabler for, e.g., lobe-based quantitative analysis for diagnostics or more accurate interventional planning. The detection of fissures is thereby usually a first step in a more comprehensive segmentation framework. Although many approaches have been presented in the past addressing fissure detection, there are still several limitations. In this paper, we review one of the most prominent algorithms for fissure detection which is based on eigenvalue analysis of the Hessian matrix and discuss its inherent limitations. In order to overcome these shortcomings, we propose a novel line enhancing filter using multiple hypotheses testing. Due to the large search space of a potential three-dimensional surface orientation, we search for fissure line pieces in two-dimensional cut planes. For each voxel inside the lungs, we match the local two-dimensional neighborhood around the voxel with a fissure template model representing a bright line on a dark background. By testing out various rotated versions of the template model, we are able to detect fissures of different orientations. In contrast to the eigenvalue analysis of the Hessian matrix, the local neighborhood to be considered can be effectively varied for the new filter with a limited set of parameters thus providing more flexibility. The new line enhancing filter has shown on real clinical cases that it is indeed superior compared to the state of the art by giving good responses even for faint fissures and in the presence of high noise.

8669-124, Session PSMon

Steerable wavelet transform for atlas based retinal lesion segmentation

Sharib Ali, Kedir M. Adal, Désiré Sidibé, Univ. de Bourgogne (France); Edward Chaum, The Univ. of Tennessee Health Science Ctr. (United States); Thomas P. Karnowski, Oak Ridge National Lab. (United States); Fabrice Mériaudeau, Univ. de Bourgogne (France)

Computer aided diagnosis and follow up can help in prevention and treatment of diabetes and its related complications. Screening of diabetes related disease in the eyes is done by a special low cost fundus camera. A follow up of the patients visiting at di_erent time intervals for screening brings us to the problem of image analysis for change detection and its cost per patient. It is very likely that human annotations for the lesions may be erroneous and often time consuming. Since the ethnic background plays a signi_cant role in retinal pigment epithelium, visibility of the choroidal vasculature and overall retinal luminance in patients and retinal images, an ethnicity based atlas can provide a solution, simplify the image processing steps and increase the detection rate. In this article, we present a novel method of building a retinal atlas of a speci_c ethnic group and use this atlas for exudates segmentation. To improve the detection accuracy, steerable _lters are used to enhance the lesions. Experiments with the publicly available HEI-MED dataset show the good performance of the proposed method.

8669-125, Session PSMon

Automated segmentation of MS lesions in brain MR images using localized trimmed-likelihood estimation

Alfiia Galimzianova, Žiga Špiclin, Boštjan Likar, Franjo Pernuš, Univ. of Ljubljana (Slovenia)

Diagnosis and prognosis of patients with multiple sclerosis (MS) rely on quantitative markers derived from the analysis of magnetic resonance (MR) images. To compute these markers, a segmentation of lesions in the brain tissues, which are characteristic for MS disease, is needed. In this paper, we propose an unsupervised method for segmenting MS lesions that employs localized trimmed-likelihood estimation (TLE) to model the intensity distributions of normal appearing brain tissues (NABT). Compared to the original whole-brain TLE approach, the proposed method employs a set of three-component Gaussian mixture models for each of the spatially localized and non-overlapping subregions of the brain. The subregions were assigned by the customized balanced box decomposition that takes into account the spatial distribution and the cardinality of NABT tissues, as obtained from the initial whole-brain TLE. The proposed method was tested and compared to the original TLE approach on publicly available synthetic BrainWeb datasets. The results indicate a higher average Dice similarity coefficient both for the segmentation of NABT and MS lesions by using the proposed spatially localized TLE as compared to the original whole-brain TLE, which is due to the fact that the proposed method yields a more accurate NABT model and thus detects fewer false NABT outliers.

8669-126, Session PSMon

Development of a novel constellation based landmark detection algorithm

Ali Ghayoor, Jatin G. Vaidya, Hans J. Johnson, The Univ. of Iowa (United States)

Anatomical landmarks such as the anterior commissure (AC) and posterior commissure (PC) are commonly used by researchers for co-registration of images. In this paper, we present a novel, automated approach for landmark detection that combines morphometric constraining and statistical shape models to provide accurate estimation of the landmark points. This method is made robust to large rotations in initial head orientation by extracting extra information of the eye centers using a radial Hough transform and exploiting the centroid of head mass (CM) using a novel estimation approach. To evaluate the effectiveness of this method, the algorithm is trained on a set of 20 images with manually selected landmarks, and a test dataset is used to compare the automatically detected against the manually detected landmark locations of the AC, PC, midbrain-pons junction (MPJ), and fourth ventricle notch (VN4). The results show that the proposed method is accurate as the average error between the automatically and manually labeled landmark points is less than 1 mm. Also, the algorithm is shown to be robust as it is reliably validated over a large dataset including different kinds of images with various orientation, spacing and origin.

8669-127, Session PSMon

Breast segmentation in MRI: quantitative evaluation of three methods

Albert Gubern-Mérida, Univ. of Girona (Spain) and Radboud Univ. Nijmegen Medical Ctr. (Netherlands); Lei Wang, Fraunhofer MEVIS (Germany); Michiel Kallenberg, Radboud Univ. Nijmegen Medical Ctr. (Netherlands); Robert Martí, Univ. of Girona (Spain); Horst K. Hahn, Fraunhofer MEVIS (Germany); Nico Karssemeijer, Radboud Univ. Nijmegen Medical Ctr. (Netherlands)

A precise segmentation of breast tissue is often required for computer-aided diagnosis (CAD) of breast MRI. Only a few methods have been proposed to automatically segment breast in MRI. Authors reported satisfactory performance, but a fair comparison has not been done yet as all breast segmentation methods were evaluated on their own data sets with different manual annotations. Moreover, breast volume overlap measures, which were commonly used for evaluations, do not seem to be adequate to accurately quantify the segmentation qualities. Breast volume overlap measures are not sensitive to small errors, such as local misalignments, because breast appears to be much larger than other structures. In this work, two atlas-based approaches and a breast segmentation method based on Hessian sheetness filter were exhaustively evaluated and benchmarked on a data set of 52 manually annotated breast MR images. Three quantitative measures including percentage of missed dense tissue, percentage of missed pectoral muscle and pectoral surface distance were defined to objectively reflect the practical use of breast segmentation in CAD methods. The evaluation measures provided important evidence to conclude that the three evaluated techniques performed accurate breast segmentations. More specifically, the atlas-based methods appeared to be more precise, but required larger computation time than the sheetness-based breast segmentation approach.

8669-128, Session PSMon

Fuzzy model based object delineation via energy minimization

Krzysztof C. Ciesielski, West Virginia Univ. (United States) and Univ. of Pennsylvania (United States); Jayaram K. Udupa, Dewey Odhner, Univ. of Pennsylvania (United States)

We study the problem of automatic delineation of an anatomic object in an image, where the object is solely identified by its anatomic prior, which is independent of the recorded image properties (intensities, resolution, etc). We form such priors in the form of fuzzy models to facilitate the segmentation of images acquired via different imaging modalities (like CT, MRI, or PET), in which the recorded image properties are usually different. Our main interest is in delineating different body organs in medical images for automatic anatomy recognition (AAR).

The AAR system we are developing consists of three main components: (C1) building body-wide groupwise fuzzy anatomic models; (C2) recognizing the body organs geographically and then delineating them by employing the models; (C3) generating quantitative descriptions. This paper focuses on (C2) and presents a unified approach for model-based segmentation within which several different strategies can be formulated, ranging from model-based hard/fuzzy thresholding to model-based graph cut, fuzzy connectedness, and random walker methods and algorithms. This is an important theoretical advance whose empirical significance and results will be presented in the full paper.

8669-129, Session PSMon

Consistent 4D brain extraction of serial brain MR images

Yaping Wang, Northwestern Polytechnical Univ. (China); Gang Li, Jingxin Nie, The Univ. of North Carolina at Chapel Hill (United States); Pew-Thian Yap, UNC at Chapel Hill (United States) and UNC (United States); Lei Guo, Northwestern Polytechnical Univ. (China); Dinggang Shen, UNC at Chapel Hill (United States)

Accurate and consistent skull stripping of serial brain MR images is of great importance in longitudinal studies that needs to detect subtle brain morphological changes. To avoid inconsistency and potential bias introduced by independently skull stripping each image at each time point, we propose an effective method that is capable of skull stripping serial brain MR images simultaneously. Specifically, all serial images of the same subject are affine aligned in a groupwise manner to a common space to avoid potential bias introduced by asymmetric transforms. A probability map, which encapsulates prior information gathered from a population of real brain images, is then warped to the aligned serial images for guiding skull-stripping via a deformable surface evolution mechanism. The same initial meshes representing the brain surfaces are first placed on all aligned serial images, and then all these meshes are simultaneously evolved to the respective target brain boundaries, driven by the intensity-based force, the probability map, as well as spatial and temporal smoothness. Imposing temporal smoothness constraint helps achieve longitudinally consistent results. Evaluations on 20 subjects, each with 4 time points, from the ADNI database indicate that our method gives more accurate and consistent result compared with 3D skull-stripping method. To better show the advantages of our 4D method over 3D method, we compute the Dice ratio in a ring (±5mm) surrounding the ground truth brain boundary; our 4D method shows around 3% of improvement over the 3D method. Our 4D method also gives both smaller surface-to-surface distances, with reduced variance.

8669-130, Session PSMon

Statistical representation of high-dimensional enhancement fields with application to consistent enhancement of chest x-ray images

Zhiqiang Lao, Carestream Health, Inc. (United States); Xin Zheng, Nanjing Univ. (China); Quncai Zou, NJM Insurance Group (United States)

This paper proposes a statistical model of enhancement field (SMEF)

aiming to effectively capture the statistics of high-dimensional enhancement fields which can then be leveraged to regularize the enhancement of portable chest radiograph images captured in the intensive care unit (ICU). Wavelet-packet transformation (WPT) of enhancement fields coupled with PCA in each wavelet band are used to more accurately estimate a prior pdf of high-dimensional enhancement fields from limited number of training samples. As a result, more consistent enhancement results can be obtained. In experiments, we first demonstrate the ability of SMEF to improve the visibility of CR ICU images and then demonstrate the ability of SMEF to provide more consistent image enhancement solution, via comparing the localized image enhancement algorithm, CLAHE, with its SMEF-constrained version. The proposed SMEF framework can potentially incorporate various image enhancement algorithms to improve consistency and stability.

8669-131, Session PSMon

Localizing and segmenting Crohn's disease affected regions in abdominal MRI using novel context features

Dwarikanath Mahapatra, Peter J. Schüffler, ETH Zurich (Switzerland); Jeroen A.W. Tielbeek, Amsterdam Medical Center (Netherlands); Joachim M Buhmann, ETH Zurich (Switzerland); Franciscus M Vos, Univ. van Amsterdam (Netherlands) and Technische Univ. Delft (Netherlands)

Crohn's disease (CD) is an autoimmune inflammatory bowel disease (IBD) that may affect any part of the gastrointestinal tract causing abdominal pain, diarrhea, vomiting or weight loss. Assessment of CD severity using modern computational analysis tools is essential to determine therapeutic strategy. Current reference standards for diagnosis like colonoscopy is invasive, requires extensive bowel preparation, and gives information only on superficial abnormalities. Therefore it is beneficial to have a non-invasive approach to detect CD.

We propose an automated method to localize and segment CD afflicted regions from input abdominal magnetic resonance (MR) images, without explicit segmentation of the bowel wall. It will serve as a tool to assist clinicians, reduce reliance on colonoscopy and help in quick diagnosis of CD. We extend long range spatial context features by incorporating distance and orientation along with 3D curvature features to derive context information from multiple locations. CD affected regions are first localized using random forest (RF) classifiers trained on a set of visual features. This gives a 3D volume of interest (VOI) encompassing the diseased area. In the second stage, each voxel in the VOI is further classified (using RF classifiers) as either diseased or normal, thus effectively segmenting the abnormal region. Experiments on real patient data show that our features achieve high sensitivity and can successfully segment out the pixels belonging to CD affected regions.

8669-132, Session PSMon

Glottis segmentation using dynamic programming

Jing Chen, Bahadir Gunturk, Melda Kunduk, Louisiana State Univ. (United States)

High speed videoendoscopy (HSV) is a promising laryngeal imaging technique which has a tremendous potential to further the assessment of vocal fold vibratory behavior during phonation. Due to the vast volume of HSV data, an automated and accurate segmentation of glottal opening is required for objective quantification and analysis of vocal fold vibratory characteristics. In this study, a dynamic programming based algorithm is presented for glottis segmentation. The underlying idea is to track the glottal edge in gradient image, where the average gradient magnitude along edge path is assumed to be maximal. To achieve accurate segmentation results and enable further analysis, we addressed different aspects of the problem, including reflection removal, detection of posterior and anterior commissure and determination of open and closed portions of glottal area. Reflection removal, which is essential for robust segmentation, is also achieved by dynamic programming. Posterior and anterior commissures in each frame of HSV data help pre-define the range of glottal area which needs to be segmented and therefore decrease the segmentation cost. In addition to the proposed algorithm, three other methods (including active contour, standard dynamic programming and fixed-threshold segmentation) have been implemented. The experimental results show that the proposed algorithm is more efficient and accurate than the others investigated in this study.

8669-133, Session PSMon

Effects of T2-weighted MRI based cranial volume measurements on studies of the aging brain

Phong V. Vuong, David Drucker, Chris Schwarz, Evan Fletcher, Charles DeCarli, Owen Carmichael, Univ. of California, Davis (United States)

Many brain aging studies use total intracranial volume (TIV) as a proxy measure of premorbid brain size that is unaffected by neurodegeneration. T1-weighted Magnetic Resonance Imaging (MRI) sequences are commonly used to measure TIV, but T2-weighted MRI sequences provide superior contrast between the cerebrospinal fluid (CSF) bounding the premorbid brain space and surrounding dura mater. In this study, we compared T1-based and T2-based TIV measurements to assess the practical impact of this superior contrast on studies of brain aging. 810 Alzheimer's Disease Neuroimaging Initiative (ADNI) participants, including healthy elders and those with mild cognitive impairment (MCI) and Alzheimer's Disease (AD), received T1-weighted and T2-weighted MRI at their baseline evaluation. TIV was automatically estimated from T1-weighted images using FreeSurfer version 4.3 (T1TIV), and an automated active contour method was used to estimate TIV from T2-weighted images (T2TIV). The correlation between T1TIV and T2TIV was high (.93), and disagreement was greater on larger heads. However, correcting a FreeSurfer-based measure of total parenchymal volume by dividing it by T2TIV led to stronger expected associations with a standardized measure of cognitive dysfunction (MMSE) in Poisson regression models among individuals with AD (z=1.73 vs. 1.09) and MCI (z=3.15 vs. 2.79) than a corresponding parenchymal volume measure divided by T1TIV. This effect was enhanced when the analysis was restricted to the cases where T1TIV and T2TIV disagreed the most. These findings suggest that T2-based TIV measurements may be higher fidelity than T1-based TIV measurements, thus leading to greater sensitivity to detect biologically plausible brain-behavior associations.

8669-134, Session PSMon

Food image analysis for measuring food Intake in free living conditions

Robert Dibiano, Bahadir Gunturk, Louisiana State Univ. (United States); Corby Martin, Pennington Biomedical Research Ctr. (United States)

Measuring the type and amount of food intake of free-living (outside controlled clinical research centers) people is an important task in nutrition research. One practical method is to provide camera-equipped cellphones to participants, who are trained to take pictures of their food selection and send these pictures to the researchers over wireless network. These pictures can then be analyzed by registered dietitians to estimate food intake, but such a process is labor intensive and prone to errors. In this paper, we describe a computer vision system to estimate food intake from the pictures captured and sent by participants. We describe the system in detail, including segmentation, pattern classification, volume estimation modules, and provide comprehensive experimental results to evaluate its performance.

8669-135, Session PSMon

DEeP random walks

Mandana Javanshir Moghaddam, Royal Institute of Technology (Sweden); Abouzar Eslami, Nassir Navab, Technical Univ. of Munich (Germany)

In this paper, we proposed distance enforced penalized (DEeP) random walks segmentation framework to delineate coupled boundaries by modifying classical random walks formulations. We take into account curves inter-dependencies and incorporate associated distances into weight function of conventional random walker. This effectively leverages segmentation of weaker boundaries guided by stronger counterparts, which is the main advantage over classical random walks techniques where the weight function is only dependent on intensity differences between connected pixels, resulting in unfavorable outcomes in the context of poor contrasted images. First, we applied our developed algorithm on synthetic data and then on cardiac magnetic resonance (MR) images for detection of myocardium borders. We obtained encouraging results and observed that proposed algorithm prevents epicardial border to leak into right ventricle or cross back into endocardial border that often observe when conventional random walker is used. We applied our method on forty cardiac MR images and quantified the results with corresponding manual traced borders as ground truths. We found the Dice coefficients 70% ± 14% and 43% ±14% respectively for DEeP random walks and conventional one.

8669-136, Session PSMon

Analysis of brain white matter hyperintensities using pattern recognition techniques

Mariana Bento, Letícia Rittner, Simone Appenzeller, Aline Lapa, Roberto Lotufo, Univ. Estadual de Campinas (Brazil)

The brain white matter is responsible for the transmission of electrical signals through the central nervous system. Lesions in the brain white matter, called white matter hyperintensity (WMH), can cause a significant functional deficit. WMH are commonly seen in normal aging, but also in a number of neurological and psychiatric disorders. We propose here an automatic approach for WHM analysis in order to distinguish regions of interest between normal and non-normal white matter (identification step) and also to distinguish different types of lesions based on their etiology: demyelinating or ischemic (classification step). The method combines texture analysis with the use of classifiers, such as Support Vector Machine (SVM), Nearst Neighboor (1NN) and Optimum Path Forest (OPF). Experiments with real brain MRI data showed that the proposed method is suitable to identify and classify the brain lesions.

8669-137, Session PSMon

An information theoretic clustering approach to automated medical image segmentation

Sunanda D. Mitra, Enrique Corona, Jason E. Hill, Brian Nutter, Texas Tech Univ. (United States)

Automated segmentation of medical images is a challenging problem. The number of segments in a medical image may be unknown a priori, due to the presence or absence of pathological anomalies. Unsupervised learning techniques with a foundation in information theory may provide a solid approach to the solution of this problem. We have developed the Improved “Jump” Method (IJM), a technique that efficiently finds a suitable number of clusters representing different tissue characteristics in an image. IJM works by optimizing an objective function that quantifies the quality of particular cluster configurations. Recent developments involving interesting relationships between Spectral Clustering (SC) and kernel Principal Component Analysis (kPCA) are used to extend IJM to the non-linear domain. This novel SC approach maps the data to a new space where points belonging to the same cluster are collinear if the parameters of a Radial Basis Function (RBF) kernel are adequately selected. The projection of these points onto the unit sphere allows IJM to measure the quality of tested configurations, yielding an algorithm that simultaneously selects the number of clusters and the RBF kernel parameter. Validation of this method is sought via segmentation of MR brain images in a combination of all major modalities. Such labeled MRI datasets serve as benchmarks for any segmentation algorithm. As an example, the effectiveness of IJM is demonstrated in the segmentation of uterine cervix color images for early identification of cervical neoplasia as an aid to cervical cancer diagnosis. Further studies are in progress in segmentation and detection of multiple sclerosis (MS) lesions.

8669-138, Session PSMon

Automated segmentation of pulmonary lobes in chest CT scans using evolving surfaces

Pechin Lo, Univ. of California, Los Angeles (United States); Eva M. van Rikxoort, Radboud Univ. Nijmegen Medical Ctr. (Netherlands); Fereidoun Abtin, Shama Ahmad, Arash Ordookhani, University of California, Los Angeles (United States); Jonathan G. Goldin, Matthew S. Brown, Univ. of California, Los Angeles (United States)

Segmentation of the pulmonary lobes from chest CT scans is a challenging problem, especially with the presence of incomplete pulmonary fissures. We present an iterative approach for the segmentation of pulmonary lobes via a surface that evolves based on a voxel based fissure confidence function and a smooth prior. The surface is constructed such that it separates the whole lung at all times, and is represented as a height map above a 2D reference plane. A surface evolution process is used to fit the surface to a pulmonary fissure in a scan. At each iteration, the height of all points in the map is adjusted such that the overall confidence is maximized, followed by Laplacian smoothing to enforce a smooth prior on the surface. The proposed method was trained and tuned on 18 CT scans from a clinical trial, and tested on 41 scans of different patients with severe emphysema from another clinical trial. Average overlap ratio of the segmented upper and lower lobes of the left and right lungs are 0.96 and 0.91 respectively. Average overlap ratio for the right middle lobes is 0.86, where minor manual intervention was needed for six cases, and with seven cases excluded because the minor fissure was almost entirely not visible in the CT scan.

8669-139, Session PSMon

A multiscale graph cut approach to bright-field multiple cell image segmentation using a Bhattacharyya measure

Justin W. Wan, Soo Min Kang, Univ. of Waterloo (Canada)

Automatic segmentation of bright-field cell images is important to cell biologists, but difficult to achieve due to the complex nature of the cells in bright-field images (poor contrast, broken halo, missing boundaries), resulting in poor segmentation by standard methods such as level set and active contours. The existence of multiple cells per image frame poses additional challenges in that individual cells may have very different shapes and intensity profiles that make it difficult for any single model to capture all of the variations. In this paper, we present a robust segmentation method which combines the techniques of graph cut, multiresolution, and Bhattacharyya measure, performed in a multiscale framework, to locate multiple cells in bright-field images. This approach addresses the issue of low contrast by capturing the difference in intensity profiles of the cells and background using a Bhattacharyya measure based graph cut method. The resulting segmentation on the entire image frame provides a coarse scale segmentation which captures the large scale objects, the cell blobs (isolated cells, groups of cells).

To capture the local behaviour, the idea is to "zoom in" at each of the cell blobs. Each connected piece will be identified and fitted in a local window. Then a small scale segmentation at different regions of interest is performed, yielding more refined boundary if there is only one cell and separating the individual non-overlapping cells in the case of a cell group. We illustrate the effectiveness of the method by segmentation results of C2C12 cells in bright-field images.

8669-140, Session PSMon

Automatic segmentation of abdominal wall in ventral hernia CT: a pilot study

Zhoubing Xu, Vanderbilt Univ. (United States); Wade M. Allen, Institute of Imaging Science, Vanderbilt Univ. (United States); Benjamin K. Poulose, General Surgery, Vanderbilt Univ. Medical Ctr. (United States); Bennett A. Landman, Vanderbilt Univ. (United States) and Institute of Imaging Science, Vanderbilt Univ. (United States)

The treatment of ventral hernias (VH) has been a challenging problem for medical care. Repair of these hernias is fraught with failure; recurrence rates ranging from 24-43% have been reported, even with the use of biocompatible mesh. Currently, computed tomography (CT) is used to guide intervention through expert, but qualitative, clinical judgments; notably, quantitative metrics based on image-processing are not used. We propose that image segmentation methods to capture the three-dimensional structure of the abdominal wall and its abnormalities will provide a foundation on which to measure geometric properties of hernias and surrounding tissues and, therefore, to optimize intervention. To date, automated segmentation algorithms have not been presented to quantify the abdominal wall and potential hernias. In this pilot study with four clinically acquired CT scans on post-operative patients, we demonstrate a novel approach to geometric classification of the abdominal wall and essential abdominal features (including bony landmarks and skin surfaces). Our approach uses a hierarchical design in which the abdominal wall is isolated in the context of the skin and bony structures using level set methods. All segmentation results were quantitatively validated with surface errors based on manually labeled ground truth. Mean surface errors for the outer surface of the abdominal wall were less than 2mm. This approach establishes a baseline for characterizing the abdominal wall for improving VH care.

8669-141, Session PSMon

Graph cuts based left atrium segmentation refinement and right middle pulmonary vein extraction in C-arm CT

Dong Yang, Yefeng Zheng, Siemens Corporate Research (United States); Matthias John, Healthcare Sector, Siemens AG (Germany)

Automatic segmentation of the left atrium (LA) with the left atrial appendage (LAA) and the pulmonary vein (PV) trunks is important for intra-operative guidance in radio-frequency catheter ablation to treat atrial fibrillation (AF). Robust segmentation of the left atrium from the C-arm CT images has been realized by a model-based method with marginal space learning (MSL). However, on some data, the mesh from the model-based segmentation cannot fit the true boundary of the left atrium well in the image since the method does not make full use of local intensities distribution. Moreover, it is difficult to estimate the large unpredictable variations in the pulmonary veins completely with the models. In this paper, a graph-based method is proposed by exploiting the graph cuts method to refine results from the model-based segmentation and extract extra right middle pulmonary veins. We first build regions of interest to define the consideration scopes for processing. The region growing method is used to construct graphs within the regions of interest for the graph cuts optimization. Then the graph cuts optimization is conducted by the standard procedures and its results would be assigned into different parts of the left atrium. For the extraction of right middle pulmonary veins, occational outliers from optimization are removed by examining multiple criteria. Experiments demonstrate that the proposed graph-based method is effective and efficient to realize both the refinement and the extraction.

8669-143, Session PSMon

Cortical thickness changes related to the processes of maturation and aging in healthy brains

Heitor Cunha, Univ. of São Paulo (Brazil); Antonio C. Santos, Univ. de São Paulo (Brazil); Sara Rosset, Univ. of São Paulo (Brazil); Carlos E. G. Salmon, Univ. de São Paulo (Brazil)

Normal aging is accompanied by global as well as regional structural changes. While these age-related changes in gray matter volume have been extensively studied, less has been done using newer morphological indexes, such as cortical thickness and surface area and the studies usually focus on subjects older than 19. Here, we analyzed structural images of 143 healthy volunteers, ranging from 6 to 86 years of age, using FreeSurfer to support the parcellation, and proposed a way to compute the regional changes of cortical thickness that occurs in human brains from childhood to elderliness. We separated the whole process in two stages: maturation and aging, and compute the best threshold for each region, allowing to identify when those processes begin, their velocities and the relation to some degenerative diseases.

8669-144, Session PSMon

A registration and atlas propagation based framework for automatic whole heart segmentation of CT volumes

Xiahai Zhuang, Shanghai Advanced Research Institute (China); Jingjing Song, Songhua Zhan, Shu Guang Hospital, Shanghai Univ. of Traditional Chinese Medicine (China); Tian Lan, Hui Huang, Shanghai Advanced Research Institute (China); Mingxing Hu, Sebastien Ourselin, Ctr. for Medical Image Computing, Univ. College London (United Kingdom); Qiang Li, Shanghai Advanced Research Institute (China)

Cardiac computed tomography (CT) is widely used in clinics for diagnosing heart diseases and assessing functionality of the heart. It is therefore desirable to achieve automatic segmentation of the heart for functional analysis, since manual work can be tedious and subject to bias. However, automating this segmentation is challenging due to the large shape variability of the heart and the poor contrast between substructures such as those in the right ventricle and right atrium region in CT angiography images. In this work, we develop a fully automatic segmentation framework for cardiac CT volumes. This framework is based on image registration and atlas propagation techniques. Also, we investigate and compare the segmentation performance using single and multiple atlas propagation and segmentation strategies. In multiple atlas segmentation, a ranking-and-selection scheme is used to identify the best atlas(es) from an atlas pool for an unseen image. We evaluate the performance of the different segmentation schemes using clinical data and the preliminary results show that the proposed multiple atlas segmentation method can achieve a mean Dice score of 0.912+-0.04 for the five substructures of the heart.

8669-145, Session PSMon

Automatic segmentation of the preterm neonatal brain with MRI using supervised classification

Sabina Chita, Image Sciences Institute, Univ. Medical Ctr. Utrecht (Netherlands); Manon J. N. L. Benders, Wilhelmina Children's Hospital, Univ. Medical Ctr. Utrecht (Netherlands); Pim Moeskops, Univ. Medical Ctr. Utrecht (Netherlands); Karina J. Kersbergen, Wilhelmina Children's Hospital, Univ. Medical Ctr. Utrecht (Netherlands); Max A. Viergever, Ivana Isgum, Image Sciences Institute, Univ. Medical Ctr. Utrecht (Netherlands)

Cortical folding ensues around 13-14 weeks gestational age and a qualitative analysis of the cortex around this period is required to observe and better understand the folds arousal.

A quantitative assessment of cortical folding can be done using the cortical surface area, respectively by using segmentations of unmyelinated white matter (UWM), cortical grey matter (CoGM) and cerebrospinal fluid in the extracerebral space (CSF).

This work presents a method for automatic segmentation of these tissue types in preterm infants.

A set of T1- and T2-weighted images of ten infants scanned at 30 weeks corrected age was used.

The reference standard was obtained by manual expert segmentation.

The method employs supervised pixel classification in three subsequent stages.

The classification is performed based on the set of spatial and texture features.

Segmentation results are evaluated in terms of Dice coefficient (DC), Hausdorff distance, and modified Hausdorff distance (MHD) defined as 95th percentile of the HD.

The method achieved DC of 0.94 for UWM, 0.73 for CoGM and 0.85 for CSF.

The HD and MHD were 6.75 and 0.34 for UWM, 6.39 and 0.85 for CoGM, and 7.43 and 0.83 for CSF, respectively.

The presented method can readily provide volumetric measurements of the segmented tissues, and it enables quantification of cortical characteristics.

Therefore, the method provides a basis for evaluation of clinical relevance of these biomarkers in the given population.

8669-146, Session PSMon

Multi-organ segmentation from 3D abdominal CT images using patient-specific weighted-probabilistic map

Chengwen Chu, Masahiro Oda, Nagoya Univ. (Japan); Takayuki Kitasaka, Aichi Institute of Technology (Japan); Kazunari Misawa, Aichi Cancer Ctr. Hospital (Japan); Michitaka Fujiwara, Yuichiro Hayashi, Nagoya Univ. (Japan); Robin Wolz, Daniel Rueckert, Imperial College London (United Kingdom); Kensaku Mori, Nagoya Univ. (Japan)

The organ segmentation of CT images is a basic function of computer-aided diagnosis and surgery assistance systems. Many of these systems implement organ segmentation methods that are limited to targeting specific organs for segmentation and are not robust in dealing with the inter-subject differences in regards to organ shape and position. In this paper, we propose an automated method for the multi-organ segmentation of abdominal 3D CT images by utilizing a patient-specific, weighted-probabilistic map for organ existence.This is achieved using a two-step process. First, we prepare for segmentation by dividing an atlases database into multiple clusters. This is done using a pair of training images and a corresponding manual segmentation data set. In the next step, we choose a cluster whose template image is the most similar to the test image. We then weight all of the atlases in the selected cluster by calculating similarities between the atlases and the test image to generate a specific probabilistic map dynamically for each test image. We use the generated map in MAP estimation to obtain a rough segmentation result and then refine it by using a graph-cut method. Our method can simultaneously segment four organs including the liver, spleen, pancreas and kidneys. Our weighting scheme greatly reduces segmentation error due to inter-subject differences. We applied our method to 100 cases of CT images showing that our method can segment the liver, spleen, pancreas and kidneys with Jaccard indices of 90.8%, 82.5%, 56.1%, 81.4%, respectively.

8669-147, Session PSMon

Automatic left ventricle apical plane detection In 3D echocardiography

Joao S. Domingos, Univ. of Oxford (United Kingdom); Daniel Augustine, Paul Leeson, John Radcliffe Hospital (United Kingdom); J. Alison Noble, Univ. of Oxford (United Kingdom)

Real-time 3D echocardiography is an emerging imaging modality that provides 3D visualization of cardiac structures in multiple planes, thus enabling a more complete and rapid assessment of cardiac function. However, despite these advantages, sonographers experience difficulties in navigating the 3D volumes and extracting the standardized views, making it a time-consuming procedure. We propose a new robust method to automatically detect the most common apical views of the left ventricle (LV). LV standard apical view finding consists of two steps: 1) a real-time Kalman filter based tracking framework using subdivision surfaces performs segmentation of the LV blood pool, enabling extraction of its centerline and thus volume slicing by rotating a moving plane overt the previous; 2) each slice is then classified by a variant of the AdaBoost learning framework in order to detect standardized views. Evaluation performed on a combination of healthy and clinical patients' yields an accuracy of 87.5%.

8669-148, Session PSMon

Shape manifold regression with spherical harmonics for hippocampus shape analysis

Xuejiao Chen, Wenjing Li, Institute of Automation (China); Jing Hua, Wayne State Univ. (United States); Xiaopeng Zhang, Huiguang He, Institute of Automation (China)

Shape regression analysis is a powerful tool to study local shape changes as a function of an independent regression variable. In this paper, we introduce spherical harmonic (SPHARM) representation to surface manifold learning and shape regression. With SPHARM coordinate, we construct a shape space and apply kernel regression for manifold learning. We also use root mean square distance (RMSD) to measure the deformation degree of the surface, and find out that kernel regression is more suitable to analyze hippocampus changes than linear model. We also investigate the particular changing area. With combining SPHARM and kernel regression together, we reconstruct the developing model of hippocampus and discover that the hippocampus have significant changes in the frontal area and tail area, especially in CA1 subfield.

8669-149, Session PSMon

Computation on shape manifold for atlas generation: application to whole heart segmentation of cardiac MRI

Xiahai Zhuang, Shanghai Advanced Research Institute (China); Wenzhe Shi, Haiyan Wang, Daniel Rueckert, Sebastien Ourselin, Biomedical Image Analysis Group, Imperial College London (United Kingdom)

In this work, we investigate the computation on shape manifold, which is considered as a subspace of Riemannian manifold, for atlas generation and application to atlas propagation based segmentation. We formulate the computation of Frechet mean via the Log-Euclidean framework for Nadaraya-Watson kernel regression modelling. In this formulation, we directly compute the Frechet mean of shapes via fast vectorial operations on velocity fields. By using image similarity metric to estimate the distance of shapes in the assumed manifold, we can estimate a close shape of an unseen image using Naderaya-Watson kernel regression function. We applied this estimation to generate subject-specific atlas for whole heart segmentation of MRI data. The segmentation results on clinical data demonstrated an improved performance compared to existing methods, thanks to the usage of subject- specific atlases which had more similar shape to the unseen images.

8669-151, Session PSMon

Interactive 3D segmentation method based on uncertain local region updating in hierarchical MRF graph

Sang Hyun Park, Seoul National Univ. (Korea, Republic of); Il Dong Yun, Hankuk Univ. of Foreign Studies (Korea, Republic of)

In this paper, we propose an interactive three-dimensional segmentation method. Segmentation of organs in medical image often requires huge amount of user interactions and suffers from inter and intra user variability due to shape deformation and ambiguous boundaries. Unlike existing interactive segmentation methods which only depend on fine user guidance, the proposed method use prior knowledge of training data as well as the user guidance. Based on the prior knowledge, most distinguishable parts of an object are automatically segmented, while labels of some vague parts are queried to user. To systematically model the problem, hierarchical Markov random field (HMRF) model and active learning scheme are used. The HMRF model, originally used for automatic segmentation, reflects local region characteristics well by making adaptive local prior. We expand the method to receive user interactions on the vague regions iteratively. For efficiency, the active learning scheme is incorporated into the HMRF framework when the user interactions are received. Based on the active learning strategy, uncertainty of local regions is firstly computed, and only small number of uncertain regions is selected to update the model. Since the HMRF structure maintains connectivity of local regions and constrains global optimality, the segmentation is changed as a whole even though the small parts with high uncertainty are updated. For evaluation, the proposed method is applied to bone segmentation of knee MR images. The evaluation demonstrates that the efficiency of the proposed method is enhanced against graph cut based method or manual editing.

8669-152, Session PSMon

Prostate segmentation in 3D TRUS using convex optimization with shape constraint

Wu Qiu, Jing Yuan, Eranga Ukwatta, David Tessier, Aaron Fenster, Robarts Research Institute, Western Univ. (Canada)

An efficient and accurate segmentation of 3D end-firing transrectal ultrasound (TRUS) images plays an central role in the planning and treatment of 3D TRUS guided prostate biopsy. In this paper, we propose a novel convex optimization based approach to delineating of prostate boundaries from 3D TRUS images. The technique makes use of the approximate rotational symmetry of prostate shapes and reduces the original 3D segmentation problem to a sequence of simple 2D segmentation sub-problems by means of rotationally reslicing the 3D TRUS images. In practice, this significantly decreases the computational load, facilitates introducing learned shape information and improves segmentation efficiency and accuracy. For each 2D resliced frame, we introduce a new convex optimization based contour evolution method to locate the 2D slicewise prostate boundary subject to the additional shape constraint. The proposed contour evolution method provides a fully time implicit scheme to move the contour to its globally optimal position at each discrete time, which allows a large evolving time step-size to accelerate convergence. Moreover, the proposed algorithm is implemented on a GPU to achieve a high performance. Quantitative validations on twenty 3D TRUS patient prosate images demonstrate the proposed approach can obtain a DSC of 93.7±2.5%, a sensitivity of 91.2±3.1%, a MAD of 1.37±0.3mm, and a MAXD of 3.02±0.44mm. The mean segmentation time for the dataset was 18.3±2.5s, in addition to 25s for initialization. Our proposed method exhibits the advantages of accuracy, efficiency and robustness compared to the level set and active contour based methods.

8669-153, Session PSMon

A robust model-based approach to detect the mitral annulus in 3D ultrasound

Bastian Graser, Diana Wald, Mathias Seitel, Deutsches Krebsforschungszentrum (Germany); Manuel Grossgasteiger, Raffaele de Simone, Ruprecht-Karls-Univ. Heidelberg (Germany); Hans-Peter Meinzer, Ivo Wolf, Deutsches Krebsforschungszentrum (Germany)

About 40.000 mitral reconstructions are performed every year in the United States. To ensure a successful and durable outcome of the operation, precise quantification of the mitral annulus is essential. We propose a fast semi-automatic method to create a detailed model of the mitral annulus from 3D ultrasound. The idea is to combine image information with anatomical knowledge in form of a standard mitral annulus model. We achieve this by considering two kinds of energies. An external energy for adjust the model to the ultrasound image and an internal energy to keep the shape realistic. This way, the method can cope with strong artifacts and incomplete images, which makes it suitable for clinical standard images. By comparing the resulted models to manually created ground truth data of 39 patients, we achieved a mean error of 3.42 mm. This is comparable to the determined standard deviation of the expert (2.92 mm), meaning the resulting models are close to the expert's estimation. The overall time to create mitral annulus model from 3D ultrasound image is less than a minute, which is acceptable for the clinical routine.

8669-154, Session PSMon

Segmentation of the left heart ventricle in ultrasound images using a region based snake

Matilda Landgren, Niels Christian Overgaard, Anders Heyden, Lund Univ. (Sweden)

Ultrasound imaging of the heart is a non-invasive method widely used for different applications. One of them is to measure the blood volume in the left ventricle at different stages of the heart cycle. This demands a proper segmentation of the left ventricle and a (semi-) automated method would decrease intra-variability as well as workload. This paper presents a semi-automated segmentation method that uses a region based snake. To avoid any unwanted concavities in the segmentations

due to the cardiac valve we use two anchor points in the snake that are located to the left and to the right of the cardiac valve respectively. For the possibility of segmentations in different stages of the heart cycle these anchor points are tracked through the cycle. This tracking is based both on the resemblance of a region around the anchor points and a prior model of the movement in the y-direction of the anchor points. The region based snake functional is the sum of two terms, a regularizing term and a data term. It is our data term that is region based since it involves the integration of a two-dimensional subdomain of the image plane. A segmentation of the left ventricle is obtained by minimizing the functional which is done by continuously reshaping the contour until the optimal shape and size is obtained. The developed method shows promising results.

8669-155, Session PSMon

Automatic systole-diastole classification of mitral valve complex from RT-3D echocardiography based on multiresolution processing

Gary K. W. Tsui, Kwan-Yee K. Wong, The Univ. of Hong Kong (Hong Kong, China); Alex P. W. Lee, The Chinese Univ. of Hong Kong (Hong Kong, China)

In the context of image processing, a set of image-slices from the systolic volumes should have a single large region of cardiac tissues (brighter pixels) while another set of image-slices from the diastolic volumes should have two large disconnected areas of cardiac tissues. Our proposed method is composed of the following two stages: i) volumetric data preprocessing and ii) multiresolution based systole-diastole classification. The proposed method first resamples the data with radial-plane cuts. Each radial-plane, essentially an image-slice of the volumetric data, is evenly spaced at an angular offset. Then, the proposed method applies a binarization filter and a median noise filter to images to separate the cardiac tissues from the blood and remove noise that is inherent in the echocardiographic data. Next, it proceeds with the classification based on the proposed multiresolution processing scheme, where it breaks down and analyzes the filtered images from coarse to fine resolution scales. Our classifier then computes the classifications based on the numbers of connected regions, relying on each pixel's 8-neighborhood connectivity, from each resolution scale. The proposed method was evaluated and compared with the classification results produced by a cardiologist. The evaluation, based on 176 RT-3D-TEE volumes, indicated that the proposed method, without the use of computationally intensive algorithms and the use of any training database, achieved an average classification accuracy of 91.04% +- 7.84%. We also demonstrated that, without the multiresolution processing scheme, an average classification accuracy of 79.42% +- 10.59% can still be achieved.

8669-156, Session PSMon

Learning based ensemble segmentation of anatomical structures in liver ultrasound image

Xuetao Feng, Xiaolu Shen, Qiang Wang, Samsung Advenced Institute of Technology (China); Jung-Bae Kim, Samsung Advenced Institute of Technology (Korea, Republic of); Zhihui Hao, Samsung Advenced Institute of Technology (China); Youngkyoo Hwang, Won-Chul Bang, James D. K. Kim, Samsung Advenced Institute of Technology (Korea, Republic of); Ji-Yeun Kim, Samsung Advenced Institute of Technology (China)

Automatic segmentation of anatomical structure is crucial for computer aided diagnosis and image guided online treatment. In this paper, we present a novel approach for fully automatic segmentation of all anatomical structures from a target liver organ in a coherent framework. Firstly, all regional anatomical structures such as vessel, tumor, diaphragm and liver parenchyma are detected simultaneously using random forest classifiers. They share the same feature set and classification procedure. Secondly, an efficient region segmentation algorithm is used to obtain the precise shape of these regional structures. It is based on level set with proposed active set evolution and multiple features handling which achieves 10 times speedup over existing algorithms. Thirdly, the liver boundary curve is extracted via a graph-based model. The segmentation results of regional structures are incorporated into the graph as constraints to improve the robustness and accuracy. Experiment is carried out on an ultrasound image data set with 942 images captured with liver motion and deformation from a number of different views. Quantitative results demonstrate the efficiency and effectiveness of the proposed algorithm.

8669-157, Session PSMon

Gland segmentation of breast ultrasound exams

Rui P. Quaresma Braz, Manuela Pereira, Instituto de Telecomunicações, Univ. da Beira Interior (Portugal); António M. G. Pinheiro, Univ. da Beira Interior (Portugal); Mário Freire, Instituto de Telecomunicações, Univ. da Beira Interior (Portugal); José Moutinho, Univ. da Beira Interior (Portugal)

A novel approach for the mammary gland region segmentation of Ultrasound Breast exams is proposed. This method is important because the mammary gland is the Region of Interest for pathological diagnosis. From our knowledge, this problem was also addressed by [1]. Moreover, the work presented in [2] is extended using an adaboost classifier and a cross validation of the resulting method is presented.

Five different methods that enhance the transition areas or remove the speckle were selected: Non-linear diffusion, Speckle Reducing Anisotropic Diffusion, Entropy filter, Laplacian filter and Homomorphic filter. The result of these processing methods define features used as weak classifiers by an Adaboost classifier, resulting in a rough tissue segmentation. A new method is proposed to interpolate the Adaboost result into an accurate tissue separation line, using graph theory. This step overcomes the problem of the discontinuities between the several areas classified.

The developed segmentation method was applied to a database of 61 images, 34 without masses and 27 with masses collected using digital support, and segmented by an experienced medical oncologist in Centro Hospitalar da Cova da Beira in Portugal. The presented results were obtained using cross-validation.

8669-158, Session PSMon

3D seam selection techniques with application to improved ultrasound mosaicing

Jason F. Kutarnia, Peder C. Pedersen, Worcester Polytechnic Institute (United States)

In this work we introduce two different techniques for the global optimization of surfaces and apply them to the task of finding the optimal stitching seam between neighboring and overlapping 3D ultrasound volumes. Existing techniques for US mosaicing, based on interpolation or planar seams, introduce artifacts into the composite volume especially when using a large number of clinical scans. Our first method models the seam as a B-spline surface and treats its calculation as a shape optimization problem. In this case the optimal location of the surface-defining control points is a large scale constrained optimization problem, which is solved using a cooperatively coevolving particle swarm based approach. The second method treats the seam selection as a voxel labeling problem, where each voxel in the composite volume is labeled with its respective source volume. Therefore if we have N volumes, each

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voxel in the composite volume may be assigned one of the N labels. The optimal labeling, which implicitly defines a seam, minimizes the intensity and gradient difference between adjacent volumes The formulation is optimized using graphcuts, which guarantees that a global minimum is achieved due to the submodularity of the energy function. The final composite volume is constructed voxel-wise by taking the value of the source volume, which is designated by its label. Our application of this procedure is the construction of composite ultrasound image volumes for incorporation into an ultrasound simulator. These methods are validated on clinical US data acquired from obstetrics patients.

8669-159, Session PSMon

Semiautomatic segmentation of atherosclerotic carotid artery lumen using 3D ultrasound imaging

Md Murad Hossain, Khalid AlMuhanna, George Mason Univ. (United States); Limin Zhao, Brajesh K. Lal, Veterans Affairs Maryland Health Care System (United States); Siddhartha Sikdar, George Mason Univ. (United States)

Carotid atherosclerosis is a major cause of stroke. Imaging and monitoring plaque progression in 3D can better classify disease severity and potentially identify vulnerability to rupture. In this paper we propose and validate a new semiautomatic carotid lumen segmentation algorithm based on 3D ultrasound imaging that is designed to work in the presence of poor boundary contrast and complex 3D lumen geometries. Our algorithm uses a distance regularized level set evolution with a novel initialization and stopping criteria to localize the lumen-intima boundary (LIB). The external energy is a combination of region based and edge based energy. Initialization of LIB segmentation is first done in the longitudinal slice where the geometry of the carotid bifurcation is best visualized and then reconstructed in the cross sectional slice to guide the 3D initialization. Manual initialization of contour is done only on starting slice of common carotid, bifurcation, and internal and external carotid. User also initializes points on boundary for every slice. A combination of changes in modified Hausdorff distance (MHD) between contours at successive iterations and a stopping boundary formed from initial points is used as a stopping criterion to avoid over or under segmentation. The proposed algorithm is evaluated against manually segmented boundaries by calculating dice similarity coefficient (DSC), HD and MHD in common (C), bulb (B) and internal (I) region to get the better understanding of performance. Results from five subjects with >50% carotid stenosis showed good agreement with manual segmentation; between algorithm & manuals: DSC (C: 86.49± 9.38, B: 82.21±8.49, I: 78.96±7.55), MHD (C: 3.79 ± 1.64, B: 4.09 ± 1.71, I: 4.12 ± 2.01), HD (C: 8.07±2.59, B: 10.09±3.95, I: 11.28±5.06); inter observers: DSC (C: 88.31±5, B: 82.45±7.57, I: 82.03±8.83), MHD (C: 3.77±2.09, B: 4.32±1.88, I: 4.56±2.24), HD (C: 7.61±2.67, B: 10.22±4.30, I: 10.63±4.94). The method is a first step for full 3D characterization of plaque progression, and is currently being evaluated in a longitudinal study of asymptomatic carotid stenosis.

8670-1, Session 1

Hyperspectral signature analysis of skin parameters

Saurabh Vyas, Johns Hopkins Univ. Applied Physics Lab. (United States) and Johns Hopkins Univ. (United States); Amit Banerjee, Johns Hopkins Univ. Applied Physics Lab. (United States); Luis Garza, Sewon Kang, Johns Hopkins Univ. (United States); Philippe Burlina, Johns Hopkins Univ. Applied Physics Lab. (United States) and Johns Hopkins Univ. (United States)

The temporal analysis of changes in biological skin parameters, including melanosome concentration, collagen concentration and blood oxygenation, may serve as a valuable tool in diagnosing the progression of malignant skin cancers and in understanding the pathophysiology of cancerous tumors. Quantitative knowledge of these parameters can also be useful in applications such as wound assessment, and point-of-care diagnostics, amongst others. We propose an approach to estimate in vivo skin parameters using a forward computational model based on Kubelka-Munk theory and the Fresnel Equations. We use this model to map the skin parameters to their corresponding hyperspectral signature. We then use machine learning based regression to develop an inverse map from hyperspectral signatures to skin parameters. In particular, we employ support vector machine based regression to estimate the in vivo skin parameters given their corresponding hyperspectral signature. We build on our work from SPIE 2012, and validate our methodology on an in vivo dataset. This dataset consists of 241 signatures collected from in vivo hyperspectral imaging of patients of both genders and Caucasian, Asian and African American ethnicities. In addition, we also extend our methodology past the visible region and through the short-wave infrared region of the electromagnetic spectrum. We find promising results when comparing the estimated skin parameters to the ground truth, demonstrating good agreement with well-established physiological precepts. This methodology can have potential use in non-invasive skin anomaly detection and for developing minimally invasive pre-screening tools.

8670-2, Session 1

Down syndrome detection from facial photographs using machine learning techniques

Qian Zhao, Kenneth Rosenbaum, Raymond Sze, Children's National Medical Ctr. (United States); Dina Zand, Children's National Medical Center (United States); Marshall Summar, Marius G. Linguraru, Children's National Medical Ctr. (United States)

Down syndrome is the most commonly occurring chromosomal condition; one in every 691 babies in United States is born with it. Patients with Down syndrome have an increased risk for heart defect, respiratory and hearing problems and the early detection of the syndrome is fundamental for managing the disease. Clinically, facial appearance is an important indicator in diagnosing Down syndrome and it paves the way for computer-aided diagnosis based on facial image analysis. In this study, we propose a novel method to detect Down syndrome using photography for facial dysmorphology. Geometric features based on facial anatomical landmarks and local texture features based on the Contourlet transform and local binary pattern are investigated to represent the facial characteristics. Then a support vector machine classifier is used to discriminant normal and abnormal cases. Finally, the accuracy, precision and recall are used to evaluate the method. The comparison among the geometric, local texture and combined features was performed using the leave-one-out validation. All experiments are repeated ten times to obtain the average performance. Our method achieved 86.75% accuracy with high precision and recall for the combined features; the detection results were significantly higher than using only geometric or texture features. The promising results indicate that our method has the potential for automated assessment for Down syndrome from simple, noninvasive imaging data.

8670-3, Session 1

Region detection in medical images using HOG classifiers and a body landmark network

Marius Erdt, Oliver Knapp, Klaus Drechsler, Stefan Wesarg, Fraunhofer-Institut für Graphische Datenverarbeitung (Germany)

Automatic detection of anatomical structures and regions in 3D medical images is important for several computer aided diagnosis tasks. In this work, a new method for simultaneous detection of multiple anatomical areas is proposed. The method consists of two steps: first, single rectangular region candidates are detected independently using 3D variants of Histograms of Oriented Gradients (HOG) features. These features are robust against small changes of regions in rotation and scale which typically occur between different individuals. In a second step, the positions of the detected candidates are refined by incorporating a body landmark network that exploits anatomical relations between different structures. The landmark network consists of a principle component based statistical modeling of the relative positions between the detected regions in training images.

The method has been evaluated on thoracic/abdominal CT images of the portal venous phase. In 216 CT images, seven different structures have been trained. Results show an increase in performance using the combination of HOGs and the landmark network in comparison to using independent classifiers without anatomical relations.

8670-4, Session 1

Automatic segmentation of kidneys from non-contrast CT images using efficient belief propagation

Jianfei Liu, National Institutes of Health (United States); Marius G. Linguraru, Children's National Medical Ctr. (United States); Shijun Wang, Ronald M. Summers, National Institutes of Health (United States)

Kidney segmentation is a critical step in the automated computer-aided diagnosis of the abdomen from CT data. An important application is the detection of extracolonic findings from CT colonography (CTC) images because 8.6% of the patients undergoing CTC exams were found to have unknown extracolonic findings. However, the detection of extracolonic findings is not the primary screening purpose of the CTC protocols, which address the detection of colon cancer. Therefore, kidneys are poorly imaged in the non-contrast CTC images and have similar intensity distributions to their surrounding tissues. The accurate segmentation of the kidneys becomes more difficult if the kidney parenchyma touches its neighboring organs. In this paper, we present a fully automatic kidney segmentation algorithm to support abdominal diagnosis from CTC data. It is built upon three major contributions: 1) localize kidney search regions by exploiting the segmented liver and spleen as well as body symmetry; 2) construct a probabilistic shape prior; 3) employ efficient belief propagation on the shape prior to extract kidneys. We evaluated the accuracy on five non-contrast CTC datasets with manual kidney segmentation as the ground-truth. The Dice volume overlaps were 88%/89%, the root-mean-squared errors were 3.4 mm/2.8 mm, and the average surface distances were 2.1 mm/1.9 mm for the left/right kidney respectively. We also validated the robustness on 27 additional CTC cases, and 23 datasets were successfully segmented. The results demonstrated that the proposed algorithm could automatically and accurately segment kidneys from CTC images, given the prior correct segmentation of the liver and spleen.

8670-5, Session 1

Robust detection of renal calculi from non-contract CT images using tv-flow and mser features

Jianfei Liu, Shijun Wang, National Institutes of Health (United States); Marius G. Linguraru, Children's National Medical Ctr. (United States); Ronald M. Summers, National Institutes of Health (United States)

Renal calculi are one of the most painful urologic disorders causing 3 million treatments per year in the United States. The objective of this paper is the automated detection of renal calculi from CT colonography (CTC) images because they are one of the major extracolonic findings. However, the primary purpose of the CTC protocols is not for the detection of renal calculi, but for screening of colon cancer. The kidneys are imaged with significant amounts of noise in the non-contrast CTC images, which makes the detection of renal calculi extremely challenging. We propose a computer-aided diagnosis method to detect renal calculi in CTC images. It is built on three novel techniques: 1) total variation (TV) flow to reduce image noise while keeping calculi, 2) maximally stable extremal region (MSER) features to find calculus candidates, 3) salient feature descriptors based on intensity properties to train a support vector machine classifier and filter false positives. We selected 23 CTC cases with 36 renal calculi to analyze the detection algorithm. The calculus size ranged from 1.0mm to 6.8mm. Fifteen cases were selected as the training dataset, and the remaining 8 cases were used for testing dataset. The area under the receiver operating characteristic curve (AUC) values were 0.92 in the training datasets and 0.93 in the testing datasets (The confidence interval reported from ROCKIT is [0.8799, 0.9591]). These encouraging results demonstrated that our detection algorithm can robustly and accurately identify renal calculi from CTC images.

8670-6, Session 2

Preliminary results of automated removal of degenerative joint disease in bone scan lesion segmentation

Gregory H. Chu, Pechin Lo, Martin Auerbach, Jonathan G. Goldin, Univ. of California, Los Angeles (United States); Keith Henkel, MedQIA (United States); Ashley Banola, Univ. of California, Los Angeles (United States); Darren Morris, MedQIA (United States); Heidi Coy, Matthew S. Brown, Univ. of California, Los Angeles (United States)

Whole-body bone scintigraphy (or bone scan) is a highly sensitive method for visualizing bone metastases and is the accepted standard imaging modality for detection of metastases and assessment of treatment outcomes. The development of a quantitative biomarker on bone scans for treatment response assessment may have a significant impact on the evaluation of novel oncologic drugs directed at bone metastases. An automated bone scan lesion segmentation system has been previously developed using intensity normalization and anatomy-specific thresholds. It was noted that false positives of the previous system were, in large part, due to high radiotracer uptake in degenerative joint disease (DJD), and manual removal of these areas can be time-consuming and subjective. On bone scans, DJD often manifests as areas of high intensity uptake that exhibits bilateral symmetry about the vertical midline of the patient. In this paper, we use a simple pattern recognition approach to identify and remove symmetric degenerative joint disease using features such as lesion area, intensity, and bilateral symmetry descriptors like the perpendicular distance from the lesion to the patient midline, and the projectional distance from the top of the midline to the point of perpendicular intersection. Training examples are provided by a joint reading session by two physicians in a set of 45 whole body bone scans. We compare the overlap ratio of anatomy-specific thresholding only to anatomy-specific thresholding plus degenerative joint disease removal. Anterior (AP) scans and posterior (PA) scans are evaluated separately. The results of a two-fold cross validation show that, although no statistically significant improvement in overlap ratio was found, the automated removal of DJD improved the overlap ratio in 68.9% of AP scans and 53.3% of PA scans.

8670-7, Session 2

Segmenting the thoracic, abdominal and pelvic musculature on CT scans combining atlas-based model and active contour model

Weidong Zhang, Jiamin Liu, Jianhua Yao, Ronald M. Summers, National Institutes of Health (United States)

Segmentation of the musculature is very important for accurate organ segmentation, analysis of body composition, and localization of tumors in the muscle. In research fields of computer assisted surgery and computer-aided diagnosis (CAD), muscle segmentation in CT images is a necessary pre-processing step. This task is particularly challenging due to the large variability in muscle structure and the overlap in intensity between muscle and internal organs. This problem has not been solved completely, especially for all of thoracic, abdominal and pelvic regions. We propose an automated system to segment the musculature on CT scans. The method combines an atlas-based model, an active contour model and prior segmentation of fat and bones. First, body contour, fat and bones are segmented using existing methods. Second, atlas-based models are pre-defined using anatomic knowledge at multiple key positions in the body to handle the large variability in muscle shape. Third, the atlas model is refined using active contour models (ACM) that are constrained using the pre-segmented bone and fat. Before refining using ACM, the initialized atlas model of next slice is updated using previous atlas. The muscle is segmented using threshold and smoothed in 3D volume space. Thoracic, abdominal and pelvic CT scans were used to evaluate our method, and five key position slices for each case were selected and manually labeled as the reference. Compared with the reference ground truth, the overlap ratio of true positives is 91.1%±3.5%, and that of false positives is 5.5%±4.2%.

8670-8, Session 2

Automated measurement of diagnostic angles for hip dysplasia

Sepp de Raedt, Inger Mechlenburg, Maiken Stilling, Lone Rømer, Kjeld Søballe, Aarhus Univ. Hospital (Denmark); Marleen de Bruijne, Erasmus MC (Netherlands) and Univ. of Copenhagen (Denmark)

A fully automatic method for measuring diagnostic angles of hip dysplasia is presented. The method consists of the automatic segmentation of CT images and detection of anatomical landmarks on the femur and acetabulum. The standard angles used in the diagnosis of hip dysplasia are subsequently automatically calculated.

Previous work in automating the measuring of angles required the manual segmentation or delineation of the articular joint surface. In the current work, a sheetness measure is used to detect the sheet-like structure of the bone surface and obtain an accurate segmentation using graph-cuts. The detection of the anatomical reference points is achieved using heuristics based on ray firing and the distance to the acetabulur joint surface.

Experiments using 26 patients, showed a good agreement with gold standard manual measurements by an expert radiologist as performed in daily practice. The average difference for the five angles was between ?1.1 and 2.0 degrees with a concordance correlation coefficient between 0.87 and 0.93.

The method can be used in clinical practice to replace the current manual measurements or as an aid to the radiologist. In the future, the method will be integrated into an intraoperative surgical guidance system.

8670-9, Session 2

Support vector machine classification supported by cross-correlation applied to bone age assessment

Daniel Haak, Markus Harmsen, Thomas M. Deserno, Benedikt Fischer, RWTH Aachen (Germany); Hauke Schramm, Fachhochschule Kiel (Germany); Thomas Seidl, RWTH Aachen (Germany)

Bone age assessment (BAA) on hand radiographs is a frequent and time consuming task in radiology. The bone age reflects the skeletal maturity and therefore indicates disease when differing significantly from the chronological age. Content-based image retrieval (CBIR) of epiphyseal regions extracted from the University of Southern California (USC) hand atlas has been presented by Fischer et al. Using all 19 patches of the query image, similar patches are retrieved from the database. The retrieval approach is based on the k nearest neighbor (kNN) method and BAA is calculated algebraically from a weighted sum of reference ages linked to the most similar patterns. An error rate of 0.97 years is reported. We now present a method for (semi)automatic BAA which is done in several steps: (i) extract 14 epiphyseal regions from the radiographs, (ii) for each region, retain image features, (iii) build a classifier model (training phase), (iv) evaluate performance on cross validation schemes (testing phase), (v) classify unknown hand images (application phase). We combine a support vector machine (SVM) with cross-correlation to a prototype patch for each class. These prototypes are selected randomly for each class. A systematic evaluation is presented comparing SVM with k nearest neighbor (kNN) classification on 1,097 images of 30 diagnostic classes using the University of Southern California (USC) hand atlas. Mean error in age prediction yields 1.0 years and 0.83 years for 5NN and SVM, respectively. SVM using prototypes clearly outperforms our previous CBIR-based results with a mean error of 0.97 years.

8670-10, Session 2

Cortical thickness estimation of the proximal femur from multi-view dual-energy X-ray absorptiometry (DXA)

Nikolaos Tsaousis, Andrew H. Gee, Graham M. Treece, Univ. of Cambridge (United Kingdom); Kenneth E. Poole, Univ. of Cambridge (United Kingdom)

Hip fracture is the leading cause of acute orthopaedic hospital admission amongst the elderly, with around a third of patients not surviving one year post-fracture. Although various preventative therapies are available, patient selection is difficult. The current state-of-the-art risk assessment tool (FRAX) ignores focal structural defects, such as cortical bone thinning, a critical component in characterizing hip fragility. Cortical thickness can be measured using CT, but this is expensive and involves a significant radiation dose. Instead, Dual-Energy X-ray Absorptiometry (DXA) is currently the preferred imaging modality for assessing hip fracture risk and is used routinely in clinical practice. Our ambition is to develop a tool to measure cortical thickness using multi-view DXA instead of CT. In this initial study, we work with digitally reconstructed radiographs (DRRs) derived from CT data as a surrogate for DXA scans: this enables us to directly compare the thickness estimates with the gold standard CT results. Our approach involves a model-based femoral shape reconstruction followed by a data-driven algorithm to extract numerous cortical thickness point estimates. In a series of experiments on the shaft and trochanteric regions of 48 proximal femurs, we validated our algorithm and established its performance limits using 20 views in the range 0-171 degrees: estimation errors were -0.21 +/- 0.70 mm (mean +/- one standard deviation). In a more clinically viable experimental setup using four views in the range 0-51 degrees where no other bony structures obstruct the projection of the femur, measurement errors where 0.10 +/- 1.07 mm.

8670-11, Session 2

Detection of vertebral degenerative disc disease based on cortical shell unwrapping

Hector E. Muñoz, Jianhua Yao, National Institutes of Health (United States); Joseph E. Burns, Univ. of California, Irvine (United States); Ronald M. Summers, National Institutes of Health (United States)

Degenerative disc disease (DDD) can be identified as hyperdense regions of bone and osseous spur formation in the spine that become more prevalent with age. These regions can act as confounding factors in the search for alternative hyperdense foci such as neoplastic processes. We created a preliminary CAD system that detects DDD in the spine on CT images. After the spine is segmented, the cortical shell of each vertebral body is unwrapped onto a 2D map. Candidates are detected from the 2D map based on their intensity and gradient. The 2D detections are remapped into 3D space and a levelset algorithm is applied to more fully segment the 3D lesions. Features generated from 2D unwrapped map and 3D segmentation are combined to train a support vector machine (SVM) classifier. The classifier was trained on 20 cases with DDD, which were marked by a radiologist. The pre-SVM program detected 164/193 ground truth lesions. Preliminary results showed 69.65% sensitivity with a 95% confidence interval of (64.47%, 73.92%), at an average of 9.8 false positives per patient.

8670-12, Session 3

Comparison of demons deformable registration-based methods for texture analysis of serial thoracic CT scans

Alexandra R. Cunliffe, Hania A. Al-Hallaq, The Univ. of Chicago Medical Ctr. (United States); Xianhan M. Fei, Univ. of Chicago Medical Ctr. (United States); Rachel E. Tuohy, Samuel G. Armato III, The Univ. of Chicago Medical Ctr. (United States)

To determine how image texture features may be altered by three image registration methods, “normal” baseline and follow-up computed tomography (CT) scans from 27 patients were analyzed. Nineteen texture feature values were calculated in over 1,000 32x32-pixel regions of interest (ROIs) randomly placed in the baseline scan. All three methods used demons registration to map baseline scan ROIs to anatomically matched locations in the corresponding transformed follow-up scan. For the first method, the follow-up scan transformation required subsampling to achieve a voxel size identical to that of the baseline scan. For the second method, the follow-up scan was transformed through affine registration to the baseline scan to achieve global alignment. For the third method, the follow-up scan was directly deformed to the baseline scan using demons deformable registration. Feature values in matched ROIs were compared using Bland-Altman 95% limits of agreement. For each feature, the range spanned by the 95% limits was normalized to the mean feature value to obtain the normalized range of agreement, nRoA. Wilcoxon signed-rank tests were used to compare nRoA values across features for the three methods. Significance for individual tests was adjusted using the Bonferroni method. nRoA was significantly smaller for affine-registered scans than for the resampled scans ($p=0.003$), indicating lower feature value variability between baseline and follow-up scan ROIs using this method. For both of these methods, however, nRoA was significantly higher than when feature values were calculated directly on demons-deformed follow-up scans ($p<0.001$). Across features and methods, nRoA values remained below 26%.

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8670-13, Session 3

Normalization of CT scans reconstructed with different kernels to reduce variability in emphysema measurements

Leticia Gallardo Estrella, Bram van Ginneken, Eva M. van Rikxoort, Radboud Univ. Nijmegen Medical Ctr. (Netherlands)

Chronic Obstructive Pulmonary Disease (COPD) is a lung disease characterized by progressive airflow limitation caused by emphysema and chronic bronchitis. Emphysema is quantified from chest computed tomography (CT) scans as the percentage of attentuation values below a fixed threshold. The emphysema quantification varies substantially between scans reconstructed with different kernels, limiting the possibilities to compare emphysema quantifications obtained from scans with different reconstruction parameters. In this paper we propose a method to normalize scans reconstructed with different kernels to have the same characteristics as scans reconstructed with a reference kernel and investigate if this normalization reduces the variability in emphysema quantification. The proposed normalization splits a CT scan into different frequency bands based on hierarchical unsharp masking. Normalization is performed by changing the energy in each frequency band to the average energy in each band in the reference kernel. A database of 15 subjects with COPD was constructed for this study. All subjects were scanned at total lung capacity and the scans were reconstructed with four different reconstruction kernels. The normalization was applied to all scans. Emphysema quantification was performed before and after normalization. It is shown that the emphysema score varies substantially before normalization but the variation diminishes after normalization.

8670-14, Session 3

Pulmonary emphysema classification based on an improved texton learning model by sparse representation

Min Zhang, Xiangrong Zhou, Gifu Univ. School of Medicine (Japan); Satoshi Goshima, Gifu Univ. Hospital (Japan); Chisako Muramatsu, Huayue Chen, Takeshi Hara, Gifu Univ. School of Medicine (Japan); Ryujiro Yokoyama, Masayuki Kanematsu, Gifu Univ. Hospital (Japan); Hiroshi Fujita, Gifu Univ. School of Medicine (Japan)

In this paper, we present to use a texture classification method based on texton learned via sparse representation with new feature histogram maps in the classification of emphysema. First, an overcomplete dictionary of textons is learned via K-SVD learning on each class image patches in the training dataset. In this stage, High pass filter is introduced to exclude patches in smooth area to speed up the dictionary learning process. Second, 3D joint SR coefficients and intensity histograms of the test images are used for characterizing regions of interest (ROI)s instead of conventional 2D histograms constructed from SR coefficients of the test images over the dictionary. Classification is then performed using a classifier with a histogram dissimilarity measure as distance. 470 annotated ROIs extracted from 14 test subjects, including 6 PSE subjects, 5 CLE subjects and 3 PLE subjects are used to evaluate the effectiveness and robustness of the proposed method. The test subjects, including 14 mild, moderate and severe emphysema with three different subtypes, are used to evaluate the effectiveness and robustness of the proposed method. The proposed method is tested on 167 PSE, 240 CLE and 63 PLE annotated regions of interest consisting of mild, moderate and severe pulmonary emphysema. The performance of the proposed system, with an accuracy of around 74%, 88% and 89% for PSE, CLE and PLE separately.

8670-15, Session 3

Normalization of chest radiographs

Rick Philipsen, Pragnya Maduskar, Laurens E. Hogeweg, Bram van Ginneken, Radboud Univ. Nijmegen Medical Ctr. (Netherlands)

The clinical use of computer-aided diagnosis (CAD) systems is increasing. A possible limitation of CAD systems is that they are typically trained on data from a small number of sources and as a result, they may not perform optimally on data from different sources. In particular for chest radiographs, it is known that acquisition settings, detector technology, proprietary post-processing and, in the case of analog images, digitization, can all influence the appearance and statistical properties of the image. In this work we investigate if a simple energy normalization procedure is sufficient to increase the robustness of CAD in chest radiography. We evaluate the performance of a supervised lung segmentation algorithm, trained with data from one type of machine, on twenty images each from five different sources. The results, expressed in terms of Jaccard index, increase from 0.530 +/- 0.290 to 0.914 +/- 0.041 when energy normalization is omitted or applied, respectively. We conclude that energy normalization is an effective way to make the performance of lung segmentation satisfactory on data from different sources.

8670-16, Session 3

Improved texture analysis for automatic detection of tuberculosis (TB) on chest radiographs with bone suppression images

Pragnya Maduskar, Laurens E. Hogeweg, Rick Philipsen, Steven Schalekamp, Bram van Ginneken, Radboud Univ. Nijmegen Medical Ctr. (Netherlands)

Computer aided detection (CAD) of tuberculosis (TB) on chest radiographs (CXR) is challenging due to overlapping structures. Suppression of normal structures can reduce overprojection effects and can enhance the appearance of diffuse parenchymal abnormalities. In this work, we compare two CAD systems to detect textural abnormalities in chest radiographs of TB suspects. One CAD system was trained and tested on the original CXR and the other CAD system was trained and tested on bone suppression images (BSI). BSI were created using a commercially available software (ClearRead 2.4, Riverain Medical). The CAD system is trained with 431 normal and 434 abnormal images with manually outlined abnormal regions. Subtlety rating (1-3) is assigned to each abnormal region, where 3 refers to obvious and 1 refers to subtle abnormalities. Performance is evaluated on normal and abnormal regions from an independent dataset of 900 images. These contain in total 454 normal and 1127 abnormal regions, which are divided into 3 subtlety categories containing 280, 527 and 320 abnormal regions respectively. For normal regions, original/BSI CAD has an average abnormality score of 0.094±0.027/0.085±0.032 ($p < 0.001$). For abnormal regions, subtlety 1, 2, 3 categories have average abnormality scores for original/BSI of 0.155±0.073/0.156±0.089 ($p = 0.73$), 0.194±0.086/0.207±0.101 ($p < 0.001$), 0.225±0.119/0.247±0.117 ($p < 0.001$) respectively. CAD prototype is benefited by BSI in terms of increased accuracy of abnormality probabilistic maps. We therefore conclude that the use of bone suppression results in slightly but significantly improved automated detection of textural abnormalities in chest radiographs.

8670-17, Session 4

A method for automatic matching of multi-timepoint findings for enhanced clinical workflow

Lakshminarasimhan Raghupathi, Dinesh M. Siddu, Pandu R.

Devarakota, Siemens Information Systems Ltd. (India); Gerardo Hermosillo Valadez, Matthias Wolf, Siemens Medical Solutions USA, Inc. (United States)

Non-interventional diagnostics (CT or MR) enables early identification of diseases like cancer. Often, lesion growth assessment done during follow-up is used to distinguish between benign and malignant ones. Correspondences need to be found for lesions localized at each time point. Manually matching the radiological findings can be time consuming as well as tedious due to possible differences in orientation and position between scans. Also, the complicated nature of the disease makes the physicians to rely on multiple modalities (PET-CT, PET-MR) where it is even more challenging. Here, we propose an automatic feature-based matching that is robust to change in organ volume, subpar or no registration that can be done with very less computations. Traditional matching methods rely mostly on accurate image registration and applying the resulting deformation map on the findings coordinates. This has disadvantages when accurate registration is time-consuming or may not be possible due to vast organ volume differences between scans. Our novel matching proposes supervised learning by taking advantage of the underlying CAD features that are already present and considering the matching as a classification problem. In addition, the matching can be done extremely fast and at reasonable accuracy even when the image registration fails for some reason. Preliminary results on real-world multi-time point thoracic CT data showed an accuracy of above 90% with negligible false positives.

8670-18, Session 4

Tracking time interval changes of pulmonary nodules on follow-up 3D CT images via image-based risk score of lung cancer

Yoshiki Kawata, Noboru Niki, Univ. of Tokushima (Japan); Hironobu Ohamatsu, Masahiro Kusumoto, Takaaki Tsuchida, National Cancer Ctr. Hospital East (Japan); Kenji Eguchi, Teikyo Univ. (Japan); Masahiro Kaneko,, Tokyo Health Service Association (Japan); Noriyuki Moriyama, National Cancer Ctr. (Japan)

In the recent release of positive results from the National Lung Screening Trial (NLST) in the US showing that CT screening does in fact have a positive impact on the reduction of lung cancer related mortality. While this study does show the efficacy of CT based screening, physicians often face the problem of deciding appropriate management strategies for maximizing patient survival and for preserving lung function. Distinguishing a subset of patients with less invasive nodules and a better prognosis remains a substantial and challenging problem. In this work, we present a computer-aided follow-up (CAF) scheme for helping physicians to track interval changes of pulmonary nodules on three dimensional (3D) CT images and to decide the treatment strategies without making any under or over treatment. The elucidation of the subcategorization of a pulmonary nodule type in CT images is an important preliminary step towards developing the nodule management that are specific to each patient. We focus on analyzing CT histograms to evaluate the volumetric distribution of CT values within pulmonary nodules. In this scheme, we compute image-based risk score for predicting the likelihood of lung cancer with poor prognosis and then track the time interval changes of pulmonary nodules on a feature space spanned by the image-based risk score and nodule size. Through applying our scheme to follow-up 3D CT images of pulmonary nodules, we demonstrate the potential usefulness of the CAF scheme which can provide the trajectories that can characterize time interval changes of benign and malignant nodules.

8670-19, Session 4

Measurement of spiculation index in 3D for solitary pulmonary nodules in volumetric lung CT images

Ashis K. Dhara, Sudipta Mukhopadhyay, Indian Institute of Technology Kharagpur (India); Niranjan Khandelwal, Postgraduate Institute of Medical Education & Research (India)

In this paper a differential geometry based method is proposed for calculating surface spiculation of solitary pulmonary nodule (SPN) in 3D from lung CT images. Spiculation present in SPN is an important shape feature to assist radiologists for measurement of malignancy. Performance of Computer Aided Diagnostic (CAD) system depends on the accurate estimation of feature like spiculation. In the proposed method, the peak of the spicules is identified using the property of Gaussian and mean curvature calculated at each surface point on segmented SPN. Once the peak point for a particular SPN is identified, the nearest valley points for the corresponding peak point are determined. The area of cross-section of the plane passing through the valley points is the base of that spicule. The solid angle subtended by the base of spicule at peak point and the distance of peak point from nodule base are taken as the measures of spiculation. The spiculation index (SI) for a particular SPN is the weighted combination of all the spicules present in that SPN. The proposed method is validated on 95 SPN from Imaging Database Resources Initiative (IDRI) public database. It has achieved 87.4% accuracy in calculating quantified spiculation index compared to the spiculation index provided by radiologists in IDRI database.

8670-20, Session 4

Robust airway extraction based on machine learning and minimum spanning tree

Tsutomu Inoue, Yoshiro Kitamura, Yuanzhong Li, Wataru Ito, FUJIFILM Corp. (Japan)

Because conventional airway extraction methods often fail to extract peripheral airways with low image contrast, Virtual Bronchoscopy has become widely used only for the evaluation of proximal airway diseases. Aiming to expand applications of Virtual Bronchoscopy, our purpose is to propose a novel method which can extract both proximal and peripheral airways robustly.

8670-21, Session 5

Automatic age-related macular degeneration detection and staging

Mark J.J. P. van Grinsven, Yara T. E. Lechanteur, Johannes P. H. van de Ven, Bram van Ginneken, Thomas Theelen, Clara I. Sánchez, Radboud Univ. Nijmegen Medical Ctr. (Netherlands)

Age-related macular degeneration (AMD) is a degenerative disorder of the central parts of the retina, which mainly affects older people and leads to permanent loss of vision in advanced stages of the disease. AMD grading of non-advanced AMD patients allows risk assessment for the development of advanced AMD and enables timely treatment of patients, to prevent vision loss. AMD grading is currently performed manually on color fundus images, which is time consuming and expensive. In this paper, we propose a supervised classification method to distinguish high risk AMD patients from low risk AMD patients and provide an exact AMD stage determination. The method is based on the analysis of the number and size of drusen on color fundus images, as drusen are the early characteristics of AMD. An automatic drusen detection algorithm is used to detect all drusen. A weighted histogram of the detected drusen is constructed to summarize the drusen extension and size and fed into

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a random forest classifier in order to separate low risk from high risk patients and to allow exact AMD stage determination. Experiments show the proposed method achieved similar performance as human observers in distinguishing low risk from high risk AMD patients, obtaining areas under the Receiver Operating Characteristic curve of 0.929 and 0.934. A weighted kappa agreement of 0.641 and 0.622 versus two observers were obtained for AMD stage evaluation. Our method allows for quick and reliable AMD staging at low costs.

8670-22, Session 5

Automated detection of microaneurysms using robust blob descriptors

Kedir M. Adal, Sharib Ali, Désiré Sidibé, Univ. de Bourgogne (France); Thomas P. Karnowski, Oak Ridge National Lab. (United States); Fabrice Meriaudeau, Univ. de Bourgogne (France); Edward Chaum, University of Tennessee Health Science Center (UTHSC) (United States)

Microaneurysms (MAs) are among the first signs of diabetic retinopathy (DR) that can be seen as round dark-red structures in digital color fundus photographs of retina. In recent years, automated computer-aided detection and diagnosis (CAD) of MAs has attracted many researchers due to its low-cost and versatile nature. However, the variations in size, shape, intensity of MAs, together with the presence of other retina vascular structures makes the design of CAD systems very challenging. In this paper, the MA detection problem is modeled as finding interest points from a given image and several interest point descriptors are introduced and integrated with machine learning techniques to detect MAs. The proposed approach starts by applying a novel fundus image contrast enhancement technique using Singular Value Decomposition (SVD) of fundus images. Then, Hessian-based candidate selection algorithm is applied to extract image regions which are more likely to be MAs. For each candidate region, robust low-level blob descriptors such as SURF (Speeded Up Robust Features) are extracted. Moreover, features extracted from Intensity Normalized Radon Transform are added with SURF descriptors in order to further characterize candidate MA regions. The combined features are classified using SVM which has been trained using manually annotated training images. The performance of the overall system is evaluated on Retinopathy Online Challenge (ROC) competition database. Preliminary results show the competitiveness of the proposed candidate selection techniques against state-of-the art methods as well as the promising future for the proposed descriptors to be used in the localization of MAs from fundus images.

8670-23, Session 5

Changes in quantitative 3D shape features of the optic nerve head associated with age

Mark A. Christopher, Li Tang, The Univ. of Iowa Hospitals and Clinics (United States); John H Fingert, University of Iowa (United States); Todd E. Scheetz, The Univ. of Iowa (United States); Michael D. Abramoff, The Univ. of Iowa Hospitals and Clinics (United States)

Optic nerve head (ONH) morphology is an important biological feature of the eye used by clinicians to diagnosis and monitor to the progression of diseases such as glaucoma. ONH morphology is commonly examined using stereo fundoscopy. This modality provides stereo image pairs of the ONH that retain 3D information useful for characterizing morphology. In order to extract the information describing ONH morphology, we applied a stereo correspondence algorithm to a set stereo fundus images. Using this ONH morphology data, quantitative 3D ONH shape features were derived using principal component analysis from stereo images of 200 subjects from the Ocular Hypertension Treatment Study (OHTS) varying in age from 40 to 73 years. Using regression analysis, several of these features were found to have a significant ($p < 0.05$) association with age. In addition, a classifier was constructed to predict age based solely on the significant 3D ONH shape features. This classifier achieved an area under receiver operating characteristic curve of 0.842 in predicting a binary age variable. The use of objective, quantitative features revealed hidden relationships between ONH morphology and age. The use of these features could similarly allow specific aspects of ONH morphology to be isolated and associated with glaucoma, disease progression and outcomes, and genetic factors.

8670-24, Session 5

Automated retinal vessel type classification in color fundus images

Honggang Yu, Eduardo S. Barriga, VisionQuest Biomedical, LLC (United States); Carla P. Agurto Rios, The Univ. of New Mexico (United States); Sheila Nemeth, Visionquest Biomedical LLC (United States); Wendall Bauman, Retina Institute of South Texas (United States); Peter Soliz, VisionQuest Biomedical, LLC (United States)

Automated retinal vessel type classification is an essential first step toward machine-based quantitative measurement of various vessel topological parameters and identifying vessel abnormalities and changes for cardiovascular disease risk analysis. This paper presents a new and accurate automatic artery and vein classification method developed for arteriolar-to-venular width ratio (AVR) and vessel tortuosity measurements. This method applies illumination normalization, automated retinal vessel segmentation, and a partial least squares (PLS) classifier. The PLS classifier uses normalized color information, color variation and multi-scale morphological features extracted from multiple color spaces. We trained and tested the algorithm on a set of 93 color fundus images using manually defined arteries and veins as the reference standard. The proposed method achieved an area under the ROC curve (AUC) of 93.5%. The proposed methodology outperforms the start-of-art unsupervised and supervised classification methods which were applied on the same region of interest in retinal images.

8670-25, Session 5

Retrieving clinically relevant diabetic retinopathy images using a multi-class multiple-instance framework

Parag S. Chandakkar, Ragav Venkatesan, Baoxin Li, Arizona State Univ. (United States)

Diabetic retinopathy (DR) is a vision-threatening complication that arises due to prolonged presence of diabetes. When detected and diagnosed at early stages, the effect of DR on vision can be greatly reduced. Content-based image retrieval can be employed to provide a clinician with instant references to archival and standardized images that are clinically relevant to the image under diagnosis. This is an innovative way of utilizing the vast expert knowledge hidden in archives of previously diagnosed fundus camera images that helps an ophthalmologist in improving the performance of diagnosis. In this paper, with a focus on two significant DR clinical findings, namely, microaneurysm and neovascularization, the authors propose a multi-class multiple-instance image retrieval framework that makes use of a modified color correlogram and statistics of steerable Gaussian Filter responses for retrieving clinically relevant images from a database. Experiments are performed using fundus camera images and the results compared with other prior-art methods demonstrate the improved performance of the proposed approach.

8670-27, Session 6

Classification of Alzheimer's disease using regional saliency maps from brain MR volumes

Andrea Marcella Pulido, Univ. Nacional de Colombia (Colombia); Andrea Rueda Olarte, Universidad Nacional de Colombia (Colombia); Eduardo Romero Castro, Univ. Nacional de Colombia (Colombia)

Accurate diagnosis of Alzheimer's disease (AD) from structural Magnetic Resonance (MR) images is difficult due to the complex alteration of patterns in brain anatomy that could indicate the presence or absence of the pathology. Currently, an effective approach that allows to interpret the disease in terms of global and local changes is not available in the clinical practice. In this paper, we propose an approach for classification of brain MR images, based on finding pathology-related patterns through the identification of regional structural changes. The approach combines a probabilistic Latent Semantic Analysis (pLSA) technique, which allows to identify image regions through latent topics inferred from the brain MR slices, with a bottom-up Graph-Based Visual Saliency (GBVS) model, which calculates maps of relevant information per region. Regional saliency maps are finally combined into a single map on each slice, obtaining a master saliency map of each brain volume. The proposed approach includes a one-to-one comparison of the saliency maps which feeds a Support Vector Machine (SVM) classifier, to group test subjects into normal or probable AD subjects. A set of 56 brain MR images from healthy (28) and pathological (28) subjects, splitted into a training set (20 non-demented and 20 demented subjects) and one testing set (16 subjects), was used to evaluate the performance of the proposed approach. Preliminary results show that the proposed method reaches a classification accuracy of 68.75%

8670-28, Session 6

Improved multimodal biomarkers for Alzheimer's disease and mild cognitive impairment diagnosis - data from ADNI

Antonio Martínez-Torteya, Víctor M. Treviño-Alvarado, José G. Tamez-Peña, Tecnológico de Monterrey (Mexico)

An accurate diagnosis of Alzheimer's disease (AD) and mild cognitive impairment (MCI) confers many benefits. Studies have shown that multimodal biomarkers provide better diagnosis accuracy of AD and MCI than unimodal biomarkers. Nevertheless, proposed biomarkers have been constructed from unimodal approaches. The objective of this work was to obtain improved AD and MCI diagnostic biomarkers, unbiasedly exploring multimodal combinations of features using machine learning techniques. Data was obtained from the ADNI database, and all available baseline information (e.g. MRI analyses, PET analyses and laboratory essays) from AD, MCI and healthy control (HC) subjects with available diagnosis up to June 2012 was obtained. After preprocessing, 47 HC, 83 MCI and 43 AD subjects were used. The database contained more than 980 features. A feature selection strategy based on genetic algorithms was used to obtain compact and accurate biomarkers based on simple nearest centroid classifiers trained in a cross-validation manner. The biomarkers for HC vs. AD, HC vs. MCI and MCI vs. AD achieved accuracies in the train subjects of 0.983, 0.871 and 0.917, and an AUROC of 0.994, 0.882 and 0.922, respectively. The proposed biomarkers were compact, having only 8, 11 and 5 features. Those models included several widely accepted biomarkers and novel image and biochemical features. Multimodal biomarkers constructed unbiasedly from variables with both strong and subtle AD associations had better performance than those based solely on strongly AD associated features.

8670-29, Session 7

Effect of CADe on radiologists' performance in detection of "difficult" polyps in CT colonography

Kenji Suzuki, The Univ. of Chicago (United States); Masatoshi Hori, Osaka Univ. (Japan); Gen Iinuma, National Cancer Ctr. (Japan); Abraham H. Dachman, The Univ. of Chicago (United States)

To investigate the actual usefulness of computer-aided detection (CADe) of polyps as a second reader, we conducted a free-response observer performance study with radiologists in the detection of "difficult" polyps in CT colonography (CTC) from a multicenter clinical trial. The "difficult" polyps were defined as the ones that had been "missed" by radiologists in the clinical trial or rated "difficult" in our retrospective review. Our advanced CADe scheme utilizing massive-training artificial neural networks (MTANNs) technology was sensitive and specific to the "difficult" polyps. Four board-certified abdominal radiologists including 3 CTC experts participated in this observer study. They were instructed, first without and then with our CADe, to indicate the location of polyps and their confidence level regarding the presence of polyps. Our CADe scheme achieved a sensitivity of 74% with 3.1 false positives (FPs) per patient for an observer study database containing 20 patients with 23 polyps including 14 false-negative (FN) and 7 "difficult" polyps and 10 negative patients. With CADe, the average by-polyp sensitivity of radiologists was improved from 53% (47% for polyps 6-9 mm; 66% for polyps > 10 mm) to 63% (60% for polyps 6-9 mm; 69% for polyps > 10 mm) at a statistically significant level (P=0.037). The PPV was also improved from 57% to 67% with CADe (P=0.098). Thus, our CADe scheme utilizing the MTANN technology improved the diagnostic performance of radiologists, including expert readers, in the detection of "difficult" polyps in CTC.

8670-30, Session 7

Computer-aided detection of early cancer in the esophagus using HD endoscopy images

Fons van der Sommen, Svitlana Zinger, Technische Univ. Eindhoven (Netherlands); Erik J. Schoon, Catharina-ziekenhuis (Netherlands); Peter H. N. de With, Technische Univ. Eindhoven (Netherlands)

Esophageal cancer is the fastest rising type of cancer in the Western world. The recent development of High Definition (HD) endoscopy has enabled the specialist physician to identify cancer at an early stage. Nevertheless, it still requires considerable effort and training to be able to recognize these irregularities associated with early cancer. As a first step towards a Computer-Aided Detection (CAD) system that aids the physician in finding these early stages of cancer, we propose an algorithm that is able to identify irregularities in the esophagus automatically, based on HD endoscopic images. The concept is based on tile-based processing, so our system is not only able to identify that an endoscopic image contains early cancer, but it can also locate it. The identification is based on the following steps: (1) pre-processing, (2) feature extraction with dimensionality reduction, (3) classification. We evaluate the performance in RGB, HSI and YCbCr color space using the Color Histogram (CH) and Gabor features for the detection of tumors and early stage cancer. For classification, we employ a Support Vector Machine (SVM) and evaluate its performance using different parameters and kernel functions. Our experiments and clinical validation of the results show that our approach is promising for a CAD system that aids the physician in finding early stage cancer. Our system achieves a classification accuracy 95.9% on 50x50 pixel tiles of tumorous and normal tissue and reaches an Area Under the Curve (AUC) of 0.990.

8670-31, Session 7

Low-dose dual-energy electronic cleansing for fecal-tagging CT Colonography

Wenli Cai, Da Zhang, June-Goo Lee, Hiroyuki Yoshida, Massachusetts General Hospital (United States)

Dual-energy electronic cleansing (DE-EC) provides a promising means for cleansing the tagged fecal materials in fecal-tagging CT colonography (CTC). However, the increased radiation dose due to the double exposures in dual-energy CTC (DE-CTC) scanning is a major limitation for the use of DE-EC in clinical practice. The purpose of this study was to develop and evaluate a low-dose DE-EC scheme in fecal-tagging DE-CTC.

In this study, a custom-made anthropomorphic colon phantom, which was filled with simulated tagged materials by non-ionic iodinated contrast agent (Omnipaque iohexol, GE Healthcare, Milwaukee, WI), was scanned by a dual-source CT scanner (SOMATON Definition Flash) at two photon energies: 80 kVp and 140 kVp with nine different tube current settings ranging from 12 to 74 mAs for 140 kVp, and then reconstructed by soft-tissue reconstruction kernel (B30f). The DE-CTC images were subjected to a low-dose DE-EC scheme. First, our image-space DE-CTC denoising filter was applied for reduction of image noise. Then, the noise-reduced images were processed by a virtual lumen tagging method for reduction of partial volume effect and tagging inhomogeneity. The results were compared with the registered CTC images of native phantom without fillings.

Preliminary results showed that our low-dose DE-EC scheme achieved the cleansing ratios, defined by the proportion of the cleansed voxels in the tagging mask, between 95.16% (12 mAs) and 95.38% (74 mAs). Also, the soft-tissue preservation ratios, defined by the proportion of the persevered voxels in the soft-tissue mask, were maintained in the range between 96.11% and 97.18%.

8670-32, Session 7

Blood vessel-based liver segmentation through the portal phase of a CT dataset

Ahmed S. Maklad, Mikio Matsuhiro, Hidenobu Suzuki, Yoshiki Kawata, Noboru Niki, Tohru Utsunomiya, Mitsuo Shimada, Noriyuki Moriyama, Univ. of Tokushima (Japan)

Blood vessels are dispersed throughout the human body organs and carry unique information for each person. This information can be used to delineate organ boundaries. The proposed method relies on abdominal blood vessels (ABV) to segment the liver considering the potential presence of tumors through the portal phase of a CT dataset. ABV are extracted and classified into hepatic (HBV) and nonhepatic (non-HBV) with a small number of interactions. HBV and non-HBV are used to guide an automatic segmentation of liver. HBV are used to individually segment the core region of the liver. This region and non-HBV are used to construct a boundary surface between liver and other organs to separate them. The core region is classified based on extracted posterior distributions of its histogram into low intensity tumor (LIT) and non-LIT core regions. Non-LIT case includes normal part of liver, HBV, and high intensity tumors if any. Each core region is extended based on its corresponding posterior distribution. Extension is completed when it reaches either a variation in intensity or the constructed boundary surface. The method was applied to 80 datasets (30 Medical Image Computing and Computer Assisted Intervention (MICCAI) and 50 non-MICCAI data) including 60 datasets with tumors. Our results for MICCAI-test data were evaluated by sliver07 [1] with an overall score of 79.6, which ranks sixth best on the site. Results from our approach are very promising. It seems a promising method for segmenting livers of various shapes and sizes and low intensity hepatic tumors as well.

8670-33, Session 7

Image patch-based method for automated detection of focal liver lesions on CT

Hayit Greenspan, Tel Aviv Univ. (Israel); Raghav Pasari, Daniel Rubin, Stanford Univ. (United States)

We developed a method for automated detection of liver lesions in CT images based on image patch representation and bag-of-visual-words (BoVW). BoVW analysis has been extensively used in the computer vision domain to analyze scenery images. In the current work we focus on utilizing it for liver lesion detection. The methodology includes building a dictionary for a training set using local descriptors and representing a region (scan window) in the image using a visual word histogram. Classification of a scan window to normal liver or a lesion is performed using a Support vector machine (SVM) classifier, and the overall classification of a scan window is based on the vote of its constituent patches.

Data: 73 abdominal CT images; total of 159 liver lesions (60 cysts, 74 metastasis, 25 hemangiomas). In each image, a radiologist drew ROIs around each liver lesion and two regions of normal liver, and demarcated the liver boundary. Results: F1 is 0.76. Recall is 84%, with precision of 73%. Results show the ability to detect lesions, even very distorted in shape. Missed lesions are usually very small lesions. Most of the false-positives include scan windows at the boundary of a lesion; i.e the scan window itself was not correctly classified as a lesion, but in fact a lesion was present at a nearby location and this lesion was found (correctly) by windows that were more overlapping with it. Additional results will be provided, on a larger dataset, with a focus on the lesion detection accuracy.

8670-34, Session 8

Visual analysis of longitudinal brain tumor perfusion

Sylvia Glaßer, Steffen Oeltze, Otto-von-Guericke Univ. Magdeburg (Germany); Uta Preim, Univ. Hospital Magdeburg (Germany); Atle Bjornerud, The Norwegian Radium Hospital (Norway) and Univ. of Oslo (Norway); Helwig Hauser, Univ. of Bergen (Norway); Bernhard Preim, Otto-von-Guericke-Univ. Magdeburg (Germany)

In clinical research on diagnosis and evaluation of brain tumors, longitudinal perfusion MRI studies are acquired for tumor grading as well as to monitor and assess treatment response and patient prognosis. Within this work, we demonstrate how visual analysis techniques can be adapted to multidimensional datasets from such studies within a framework to support the computer-aided diagnosis of brain tumors. Our solution builds on two innovations: First, we introduce a pipeline yielding comparative, co-registered quantitative perfusion parameter maps over all time steps of the longitudinal study. Second, based on these time-dependent parameter maps, visual analysis methods were developed and adapted to reveal valuable insight into tumor progression, especially regarding the clinical research area of low grade glioma transformation into high grade gliomas. Our examination of four longitudinal brain studies demonstrates the suitability of the presented visual analysis methods and comprises new possibilities for the clinical researcher to characterize the development of low grade gliomas.

8670-35, Session 8

Differentiating cerebral lymphomas and GBMs featuring luminance distribution analysis

Toshihiko Yamasaki, Tsuhan Chen, Cornell Univ. (United States);

Toshinori Hirai, Ryuji Murakami, Kumamoto Univ. (Japan)

Differentiating lymphomas and glioblastoma multiformes (GBMs) is important for proper treatment planning. A number of works have been proposed but there are still some problems. For example, many works depend on thresholding a single feature value, which is susceptible to noise. Non-typical cases that do not get along with such simple thresholding can be found easily. In other cases, experienced observers are required to extract the parameters, which is costly. And even if experts are involved, inter-observer variance becomes another problem. In addition, most of the works use only one or a few slice(s) because 3D tumor segmentation is difficult and time-consuming.

In this paper, we propose a tumor classification system that analyzes the luminance distribution of the whole tumor region. The 3D MRIs are segmented within a few tens of seconds by using our fast 3D segmentation algorithm. Then, the luminance histogram of the whole tumor region is generated. The typical cases are classified using the histogram range thresholding. The non-typical cases are learned and classified by a support vector machine (SVM). The whole pipeline is semi-automatic. Therefore, even novice users can use the system easily and get the same results as experts.

The experiments were conducted using 40 MRI datasets (20 lymphomas and 20 GBMs) with non-typical cases. The classification accuracy of the proposed method was 91.1% and it was improved up to 95.4% when the algorithm was combined with apparent diffusion coefficients (ADC) thresholding. On the other hand, the conventional ADC thresholding yielded only 67.5% accuracy.

8670-36, Session 8

Assessment of quantitative cortical biomarkers in the developing brain of preterm infants

Pim Moeskops, Manon J. N. L. Benders M.D., Paul C. Pearlman, Karina J. Kersbergen, Alexander Leemans, Max A. Viergever, Ivana Isgum, Univ. Medical Ctr. Utrecht (Netherlands)

The cerebral cortex rapidly develops its folds during the second and third trimester of pregnancy. In preterm birth, this growth might be disrupted and influence neurodevelopment. The aim of this work is to extract quantitative biomarkers describing the cortex and evaluate them on a set of preterm infants without brain pathology.

For this study, a set of 19 preterm - but otherwise healthy - infants scanned coronally with 3T MRI after 30 gestational weeks were selected. In ten patients (test set), the gray and white matter were manually annotated by an expert on the T2-weighted scans. Manual segmentations were used to extract cortical volume, surface area, thickness, and curvature using voxel-based methods. To compute these biomarkers per region in every patient, a template brain image has been generated by iterative registration and averaging of the scans of the remaining nine patients. This template has been manually divided in eight regions, and is transformed to every test image using elastic registration.

In the results, gray and white matter volumes and cortical surface area appear symmetric between hemispheres, but small regional differences are visible. Cortical thickness seems slightly higher in the right parietal lobe than in other regions. The parietal lobes exhibit a higher global curvature, indicating more complex folding compared to other regions.

The proposed approach can potentially - together with an automatic segmentation algorithm - be applied as a tool to assist in early diagnosis of abnormalities and prediction of the development of the cognitive abilities of these children.

8670-37, Session 8

Computer-aided diagnosis of acute ischemic stroke based on cerebral hypoperfusion using 4D CT angiography

Jean-Paul Charbonnier, Image Sciences Institute (Netherlands); Ewoud J. Smit, Univ. Medical Ctr. Utrecht (Netherlands); Max A. Viergever, Image Sciences Institute (Netherlands); Birgitta K. Velthuis, Univ. Medical Ctr. Utrecht (Netherlands); Pieter C. Vos, Image Sciences Institute (Netherlands)

The presence of collateral blood flow is found to be a strong predictor of patient outcome after acute ischemic stroke. Collateral blood flow is defined as an alternative way to provide oxygenated blood to ischemic cerebral tissue. Assessment of collateral blood supply is currently performed by visual inspection of a Computed Tomography Angiogram (CTA) which introduces inter-observer variability and depends on the grading scale. Furthermore, variations in the arterial contrast arrival time may lead to underestimation of collateral blood supply in a CTA which exerts a negative influence on the prediction of patient outcome. In this study, the feasibility of a Computer-aided Diagnosis system is investigated capable of objectively predicting patient outcome. We present a novel automatic method for quantitative assessment of cerebral hypoperfusion in timing-invariant (i.e. delay insensitive) CTA (TI-CTA). The proposed Vessel Density Symmetry algorithm automatically generates descriptive maps based on hemispheric asymmetry of blood vessels. Intensity and symmetry based features are extracted from these descriptive maps and subjected to a best-first-search feature selection. Linear Discriminant Analysis is performed to combine selected features into a likelihood of good patient outcome. Receiver operating characteristic (ROC) analysis is conducted to evaluate the diagnostic performance of the CAD by leave-one-patient-out cross validation. A Positive Predicting Value of 1 was obtained at a sensitivity of 25% with an area under the ROC-curve of 0.86. The results show that the CAD is feasible to objectively predict patient outcome. The presented CAD could make an important contribution to acute ischemic stroke diagnosis and treatment.

8670-38, Session 8

Automatic detection and segmentation of ischemic lesions in computed tomography images of stroke patients

Pieter C. Vos, Image Sciences Institute, Univ. Medical Ctr. Utrecht (Netherlands); J. Matthijs Biesbroek, Nick A. Weaver, Birgitta K. Velthuis, Univ. Medical Ctr. Utrecht (Netherlands); Max A. Viergever, Image Sciences Institute, Univ. Medical Ctr. Utrecht (Netherlands)

Stroke is the third most common cause of death in developed countries. Clinical trials are currently investigating whether advanced Computed Tomography can be of benefit for diagnosing stroke at the acute phase.

These trials are based on large patients cohorts that need to be manually annotated to obtain a reference standard of tissue loss at follow-up, resulting in extensive workload for the radiologists.

Therefore, there is a demand for accurate and reliable automatic lesion segmentation methods.

This paper presents a novel method for the automatic detection and segmentation of ischemic lesions in CT images. The method consists of multiple sequential stages.

In the initial stage, pixel classification is performed using a naive Bayes classifier in combination with a tissue homogeneity algorithm in order to localize ischemic lesion candidates. In the next stage, the candidates are segmented using a marching cubes algorithm. Regional statistical

analysis is used to extract features based on local information as well as contextual information from the contra-lateral hemisphere. Finally,

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the extracted features are summarized into a likelihood of ischemia by a supervised classifier.

An area under the Receiver Operating Characteristic curve of 0.91 was obtained for the identification of ischemic lesions. The method performance on lesion segmentation reached a Dice similarity coefficient (DSC) of 0.74 +/- 0.09, whereas an independent human observer obtained a DSC of 0.79 +/- 0.11 in the same dataset.

The experiments showed that it is feasible to automatically detect and segment ischemic lesions in CT images, obtaining a comparable performance as human observers.

8670-39, Session 8

Detection of white matter lesions in cerebral small vessel disease

Medhat M. Riad, Radboud Univ. Nijmegen Medical Ctr. (Netherlands); Bram Platel, Fraunhofer MEVIS (Germany); Frank-Erik de Leeuw, Nico Karssemeijer, Radboud Univ. Nijmegen Medical Ctr. (Netherlands)

White matter lesions (WML) are diffuse white matter abnormalities commonly found in older subjects and are important indicators of stroke, multiple sclerosis, dementia and other disorders. We present an automated WML detection method and evaluate it on a dataset of small vessel disease (SVD) patients. In early SVD, small WMLs are expected to be of importance for the prediction of disease progression. Commonly used WML segmentation methods tend to ignore small WMLs and are mostly validated on the basis of total lesion load or a Dice coefficient for all detected WMLs. Therefore, in this paper, we present a method that is designed to detect individual lesions, large or small, and we validate the detection performance of our system with FROC (free-response ROC) analysis. For the automated detection, we use supervised classification making use of multimodal voxel based features from different magnetic resonance imaging (MRI) sequences, including volume intensities, tissue probabilities, voxel locations and distances, neighborhood textures and others. After preprocessing, including coregistration, brain extraction, bias correction, intensity normalization, and non-linear registration, ventricle segmentation is performed and features are calculated for each brain voxel. A gentle-boost classifier is trained using these features from 50 manually annotated subjects to give each voxel a probability of being a lesion voxel. We perform ROC analysis to illustrate the benefits of using additional features to the commonly used voxel intensities; significantly increasing the area under the curve (Az) from 0.81 to 0.96 ($p<0.05$). We perform the FROC analysis by testing our classifier on 50 previously unseen subjects and compare the results with manual annotations performed by two experts. Using the first annotator results as our reference, the second annotator performs at a sensitivity of 0.90 with an average of 41 false positives per subject while our automated method reached the same level of sensitivity at approximately 180 false positives per subject.

8670-40, Session 9

Automatic stent strut detection in intravascular OCT images using image processing and classification technique

Hong Lu, Madhusudhana Gargesha, Zhao Wang, Case Western Reserve Univ. (United States); Daniel Chamie, Guilherme F. Attizani, Tomoaki Kanaya, Univ. Hospitals of Cleveland (United States); Soumya Ray, Case Western Reserve Univ. (United States); Marco A. Costa, Univ. Hospitals of Cleveland (United States); Andrew M. Rollins, Case Western Reserve Univ. (United States); Hiram G. Bezerra, Univ. Hospitals of Cleveland (United States); David L. Wilson, Case Western Reserve Univ. (United States)

Intravascular OCT (iOCT) is the lone imaging modality with the resolution and contrast to provide in vivo assessments of tissue healing following stent implantation. Our Cardiovascular Imaging Core Laboratory has served >20 international stent clinical trials with >2000 stents analyzed. Each stent requires 6-16hrs of manual analysis time, and we are developing highly automated software to reduce this extreme effort. Using classification technique, physically meaningful image features, forward feature selection to limit overtraining, and leave-one-stent-out cross validation, we detected stent struts. To determine tissue coverage areas, we estimated stent “contours” by fitting detected struts and interpolation points from linearly interpolated tissue depths to a periodic cubic spline. Tissue coverage area was obtained by subtracting lumen area from the stent area. Detection was compared against manual analysis of 508 images and 4392 struts. We obtained good (baseline: recall=90±3%, precision=91±3%; follow-up: recall=94±1%, precision=85±6%) stent strut detection. This approached inter-observer variability (recall=93%, precision=96%). Observers are biased to not analyze every strut, leading to false positives (FPs) and underestimated precision of the algorithm. Differences in stent and tissue coverage areas are 0.12 ± 0.20 mm2 and 0.11 ± 0.20 mm2, respectively. The coefficient of variation (std/mean) is 3% and 14% for stent and tissue coverage areas, respectively. We are developing software which will enable visualization, review, and editing of automated results, so as to provide a comprehensive stent analysis package. This should enable better and cheaper stent clinical trials, so that manufacturers can optimize the myriad of parameters (drug, coverage, bioresorbable versus metal, etc.) for stent design.

8670-41, Session 9

Computerized detection of non-calcified plaques in coronary CT angiography: topological soft-gradient detection method for plaque prescreening

Jun Wei, Chuan Zhou, Heang-Ping Chan, Aamer R. Chughtai, Smita Patel, Prachi Agarwal, Jean W. Kuriakose, Lubomir M. Hadjiiski, Ella A. Kazerooni, Univ. of Michigan Health System (United States)

Non-calcified plaque (NCP) detection in coronary CT angiography (cCTA) is challenging due to the low CT number of NCP, the large number of coronary arteries and multiple phase CT acquisition. We are developing computer-vision methods for automated detection of NCPs in cCTA. A data set of 62 cCTA scans with 87 NCPs was collected retrospectively from patient files. Multiscale coronary vessel enhancement and rolling balloon tracking were first applied to each cCTA volume to extract the coronary artery trees. Each extracted vessel was multiplanar-reformatted to a straightened volume composed of cCTA slices perpendicular to the vessel centerline. A new topological soft-gradient (TSG) detection method was developed to prescreen for both positive and negative remodeling candidates by analyzing the 2D topological features of the radial gradient field surface along the vessel wall. Nineteen features were designed to describe the relative location along the coronary artery, shape, distribution of CT values, and radial gradients of each NCP candidate. With a machine learning algorithm and a two-loop leave-one-case-out training and testing resampling method, useful features were selected and combined into an NCP likelihood measure to differentiate TPs from FPs. The detection performance was evaluated by FROC analysis. Our TSG method achieved a sensitivity of 96.6% with 35.4 FPs/scan at prescreening. Classification with the NCP likelihood measure reduced the FP rates to 13.1, 10.0 and 6.7 FPs/scan at sensitivities of 90%, 80%, and 70%, respectively. These results demonstrated that the new TSG method is useful for computerized detection of NCPs in cCTA.

8670-42, Session 9

Computer-aided scheme for functional index computation of left ventricle in cardiac CTA: segmentation and partitioning of left ventricle

Hui Huang, Xiahai Zhuang, Yi Shao, Tian Lan, Liu Liu, Qiang Li, Shanghai Advanced Research Institute (China)

Functional indices of the left ventricle of the heart, such as ejection fraction and regional wall motion/thickening, are commonly used for assessing the contractility and functionality of the heart in clinical practice. An important step for computer-aided determination of functional indices is the automated segmentation of the heart from computed tomography angiography (CTA) and the partitioning of the left ventricle into 16 segments. We develop a fully automatic scheme which not only segments the whole heart from cardiac CTA images, but also partitions the left ventricle, including the blood pool and myocardium, into 16 segments of bull's eye plot. The segmentation is based on image registration and atlas propagation techniques, whereas the bull's eye plot is first obtained through atlas propagation and then further improved to correct inconsistency across different subjects, uneven size for each segment and "zig-zag" edges between them. In this preliminary study, a cohort of ten clinical CTA data were employed to compute and evaluate the regional functional indices as well as the global indices by use of the segmentation and partitioning method for left ventricle. More than 40 clinical CTA data will be used in the final version.

8670-43, Session 9

Computer-based assessment of left ventricular wall stiffness in patients with ischemic dilated cardiomyopathy

Yi Su, Soo Kng Teo, A*STAR Institute of High Performance Computing (Singapore); Ru San Tan, National Heart Ctr. Singapore (Singapore) and National Univ. of Singapore (Singapore); Chi Wan Lim, A*STAR Institute of High Performance Computing (Singapore); Liang Zhong, National Heart Ctr. Singapore (Singapore)

Ischemic dilated cardiomyopathy (IDCM) is a degenerative disease of the myocardial tissue accompanied by left ventricular (LV) structural changes such as interstitial fibrosis. This can induce increased LV wall stiffness. However, quantification of LV wall stiffness in vivo is extremely difficulty, particularly in ventricles with complex geometry. Therefore, we sought to (i) develop a computer-based assessment of LV wall stiffness from cardiac magnetic resonance (CMR) imaging in terms of a nominal stiffness index (E*); and (ii) investigate whether E* can offer an insight into cardiac mechanics in IDCM. CMR scans were performed in 5 normal subjects and 5 patients with IDCM. For each data sample, an in-house software was used to generate a 1-to-1 corresponding mesh pair of the LV from the ED and ES phases. The E* values are then computed as a function of local ventricular wall strain. We found that E* in the IDCM group (40.66 – 215.12) was at least one order of magnitude larger than the normal control group (1.00 – 6.14). In addition, the IDCM group revealed much higher inhomogeneity of E* values manifested by a greater spread of E* values throughout the LV. In conclusion, there is a substantial elevated ventricular stiffness index in IDCM. This would suggest that E* could be used as discriminator for early detection of disease state. The computational performance per data sample took approximately 25 seconds, which demonstrates its clinical potential as a real-time cardiac assessment tool.

8670-44, Session 9

Patient-specific coronary artery blood flow simulation using myocardial volume partitioning

Kyung Hwan Kim, Samsung Advanced Institute of Technology (Korea, Republic of); Dongwoo Kang, The Univ. of Southern California (United States); Nahyup Kang, Ji-Yeon Kim, Hyong-Euk Lee, James D. K. Kim, Samsung Advanced Institute of Technology (Korea, Republic of)

Using computational simulation, we can analyze cardiovascular disease in non-invasive and quantitative manners. More specifically, computational modeling and simulation technology has enabled us to analyze functional aspect such as blood flow, as well as anatomical aspect such as stenosis, from medical images without invasive measurements. Note that the simplest ways to perform blood flow simulation is to apply patient-specific coronary anatomy with other average-valued properties; in this case, however, such conditions cannot fully reflect accurate individual physiological properties.

To resolve this limitation, we present a new patient-specific coronary blood flow simulation method by myocardial volume partitioning considering artery/myocardium structural correspondence. We focus on that blood supply is closely related to the mass of each myocardial segment corresponding to the artery. Therefore, we applied this concept for setting-up simulation conditions in the way to consider many patient-specific features as possible from medical image: First, we segmented coronary arteries and myocardium separately from cardiac CT; then the myocardium is partitioned into multiple regions based on coronary vasculature. The myocardial mass and required blood mass for each artery are estimated by converting myocardial volume fraction. Finally, the required blood mass is used as boundary conditions for each artery outlet, with given average aortic blood flow rate and pressure.

To show effectiveness of the proposed method, fractional flow reserve (FFR) by simulation using CT image has been compared with invasive FFR measurement of real patient data, and as a result, 77% of accuracy has been obtained.

8670-45, Session 10

Automated assessment of bilateral breast volume asymmetry as a breast cancer biomarker during mammographic screening

Alex C. Williams, Austin Hitt, Middle Tennessee State Univ. (United States); Sophie Voisin, Georgia Tourassi, Oak Ridge National Lab. (United States)

The biological concept of bilateral symmetry as a marker of developmental stability and good health is well established. Although most individuals deviate slightly from perfect symmetry, humans are essentially considered bilaterally symmetrical. Consequently, increased fluctuating asymmetry of paired structures could be an indicator of disease. There are several published studies linking bilateral breast size asymmetry with increased breast cancer risk. These studies were based on radiologists' manual measurements of breast size from mammographic images. We aim to develop a computerized technique to assess fluctuating breast volume asymmetry in screening mammograms and investigate whether it correlates with the presence of breast cancer. Using a large database of screening mammograms with known ground truth we applied automated breast region segmentation and automated breast size measurements in CC and MLO views using three well established methods. All three methods confirmed that indeed patients with breast cancer have statistically significantly higher fluctuating asymmetry of their breast volumes. However, statistically significant difference between patients with cancer and benign lesions was observed only for the MLO views. The study suggests that automated assessment of global bilateral asymmetry could serve as a breast cancer

risk biomarker for women undergoing mammographic screening. Such biomarker could be used to alert radiologists or computer-assisted detection (CAD) systems to exercise increased vigilance if higher than normal cancer risk is suspected.

8670-46, Session 10

A fully-automated software pipeline for integrating breast density and parenchymal texture analysis for digital mammograms: parameter optimization in a case-control breast cancer risk assessment study

Yuanjie Zheng, The Univ. of Pennsylvania Health System (United States); Yan Wang, Brad M. Keller, Univ. of Pennsylvania School of Medicine (United States); Emily F. Conant, The Univ. of Pennsylvania Health System (United States); James C. Gee, Univ. of Pennsylvania (United States); Despina Kontos, The Univ. of Pennsylvania Health System (United States)

Estimating a woman's risk of developing breast cancer is becoming increasingly important in clinical practice. Mammographic density, estimated as the percent of dense (PD) tissue area within the breast, has been shown to be the strongest risk factor. Studies also support a relationship between mammographic texture and breast cancer risk. We described a fully-automated software pipeline for computerized analysis of mammography parenchymal patterns by quantitatively measuring both mammographic density and texture properties. It combines advanced computerized algorithms of pattern recognition, computer vision and machine learning and offers a standardization analysis tool for case-control breast cancer risk assessment studies. Different from many existing methods performing parenchymal texture analysis within certain region specified in breast, our pipeline extracts texture descriptors for points on a spatial regular lattice and from a surrounding window of each lattice point, in order to characterize the local mammographic appearance of breast. With the raw and vendor postprocessed digital mammograms of 472 women, we performed several case-control clinical studies in order to optimize the lattice related parameters of our pipeline, investigate if Z-score normalization can help on improving the pipeline's performance, and evaluate PD and our texture features. Our results show that Z-score normalization of mammograms improves the case-control discriminations of our texture features. Also, we found that the combination of PD and our texture features (computed with the optimized pipeline parameters) from vendor postprocessed digital mammograms achieved an AUC (area under curve) value of 0.8, which is a significant improvement from the AUC value of 0.73 obtained with PD only.

8670-47, Session 10

Fully-automated fibroglandular tissue segmentation and volumetric density estimation in breast MRI by integrating a continuous max-flow model and a likelihood atlas

Shandong Wu, Susan P. Weinstein, Emily F. Conant, Despina Kontos, The Univ. of Pennsylvania Health System (United States)

Studies suggest that the relative amount of fibroglandular tissue in the breast as quantified in breast MRI can be predictive of the risk for developing breast cancer. Automated segmentation of the fibroglandular tissue from breast MRI data could therefore be an essential component in quantitative risk assessment. In this work we propose a new fully-automated 3D segmentation algorithm, namely the continuous max-flow (CMF)-Atlas method, to estimate the volumetric amount of fibroglandular tissue in breast MRI. Our method goes through a first step of applying a continuous max-flow model in the MR image intensity space to produce an initial voxel-wise likelihood map of being fibroglandular tissue. Then we further incorporate an a-priori learned fibroglandular tissue likelihood atlas to refine the initial likelihood map to achieve enhanced segmentation, from which the relative (e.g., percent) volumetric amount of fibroglandular tissue (FT%) in the breast is computed. Our method is evaluated by a representative dataset of 16 3D bilateral breast MRI scans (32 breasts, 896 tomographic MR slices in total). A high correlation (r=0.95) is achieved in FT% estimation, and the overall averaged spatial segmentation agreement is 0.77 in terms of Dice's coefficient, between the automated segmentation and the manual segmentation obtained from an experienced breast imaging radiologist. The automated segmentation method also runs time-efficiently at ~1 minute for each 3D MR scan (56 slices), compared to ~15 minutes needed for manual segmentation. Our method can serve as an effective tool for processing large scale clinical breast MR datasets for quantitative fibroglandular tissue estimation.

8670-48, Session 10

Breast segmentation in MR images using three-dimensional spiral scanning and dynamic programming

Luan Jiang, Yanyun Lian, Shanghai Advanced Research Institute (China); Yajia Gu, Fudan Univ. Cancer Hospital (China); Qiang Li, Shanghai Advanced Research Institute (China)

Magnetic resonance (MR) imaging has been widely used for risk assessment and diagnosis of breast cancer in clinic. To develop a computer-aided diagnosis (CAD) system, breast segmentation is the first important and challenging task. The accuracy of subsequent quantitative measurement of breast density and abnormalities depends on accurate definition of the breast area in the images. The purpose of this study is to develop and evaluate a fully automated method for accurate segmentation of breast in three-dimensional (3-D) MR images. A fast method was developed to identify bounding box, i.e., the volume of interest (VOI), for breasts. A 3-D spiral scanning method was used to transform the VOI of each breast into a single two-dimensional (2-D) generalized polar-coordinate image. Dynamic programming technique was applied to the transformed 2-D image for delineating the "optimal" contour of the breast. The contour of the breast in the transformed 2-D image was utilized to reconstruct the segmentation results in the 3-D MR images using interpolation and lookup table. The preliminary results on 17 cases show that the proposed method can obtain accurate segmentation of the breast based on subjective observation. With the manually delineated region of two breasts in a case, an overlap index of 93.36% and 92.59%, and a volume agreement of 96.64% and 97.06% were achieved, respectively. It took approximately 6 minutes for our method to segment the breast in an MR scan of 254 slices.

8670-49, Session 10

Symmetry-based detection and diagnosis of DCIS in breast MRI

Abhilash Skrikantha, Fraunhofer MEVIS (Germany) and Univ. de Bourgogne (France); Markus T. Harz, Lei Wang, Fraunhofer MEVIS (Germany); Bram Platel, Fraunhofer MEVIS (Netherlands); Ritse M. Mann, Radboud Univ. Nijmegen Medical Ctr. (Netherlands); Horst K. Hahn, Heinz-Otto Peitgen, Fraunhofer MEVIS (Germany)

The delineation and diagnosis of non-mass-like lesions, most notably DCIS (ductal carcinoma in situ), is among the most challenging tasks in breast MRI reading. For human observers, DCIS is not always easy to differentiate from patterns of active parenchymal enhancement. Therefore, it is no surprise that CADe/CADx approaches often completely fail to classify DCIS. Of the several approaches that have tried to devise such computer aid, none achieve performances similar to mass detection

and classification in terms of sensitivity and specificity.

In our contribution, we show a novel approach to combine anatomic breast symmetry calculated on subtraction images, descriptive kinetic parameters, and lesion candidate morphology to achieve performances comparable to computer-aided methods used for masses. We have based the development of the method on dynamic contrast-enhanced (DCE) MRI data of 18 DCIS cases with hand-annotated lesions, complemented by DCE-MRI data of nine normal cases. We propose a novel metric to quantify the symmetry of contralateral breasts and derive a strong indicator for potentially malignant changes from this metric. Also, we propose a novel metric for the description of elongatedness of a finding. Our combined scheme then achieves a sensitivity of 89% with a specificity of 78%, matching CAD results for breast MRI on masses.

The processing pipeline is intended to run on a CAD server, hence we designed all processing to be automated and free of per-case parameters.

8670-50, Session 10

Association between bilateral asymmetry of kinetic features computed from the DCE-MRI images and breast cancer detection

Qian Yang, Lihua Li, Hangzhou Dianzi Univ. (China); Bin Zheng, Univ. of Pittsburgh (Armenia); Juan Zhang, Zhejiang Cancer Hospital (China); Chengjie Zhang, Hangzhou Dianzi Univ. (China)

Dynamic contrast-enhanced magnetic resonance imaging (DCE-MRI) of breast yields high sensitivity but relatively lower specificity. To improve diagnostic accuracy of DCE-MRI, we investigated the association between bilateral asymmetry of kinetic features computed from the left and right breasts and breast cancer detection with the hypothesis of that due to the growth of angiogenesis associated with malignant lesions, the average dynamic contrast enhancement computed from the breasts depicting malignant lesions should be higher than negative or benign breasts. To test this hypothesis, we assembled a database involving 131 DCE-MRI examinations including 82 malignant and 49 benign cases. We developed a computerized scheme that automatically segments breast areas depicted on MR images, performs image registration, and computes kinetic features related to the bilateral asymmetry of contrast enhancement ratio between two breasts. The scheme then used an artificial neural network (ANN) to classify between malignant and benign cases. To identify the optimal approach to compute the bilateral kinetic feature asymmetry, we tested 4 different thresholds tentatively to segment the enhanced pixels from DCE-MRI images and compute the kinetic features. Using the optimal threshold, the ANN had a classification performance measured by the area under the ROC curve of AUC=0.79±0.04. The positive and negative predictive values were 0.75 and 0.67, respectively. The study suggested that the bilateral asymmetry of kinetic features or contrast enhancement of breast background tissue could provide valuable supplementary information to distinguish between the malignant and benign cases, which can be fused into existing computer-aided detection schemes to improve classification performance.

8670-51, Session 11

A prostate cancer computer-aided diagnosis system using multimodal magnetic resonance imaging and targeted biopsy labels

Peter R. Liu, Shijun Wang, Baris Turkbey, Kinzya Grant M.D., Peter A. Pinto, Peter Choyke, Bradford J Wood M.D., Ronald M. Summers M.D., National Institutes of Health (United States)

We propose a new method for prostate cancer classification based on supervised statistical learning methods by integrating T2-weighted, diffusion-weighted, and dynamic contrast-enhanced MRI images with targeted prostate biopsy results. In the first step of the method, all three imaging modalities are registered based on the image coordinates encoded in the DICOM images. In the second step, local statistical features are extracted in each imaging modality to capture intensity, shape, and texture information at every biopsy target. Finally, using support vector machines, supervised learning is conducted with the biopsy results to train a classification system that predicts the pathology of suspicious cancer lesions. The algorithm was tested with a dataset of 54 patients that underwent 164 targeted biopsies (58 positive, 106 negative). The proposed tri-modal MRI algorithm shows significant improvement over a similar approach that utilizes only T2-weighted MRI images (p= 0.048). The areas under the ROC curve for these methods were 0.82 (95% CI: [0.71, 0.93]) and 0.73 (95% CI: [0.55, 0.84]), respectively.

8670-52, Session 11

Computer-aided diagnosis of prostate cancer: robustness of quantitative image analysis on T2-weighted and diffusion-weighted MR images

Yahui Peng, Yulei Jiang, Tatjana Antic, Maryellen L. Giger, Scott Eggener, Aytekin Oto, The Univ. of Chicago Medical Ctr. (United States)

Purpose: To develop and evaluate robustness of quantitative T2-weighted and diffusion-weighted (DW) MR image features in distinguishing prostate cancer (PCa) from normal tissue on scans from two different MR systems.

Materials and Methods: The study included two image datasets: 48 PCa patients (61 PCa and 43 normal tissue regions of interest [ROIs]) imaged with Phillips scanners, and 71 PCa patients (102 PCa and 59 normal tissue ROIs) imaged with GE scanners. A radiologist manually drew ROIs via consensus histology-MR correlation with a pathologist. T2-weighted texture features and apparent diffusion coefficient (ADC) features were investigated. Area under the receiver operating characteristic (ROC) curve (AUC) was used to characterize feature performance in distinguishing PCa from normal tissue ROIs. Linear discriminant analysis (LDA) was used to combine image features in either leave-one-out or cross-vendor validations. Spearman correlation (?) was calculated between image features and tumor-specific Gleason score (GS)

Results: ADC 10th percentile, ADC average, and T2-weighted sum average yielded AUC values (±standard error) of 0.92±0.03, 0.89±0.03, and 0.86±0.04 on Phillips images, and 0.89±0.03, 0.87±0.03, and 0.72±0.04 on GE images, respectively. The three-feature combination yielded AUC values of 0.95±0.02 and 0.89±0.02 on Phillips and GE images, respectively. Training with Phillips images and test with GE images, and vice versa, produced AUC values of 0.89±0.03 and 0.95±0.02, respectively. Both ADC features correlated moderately with GS (? = -0.27 to -0.34).

Conclusion: ADC 10th percentile, ADC average, and T2-weighted sum average are effective in distinguishing PCa from normal tissue, and appear robust over different MR scanners.

8670-53, Session 11

Ultrasound RF time series for tissue typing: first in-vivo clinical results

Mehdi Moradi, Sara Mahdavi, Guy Nir, Edward C. Jones, Larry Goldenberg, Septimiu E. Salcudean, The Univ. of British Columbia (Canada)

The low diagnostic value of ultrasound in prostate cancer imaging has resulted in an effort to enhance the tumor contrast using ultrasound-based technologies that go beyond traditional B-mode imaging. Ultrasound RF time series, formed by echo samples originating from the same location over a few seconds of imaging, has been proposed and experimentally used for tissue typing with the goal of cancer detection.

In this work, for the first time we report the in-vivo clinical use of spectral parameters extracted from RF time series in prostate cancer detection. An image processing pipeline is designed to register the ultrasound data to wholemount histopathology references acquired from prostate specimens that are removed in radical prostatectomy after imaging. Support vector machine classification is used to detect cancer in 524 regions of interest of size 5x5 mm, each forming a feature vector of five spectral RF time series parameters, in six patients. ROC curves for individual cases with leave-one-patient-out cross validation are presented.

8670-54, Session 11

Iterative multiple reference tissue method for estimating pharmacokinetic parameters on prostate DCE MRI

Shoshana Ginsburg, Rutgers, The State Univ. of New Jersey (United States); B. Nicolas Bloch, Boston Medical Ctr. (United States); Neil M. Rofsky, The Univ. of Texas Southwestern Medical Ctr. at Dallas (United States); Elizabeth M. Genega, Beth Israel Deaconess Medical Ctr. (United States); Robert E. Lenkinski, The Univ. of Texas Southwestern Medical Ctr. at Dallas (United States); Anant Madabhushi, Rutgers, The State Univ. of New Jersey (United States)

Pharmacokinetic (PK) parameters are probes of tissue status that can be assessed by analysis of dynamic contrast-enhanced (DCE) MRI and are useful for prostate cancer (CaP) detection and grading. Traditionally, PK analysis requires knowledge of the time-resolved concentration of the contrast agent in the blood plasma, the arterial input function (AIF). However, the multiple reference tissue method (MRTM) enables the estimation of PK parameters without the AIF by leveraging PK parameter values from the literature for a reference tissue in the field of view. Nevertheless, PK parameters estimated in the prostate vary significantly between patients. In this paper we present a novel scheme, iterative MRTM (IMRTM), to estimate PK parameter values in the absence of the AIF without making any assumptions about the PK parameter values of a reference tissue. We implement our method for PK analysis on 15 prostate DCE MRI studies with CaP in either the central gland or the peripheral zone. Values for the PK parameters K^trans and v_e estimated via IMRTM average 0.29 and 0.58 for normal central gland, 0.28 and 0.60 for normal peripheral zone, and 0.32 and 0.56 for CaP. While both MRTM and IMRTM provide PK parameter values that are biologically feasible, IMRTM has the advantage that it invokes patient-specific information rather than relying on population-based PK parameter values in performing PK analysis.

8670-55, Session 11

Automatic abdominal lymph node detection method based on local intensity structure analysis from 3D x-ray CT images

Yoshihiko Nakamura, Yukitaka Nimura, Nagoya Univ. (Japan); Takayuki Kitasaka, Shinji Mizuno, Aichi Institute of Technology (Japan); Kazuhiro Furukawa, Hidemi Goto, Nagoya Univ. School of Medicine (Japan); Michitaka Fujiwara, Nagoya Univ. (Japan); Kazunari Misawa, Aichi Cancer Ctr. Research Institute (Japan); Masaaki Ito, National Cancer Ctr. Hospital East (Japan); Shigeru Nawano, International Univ. of Health and Welfare (Japan); Kensaku Mori, Nagoya Univ. (Japan)

This paper presents an automated method of abdominal lymph node detection to aid the preoperative diagnosis of the abdominal cancer surgery.

In the abdominal cancer surgery, surgeons must resect not only the tumor and metastases but also lymph nodes that have the possibility of metastasis.

This procedure is called as lymphadenectomy or lymph node dissection.

Insufficient lymphadenectomy has high risk for relapse.

However, excessive resection decreases patient's quality of life.

Therefore, it is important to understand the location and the structure of a lymph node in order to make a suitable surgical plan.

In this paper, we propose an improved method for automated abdominal lymph node detection.

The proposed method consists of candidate lymph node detection process and false positive reduction process.

Candidate lymph nodes are detected by using a multi-scale blob-like enhancement filter based on local intensity structure analysis.

However, the detection results include many false positives in normal organs.

In order to reduce false positives, the proposed method utilizes a classifier based on support vector machine with texture and shape information.

The experimental results revealed that the method can detect 70.5% lymph nodes with 13.2 false positives per case.

8670-56, Session 12

Detection of microcalcifications in breast tomosynthesis reconstructed with multiscale bilateral filtering regularization

Ravi K. Samala, Heang-Ping Chan, Yao Lu, Lubomir M. Hadjiiski, Jun Wei, Univ. of Michigan Health System (United States); Berkman Sahiner, U.S. Food and Drug Administration (United States); Mark A. Helvie, Univ. of Michigan Health System (United States)

We are developing a CAD system to assist radiologists in detecting microcalcification clusters (MCs) in digital breast tomosynthesis (DBT). In this study, we designed the CAD system based on an enhanced DBT volume that was reconstructed with the iterative simultaneous algebraic reconstruction technique (SART) regularized by a new multiscale bilateral filtering (MS-BiF) method. The MS-BiF method utilizes the multiscale structures of the breast to selectively enhance MCs and preserve mass spiculations while smoothing noise in the DBT images. The CAD system first extracted the enhancement-modulated calcification response (EMCR) in the DBT volume. Detection of the seed points for MCs and individual calcifications were guided by the EMCR. MC candidates were formed by dynamic clustering. FPs were further reduced by analysis of the feature characteristics of the MCs. With IRB approval, two-view DBT of 91 subjects with biopsy-proven MCs and 38 subjects without MCs were collected. 78 views from 39 subjects with MCs were used for training and the remaining cases were used for independent testing. The cases without MCs were used for estimation of the FP rates. For view-based detection, a sensitivity of 85% was achieved at 2.71 FPs/volume. For case-based detection, the same sensitivity was obtained at 1.07 FPs/volume. The results indicate that the new MS-BiF method is useful in improving the detection accuracy of clustered microcalcifications. An effective CAD system for microcalcification detection in DBT has the potential to eliminate the need for additional mammograms, thereby reducing patient dose and reading time.

8670-58, Session 12

Neural network training by maximization of the area under the ROC curve: application to characterization of masses on breast ultrasound as malignant or benign

Berkman Sahiner, Xin He, Weijie Chen, U.S. Food and Drug Administration (United States); Heang-Ping Chan, Lubomir M. Hadjiiski, Univ. of Michigan Health System (United States); Nicholas A. Petrick, U.S. Food and Drug Administration (United States)

Back-propagation neural networks (BPNs) are traditionally trained using error measures such as sum-of-squares or cross-entropy. If the training sample size is small, and the neural network has a large number of hidden layer nodes, the BPN may be overtrained, i.e., it may fit the training data well, but may generalize poorly to independent test data. In this study, we investigated a training technique that maximized the approximate area under the ROC curve (AUC) to reduce overtraining. In general, the non-parametric AUC is a discontinuous function of the neural network output, which makes it unsuitable for gradient descent algorithms such as back-propagation. We used a semi-differentiable approximation to AUC, which appeared to provide reasonable training for the datasets explored in this study. We performed a simulation study using synthetic datasets consisting of Gaussian mixtures, which indicated that the artificial neural network trained using the AUC-maximization method may be less prone to overtraining. The advantage of the AUC-maximization method was consistently observed over different values of hidden layer BPN nodes, training sample sizes, and the feature spaces studied in our simulation study. For a four-hidden-node BPN trained using 50 training samples per class, the average test AUC was 0.907 (SE: 0.003) with AUC-maximization and 0.861 (SE: 0.004) with the sum-of-squares method. The difference in test performance between the AUC-maximization method and the traditional BPN training was larger when the training sample size was smaller. We also applied this new method to a dataset previously acquired for characterization of masses on breast ultrasound as malignant or benign. Our results with this real-world dataset had the same trend as our simulation study in that the AUC-maximization technique was less prone to overtraining than the sum-of-squares method.

8670-59, Session 12

Finding lesion correspondences in different views of automated 3D breast ultrasound

Tao Tan, Radboud Univ. Nijmegen Medical Ctr. (Netherlands); Bram Platel, Fraunhofer MEVIS (Germany); Michael Hicks, Ritse M. Mann, Nico Karssemeijer, Radboud Univ. Nijmegen Medical Ctr. (Netherlands)

Screening with automated 3D breast ultrasound (ABUS) is gaining popularity. However, the acquisition of multiple views required to cover an entire breast makes radiologic reading time-consuming. Linking lesions across views can facilitate the reading process. In this paper, we propose a method to automatically predict the position of a lesion in the target ABUS views, given the location of the lesion in a source ABUS view. We combine features describing the lesion location with respect to the nipple, the transducer and the chestwall, with features describing lesion properties such as intensity, spiculation, blobness, contrast and lesion likelihood. By using a grid search strategy, the location of the lesion was predicted in the target view. Our method achieved an error of 15.64 mm+/-16.13 mm. The error is small enough to help locate the lesion with minor additional interaction.

8670-60, Session 12

Computer-aided lesion diagnosis in B-mode ultrasound by border irregularity and multiple sonographic features

Jong-Ha Lee, Yeong Kyeong Seong, Chu-Ho Chang, Samsung Advanced Institute of Technology (Korea, Republic of); Eun Young Ko, SAMSUNG Medical Ctr. (Korea, Republic of); Kyoung-Gu Woo, Samsung Advanced Institute of Technology (Korea, Republic of)

Early detection of breast tumor is critical in determining the best possible treatment approach. To evaluate breast tumors via ultrasound, radiologists consider several features in the image, such as lesion shape, orientation, echo pattern, and posterior acoustic. Interpretation of ultrasound images, however, is subjective and variability is very high due to its low image resolution and the different experiences of radiologists who analyze the tumor features. In order to remove operator dependency and increase diagnostic accuracy, the computer-aided diagnosis (CAD) system provides a valuable method for breast tumor detection and classification. This research discusses the novel feature extraction techniques that provide accurate classification results for breast tumor in the CAD system. Totally 290 features were extracted using the newly developed border irregularity feature extractor as well as previous sonographic feature extractors. To demonstrate the effectiveness of the extracted features, sonograms of 4,107 pathologically proven breast cases with 2,508 malignancy cases were analyzed and classified into benign and malignant categories. Receiver operator characteristic analysis was used to determine performance of the system. Experimental results showed that using only border irregularity features; the area under the ROC curve (A_z) was 0.92, which was significantly higher than the previous sonographic features without border irregularity features (A_z=0.61). The A_z of all 290 features was the highest with 0.931. The clinical results demonstrate that the proposed feature combination can be an integral part of ultrasound CAD systems to help accurately distinguish benign from malignant tumors.

8670-61, Session 12

A robust region-based active contour model with point classification for ultrasound breast tumor segmentation

Zhihua Liu, Lidan Zhang, Haibing Ren, Ji-Yeun Kim, Samsung Advanced Institute of Technology (China)

Tumor segmentation is one of the key technologies for computer-aided diagnosis (CAD) system. In this paper, we propose a robust region-based active contour model (ACM) with point classification to segment high-variant breast tumors in ultrasound images. First, a local signed pressure force function (LSPF) is proposed to classify the contour points into two classes: local low contrast class and local high contrast class. Then, we build a sub-model for each class. For low contrast class, the sub-model is built by combining the global energy with local energy model and it can evolve level set curve to avoiding sensitivity of initialization. For high contrast class, the sub-model is just the local energy model and it can drive the curve to converge for high intensity contrast. Finally, the two sub-models are added and Chan-Vese energy measure is merged into it. We compare our method with other state-of-art methods on a very large ultrasound database and the result shows that our method can achieve better performance.

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8670-65, Session 12

Fast microcalcification detection in ultrasound images using image enhancement and threshold adjacency statistics

Baek Hwan Cho, Chu-Ho Chang, Jong-Ha Lee, Samsung Advanced Institute of Technology (Korea, Republic of); Eun Young Ko, SAMSUNG Medical Ctr. (Korea, Republic of); Yeong Kyeong Seong, Kyoung-Gu Woo, Samsung Advanced Institute of Technology (Korea, Republic of)

The existence of microcalcifications (MCs) is an important marker of malignancy in breast cancer. In spite of the benefits in mass detection for dense breasts, ultrasonography is believed that it might not reliably detect MCs. For computer aided diagnosis systems, however, accurate detection of MCs has the possibility of improving the performance in both Breast Imaging-Reporting and Data System (BI-RADS) lexicon description for calcifications and mass malignancy classification. We propose a new efficient and effective method for MC detection using threshold adjacency statistics (TAS) and image enhancement. The main idea of TAS is to threshold an image and to count the number of white pixels with a given number of adjacent white pixels. Our contribution is to adopt TAS features and apply image enhancement to facilitate MC detection in ultrasound images. We employed fuzzy logic, tophat filter, and texture filter to enhance images for MCs. Using a total of 591 images, the classification accuracy of the proposed method in MC detection showed 82.75%, which is comparable to that of Haralick texture features (81.38%). When combined, the performance was as high as 85.11%. In addition, our method also showed the ability in mass classification when combined with existing features. In conclusion, the proposed method exploiting image enhancement and TAS features has the potential to deal with MC detection in ultrasound images efficiently and extend to the real-time localization and visualization of MCs.

8670-62, Session PSWed

Psychophysical similarity measure based on multi-dimensional scaling for retrieval of similar images of breast masses on mammograms

Kohei Nishimura, Chisako Muramatsu, Gifu Univ. School of Medicine (Japan); Mikinao Oiwa, Misaki Shiraiwa, Tokiko Endo, Nagoya National Hospital (Japan); Kunio Doi, Gunma Prefectural Collage of Health Sciences (Japan) and The Univ. of Chicago (United States); Hiroshi Fujita, Gifu Univ. School of Medicine (Japan)

For retrieving reference images which may be useful to radiologists in their diagnosis, it is necessary to determine a reliable similarity measure which would agree with radiologists' subjective impression. In this study, we propose a new similarity measure for retrieval of similar images, which may assist radiologists in the distinction between benign and malignant masses on mammograms, and investigated its usefulness. In our previous study, to take into account the subjective impression, the psychophysical similarity measure was determined by use of an artificial neural network (ANN), which was employed to learn the relationship between radiologists' subjective similarity ratings and image features. In this study, we propose a psychophysical similarity measure based on multi-dimensional scaling (MDS) in order to improve the accuracy in retrieval of similar images. Twenty-seven images of masses, 3 each from 9 different pathologic groups, were selected, and the subjective similarity ratings for all possible 351 pairs were determined by 8 expert physicians. MDS was applied using the average subjective ratings, and the relationship between each output axis and image features was modeled by the ANN. The MDS-based psychophysical measures were determined by the distance in the modeled space. With a leave-one-out test method, the conventional psychophysical similarity measure was moderately correlated with subjective similarity ratings (r=0.68), whereas the psychophysical measure based on MDS was highly correlated (r=0.81). The result indicates that a psychophysical similarity measure based on MDS would be useful in the retrieval of similar images.

8670-63, Session PSWed

Automatic localization of the nipple in mammograms using Gabor filters and the Radon transform

Jayasree Chakraborty, Sudipta Mukhopadhyay, Indian Institute of Technology Kharagpur (India); Rangaraj M. Rangayyan, Univ. of Calgary (Canada); Anup Sadhu, Medical College and Hospital Kolkata (India); Paulo Mazzoncini Azevedo Marques, Univ. de São Paulo (Brazil)

The nipple is an important landmark in mammograms. Detection of the nipple is useful for alignment and registration of mammograms in computer-aided diagnosis of breast cancer. In this paper, a novel approach is proposed for automatic detection of the nipple based on the oriented patterns of the breast tissues present in mammograms. The Radon transform is applied to the oriented patterns obtained by a bank of Gabor filters to detect the linear structures related to the tissue patterns. The detected linear structures are then used to locate the nipple position using the characteristics of convergence of the tissue patterns towards the nipple. The performance of the method was evaluated with 200 scanned-film images from the mini-MIAS database and 150 digital radiography (DR) images from a local database. Average errors of 5.84 mm and 6.36 mm were obtained with respect to the reference nipple location marked by a radiologist for the mini-MIAS and the DR images, respectively.

8670-64, Session PSWed

Preliminary investigation on CAD system update: effect of selection of new cases on classifier performance

Chisako Muramatsu, Kohei Nishimura, Takeshi Hara, Hiroshi Fujita, Gifu Univ. School of Medicine (Japan)

When a computer-aided diagnosis (CAD) system is used in clinical practice, it is desirable that the system is constantly and automatically updated with new cases obtained for performance improvement. In this study, the effect of different case selection methods for the system updates was investigated. For the simulation, the data for classification of benign and malignant masses on mammograms were used. Six image features were used for training three classifiers: linear discriminant analysis (LDA), support vector machine (SVM), and k-nearest neighbor (kNN). Three datasets, including dataset I for initial training of the classifiers, dataset T for intermediate testing and retraining, and dataset E for evaluating the classifiers, were randomly sampled from the database. As a result of intermediate testing, some cases from dataset T were selected to be added to the previous training set in the classifier updates. In each update, cases were selected using 4 methods: selection of (a) correctly classified samples, (b) incorrectly classified samples, (c) marginally classified samples, and (d) random samples. For comparison, system updates using all samples in dataset T were also evaluated. In general, the average areas under the receiver operating characteristic curves (AUCs) were almost unchanged with method (a), whereas AUCs generally degraded with method (b). The AUCs were improved with methods (c) and (d), although use of all available cases generally provided the best or nearly best AUCs. In conclusion, CAD systems may be improved by retraining with new cases accumulated during practice.

8670-66, Session PSWed

Model-based position correlation between breast images

Joachim Georgii, Fabian Zöhrer, Horst K. Hahn, Fraunhofer MEVIS (Germany)

Today, breast diagnosis is based on images of different projections and modalities in order to increase the sensitivity and specificity of the diagnosis. However, as the resolution of the images increases and more and more 3D modalities such as 3D ultrasound and tomosynthesis are used, the task to manually find corresponding locations in different views or modalities becomes very time consuming. For that reason, we aim at supporting radiologist by automatically synchronizing cursor positions between different views of the breast.

The challenges of this registration problem are two-fold. First, one observes non-linear behavior in the position correlation due to the different compressions of the breast in CC and MLO projections. Secondly, the correlation depends on the patient-individual breast shape. In order to solve these issues, we use a pre-computed FE model of the breast providing the non-linearity of the correlation combined with patient-individual mapping approach to account for the individual breast shape.

First, we have developed a generic FE breast model, which is used to compute the tissue compression in different projections of the model (e.g. MLO, CC). Second, we propose an efficient mapping step, which computes the transformation between the patient images and the analogously compressed FE model based on the contour of the breast. While our approach is general enough to incorporate different breast modalities at the end, for simplicity reasons we will focus only on different tomosynthesis/mammogram projections in this work.

8670-67, Session PSWed

Boosting framework for mammographic mass classification with combination of CC and MLO view information

Dae Hoe Kim, Jae Young Choi, Yong Man Ro, KAIST (Korea, Republic of)

In breast cancer screening practice, radiologists compare multiple views during the interpretation of mammograms to detect breast cancers. Hence, it is natural that information derived from multiple mammograms can be used for computer-aided detection (CAD) system to obtain better sensitivity and/or specificity. However, similarity features derived from the combination of cranio-caudal (CC) and mediolateral oblique (MLO) views are weak for classifying masses, because a breast is elastic and deformable. In this study, therefore, a new mass classification with boosting algorithm is proposed, aiming to reduce FPs by combining the information of CC and MLO view mammograms. The proposed method has been developed under the following facts: (1) classifiers trained using similarity features are rather weak classifier; (2) boosting technique generates a single strong classifier by combining multiple weak classifiers. By combining the classifier ensemble framework with similarity features, we are able to improve mass classification performance in two-view analysis. In this study, 192 mammogram cases were collected from the public DDSM database (DB) to demonstrate the effectiveness of the proposed method in terms of improving mass classification. Results show that our proposed classifier ensemble method can improve an area under the ROC curve (AUC) of 0.7479, compared to the best single support vector machine (SVM) classifier using feature-level fusion (AUC of 0.7123). In addition, the weakness of similarity features is experimentally found to prove the feasibility of the proposed method.

8670-68, Session PSWed

Integration of DCE-MRI and DWI for heterogeneity assessment in breast ductal carcinoma

Carlos A. Méndez Guerrero, Francesca Pizzorni Ferrarese, Univ. degli Studi di Verona (Italy); Paul E. Summers, Giuseppe Petralia, Istituto Europeo di Oncologia (Italy); Gloria Menegaz, Univ. degli Studi di Verona (Italy)

Diagnostic assessment using DCE-MRI in patients with breast cancer is increasing. DWI is an attractive complement as it is fast, allows for quantitative information, has high sensitivity and avoids the use of contrast.

In this work a two-steps pipeline for integrating breast diffusion and perfusion MRI for the assessment of breast lesions and quantification of their heterogeneity is proposed. First, the images acquired with the two modalities are spatially aligned using an inter-modal non-rigid registration procedure. Having both images aligned a novel voxel-wise dissimilarity-based clustering protocol is then performed exploiting the information coming from both modalities. To this end an ad-hoc distance function is developed and tested for tuning the weighting for the two modalities. The probability density functions (PDFs) of the so-identified subregions in the DWI images are extracted and compared through non-parametric testing for posterior evaluation of the tissue heterogeneity. Results show that the joint exploitation of the information brought by DCE and DWI leads to consistent results accounting for both perfusion and micro structural information yielding an improved refinement of the segmentation than the separate processing of the two modalities. By demonstrating that statistically consistent subgroups can be defined within tumors based on a combination of DCE-MRI and DWI-MRI data, we have indicated a means for objectively segmenting tumors. Subjective assessment by radiologists was performed for validation. An extended experimentation is under way for clinical validation.

8670-69, Session PSWed

Neural networks combined with region growing techniques for tumor detection in [18F]-fluorothymidine dynamic positron emission tomography breast cancer studies

Zoltan Cseh, Imperial College Healthcare NHS Trust (United Kingdom) and Univ. of Kaposvár (Hungary); James Swingland, Laura Kenny, Subrata Bose, Imperial College Healthcare NHS Trust (United Kingdom); Federico Turheimer, Imperial College Healthcare NHS Trust (United Kingdom) and King's College London (United Kingdom)

Early detection and precise localization of malignant tumors has been a primary challenge in medical imaging in recent years. Functional modalities play a continuously increasing role in these efforts. Image segmentation algorithms which enable automatic, accurate tumor visualization and quantification on noisy positron emission tomography (PET) images would significantly improve the quality of treatment planning processes and in turn, the success of treatments. In this work a novel multistep method has been applied in order to identify tumor regions in 4D dynamic [18F] fluorothymidine (FLT) PET studies of patients with locally advanced breast cancer. In order to eliminate the effect of inherently detectable high inhomogeneity inside tumors, specific voxel-kinetic classes were initially introduced by finding characteristic FLT-uptake curves with K-means algorithm on a set of voxels collected from each tumor. Image voxel sets were then split based on voxel time-activity curve (TAC) similarities, and models were generated separately on each voxel set. At first, artificial neural networks, in comparison with linear classification algorithms were applied to distinguish tumor and healthy regions relying on the characteristics of TACs of the individual voxels. The outputs of the best model with very high specificity were then

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used as input seeds for region shrinking and growing techniques, the application of which considerably enhanced the sensitivity and specificity (78.65% ± 0.65% and 98.98% ± 0.03%, respectively) of the final image segmentation model.

8670-70, Session PSWed

Improving positive predictive value in Computer-aided Diagnosis using mammographic mass and microcalcification confidence score fusion based on co-location information

Seung Hyun Lee, Dae Hoe Kim, Jae Young Choi, Yong Man Ro, KAIST (Korea, Republic of)

In this study, a novel fusion framework has been developed to combine the detection of both breast masses and microcalcifications (MCs), aiming to improve positive predictive value (PPV) in Computer-aided Diagnosis (CADx). Clinically, it has been widely accepted that a mass associated with MC is a useful indicator of predicting the malignancy of the mass. In light of this fact, given that a mass and MCs are co-located each other (i.e., they are at the same location), the proposed fusion framework combines confidence scores of the mass and MCs for the purpose of improving the probability that the mass is malignant. To this end, the popular Bayesian network model is applied to effectively combine the detection confidence scores and to achieve higher accuracy for malignant mass classification. To demonstrate the effectiveness of the proposed fusion framework, 31 mammograms were collected from the public DDSM database. The proposed fusion framework can increase the area under the receiver operating characteristic curve (AUC) from 0.7939 to 0.8806, and the partial area index (PAUC) above the sensitivity of 0.9 from 0.1270 to 0.2280, compared to the CADx system without exploiting co-location information with MCs. Based on these results, it can be expected that the proposed fusion framework can be readily applied for realizing CADx systems with the higher PPV.

8670-71, Session PSWed

Automated detection scheme of architectural distortion in mammogram using adaptive Gabor filter

Ruriha Yoshikawa, Atsushi Teramoto, Fujita Health Univ. (Japan); Tomoko Matsubara, Nagoya City Univ. (Japan); Hiroshi Fujita, Gifu Univ. School of Medicine (Japan)

Breast cancer is a serious health concern for all women. Computer-aided detection for mammography has been used for detecting mass and micro-calcification. However, there are challenges regarding the automated detection of the architectural distortion about the sensitivity. In this study, we propose a novel automated method for detecting architectural distortion. Our method consists of the analysis of the mammary gland structure, detection of the distorted region, and reduction of false positive results. We developed and adaptive Gabor filter for analyzing the mammary gland structure that decides filter parameters depending on the thickness of the gland structure. For post-processing of the Gabor filter, healthy mammary glands that run from the nipple to the chest wall are eliminated by angle analysis. Moreover, background mammary glands are removed based on the intensity output image obtained from adaptive Gabor filter.The distorted region of the mammary gland is then detected as an initial candidate using a concentration index followed by binarization and labeling. False positives in the initial candidate are eliminated using characteristic and a support vector machine. In the experiments, we compared the automated detection results with interpretations by a radiologist using 50 cases (200 images) from the Digital Database of Screening Mammography (DDSM). The resulting true positive rate was 80%, and the number of false positive per image was 1.06. There results indicate that the proposed method is useful for detecting architectural distortion in mammograms.

8670-72, Session PSWed

A pairwise image analysis with sparse decomposition

Arnaud Boucher, Nicole Vincent, Florence Cloppet, Univ. Paris Descartes (France)

This paper aims to detect the evolution between two images representing the same scene. The evolution detection problem has many practical applications, especially in medical images. Indeed, the concept of a patient “file” implies the joint analysis of different acquisitions taken at different times, and the detection of significant modifications. The research presented in this paper is carried out within the application context of the development of computer assisted diagnosis (CAD) applied to mammograms. It is performed on already registered pair of images. As the registration is never perfect, we must develop a comparison method sufficiently adapted to detect real small differences between comparable tissues. In many applications, the assessment of similarity used during the registration step is also used for the interpretation step that yields to prompt suspicious regions. In our case registration is assumed to match the spatial coordinates of similar anatomical elements.

In this paper, in order to process the medical images at tissue level, the image representation is based on elementary patterns, therefore seeking patterns, not pixels. Besides, as the studied images have low entropy, the decomposed signal is expressed in a parsimonious way. Parsimonious representations are known to help extract the significant structures of a signal, and generate a compact version of the data. This change of representation should allow us to compare the studied images in a short time, thanks to the low weight of the images thus represented, while maintaining a good representativeness. The good precision of our results show the approach effectiveness.

8670-73, Session PSWed

Breast tissue classification in mammograms using visual words

Idit Diamant, Tel-Aviv Univ. (Israel); Jacob Goldberger, Bar-Ilan Univ. (Israel); Hayit Greenspan, Tel Aviv Univ. (Israel)

The presence of Microcalcification clusters (MCC) is an important indicator for developing breast cancer. Additional indicators for cancer risk exist, such as breast tissue density type. Different methods have been developed for breast tissue classification for use in Computer-aided diagnosis systems. Recently, the visual words (VW) model has been successfully applied for different classification tasks. The goal of our work is to explore VW based methodologies for various mammography classification tasks. We focus on the challenges of classifying breast tissue density and normal tissue versus MCC.

The presented methodology is based on patch-based visual words model which includes building a dictionary for a training set using local descriptors and representing the image using a visual word histogram. Classification is then performed using k-nearest-neighbour (KNN) and Support vector machine (SVM) classifiers, with leave-one-out cross-validation method.

We tested our algorithm on the MIAS and DDSM publicly available datasets. The input is a representative region-of-interest per mammography image, manually selected and labelled by expert.

In the tissue density task, classification accuracy reached 85% using KNN and 88% using SVM, which competes with the state-of-the-art results. For MCC vs. normal tissue, accuracy reached 81% using SVM.

Results demonstrate the feasibility to classify breast tissue using our model. Currently, we are improving the results further while also investigating VW capability to classify additional important mammogram

classification problems. We expect that the methodology presented will enable high levels of classification, suggesting new means for automated tools for mammography diagnosis support.

8670-74, Session PSWed

Improving breast cancer classification with mammography, supported on an appropriate variable selection analysis

Noel Pérez, Miguel A. Guevara, Univ. do Porto (Portugal); Augusto Silva, Univ. de Aveiro (Portugal)

This work addresses the issue of variable selection within the context of breast cancer classification with mammography. A comprehensive repository of feature vectors was used including a hybrid subset gathering image-based and clinical features. It aimed to gather experimental evidence of variable selection in terms of cardinality, type and find a classification scheme that provides the best performance over the Area Under Receiver Operating Characteristics Curve (AUC) scores using the ranked features subset. We evaluated and classified a total of 300 subsets of features formed by the application of Chi-Square Discretization, Information-Gain, One-Rule and RELIEF methods in association with Feed-Forward Backpropagation Neural Network (FFBP), Support Vector Machine (SVM) and Decision Tree J48 (DTJ48) machine learning algorithms for a comparative performance evaluation based on AUC scores. A variable selection analysis was performed for Single-View Ranking and Multi-View Ranking groups of features. Features subsets representing Microcalcifications (MCs), Masses and both MCs and Masses lesions achieved AUC scores of 0.91, 0.954 and 0.934 respectively. Experimental evidence demonstrated that classification performance was improved when were combined image-based and clinical features. The most relevant clinical and image-based features were StromaDistortion and Circularity respectively. Other less relevant but worth to use due to its consistency were Contrast, Perimeter, Microcalcification, Correlation and Elongation.

8670-75, Session PSWed

Predictive features of breast cancer on Mexican screening mammography patients

Juan A. Rodriguez-Rojas, Tecnológico de Monterrey (Mexico); Margarita Garza-Montemayor M.D., Hospital San José Tec de Monerrey (Mexico); Victor M. Treviño-Alvarado, José G. Tamez-Peña, Tecnológico de Monterrey (Mexico)

Breast cancer is the most common type of cancer worldwide. In response, breast cancer screening programs are becoming common around the world and public programs now serve millions of women worldwide. These programs are expensive, requiring many specialized radiologists to examine all images. Nevertheless, the availability of trained radiologists is not sufficient in many countries as in Mexico, which is a barrier towards decreasing breast cancer mortality, pointing at the need of a triaging system that prioritizes high risk cases for prompt interpretation. Therefore we explored in an image database of Mexican patients whether high risk cases can be distinguished using image features. We collected a set of 200 digital screening mammography cases from a hospital in Mexico, and assigned low or high risk labels according to its BIRADS score. Breast tissue segmentation was performed using an automatic procedure. Image features were obtained considering only the segmented region on each view and comparing the bilateral differences of the obtained features. Predictive combinations of features were chosen using a feature selection procedure based on genetic algorithms. The best model found was able to classify low-risk and high-risk cases with an area under the ROC curve of 0.89 on a 150-fold cross-validation test. The features selected were related to the differences of signal distribution and tissue shape on bilateral views. The model found can be used to automatically identify high risk cases and trigger the necessary measures to provide prompt treatment.

8670-76, Session PSWed

Automatic assessment of patient positioning in mammography

Thomas Buelow, Kirsten Meetz, Dominik Kutra, Thomas Netsch, Rafael Wiemker, Martin Bergtholdt, Joerg Sabczynski, Philips Research (Germany); Nataly Wieberneit, Philips Medical Systems (Germany); Manuela Freund, Philips Medizin Systeme GmbH (Germany); Ingrid Schulze-Wenck, Philips Medical Systems (Germany)

Quality assurance has been recognized as crucial for the success of population-based breast cancer screening programs using x-ray mammography. In order to ensure the quality of breast cancer screening quality guidelines and criteria have been defined in the US as well as the European Union. Incorrect positioning of the breast is reported to be the major image quality issue in screening mammography. Consequently, guidelines and criteria for correct positioning and for the assessment of the positioning quality in mammograms play an important role in the quality standards.

In this paper we present a system for the automatic evaluation of the existing standardized positioning quality criteria. This involves the automatic detection of anatomic landmarks in medio-lateral oblique (MLO) and cranio-caudal (CC) mammograms, namely the pectoral muscle, the mammilla and the infra-mammary fold. Furthermore, the detected landmarks are assessed with respect to their proper presentation. This includes the assessment whether the mammilla was imaged in profile or not. Finally, the geometric relations between the detected landmarks are investigated to assess the positioning quality. This includes the evaluation whether the pectoral muscle is imaged down to the mammilla level, and whether the posterior nipple line diameter of the breast is consistent between the different views (MLO and CC) of the same breast. Results of the computerized assessment are compared to ground truth collected from two expert readers.

8670-77, Session PSWed

Automatic 3D lesion segmentation on breast ultrasound images

Hsien-Chi Kuo, The Univ. of Chicago Medical Ctr. (United States) and Univ. of Illinois at Chicago (United States); Maryellen L. Giger, Ingrid S. Reiser, The Univ. of Chicago Medical Ctr. (United States); Karen Drukker, Alexandra V. Edwards, The Univ. of Chicago (United States); Charlene A. Sennett, Univ of Chicago Dept of Radiology (United States)

Reconstructed 3D breast ultrasound images allow radiologists to detect and evaluate breast lesions in 3D. However, assessing potential cancers in 3D ultrasound can be difficult and time consuming. In this study, we evaluate a 3D lesion segmentation method, which we had previously developed for breast CT, and investigate its robustness on lesions on 3D breast ultrasound images.

Our dataset includes 98 3D breast ultrasound images from 55 patients containing 64 cancers. 54 cases had been clinically interpreted as negative on screening mammography and 44 had been clinically visible on mammography. All were from women with breast density BI-RADS 3 or 4. Tumor centers were indicated by radiologists, and initial RGI-eroded contours were automatically calculated and served as input to the active contour segmentation algorithm yielding the final lesion contour. Tumor segmentation was evaluated by determining the overlap ratio between computer-determined and manually-drawn outlines. Resulting average overlap ratios on coronal, transverse, and sagittal views were 0.60, 0.57, and 0.58, respectively. Within the groups of mammogram-negative and mammogram-positive cancers, the overlap ratios were 0.63 and 0.56, respectively, on the coronal views; similar results on the other views. The segmentation performance was not found to be correlated to tumor size. Results indicate robustness of the 3D lesion segmentation technique in multi-modality 3D breast imaging.

8670-78, Session PSWed

Quantitative evaluation of automatic methods for lesions detection in breast ultrasound images

Karem D. Marcomini, Homero Schiabel, Antonio A. Carneiro, Univ. de São Paulo (Brazil)

Ultrasound (US) is a useful diagnostic tool to distinguish benign from malignant breast masses, providing more detailed evaluation in dense breasts. Due to the subjectivity in the images interpretation, computer-aid diagnosis (CAD) schemes have been developed, increasing the mammography analysis process to include ultrasound images as complementary exams. As one of most important task in the evaluation of this kind of images is the mass detection and its contours interpretation, automated segmentation techniques have been investigated in order to determine a quite suitable procedure to perform such an analysis. Thus, the main goal in this work is investigating the effect of some processing techniques used to provide information on the determination of suspicious breast lesions as well as their accurate boundaries in ultrasound images. In tests, 80 phantom US images were preprocessed, and 5 segmentation techniques were tested. By using quantitative evaluation metrics the results were compared to a reference image delineated by an experienced radiologist. A self-organizing map artificial neural network has provided the most relevant results, demonstrating high accuracy and low error rate in the lesions representation, corresponding hence to the segmentation process for US images in our CAD scheme under tests.

8670-79, Session PSWed

Texture feature standardization in digital mammography for improving generalizability across devices

Yan Wang, Brad M. Keller, Univ. of Pennsylvania School of Medicine (United States); Yuanjie Zheng, Raymond J. Acciavatti, The Univ. of Pennsylvania Health System (United States); James C. Gee, Univ. of Pennsylvania (United States); Andrew D. A. Maidment, Despina Kontos, The Univ. of Pennsylvania Health System (United States)

Growing evidence suggests a relationship between mammographic texture and breast cancer risk. For studies performing texture analysis on digital mammography (DM) datasets from various DM systems, it is important to evaluate if different systems could introduce inherent differences in the images analyzed and how to construct a texture feature standardization scheme if such differences exist. In this study, we compared two DM systems, the GE Senographe 2000D and DS using a validated breast phantom (Rachel, Gammex). The GE 2000D and DS systems use the same detector, but slightly different automated exposure control (AEC) system, resulting in differences in dose performance. On each system, images of the phantom are acquired five times in the Cranio-Caudal (CC) view with the same clinically optimized phototimer setting. Three classes of texture features, namely grey-level histogram, co-occurrence, and run-length texture features (a total of 26 features), are generated within the breast region from the raw DM images and compared between the two systems. To alleviate system effects, a range of standardization steps are applied: z-score normalization is performed as the initial step to standardize image intensities, and the parameters in generating co-occurrence features are varied to decrease system differences introduced by detector blurring effects. To identify texture features robust to detectors (i.e. the ones minimally affected only by electronic noise), each texture feature within breast region is compared between two systems using the Kolmogorov-Smirnov (K-S) test at 0.05 significance level, where features with $p>0.05$ are deemed as robust to inherent system differences. Our approach could provide a basis for texture feature standardization across different DM imaging systems and provide a systematic methodology for selecting generalizable texture descriptors in breast cancer risk assessment.

8670-80, Session PSWed

A clinically viable capsule endoscopy video analysis platform for automatic bleeding detection

Steven Yi, Heng Jiao, Jean Xie, Peter Mui, Xyken, LLC (United States); Jonathan Leighton, Shabana Pasha, Mayo Clinic Scottsdale (United States); Mahmood Abedi, Gastroenterology Associates of Northern Virginia (United States)

In this paper, we present a novel and clinically valuable software platform for automatic bleeding detection on gastrointestinal (GI) tract from Capsule Endoscopy (CE) videos. Typical CE videos for GI tract run about 8 hours and are manually reviewed by physicians to locate diseases such as bleedings and polyps. As a result, the process is time consuming and is prone to disease miss-finding. While researchers have made efforts to automate this process, however, no clinically acceptable software is available on the marketplace today. Working with our collaborators, we have developed a clinically viable software platform called GISentinel for fully automated GI tract bleeding detection and classification. Major functional modules of the SW include: the innovative graph based NCut segmentation algorithm, the unique feature selection and validation method (e.g. illumination invariant features, color independent features, and symmetrical texture features), and the cascade SVM classification for handling various GI tract scenes (e.g. normal tissue, food particles, bubbles, fluid, and specular reflection). Initial evaluation results on the SW have shown zero bleeding instance miss-finding rate and 4.03% false alarm rate. This work is part of our innovative GI tract disease detection software platform. While the overall SW framework is designed for intelligent finding and classification of major GI tract diseases such as bleeding, ulcer, and polyp from the CE videos, this paper will focus on the automatic bleeding detection functional module.

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8670-81, Session PSWed

A method for quickly and exactly extracting hepatic vein

Qing Xiong, Yong Yuan, Luyao Wang, Huazhong Univ. of Science and Technology (China) and Wuhan National Lab. for Optoelectronics (China); Yanchun Wang, Zhen Li, Daoyu Hu, Huazhong Univ. of Science and Technology (China); Qingguo Xie, Huazhong Univ. of Science and Technology (China) and Wuhan National Lab. for Optoelectronics (China)

It is of vital importance that providing detailed and accurate information about hepatic vein (HV) for liver surgical planning such as pre-operative planning of living donor liver transplantation (LDLT). Due to the different blood flow rate of intra-hepatic vascular systems and the restrictions of CT scan, it is common that HV and hepatic portal vein (HPV) are both filled with contrast medium during the scan and in high intensity in the hepatic venous phase images. As a result, the HV segmentation result obtained from the hepatic venous phase images is always contaminated by HPV which leads to difficulty in accurate HV modeling. In this paper, we propose a method for quickly and exactly extracting HV. Based on the topological structure of intra-hepatic vessels, we analyze the anatomical features of HV and HPV. According to the analysis, three conditions are presented to identify the nodes that connect HV with HPV in the topological structure, thus to distinguish HV from HPV. The method costs less than one minute to extract HV, and it provides a correct and detailed HV model even in the event of variations in vessels. The accuracy of the HV model obtained from our method is over 97% which was evaluated by two experienced radiologists. In the following work, we will extend our work to a comprehensive clinical evaluation and apply this method to actual LDLT surgical planning.

8670-82, Session PSWed

A dimension reduction strategy for improving the efficiency of computer-aided detection for CT colonography

Bowen Song, Stony Brook Univ. (United States); Guopeng Zhang, Fourth Military Medical Univ. (China); Huafeng Wang, Wei Zhu, Zhengrong Liang, Stony Brook Univ. (United States)

Various types of features, e.g., geometric features, texture features, etc., have been introduced for polyp detection and differentiation tasks via computer aided detection and diagnosis (CAD) for computed tomography colonography (CTC). Although these features together cover more information of the data, some of them are statistically highly-related to others, which made the feature set redundant and burdened the computation task of CAD. In this paper, we proposed a new dimension reduction method which combines clustering and principal component analysis (PCA) for false positives (FPs) reduction task. First, we group all the features based on their similarity using hierarchical clustering, and then PCA is employed within each group. Different numbers of principal components are selected from each group to form the final feature set. Support vector machine (SVM) is used to perform the classification. The results show that when 3 principal components were chosen from each group we can achieve an area under the curve of ROC (receiver operating characteristics) of 0.905, which is as high as the original dataset. Meanwhile, the computation time is reduced by 70% and the feature set size is reduce by 77%. It can be concluded that the proposed method captures the most important information of the feature set and the classification accuracy is not affected after the dimension reduction. The result is promising and further investigation, such as automatically threshold setting, are worthwhile and are under progress.

8670-83, Session PSWed

Supine and prone registration of the colon for CT colonography based on dynamic programming technique

Masahiro Oda, Eiichiro Fukano, Nagoya Univ. (Japan); Takayuki Kitasaka, Aichi Institute of Technology (Japan); Tetsuji Takayama M.D., Univ. of Tokushima (Japan); Hirotsugu Takabatake M.D., Minami Sanjyo Hospital (Japan); Masaki Mori M.D., Sapporo Kosei Hospital (Japan); Hiroshi Natori M.D., Keiwakai Nishioka Hospital (Japan); Shigeru Nawano, International Univ. of Health and Welfare Mita Hospital (Japan); Kensaku Mori, Nagoya Univ. (Japan)

This paper proposes a registration method of the colon taken in two positions of CT images. CT colonography-based colon diagnosis using 3D CT images taken in supine and prone positions is time-consuming because a physician has to refer to many CT images for the diagnosis of a patient. Automated synchronization of the observing areas in the two positions is required to reduce the load on physicians. This paper proposes a novel registration method of the colon in two positions to synchronize the observing areas. The registration process utilizes the sharp curved points of the colon centerlines and haustral folds as landmarks. A dynamic programming technique finds correspondence between the haustral fold landmarks in the two positions. The experimental results using six pairs of CT images showed that the mean registration error was 4.70 [mm].

8670-84, Session PSWed

Comparison of Texture Models for Efficient Ultrasound Image Retrieval

Maggi Bansal, Vipul Sharma, Sukhwinder Singh, Panjab Univ. (India)

Due to availability of inexpensive and easily available image capturing devices, the size of digital image collection is increasing rapidly. Thus, there is need to create efficient access methods or retrieval tools to search, browse and retrieve images from large multimedia repositories. More specifically, researchers have been engaged on different ways of retrieving images based on their actual content. In particular, content based image retrieval (CBIR) systems have attracted considerable research and commercial interest in the recent years. In CBIR, visual features characterizing the image content are color, shape & texture. Currently, texture is used to quantify the image content of medical images as it is the most prominent feature that contains information about the spatial distribution of gray levels and variations in brightness. Various texture models like Haralick's Spatial Gray Level Co-occurence Matrix (SGLCM), Gray Level Difference Statistics (GLDS), First-order Statistics (FoS), Statistical Feature Matrix (SFM), Law's Texture Energy Measures (TEM), Fractal features and Fourier Power Spectrum (FPS) features exists in literature. Each of these models visualizes texture in a different way. Retrieval performance depends upon the choice of texture algorithm. Unfortunately, there is no texture model known to work best for encoding texture properties of liver ultrasound images or retrieving most similar images. An experimental comparison of different texture models for content based medical image retrieval (CBMIR) is presented in this paper. For the experiments, liver ultrasound image database is used and the retrieval performance of the various texture models is analysed in detail. The paper concludes with recommendations which texture model performs better for liver ultrasound images. Interestingly, FPS and SGLCM based Haralick's features perform well for liver ultrasound image retrieval and thus can be recommended as a simple baseline for such images.

8670-85, Session PSWed

Computer-aided detection of typhlitis on computed tomographic using visual codebook

Zhuoshi Wei, Weidong Zhang, Jianfei Liu, Jianhua Yao, Shijun Wang, Ronald M. Summers, National Institutes of Health (United States)

Abdominal computed tomographic (CT) can be used to help diagnose many clinically important abnormalities including tumors, infections, injury, and inflammation. Typhlitis is an inflammation and/or necrosis of the cecum, appendix, and ileum in patients. Typhlitis can be debilitating or life threatening, and early detection is essential to initiate proper treatment. In CT, typhlitis is often associated with thickening of the cecal wall presenting special texture pattern on the images. In this paper, we propose an automatic method for typhlitis detection in abdominal CT scans. The suspicious region of typhlitis was first detected using visual codebook constructed by clustering feature vectors from a set of training image patches. The initial detections included false positives located in muscle, kidney and liver. We reduced the false positives by applying masks of these regions obtained from whole-organ segmentation. We tested our method on a CT dataset with 11 cases of typhlitis. The reference standard was labeled using a semi-automated method. For each slice that contained a positive area, region growing was used to segment the area given a manually labeled seed point. Using ratio of overlap with the standard of reference, our method yielded true positive detection (±standard deviation) of 84.1%±19.3% and false positive detection (±standard deviation) of 39.3%±16.0%.

8670-86, Session PSWed

Volumetric detection of flat lesions for minimal-preparation dual-energy CT colonography

Janne J. Näppi, Massachusetts General Hospital (United States)

and Harvard Medical School (United States); Se Hyung Kim, Seoul National Univ. (Korea, Republic of); Hiroyuki Yoshida, Massachusetts General Hospital (United States) and Harvard Medical School (United States)

Studies in computed tomographic colonography (CTC) have indicated that computer-aided detection (CAD) systems miss many flat lesions. We developed a volumetric method for automated detection of flat lesions in dual-energy CTC (DE-CTC). The target region is a thick volumetric region encompassing the colonic mucosa that is calculated by use of a distance transform. Flat lesions are detected by use of volumetric shape features, where the image scale is adapted to the thickness of the target region. False-positive (FP) detections are reduced by use of a random-forest classifier with conventional and dual-energy features. For evaluation, 37 patients were examined by use of DE-CTC with a reduced one-day bowel preparation. The CAD scheme was trained with the DE-CTC data of 12 patients, and it was tested with the DE-CTC data of 25 patients using several thicknesses of the target region. There were 39 lesions ?6 mm in 15 patients, including 7 flat lesions. For the flat lesions, the per-patient sensitivity was 100% at a median of 1 FPs per patient, and the per-lesion sensitivity was 100% at a median of 8 FPs per patient. The thickness of the volumetric target region had a significant effect on the detection accuracy.

8670-87, Session PSWed

A shape constrained MAP-EM algorithm for colorectal segmentation

Huafeng Wang, Stony Brook Medicine (United States); Lihong C. Li, College of Staten Island (United States); Bowen Song, Fangfang Han, Zhengrong Liang, Stony Brook Medicine (United States)

The task of effectively segmenting colon areas in CT images is an important area of interest in medical imaging field. The ability to distinguish the colon wall in an image from the background is a critical step in several approaches for achieving larger goals in automated computer-aided diagnosis(CAD). The related task of polyps detection, the ability to determine which objects or classes of polyps are present in a scene, also relies on colon wall segmentation. When modeling each tissue type as a conditionally independent Gaussian distribution, the tissue mixture fractions in each voxel via the modeled unobservable random processes of the underlying tissue types can be estimated by maximum a posteriori expectation-maximization (MAP-EM) algorithm in an iterative manner. This paper presents, based on the assumption that PV effect could be fully described by a tissue mixture model, a theoretical solution to the MAP-EM segmentation algorithm. However, the MAP-EM may miss some small regions which also belong to the whole colon wall. Combined with shape constrained model, the improved algorithm is able to merge similar regions and reserve small regions. Experiment results show that new approach can refine the jagged-like boundaries and achieve better results than the previously presented MAP-EM algorithm.

8670-88, Session PSWed

Optic disk localization by a robust fusion method

Jielin Zhang, Nanyang Technological Univ. (Singapore); Fengshou Yin, Damon Wing Kee Wong, Jiang Liu, Institute for Infocomm Research (Singapore); Mani Baskaran, Ching-Yu Cheng, Tien Yin Wong, Singapore Eye Research Institute (Singapore)

The optic disk localization plays an important role in developing computer-aided diagnosis (CAD) systems for ocular diseases such as glaucoma, diabetic retinopathy and age-related macula degeneration. In this paper, we propose an intelligent fusion of methods for the localization of the optic disk in retinal fundus images. Three different approaches are developed to detect the location of the optic disk separately. The first method is the maximum crossing point method, which finds the region with the most number of blood vessel crossing points. The second one is the multi-channel thresholding method, targeting the area with the highest intensity. The final method searches the vertical and horizontal region-of-interest separately on the basis of blood vessel structure and neighborhood entropy profile. Finally, these three methods are combined using an intelligent fusion method to improve the overall accuracy.

The proposed algorithm was tested on the STARE database and the ORIGA-light database, each consisting of images with various pathologies. The preliminary result on the STARE database can achieve 81.5%, while a higher result of 99% can be obtained for the ORIGAlight database. The proposed method outperforms each individual approach and state-of-the-art method which utilizes an intensity-based approach. The result demonstrates a high potential for this method to be used in retinal CAD systems.

8670-89, Session PSWed

Region-based multi-step optic disk and cup segmentation from color fundus image

Di Xiao, Australian e-Health Research Ctr. (Australia) and Commonwealth Scientific and Industrial Research Organisation (Australia); Jane Lock, Royal Perth Hospital (Australia); Javier M. Manresa, Clinica Cadarso (Spain); Janardhan Vignarajan, Australian e-Health Research Ctr. (Australia) and Commonwealth Scientific and Industrial Research Organisation (Australia); Mei-Ling Tay-Kearney, Royal Perth Hospital (Australia); Yogesan Kanagasingam, Australian e-Health Research Ctr. (Australia) and Commonwealth Scientific and Industrial Research Organisation (Australia)

Retinal optic cup-disk-ratio (CDR) is a one of important indicators of glaucomatous neuropathy. In this paper, we aims at automated optic cup and disk segmentation and CDR computation. In the past publications, most methods usually used one- or two-step method for optic disk and cup detection or segmentation (as active contour, Hough transform, etc.) by region or gradient information. We propose a novel method for optic disk and cup detection by multiple steps for facing un-uniform illumination and weak boundary information issues in the disk and cup segmenting process.

A series of image preprocessing methods are applied on the HSL lightness image and green image extracted from color fundus image. Visual field mask and optic disk region rectangular mask are extracted for improving computational efficiency in the following optic disk and cup segmentation.

A retinal blood vessel enhancement and detection method we proposed previously is used for blood vessel detection from the green image. By using the blood vessel mask and optic disk rectangular mask, blood vessel removal operation is applied on the lightness image and green image by an efficient blood vessel inpainting algorithm developed.

A 4-quadrant thresholding method is proposed for optic disk segmentation by choosing optimal thresholds for each quadrant from their foreground and background information on the lightness image. An iterative voting method for hole and cavity filling is applied for fine-tuning the optic disk obtained from the 4-quadrant detecting results. A multi-step temporal-nasal cup detection method is proposed for temporal and nasal cup detection in sequence on the green image constrained by the detected optic disk mask. The final cup is the combination of the temporal-nasal cups and blood vessels in the optic disk region and processed by a hole and cavity filling morphological operation.

The experiments have demonstrated the robustness of the method by comparison of the automatic detecting results with the outlining results from two experts. Dice scores of the detected regions and vertical CDRs were used for the comparison.

8670-90, Session PSWed

Automated identification of retina blood vessel using a piecewise line fitting approach

Suicheng Gu, Univ. of Pittsburgh School of Medicine (United States); yi zhen, Ningli Wang, Beijing Tongren Hospital (China); Jiantao Pu, UPMC Presbyterian (United States)

As important landmarks in fundus images, retina blood vessels are associated with many important eye diseases as well as systemic diseases. Accurate identification of the vessels may be useful for quantitative assessment of the severity of the underlying diseases. We developed and tested a novel approach to automatically segment blood vessels in two-dimensional (2D) color fundus images. First, a coherence filter followed by a mean filter is applied to the green channel of the image. The green channel is chosen because of the relative high contrast of the blood vessels on this channel. The coherence filter is designed to enhance the linear structures depicted on the original image, while the mean filter is to reduce the intensity variance among different regions. Whereas the blood vessels appear darker than the surrounding tissues on the fundus image, pixels with low intensity are then retained as points-of-interest (POI) after the application of the two filters. Thereafter, a new line fitting algorithm is employed to identify the line-like structures within the circular POI. In methodology, the proposed line fitting method is less sensitive to image noise and/or artifacts as compared to the traditional least squared fitting approach. The identified lines with higher scores are treated as potential vessels. To quantitatively assess the performance of the proposed method, a public available database DRIVE consisting of 20 test images was selected for preliminary evaluation. Our experiment show that the mean accuracy on these images is 95.7%, which is comparable to the state-of-art approaches.

8670-91, Session PSWed

Automatic conjunctival provocation test combining Hough transform and self-calibrated color measurements in plain photography

Suman R. Bista, RWTH Aachen (Germany) and Univ. de Bourgogne (France); Ralph Mösges, Serkan Dogan, Anatoli Astvatsatourov, Univ. zu Köln (Germany); Thomas M. Deserno, RWTH Aachen (Germany)

The worldwide increase in allergic rhinitis/rhinoconjunctivitis has been reported. It is inflammation of the conjunctiva and its major symptom is redness caused mainly from vasodilation of the peripheral small blood vessels. In this paper, we aim at quantitatively measuring the relative redness of sclera under application of allergen solution. The patient's eye images are taken from commercial digital camera. The iris is robustly localized using a gradient-based Hough circle transform. From the center of the pupil, the region of interest (ROI) within the sclera is extracted using geometric anatomy-based a-priori information. The red color pixels are extracted thresholding the hue, saturation and value (HSV) color space. Then, redness is measured by taking mean of saturation projected into zero hue. Evaluation is performed with 92 images taken from 13 subjects, 8 responders and 5 non-responders, which were classified according to an experienced otorhinolaryngologist. Provocation is performed with 100, 1000 and 10,000 AU/ml allergic solution and normalized to control images without provocation. Relative redness yields 1.14, 1.30, and 1.60 for responders and 1.04, 1.12, and 1.11 for non-responders, indicating that our method is suitable as reliable endpoint in controlled clinical trials. None of the images failed in Hough transform and pupil center detection. Future work will further automate the segmentation procedure using anatomic heuristics. Color reference pattern might be applied to normalize the color values, obtain absolute measures, and lower the standard deviation of measurements. However, the method already has been proven its accuracy.

8670-92, Session PSWed

Training set optimization and classifier performance in a top-down diabetic retinopathy screening system

Jeffrey C. Wigdahl, Carla P. Agurto Rios, Victor Murray, Eduardo S. Barriga, Peter Soliz, VisionQuest Biomedical, LLC (United States)

Diabetic Retinopathy (DR) affects more than 4.4 million Americans age 40 and over. Automatic screening for DR has shown to be an efficient and cost effective way to lower the burden on the ophthalmologist. Triaging diabetic patients ensures timely care for those presenting with DR. Several supervised algorithms have been developed to detect pathologies related to DR, but little work has been done in determining the size of the training set that optimizes an algorithm's performance. In this paper we analyze the effect of the training sample size in the performance of a top-down DR screening algorithm for different types of statistical classifiers. Results are based on the partial least squares (PLS), support vector machines (SVM), k-nearest neighbor (kNN), and Naïve Bayes classifiers. Our dataset consisted of digital retinal images collected from a total of 745 cases (595 controls, 150 with DR). We varied the number of normal controls in the training set while keeping the number of abnormals constant and repeated each run 10 times using randomized training sets. Results show an increasing performance in terms of area under de ROC curve (AUC), with similar trends for each of the classifiers. Of these, PLS has the highest average AUC. Lower standard deviation and a flattening of the AUC curve gives evidence that there is a limit to the learning ability of the classifiers and an optimal number of cases to train on.

8670-93, Session PSWed

White matter injury detection in neonatal MRI

Irene Cheng, Nasim Hazari, Amirhossein Firouzmanesh, Rui Shen, Univ. of Alberta (Canada); Ken Poskitt, BC Children's Hospital (Canada); Steven Miller, The Hospital for Sick Children (SickKids) (Canada); Anup Basu, Univ. of Alberta (Canada)

Early detection of white matter injury in premature newborns can facilitate timely clinical treatments reducing the potential risk of later developmental deficits. It was reported that there were more than 5% premature newborns in British Columbia, Canada, among which 5-10% exhibited major motor deficits and 25-50% exhibited significant developmental and visual deficits. With the advancement of computer assisted detection systems, it is possible to automatically identify white matter injuries, which are found inside the grey matter region of the brain. Atlas registration has been suggested in the literature to distinguish grey matter from the soft tissues inside the skull. However, our subjects are premature newborns delivered at 24 to 32 weeks of gestation. During this period, the grey matter undergoes rapid changes and differs significantly from one to another. Besides, not all detected white spots represent injuries. Additional neighborhood information and expert input are required for verification. In this paper, we propose a white matter feature identification system for premature newborns, which is composed of several steps: (1) Candidate white matter segmentation; (2) Feature extraction from candidates; (3) Validation with data obtained at a later stage on the children; and (4) Feature confirmation for automated detection. The main challenge of this work lies in segmenting white matter injuries from noisy and low resolution data. Our approach integrates image fusion and contrast enhancement together with a fuzzy segmentation technique to achieve promising results. Other applications, such as brain tumor and intra-ventricular haemorrhage detection can also benefit from our approach.

8670-94, Session PSWed

Risk assessment of sleeping disorder breathing based on upper airway centerline evaluation

Noura Alsufyani, Rui Shen, Irene Cheng, Paul Major, Univ. of Alberta (Canada)

One of the most important breathing disorders in childhood is obstructive sleep apnea syndrome which affects 2–3% of children, and the reported failure rate of surgical treatment was as high as 54%. A possible reason in respiratory complications is having reduced dimensions of the upper airway which are further compressed when muscle tone is decreased during sleep. In this study, we use Cone-beam computed tomography (CBCT) to assess the location or cause of the airway obstruction. To date, all studies analyzing the upper airway in subjects with Sleeping Disorder Breathing were based on linear, area, or volumetric measurements, which are global computations and can easily ignore local significance. Skeletonization was initially introduced as a 3D modeling technique by which representative medial points of a model are extracted to generate centerlines for evaluations. Although centerlines have been commonly used in guiding surgical procedures, our novelty lies in comparing its geometric properties before and after surgeries. We apply 3D data refinement, registration and projection steps to quantify and localize the geometric deviation in target airway regions. Through cross validation with corresponding subjects' therapy data, we expect to quantify the tolerance threshold beyond which reduced dimensions of the upper airway are not clinically significant. The ultimate goal is to utilize this threshold to identify patients at risk of complications. Outcome from this research will also help establish a predictive model for training and to estimate treatment success based on airway measurements prior to intervention. Preliminary results demonstrate the feasibility of our approach.

8670-96, Session PSWed

Statistical shape modeling of human cochlea: alignment and principal component analysis

Anton A. Poznyakovskiy, Thomas Zahnert M.D., Universitätsklinikum Carl Gustav Carus Dresden (Germany); Björn Fischer, Fraunhofer-Institut für Zerstörungsfreie Prüfverfahren (Germany); Nikoloz Lasurashvili M.D., Universitätsklinikum Carl Gustav Carus Dresden (Germany); Yannis Kalaidzidis, Max-Planck-Institut für molekulare Zellbiologie und Genetik (Germany); Dirk Mürbe M.D., Universitätsklinikum Carl Gustav Carus Dresden (Germany)

The modeling of the cochlear labyrinth in living subjects is hampered by insufficient resolution of available clinical imaging methods. These methods, such as digital volume tomography, provide resolutions higher than 125 µm. This is insufficient to record the position of basilar membrane and, as a result, keep apart even the scala tympani from other scalae. This problem could be avoided by the means of atlas-based segmentation, whose seed can be obtained from cadaveric cochleae. They can endure higher radiation loads and, conversely, provide better-resolved images. The resulting surface can be used as the seed for atlas-based segmentation. To serve this purpose, we have developed a statistical shape model (SSM) of human scala tympani based on segmentations obtained from 10 µCT image stacks. After segmentation, we aligned the resulting surfaces using Procrustes alignment. This algorithm was slightly modified to accommodate single models with nodes which do not necessarily correspond to salient features and vary in number between models. We have established correspondence by mutual proximity between nodes. Rather than using the standard Euclidean norm, we have applied an alternative logarithmic norm to improve outlier treatment. The minimization was done using hill climbing. We have also split the surface nodes along an octree to reduce computation cost. Subsequently, we have computed the mean shape and the modes of variations between corresponding nodes. We expect the resulting model to provide not only better understanding in interindividual variations of cochlear anatomy, but also a step towards individual models for pre-operative diagnostics prior to cochlear implant insertions.

8670-97, Session PSWed

Survival time prediction of patients with glioblastoma multiforme tumors using spatial distance measurement

Mu Zhou, Lawrence O. Hall, Dmitry B. Goldgof, Univ. of South Florida (United States); Robert J Gillies, H. Lee Moffitt Cancer Center and Research Institute (United States); Robert A. Gatenby, H. Lee Moffitt Cancer Ctr. & Research Institute (United States)

Regional variations in tumor blood flow and necrosis are commonly observed in cross sectional imaging of clinical cancers. Several recent studies using molecular analysis of cells from different sites in the same tumor have demonstrated that intratumoral evolution is common and will likely contribute significantly to variations in survival and response to therapy. We hypothesize that radiologically-defined regional variations in tumor characteristics can be used to define distinct "habitats" that reflect the underlying evolutionary dynamics. We present an experimental framework to extract spatially explicit variations in tumor features (habitats) from multiple MRI sequences performed on patients with glioblastoma-multiforme (GBM). The MRI sequences consist of post gadolinium T1-weighted, FLAIR, and T2-weighted feature images from The Cancer Genome Atlas (TCGA). Initial tumor identification was performed by manually drawing a mask on a T1-weighted post contrast image slice. The preliminarily extracted tumor was segmented into an enhancing and non-enhancing region by the Otsu segmentation algorithm, followed by a mask mapping procedure onto the corresponding FLAIR and T2-weighted images. Then Otsu was applied on the FLAIR and T2 images separately. The proposed distance measurement applied to these segmented regions shows that the created Distance Features (DF) can be used to create a strong predictor of survival time. Results from the initial cohort of 16 cases demonstrate that slow progressing tumors have lower DF values (are less heterogeneous) compared to those with fast progression and short survival times.

8670-98, Session PSWed

Automated segmentation of brain ventricles in unenhanced CT of patients with ischemic stroke

Xiaohua Qian, Duke Univ. (United States); Jiahui Wang, The Univ. of North Carolina at Chapel Hill (United States); Qiang Li, Shanghai Advanced Research Institute (China)

We are developing an automated method for detection and quantification of ischemic stroke in computed tomography (CT). Ischemic stroke often connects to brain ventricle, therefore, ventricular segmentation is an important and difficult task when stroke is present, and is the topic of this study. We first obtained the brain region by stripping the skull, and corrected inclination angle of brain by aligning midline of brain with the vertical center line of a slice. We then estimated the intensity range of the ventricles by use of the k-means method, and obtained two segmented images of the ventricle using two thresholds selected from the estimated intensity range. One segmented ventricle might include ventricle itself and nearby stroke and the other mainly includes ventricle, therefore, the core part of nearby stroke can be extracted and removed using image difference technique. An adaptive template matching algorithm was further employed to identify objects in the fore-mentioned segmentation, and the largest connected component was identified and considered as ventricle. Finally, we refined the ventricular region by means of anatomic knowledge and morphologic feature analysis. We applied our method

to 25 unenhanced CT scan with stroke. Our method achieved average Dice index, sensitivity, and specificity of 95.1%, 97.0%, and 99.8% for the entire ventricular regions. The method has potential for detection and quantification of stroke and other neurologic diseases.

8670-99, Session PSWed

Multi-atlas based segmentation of the parotid glands of MR images in patients following head-and-neck cancer radiotherapy

Guanghui Cheng, China-Japan Union Hospital of Jilin Univ. (China); Xiaofeng Yang, Emory Univ. (United States); Ning Wu, China-Japan Union Hospital of Jilin Univ. (China); Zhijian Xu, China-Japan Union Hospital of Jilin University (China); Hongfu Zhao, China-Japan Union Hospital of Jilin Univ. (China); Tian Liu, Emory Univ. (United States)

Xerostomia (dry mouth), resulting from radiation damage to the parotid glands, is one of the most common and distressing side effects of head-and-neck cancer radiotherapy. Recent MRI studies have demonstrated that the volume reduction of parotid glands is an important indicator for radiation damage and dry mouth. In the clinic, parotid volume evaluation is exclusively based on physicians' manual contours. However, manual contouring is time-consuming and prone to inter-observer and intra-observer variability. In this report, we developed a fully automated, multi-atlas-based method for parotid-glands segmentation in 3D head-and-neck MR images. The proposed method applied a hybrid deformable image registration to map multiple patients' images to the new subject, utilized the transformation to the corresponding segmented parotid glands; then used the multiple patient-specific pairs of registered head-and-neck MR images and transformed parotid glands to train the support vector machine (SVM), and finally used the trained SVM to segment the parotid gland of the new subject. Our segmentation algorithm was tested with head-and-neck MRIs of 5 patients following radiotherapy for the nasopharyngeal cancer. The average parotid-gland volume overlapped 85% between the automatic segmentations and the physicians' manual contours. In conclusion, we have developed an automatic multi-atlas based segmentation algorithm to contour post-radiotherapy parotid glands, and demonstrated the accuracy of the proposed method.

8670-100, Session PSWed

Automated detection of abnormalities in paranasal sinus on dental panoramic radiographs by using contralateral subtraction technique based on mandible contour

Shintaro Mori, Nihon Univ. (Japan); Takeshi Hara, Motoki Tagami, Chicako Muramatsu, Gifu Univ. School of Medicine (Japan); Takashi Kaneda, Nihon Univ. (Japan); Akitoshi Katsumata, Asahi Univ. (Japan); Hiroshi Fujita, Gifu Univ. School of Medicine (Japan)

Inflammation in paranasal sinus sometimes becomes chronic to take long terms for the treatment. The finding is important for the early treatment, but general dentists may not recognize the findings because they focus on teeth treatments. The purpose of this study was to develop a computer-aided detection (CAD) system for the inflammation in paranasal sinus on dental panoramic radiographs (DPRs) by using the mandible contour and to demonstrate the potential usefulness of the CAD system by means of receiver operating characteristic analysis. The detection scheme consists of 3 steps: 1) Contour extraction of mandible, 2) Contralateral subtraction, and 3) Automated detection. The Canny operator and active contour model were applied to extract the edge at the first step. At the subtraction step, the right region of the extracted contour image was flipped to compare with the left region. Mutual information between two selected regions was obtained to estimate the shift parameters of image registration. The subtraction images were generated based on the shift parameter. Rectangle regions of left and right paranasal sinus on the subtraction image were determined based on the size of mandible. The abnormal side of the regions was determined by taking the difference between the averages of each region. Thirteen readers were responded to all cases without and with the automated results. The averaged AUC of all readers was increased from 0.69 to 0.73 with statistical significance (p=0.032) when the automated detection results were provided. In conclusion, the automated detection method based on contralateral subtraction technique improves readers' interpretation performance of inflammation in paranasal sinus on DPRs.

8670-101, Session PSWed

Recognition of upper airway and surrounding structures at MRI in pediatric PCOS and OSAS

Yubing Tong, Jayaram K. Udupa, Dewey Odhner, The Univ. of Pennsylvania Health System (United States); Sanghun Sin, Raanan Arens, Children's Hospital at Montefiore (United States)

Obstructive Sleep Apnea Syndrome (OSAS) is common in obese children with risk being 4.5 fold compared to normal control subjects. Polycystic Ovary Syndrome (PCOS) has recently been shown to be associated with OSAS that may further lead to significant cardiovascular and neuro-cognitive deficits. We are investigating image-based biomarkers to understand the architectural and dynamic changes in the upper airway and the surrounding hard and soft tissue structures via MRI in obese teenage children to study OSAS. At the previous SPIE conferences, we presented methods underlying Fuzzy Object Models (FOMs) for Automatic Anatomy Recognition (AAR) based on CT images of the thorax and the abdomen. The purpose of this paper is to demonstrate that the AAR approach is applicable to a different body region and image modality combination, namely in the study of upper airway structures via MRI.

FOMs were built hierarchically, the smaller sub-objects forming the offspring of larger parent objects. FOMs encode the uncertainty and variability present in the form and relationships among the objects over a study population. Totally 11 basic objects (17 including composite) were modeled. Automatic recognition for the best pose of FOMs in a given image were implemented by using three methods – a one-shot method that does not require search, a searching method based on Fisher linear discriminant (FLD), and a b-scale energy optimization strategy. In all, 30 multi-fold cross validation experiments based on 15 patient MRI data sets were carried out to assess the accuracy of recognition. The results indicated that the objects can be recognized with an average location error of less than 9 mm and in less than 8 seconds per object. The method shows potential for automated object segmentation of upper airway and surrounding structures at MRI.

8670-102, Session PSWed

An optimal set of landmarks for metopic craniosynostosis diagnosis from shape analysis of pediatric CT scans of the head

Carlos Sanchez Mendoza, Children's National Medical Ctr. (United States) and Univ. de Sevilla (Spain); Nabile M. Safdar, Emmarie Myers, Tanakorm Kittisarapong, Gary F. Rogers, Marius G. Linguraru, Children's National Medical Ctr. (United States)

Craniosynostosis (the premature fusion of skull sutures) is a severe condition present in one of every 2000 newborns. Metopic craniosynostosis, accounting for between 5-15% of cases, is diagnosed qualitatively in terms of skull shape abnormality, a subjective call of the surgeon. In this paper we introduce a new quantitative diagnostic

feature for metopic craniosynostosis derived optimally from systematic shape analysis of CT scans of the skull. We built a robust shape analysis pipeline that is capable of obtaining local shape differences in comparison to normal anatomy. Spatial normalization using 7-degree-of-freedom registration of the base of the skull is followed by a novel bone labeling strategy based on graph-cuts according to labeling priors. The statistical shape model built from 94 normal subjects allows matching a metopic craniosynostosis patient's anatomy to its most similar normal subject in the training set. Subsequently, the computation of local deformation from a normal subject allows for characterization of the point of maximum deformation on each of the frontal bones adjacent to the metopic suture, and on the suture itself. Our results show that the deformations at these three locations vary significantly ($p < 0.001$) between abnormal/normal subjects and that an accurate diagnosis can be achieved using linear regression from these few measurements with an area-under-the-receiver-operating-characteristic-curve of 0.97.

8670-103, Session PSWed

Characterization of T2 hyperintensity lesions in patients with mild traumatic brain injury

Jesus J. Caban, Walter Reed National Military Medical Ctr. (United States) and National Institutes of Health (United States); Savannah Green, Franklin and Marshall College (United States); Gerard Riedy, Walter Reed National Military Medical Ctr. (United States)

Mild traumatic brain injury (TBI) is often an invisible injury that is poorly understood and can be difficult to diagnose. Recent neuroimaging studies on patients diagnosed with mild TBI (mTBI) have demonstrated an increase in hyperintense brain lesions on T2-weighted MR images. This paper presents an in-depth analysis of the multi-modal and morphological properties of T2 hyperintensity lesions among service members diagnosed with mTBI. A total of 790 punctuate T2 hyperintensity lesions from 89 mTBI subjects were analyzed and used to characterize the lesions based on different quantitative measurements. Morphological analysis shows that on average, T2 hyperintensity lesions have volumes of 23mm^3 (±24.75), a roundness measure of 0.83 (±0.08) and an elongation of 7.90 (±2.49). The frontal lobe lesions demonstrated significantly more elongated lesions when compared to other areas of the brain.

8670-104, Session PSWed

Prediction of the potential clinical outcomes for post-resuscitated patients after cardiac arrest

Sungmin Hong, Bojun Kwon, Seoul National Univ. (Korea, Republic of); Il Dong Yun, Hankuk Univ. of Foreign Studies (Korea, Republic of); Sang Uk Lee, Seoul National Univ. (Korea, Republic of); Kyuseok Kim, Joonghee Kim, Department of Emergency Medicine, Seoul National University Bundang Hospital (Korea, Republic of)

Cerebral injuries after cardiac arrest are serious causes for morbidity. Many previous researches in the medical society have been proposed to prognosticate the functional recoveries of post-resuscitated patients after cardiac arrest, but the validity of suggested features and the automation of prognostication have not been made yet. This paper presents the automatic classification method which predicts the potential clinical outcomes of post-resuscitated patients who suffered from cardiac arrest. The global features and the local features are adapted from the researches from the medical society. The global features, which are consisted of the percentage of the partial volume under the uniformly increasing thresholds, represent the global tendency of apparent diffusion coefficient value in a diffusion weighted image. The local features are localized and measured on the refined local apparent diffusion coefficient minimal points. The local features represent the ischemic change of small areas in a brain. The features are trained and classified by the random forest method, which have been widely used in the machine learning society for classification. The validity of features is automatically evaluated during the classification process. The proposed method achieved the 0.129 false positive rate while maintaining the perfect true-positive rate. The area-under-curve of the proposed method was 0.9516, which showed the feasibility and the robustness of the proposed method.

8670-105, Session PSWed

A novel approach of computer-aided detection of focal ground-glass opacity in 2D lung CT images

Song Li, Xiabi Liu, Ali Yang, Kunpeng Pang, Beijing Institute of Technology (China); Chunwu Zhou, Xinming Zhao, Yanfeng Zhao, Chinese Academy of Medical Sciences (China)

Focal Ground-Glass Opacity (fGGO) plays an important role in diagnose of lung cancers. This paper proposes a novel approach for detecting fGGOs in 2D lung CT images. The approach consists of two stages: extracting regions of interests (ROIs) and labeling each ROI as fGGO or non-fGGO. In the first stage, we use the techniques of Otsu thresholding and mathematical morphology to segment lung parenchyma from lung CT images and extract ROIs in lung parenchyma. In the second stage, a Bayesian classifier is constructed based on the Gaussian mixture Modeling (GMM) of the distribution of visual features of fGGOs to fulfill ROI identification. The parameters in the classifier are estimated from training data by the discriminative learning method of Max-Min posterior Pseudo-probabilities (MMP). A genetic algorithm is further developed to select compact and discriminative features for the classifier. We evaluated the proposed fGGO detection approach through 5-fold cross-validation experiments on a set of 69 lung CT scans that contain 70 fGGOs. The proposed approach achieves the detection sensitivity of 85.7% at the false positive rate of 2.5 per scan, which proves its effectiveness. We also demonstrate the usefulness of our genetic algorithm based feature selection method and MMP discriminative learning method through comparing them with without-selection strategy and Support Vector Machines (SVMs), respectively, in the experiments.

8670-106, Session PSWed

Multimodal 3D PET/CT system for bronchoscopic procedure planning

William E. Higgins, Ronnarit Cheirsilp, The Pennsylvania State Univ. (United States)

Integrated positron emission tomography (PET) / computed-tomography (CT) scanners give 3D multimodal data sets of the chest. Such data sets offer the potential for more complete and specific identification of suspect lesions and lymph nodes for lung-cancer assessment. This in turn enables better planning of staging bronchoscopies. The richness of the data, however, makes the visualization and planning process difficult. We present an integrated multimodal 3D PET/CT system that enables efficient region identification and bronchoscopic procedure planning. The system first invokes a series of automated 3D image-processing methods to construct a 3D chest model. Next, the user interacts with a set of interactive multimodal graphical tools that facilitate procedure planning for specific regions of interest (ROIs): 1) an interactive region candidate list that enables efficient ROI viewing in all tools; 2) a virtual PET/CT bronchoscopy rendering with SUV quantitative visualization to give a "fly through" endoluminal view of prospective ROIs; 3) transverse, sagittal, coronal multi-planar reformatted (MPR) views of the raw CT, PET, and fused CT-PET data; and 4) interactive multimodal volume/surface rendering to give a 3D perspective of the anatomy and candidate ROIs. In addition the ROI selection process is driven by a semi-automatic multimodal method for region identification. In this way, the system provides both global and local information to facilitate more specific ROI

identification and procedure planning. We present results to illustrate the system's function and performance.

8670-107, Session PSWed

Content-based image retrieval for interstitial lung diseases using classification confidence

Jatindra K. Dash, Sudipta Mukhopadhyay, Indian Institute of Technology Kharagpur (India); Nidhi Prabhakar, Mandeep Garg, Niranjan Khandelwal, Post Graduate Institute of Medical Education & Research (India)

Content Based Image Retrieval (CBIR) system could exploit the wealth of High-Resolution Computed Tomography (HRCT) data stored in the archive by finding similar images or reference to assist radiologists for self learning and differential diagnosis of Interstitial Lung Diseases (ILDs). HRCT findings of ILDs are classified into several categories based on their texture like appearances. Therefore, analysis of ILDs is considered as a texture analysis problem. Many approaches have been proposed for CBIR of lung images those use texture as primitive visual content. This paper presents a new approach to CBIR for ILDs. The proposed approach makes use of a trained neural network (NN) to find the output class label of query image. The degree of confidence of the NN classifier is analyzed using Naive Bayes classifier that dynamically takes a decision on the size of the search space to be used for retrieval. The proposed approach is compared with three simple distance based and one classifier based texture retrieval approaches. The experimental results show that the proposed technique achieved highest average percentage precision of 92.60% with lowest standard deviation of 20.82%.

8670-108, Session PSWed

3D texture analysis of solitary pulmonary nodules using co-concurrence matrix from volumetric lung CT images

Ashis K. Dhara, Sudipta Mukhopadhyay, Indian Institute of Technology Kharagpur (India); Niranjan Khandelwal, Postgraduate Institute of Medical Education & Research (India)

In this paper we have investigated a new approach for texture features extraction using co-occurrence matrix from volumetric lung CT images. Traditionally texture analysis is performed in 2D and is suitable for images collected from 2D imaging modality. The use of 3D imaging modalities provide the scope of texture analysis from 3D object and 3D texture feature are more realistic to represent 3D object. In this work, Haralick's 14 texture features are extended in 3D and computed from volumetric data considering 26 neighbors. The optimal texture features to characterize the internal structure of Solitary Pulmonary Nodules (SPN) are selected based on area under curve (AUC) values of ROC curve and p values from 2-tailed Student's t test. The selected texture feature in 3D to represent SPN can be used in efficient Computer Aided Diagnostic (CAD) design plays an important role in fast and accurate lung cancer screening. The reduced number of input features to the CAD system will decrease the computational time and classification errors caused by irrelevant features. In the present work, SPN are classified from Ground Glass Nodule (GGN) using Artificial Neural Network (ANN) classifier considering top five 3D texture features and top five 2D texture features separately. Classification using 3D texture features and 2D texture features provide 97.17% and 89.1% accuracy respectively. The classification is performed on 92 SPN and 25 GGN from Imaging Database Resources Initiative (IDRI) public database.

8670-109, Session PSWed

A new 3D texture feature based computer-aided diagnosis approach to differentiate pulmonary nodules

Fangfang Han, Huafeng Wang, Bowen Song, Stony Brook Medicine (United States); Guopeng Zhang, Hong-Bing Lu, Fourth Military Medical Univ. (China); William Moore M.D., Stony Brook Medicine (United States); Hong Zhao, Northeastern Univ. (China); Zhengrong Liang, State University of New York at Stony Brook (United States)

To distinguish the pulmonary nodules from benign to malignant is of much importance in Computer-Aided Diagnosis (CADx) of lung diseases. Compared to many previous methods based on shape or growth assessing of nodules, this proposed three-dimensional (3D) texture feature based approach extracted fifty kinds of 3D textural features from gray level, gradient and curvature co-occurrence matrix, and more derivatives of the volume data of the nodules. To evaluate the presented approach, the datasets of Lung Image Database Consortium (LIDC) were downloaded. Each case of the database contains an annotation file which indicates the diagnosis results from four radiologists. In order to avoid partial-volume (PV) effect, interpolation process was carried out to the volume data with slice thickness more than 1mm, and thus we had categorized the datasets to five groups to validate the proposed approach, one group of thickness less than 1mm, two types of thickness range from 1mm to 1.25mm and greater than 1.25mm (each type contains two groups, one with interpolation and the other without). Since support vector machine (SVM) is based on statistical learning theory and aims to learning for predicting future data, so we chose it as the classifier to perform the differentiation task. The measure on the performance was based on the area under the curve (AUC) of Receiver Operating Characteristics (ROC). From 284 nodules (122 malignant and 162 benign ones), the experiments reported a mean of 0.9051 and standard deviation of 0.0397 for the AUC or Az value on average over 100 randomizations.

8670-110, Session PSWed

Integrating shape into an interactive segmentation framework

Sridharan Kamalakannan, Texas Tech Univ. (United States) and National Library of Medicine (United States); Benjamin Bryant, Hamed Sari-Sarraf, Texas Tech Univ. (United States); Rodney Long, Sameer Antani, George R. Thoma, National Library of Medicine (United States)

This paper presents a novel interactive annotation tool built on a well-known user-steered segmentation framework, namely Intelligent Scissors (IS). IS, posed as a shortest path problem, is essentially driven by lower level image based features. All the higher level knowledge about the problem domain is obtained from the user through mouse clicks. The proposed work integrates one higher level feature, namely shape up to a rigid transform, into the IS framework; thus, reducing the burden on the user and the subjectivity involved in the annotation procedure, especially during instances of occlusions, broken edges, noise and spurious boundaries. The above mentioned scenarios are commonplace in medical image annotation applications and, hence, such a tool will be of immense help to the medical community. As a first step, an offline training procedure is performed in which a mean shape and the corresponding shape variance is computed by registering training shapes up to a rigid transform in a level-set framework. The user starts the interactive segmentation procedure by providing a training segment, which is a part of the target boundary. A partial shape matching scheme based on a scale-invariant curvature signature is employed in order to extract shape correspondences and subsequently predict the shape of the unsegmented target boundary. A 'zone of confidence' is generated for the predicted boundary to accommodate shape variations. The method is evaluated on segmentation of digital chest x-ray images

for lung annotation which is a crucial step in developing algorithms for screening for Tuberculosis.

8670-111, Session PSWed

Extraction method of interlobar fissure based on multi-slice CT images

Mikio Matsuhiro, Hidenobu Suzuki, Yoshiki Kawata, Noboru Niki, Junji Ueno, Univ. of Tokushima (Japan); Yasutaka Nakano, Emiko Ogawa, Shiga Univ. of Medical Science (Japan); Shigeo Muro, Michiaki Mishima, Kyoto Univ. (Japan); Hironobu Ohmatsu, National Cancer Ctr. Hospital East (Japan); Noriyuki Moriyama, National Cancer Ctr. (Japan)

METHOD

Extraction method of interlobar fissure is described as follows.

Step1: Extraction of coarse interlobar fissure.

CT images are enhanced by maximum principal curvature of 4D curvature. We extract interlobar fissure's candidate area from maximum principal curvature of 4D curvature by threshold processing. We apply surface thinning interlobar fissure's candidate area. So we calculate 3D digital topology. We extract coarse interlobar fissure using normal vector of surface.

Step2: Extraction of fine interlobar fissure

The target domain is the area around the coarse interlobar fissure. We enhance the target domain based on normal vector. We emphasis maximum principal curvature of 4D curvature using normal vector in the target domain. We extract fine interlobar fissure in target domain.

Step3: Correction of interlobar fissure

We make mathematical formulas for construct surface using normal vector and position of fine interlobar fissure. We interpolate interlobar fissure, using mathematical formulas for construct surface.

RESULT

The extraction method of interlobar fissure was trained by multi-slice CT images of 20 normal cases and 10 lung disease cases. We applied the extraction method of interlobar fissure to other multi-slice CT images of 20 normal cases and 30 lung disease cases. Our normal cases CT data are acquired with Toshiba Aquilion. The slice thickness is 1.0 mm, electric current is 100-500 mA, voltage is 120 kV, and 300 average number of slices per scan. Each image slice is 512x512 pixels, and pixel size is 0.625-0.647mm. Our lung disease cases CT data are acquired with Toshiba Aquilion. The slice thickness is 0.5 mm or 1.0 mm, electric current is 100-500 mA, voltage is 120 kV, and 300-700 number of slices per scan. Each image slice is 512x512 pixels, and pixel size is 0.625-0.683mm. To evaluate the accuracy of the extracted interlobar fissure, we examined the recall rate and precision rate with the manual marking data. The average recall rate of interlobar fissure for normal cases was 91.7%, for lung disease cases was 91.5%. The average precision rate of interlobar fissure for normal cases was 96.0%, for lung disease cases was 94.5%.

and precision rate of interlobar fissure for normal cases and disease cases were shown in Table1.

8670-112, Session PSWed

Automated lung field segmentation in CT images using mean shift clustering and geometrical features

Sudipta Mukhopadhyay, Chanukya K. Chama, Prabir K. Biswas, Ashis K. Dhara, Indian Institute of Technology Kharagpur (India); Niranjan Khandelwal, Mahendra Kasuvinahally Madaiah, Postgraduate Institute of Medical Education & Research (India)

Automated lung field segmentation in computed tomography (CT) images using mean shift clustering and geometrical features has been proposed. Lung field segmentation (LFS) is prerequisite for development of automated computer aided diagnosis system from chest CT scans. Intensity based algorithm such as mean shift (MS) segmentation on CT images for delineation of lung field is reported as the best technique in terms of speed and accuracy in the literature. However, in presence of high dense abnormalities, accurate and automated delineation of lung field becomes difficult. An improved lung field segmentation using mean shift clustering followed by geometric property based techniques such as lung ROI created from symmetric centroid map of two normal subjects, false positives (FP) reduction module and false negatives (FN) reduction module is proposed. The performance of the proposed method is validated on images obtained from LIDC-IDRI public database of 17 subjects containing nodular pattern and from local database of 26 subjects consisting interstitial lung diseases (ILD) patterns obtained from PGIMER, Chandigarh. The proposed method has achieved mean Modified Hausdroff distance (MHD) in mm 1.46 4.31, mean dice similarity coefficient (DSC) of 0.9855 0.0288, sensitivity of 0.9771 0.0433, specificity 0.9992 0.0014 for 133 normal images from 32 subjects and MHD in mm of 7.53 12.33, DSC of 0.8839 0.1774, sensitivity of 0.8344 0.2122, mean specificity 0.9972 0.0059 for 296 abnormal images from 43 subjects.

8670-113, Session PSWed

Semi-quantitative assessment of pulmonary perfusion in children using dynamic contrast-enhanced MRI

Catalin Fetita, TELECOM & Management SudParis (France); William Thong, Ecole Polytechnique de Montréal (Canada); Phalla Ou, Hôpitaux Necker-Enfants Malades (France)

This paper addresses the study of semi-quantitative assessment of pulmonary perfusion acquired from dynamic contrast-enhanced magnetic resonance imaging (DCE-MRI) in a population mainly composed of children with pulmonary malformations. The automatic analysis approach proposed is based on the indicator-dilution theory introduced in 1954. First, a robust method is developed to segment the pulmonary artery and the lungs from anatomical MRI data, exploiting 2D and 3D mathematical morphology operators. Second, the time-dependent contrast signal of the lung regions is deconvolved by the arterial input function for the assessment of the local hemodynamic system parameters, ie. mean transit time, pulmonary blood volume and pulmonary blood flow. The discrete deconvolution method implements here a truncated singular value decomposition (tSVD) method. Parametric images for the entire lungs are generated as additional elements for diagnosis and quantitative follow-up. The preliminary results attest the feasibility of perfusion quantification in pulmonary DCE-MRI and open an interesting alternative to scintigraphy for this type of evaluation, to be considered at least as a preliminary decision in the diagnostic due to the large availability of the technique and to the non-invasive aspects.

8670-114, Session PSWed

Learning-based image preprocessing for robust computer-aided detection

Lakshminarasimhan Raghupathi, Pandu R. Devarakota, Siemens Information Systems Ltd. (India); Matthias Wolf, Siemens Medical Solutions USA, Inc. (United States)

Recent studies have shown that low dose computed tomography (LDCT) can be an effective screening tool to reduce lung cancer mortality. Computer-aided detection (CAD) would be a beneficial second reader for radiologists in such cases. Studies demonstrate that while iterative reconstructions (IR) improve LDCT diagnostic quality, it however degrades CAD performance significantly (increased false positives) when applied directly. For improving CAD performance, solutions such as retraining with newer data or applying a standard preprocessing

technique may not be suffice due to high prevalence of CT scanners and non-uniform acquisition protocols. Here, we present a learning based framework that can adaptively transform a wide variety of input data to boost an existing CAD performance. This not only enhances their robustness but also their applicability in clinical workflows. Our solution consists of applying a suitable pre-processing filter automatically on the given image based on its characteristics. This requires the preparation of ground truth (GT) of choosing a right filter resulting in improved CAD performance. Accordingly, we propose an efficient consolidation process with a novel metric. Using key anatomical landmarks, we then derive consistent feature descriptors for the classification scheme that then uses a priority mechanism to automatically choose an optimal preprocessing filter. We demonstrate CAD performance improvement using hospital-scale datasets acquired from North America, Europe and Asia. Though we demonstrated our results for a lung nodule CAD, this scheme is straightforward to extend to other post-processing tools dedicated to other organs and modalities.

8670-115, Session PSWed

Curved planar reformation and optimal path tracing (CROP) method for false positive reduction in computer-aided detection of pulmonary embolism CTPA

Chuan Zhou, Heang-Ping Chan, Yanhui Guo, Jun Wei, Lubomir M. Hadjiiski, Baskaran Sundaram, Smita Patel, Jean W. Kuriakose, Ella A. Kazerooni, Univ. of Michigan Health System (United States)

We developed a new curved planar reformation (CPR) and optimal path tracing (CROP) method to facilitate feature extraction and false positive (FP) reduction and improve our PE detection system. PE candidates were first identified in the segmented pulmonary vessels at prescreening. Based on Dijkstra's algorithm, the optimal path (OP) was traced from the pulmonary trunk bifurcation point to each PE candidate. The traced vessel was then straightened and a reformatted volume was generated using CPR. Eleven new features that characterized the intensity, gradient, and topology were extracted from the PE candidate in the CPR volume and combined with the previously developed 9 features to form a new feature space for FP classification. With IRB approval, CTPA of 59 PE cases were retrospectively collected from our patient files (UM set) and 69 PE cases from the PIOPED II data set with access permission. 595 and 800 PEs were manually marked by experienced radiologists as reference standard for the UM and PIOPED set, respectively. At a test sensitivity of 80%, the average FP rate was improved from 18.9 to 11.9 FPs/case with the new method for the PIOPED set when the UM set was used for training. The FP rate was improved from 22.6 to 14.2 FPs/case for the UM set when the PIOPED set was used for training. The improvement in the FROC curves was statistically significant ($p<0.05$) by JAFROC analysis, indicating that the new features extracted from the CROP method are useful for FP reduction.

8670-116, Session PSWed

Multiscale intensity homogeneity transformation method and its application to computer-aided detection of pulmonary embolism in computed tomographic pulmonary angiography (CTPA)

Yanhui Guo, Chuan Zhou, Heang-Ping Chan, Jun Wei, Aamer R. Chughtai, Baskaran Sundaram, Lubomir M. Hadjiiski, Smita Patel, Ella A. Kazerooni, Univ. of Michigan Health System (United States)

A 3D multiscale intensity homogeneity transformation (MIHT) method was developed to reduce false positives (FPs) in our previously developed CAD system for pulmonary embolism (PE) detection. In MIHT, the voxel intensity of a PE candidate region was transformed to an intensity homogeneity value (IHV) with respect to the local median intensity. The IHVs were calculated in multiscales (MIHVs) to measure the intensity homogeneity, taking into account vessels of different sizes and different percent occlusions. Seven new features including the entropy, gradient, and moments that characterized the intensity distributions of the candidate regions were derived from the MIHVs and combined with the previously designed features that described the shape and intensity of PE candidates for the training of a linear classifier to reduce the FPs. 59 CTPA PE cases were collected from our patient files (UM set) with IRB approval and 69 cases from the PIOPED II data set with access permission. 595 and 800 PEs were identified as reference standard by experienced thoracic radiologists in the UM and PIOPED set, respectively. FROC analysis was used for performance evaluation.

Compared with our previous CAD system, at a test sensitivity of 80%, the new method reduced the FP rate from 18.9 to 14.1/scan for the PIOPED set when the classifier was trained with the UM set and from 22.6 to 16.0/scan vice versa. The improvement was statistically significant ($p<0.05$) by JAFROC analysis. This study demonstrated that the MIHT method is effective in reducing FPs and improving the performance of the CAD system.

8670-117, Session PSWed

Quantitative consensus of supervised learners for diffuse lung parenchymal HRCT patterns

Sushravya Raghunath, Srinivasan Rajagopalan, Ronald A. Karwoski, Brian Bartholmai, Richard A. Robb, Mayo Clinic College of Medicine (United States)

Automated lung parenchymal classification usually relies on supervised learning of expert chosen regions representative of the visually differentiable HRCT patterns specific to different pathologies (eg. emphysema, ground glass, honey combing, reticular and normal). Considering the elusiveness of a single most discriminating similarity mesure, a plurality of weak learners can be combined to improve the machine learnability. Though a number of quantitative combination strategies exist, their efficacy is data and domain dependent. In this paper, we investigate multiple (N=12) quantitative consensus approaches to combine the clusters obtained with multiple (n=36) probability density-based similarity measures. Our study shows that hyper-graph based meta-clustering and probabilistic clustering provides optimal expert-metric agreement.

8670-118, Session PSWed

Automated localization of costophrenic recesses and costophrenic angle measurement on frontal chest radiographs

Pragnya Maduskar, Laurens E. Hogeweg, Rick Philipsen, Bram van Ginneken, Radboud Univ. Nijmegen Medical Ctr. (Netherlands)

Computer aided detection (CAD) of tuberculosis (TB) on chest radiographs (CXR) is difficult because the disease has varied manifestations, like opacification, hilar elevation, and pleural effusions. We have developed a CAD research prototype for TB (CAD4TB v1.08, Diagnostic Image Analysis Group, Nijmegen, The Netherlands) which is trained to detect textural abnormalities inside unobscured lung fields. If the only abnormality visible on a CXR would be a blunt costophrenic angle, caused by pleural fluid in the costophrenic recess, this is likely to be missed by texture analysis in the lung fields. The goal of this work is therefore to detect the presence of blunt costophrenic (CP) angles caused by pleural effusion on chest radiographs.

The CP angle is the angle formed by the hemidiaphragm and the

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chest wall. We define the intersection point of both as the CP angle point. We first detect the CP angle point automatically from a lung field segmentation by finding the foreground pixel of each lung with maximum y location. Patches are extracted around the CP angle point and boundary tracing is performed to detect 10 consecutive pixels along the hemidiaphragm and the chest wall and derive the CP angle from these.

We evaluate the method on a data set of 250 normal CXRs, 200 CXRs with only one or two blunt CP angles and 200 CXRs with one or two blunt CP angles but also other abnormalities. For these three groups, the CP angle location and angle measurements were correct in 91%, 88%, and 92% of all the cases, respectively. The average CP angles for the three groups are indeed different with 71.6° ± 22.9, 87.5° ± 25.7, and 87.7° ± 25.3, respectively.

8670-119, Session PSWed

Automatic organ localizations on 3D CT images by using majority-voting of multiple 2D detections based on local binary patterns and Haar-like features

Xiangrong Zhou, Shoutarou Yamaguchi, Gifu Univ. School of Medicine (Japan); Xinxin Zhou, Nagoya Bunri Univ. (Japan); Huayue Chen, Takeshi Hara, Ryujiro Yokoyama, Masayuki Kanematsu, Hiroaki Hoshi, Hiroshi Fujita, Gifu Univ. School of Medicine (Japan)

This paper describes a new approach to accomplish the automatic localization of a target organ or tissue region on 3D CT scans. The proposed approach combines the ensemble learning and the majority voting techniques to achieve a robust and quick detection. The basic idea of proposed method is to detect the 2D appearances of a 3D target region on CT images from multiple body directions, on multiple image-scales, in multiple feature spaces, and vote all the 2D detecting results back to the 3D image space to statistically decide one 3D bounding-box of the target organ. Ada-boosting algorithm was used to train the 2D detectors based on local binary patterns and Haar-like features. A collaborative voting and selecting algorithm are proposed based on coordinate histograms of three body directions. Since the architecture of the proposed method (multiple independent detections with a majority voting) naturally fits the parallel computing paradigm and multi-core CPU hardware, the proposed algorithm is easy to apply to quick and efficient organ localizations even for a whole body CT scan based on general computer. We applied this approach to localize 8 kinds of principle organ regions and 4 kinds of tissues independently on torso CT scans. In our experiments, we randomly selected 300 CT scans (with human indicated organ and tissue locations) for training the 2D detectors, and then, applied the proposed approach to localize each of the target regions on the other 1,000 CT scans for performance evaluation. The good performance and usefulness were shown in the experimental results.

8670-120, Session PSWed

Computerized segmentation of ureters in CT urography (CTU) using COMPASS

Lubomir M. Hadjiiski, Heang-Ping Chan, Luke Niland, Richard H. Cohan, Elaine M. Caoili, Chuan Zhou, Jun Wei, Univ. of Michigan Health System (United States)

We are developing a computerized system for automated segmentation of ureters on CTU, as a critical component for computer-aided diagnosis of ureter cancer. A challenge for ureter segmentation is the presence of regions not well opacified with intravenous (IV) contrast. We propose a COmbined Model-guided Path-finding Analysis and Segmentation System (COMPASS) to track the ureters in CTU. COMPASS consists of three stages: (1) adaptive thresholding and region growing, (2) path-finding and propagation, and (3) edge profile extraction and feature analysis. 114 ureters, filled with IV contrast material, on 74 CTU scans from 74 patients were segmented. On average the ureter occupied 286 CT slices (range:164 to 399, median:301). More than half of the ureters contained malignant or benign lesions and some had ureter wall thickening due to malignancy. A starting point for each of the 114 ureters was selected manually, which served as an input to the COMPASS, to initialize the tracking. The path-finding and segmentation are guided by anatomical knowledge of the ureters in CTU. The segmentation performance was quantitatively assessed by estimating the percentage of the length that was successfully tracked and segmented for each ureter. Of the 114 ureters, 75 (66%) were segmented completely (100%), 99 (87%) were segmented through at least 70% of its length, and 104 (91%) were segmented at least 50%. Previously, without the model-guided approach, 61 (54%) ureters were segmented completely (100%), 80 (70%) were segmented through at least 70% of its length, and 96 (84%) were segmented at least 50%. COMPASS improved the ureter tracking, including regions across ureter lesions, wall thickening and the narrowing of the lumen.

8670-121, Session PSWed

Computer assisted measurement of femoral cortex thickening on radiographs

Jianhua Yao, Yixun Liu, National Institutes of Health (United States); Foster Chen, Univ. of California, San Diego (United States); Ronald M. Summers, Timothy Bhattacharyya, National Institutes of Health (United States)

Radiographic features such as femoral cortex thickening have been frequently observed with atypical subtrochanteric fractures. These features may be a valuable finding to help prevent fractures before they happen. The current practice of manual measurement is often subjective and inconsistent. We developed a semi-automatic tool to consistently measure and monitor the progress of femoral cortex thickening on radiographs. By placing two seed points on each side of the femur, the program automatically extract the periosteal and endosteal layers of the cortical shell by active contour models and B-spline fitting. Several measurements are taken along the femur shaft, including shaft diameter, cortical thickness, and integral area for medial and lateral cortex. The experiment was conducted on 52 patient datasets. The semi-automatic measurements were validated against manual measurements on 52 patients and demonstrated great improvement in consistency and accuracy ($p<10-3$).

8670-122, Session PSWed

Exploring the utility of axial lumbar MRI for automatic diagnosis of intervertebral disc abnormalities

Subarna Ghosh, Vipin Chaudhary, Univ. at Buffalo (United States); Gurmeet Dhillon, Proscan Imaging, LLC (United States)

In this paper, we explore the importance of axial lumbar MRI slices for automatic detection of abnormalities. In the past, only the sagittal views were taken into account for lumbar CAD systems, ignoring the fact that a radiologist scans through the axial slices as well, to confirm the diagnosis and quantify various abnormalities like herniation and stenosis. Hence, we present an automatic diagnosis system from axial slices using CNN(Convolutional Neural Network) for dynamic feature extraction and classification of normal and abnormal lumbar discs. We show 80.81% accuracy (with a specificity of 85.29% and sensitivity of 75.56%) on 86 cases (391 discs) using only an axial slice for each disc, which implies the usefulness of axial views for automatic lumbar abnormality diagnosis in conjunction with sagittal views.

8670-123, Session PSWed

A prostate CAD system based on multiparametric analysis of DCE T1-w, and DW automatically registered images

Valentina Giannini, Anna Vignati, Simone Mazzetti, Massimo De Luca, Christian Bracco, Michele Stasi, Filippo Russo, Enrico Armando, Daniele Regge, Institute for Cancer Research and Treatment (Italy)

Prostate specific antigen (PSA)-based screening reduces the rate of death from prostate cancer (PCa) by 31%, but this benefit is associated with a high risk of overdiagnosis and overtreatment [1,2]. As prostate transrectal ultrasound (TRUS)-guided biopsy, the standard procedure for prostate histological sampling, has a sensitivity of 77% with a considerable false-negative rate, more accurate methods need to be found to detect or rule out significant disease [3]. Prostate magnetic resonance imaging (MRI) has the potential to improve the specificity of PSA-based screening scenarios as a non-invasive detection tool, in particular exploiting the combination of anatomical and functional information in a multiparametric (MP) framework. The purpose of this study was to describe a computer aided diagnosis (CAD) method that automatically produces a malignancy likelihood map by combining information from dynamic contrast enhanced (DCE) MR images and diffusion weighted (DW) images.

The CAD system consists of multiple sequential stages, from a preliminary registration of images of different sequences, in order to correct for susceptibility deformation and/or movement artifacts, to a Bayesian classifier, which fused all the extracted features into a probability map. The promising results (AUROC=0.87) should be validated on a larger dataset, but they suggest that the discrimination on a voxel basis between benign and malignant tissues is feasible with good performances. This method can be of benefit to improve the diagnostic accuracy of the radiologist, reduce reader variability and speed up the reading time, automatically highlighting probably cancer suspicious regions.

8670-124, Session PSWed

Temporal subtraction system on torso FDG-PET scans based on statistical image analysis

Yusuke Shimizu, Takeshi Hara, Gifu Univ. School of Medicine (Japan); Daisuke Fukuoka, Gifu Univ. (Japan); Xiangrong Zhou, Chisako Muramatsu, Gifu Univ. School of Medicine (Japan); Satoshi Ito, Daiyukai General Hospital (Japan); Kenta Hakozaki, Shin-ichiro Kumita, Kei-ichi Ishihara, Nippon Medical School (Japan); Tetsuro Katafuchi, Gifu Univ. of Medical Science (Japan); Hiroshi Fujita, Gifu Univ. School of Medicine (Japan)

Diagnostic imaging on FDG-PET scans was often used to evaluate chemotherapy results of cancer patients. Radiologists compare the changes of lesions' activities between previous and current examinations for the evaluations. The purpose of this study was to develop a new computer-aided diagnosis (CAD) system with temporal subtraction technique for FDG-PET scans and to show the fundamental usefulness based on an observer performance study. Z-score mapping based on statistical image analysis was newly applied to the temporal subtraction technique. The subtraction images can be obtained based on the anatomical standardization results because all of the patients' scans were deformed into standard body shape. An observer study was performed without and with CAD to evaluate the usefulness of the scheme by ROC (receiver operating characteristics) analysis. Readers provided the confidence levels from absolutely no change to definitely change between two scan on a continuous scale. The recognition performance for the 43 pairs was 96% sensitivity with 31.1 false-positive marks per scan. The average of area-under-the-ROC-curve (AUC) from 4 readers was increased from 0.85 without CAD to 0.90 with CAD (p=0.0389, DBM-MRMC). The average of interpretation time was decreased from 42.11 to 40.04 seconds per case (p=0.625, Wilcoxon test). We concluded that the CAD system for torso FDG-PET scans with temporal subtraction technique might improve the diagnostic accuracy of radiologist for cancer therapy evaluation.

8670-125, Session PSWed

A fast fully automated model-based prostate boundary segmentation using probabilistic approaches in ultrasound images

Rasa Vafaie, Javad Alirezaie, Ryerson Univ. (Canada); Paul Babyn, Univ. of Saskatchewan (Canada)

Segmentation of prostate boundaries in transrectal ultrasound (TRUS) images plays a great role in early detection of prostate cancer. Due to the low signal to noise ratio and the existence of speckle noise, the boundary outlining still remains a challenging task. In this paper, a new fully automated probabilistic approach is proposed to overcome the aforementioned limitations. In the preprocessing step, the position of the initial model is automatically estimated using prostate boundary representative patterns constructed from Iterative Least Squares Dictionary Learning Algorithm (ILS-DLA). The Expectation Maximization algorithm (EM) and Markov Random Field (MRF) theory are utilized in the deformation strategy to optimally fit the initial model on the prostate boundaries. For the purpose of real time therapy, we propose a less computational complex EM approach for obtaining the probability distribution parameters. Instead of considering each image pixel as an individual data, we used the number of pixels that have identical intensity value. We also exclude all uninformative pixels located outside of the field of view to obtain more accurate probability distribution parameters. We also propose a new internal force energy that uses 2D geometric transformations for preventing the model fault deformation. In this method, in contrast to the partial active contour model (PACM) algorithm, entire model contour has a direct impact on the internal energy and it is not required to add an extra energy term. Successful experimental results with the average Dice Similarity Coefficient (DSC) value 93.9±2.7% and computational time around 9 seconds validate the algorithm.

8670-126, Session PSWed

Segmentation of common carotid artery with Active Appearance Models from ultrasound images

Xin Yang, Huazhong Univ. of Science and Technology (China); Wanji He, Shanghai Jiao Tong Univ. (China); Aaron Fenster, The Univ. of Western Ontario (Canada); Yuchi Ming, Mingyue Ding, Huazhong Univ. of Science and Technology (China)

Carotid atherosclerosis is a major cause of stroke, a leading cause of death and disability. In this paper, a new segmentation method is proposed and evaluated for outlining the common carotid artery (CCA) from transverse view images, which were sliced from three-dimensional ultrasound (3D US) of 1mm inter-slice distance (ISD), to support the monitoring and assessment of carotid atherosclerosis. The data set consists of forty-eight 3D US images acquired from both left and right carotid arteries of twelve patients in two time points who had carotid stenosis of 60% or more at the baseline. The 3D US data were collected at baseline and three-month follow-up, where seven treated with 80mg atorvastatin and five with placebo. The baseline manual boundaries were used for Active Appearance Models (AAM) training; while the treatment data for segmentation testing and evaluation. The segmentation results were compared with experts manually outlined boundaries, as a surrogate for ground truth, for further evaluation. For the adventitia and lumen segmentations, the algorithm yielded Dice Coefficients (DC) of 92.06%±2.73% and 89.67%±3.66%, mean absolute distances (MAD) of 0.28±0.18 mm and 0.22±0.16 mm, maximum absolute distances (MAXD)

of 0.71±0.28 mm and 0.59±0.21 mm, respectively. The segmentation results were also evaluated via Pratt's figure of merit (FOM) with the value of 0.61±0.06 and 0.66±0.05, which provides a quantitative measure for judging the similarity. Experimental results indicate that the proposed method can promote the carotid 3D US usage for a fast, safe and economical monitoring of the atherosclerotic disease progression and regression during therapy.

8670-127, Session PSWed

Automatic segmentation of the lumen of the carotid artery in ultrasound B-mode images

André M. F. Santos, João M. R. Tavares, Elsa Azevedo, Luísa Sousa, Univ. do Porto (Portugal)

A new algorithm is proposed for the correct identification and segmentation of the lumen and bifurcation boundaries of the carotid artery in B-mode ultrasound images. It uses the hipoechogenic characteristics of the lumen for the carotid identification and the echogenic characteristics for the identification of the bifurcation. The images are preprocessed with the application of an anisotropic diffusion filter for speckle removal, and morphologic operators for the detection of the artery. The information obtained in this step is then used for the definition of two initial contours: one corresponding to the lumen and the other to the bifurcation boundaries, for the posterior application of the Chan-vese level set segmentation model.

A set of longitudinal B-mode images of the common carotid artery (CCA) was acquired with a GE Healthcare Vivid-e ultrasound system. All the acquired images include a part of the CCA and the bifurcation that separates the CCA into the internal and external carotid arteries. In order to achieve robustness in our acquisitions, with the highest contrast and lowest speckle noise levels as possible, the parameter settings of the scanner were defined different for each acquisition according to the associated exam.

We were able to successfully apply a carotid segmentation technique based on cervical ultrasonography. The main advantage of our segmentation method relies on the automatic identification of the carotid lumen, overcoming the limitations of the traditional methods.

8670-128, Session PSWed

Measuring coronary stent coverage of side branches in intravascular optical coherence tomographic image sequences

Ancong Wang, Jeroen Eggermont, Patrick de Koning, Hans Reiber, Jouke Dijkstra, Leids Univ. Medisch Ctr. (Netherlands)

Coronary stents are used to treat stenosis by keeping narrowed vessels open. When covering side branches, they may cause restenosis and obstruct the blood flow to the side branch. The cells of stents overlaying side branches can be extended by a balloon, but unnecessary extension should be avoided as stents can break. Accurate stent coverage measurements can help decide if extension is necessary. Intravascular optical coherence tomography (IVOCT) provides high-resolution images for precise stent coverage measurement. We proposed a semi-automatic method to measure the stent coverage of the side branches. First the stent struts and guide wires are detected to reconstruct the stent surface and the side branches are segmented. Next, the struts and side branches are transformed into 2D to show their relative location, so that the stent cells that overlay side branches can be identified. After projecting a stent cell and a side branch contour onto the stent surface, we calculate stent cell coverage defined as their overlapping areas. Evaluation on the phantom datasets shows that the difference between the algorithm results and the ground truth is not significant ($p = 0.03$). Additionally, 27 covered side branches in 12 in-vivo IVOCT datasets were used for testing. The results show that each side branch is overlaid with 1.7 ± 0.8 stent cells and the average cell coverage is 0.8 ± 0.6 mm2. The method can be used to compute stent cell size, side branch size and the stent coverage of side branches precisely, which can support the diagnosis and treatment of the patients, or in further refinements in stent designs and placements.

8670-129, Session PSWed

A centerline-based estimator of vessel bifurcations in angiography images

Maysa M. G. Macedo, Miguel A. Galarreta-Valverde, Univ. de São Paulo (Brazil); Choukri Mekkaoui, Harvard Medical School (United States); Marcel P. Jackowski, Univ. de São Paulo (Brazil)

The analysis of vascular structure based on vessel diameters, density and distance between bifurcations is an important step towards the diagnosis of vascular anomalies. Moreover, vascular network extraction allows for the study of angiogenesis. The purpose of this work is to develop a technique to detect bifurcations from vascular networks from magnetic resonance angiography and computed tomography angiography images. The vessel tracking technique employed uses the Hough transform and a matrix composed of second order partial derivatives of image intensity to estimate the scale and vessel direction, respectively. This semi-automatic technique is capable of connecting isolated tracked vessel segments and extracting a full tree from a vascular network with a minimal user intervention. Vessel shape descriptors such as curvature are used to identify bifurcations during tracking and estimate the next branch direction. We have initially applied this technique on synthetic and then demonstrate the reliability on real images.

8670-130, Session PSWed

Automatic identification of origins of left and right coronary arteries in CT angiography for coronary arterial tree tracking and plaque detection

Chuan Zhou, Heang-Ping Chan, Aamer R. Chughtai, Jun Wei, Lubomir M. Hadjiiski, Prachi Agarwal, Jean W. Kuriakose, Ella A. Kazerooni, Univ. of Michigan Health System (United States)

The goal of this study is to develop an automated method to identify the origins of the LCA and RCA as the seed points for the tracking of the coronary arterial trees. The heart region and the contrast-filled structures in the heart region are first extracted using morphological operations and EM estimation. To identify the ascending aorta, we developed a new multiscale aorta search method (MAS) method in which the aorta is identified based on a-priori knowledge of its circular shape. Because the shape of the ascending aorta in the cCTA axial view is roughly a circle but its size can vary over a wide range for different patients, multiscale circular-shape priors are used to search for the best matching circular object in each CT slice, guided by the Hausdorff distance (HD) measure as the matching metric. The location of the aorta is identified by finding the minimum HD in the heart region over the set of multiscale circular priors. An adaptive region growing method is then used to extend the above initially identified aorta down to the aortic valves. The origins at the aortic sinus are finally identified by a morphological gray level top-hat operation applied to the region-grown aorta with morphological structuring element designed for coronary arteries. For the 40 test cases, the aorta was correctly identified in 38 cases (95%). The aorta can be grown to the aortic root in 36 cases, and 36 LCA origins and 34 RCA origins can be identified within 10 mm of the locations marked by radiologists.

8670-131, Session PSWed

Automated registration of coronary arterial trees from multiple phases in coronary CT angiography (cCTA)

Lubomir M. Hadjiiski, Chuan Zhou, Heang-Ping Chan, Aamer R. Chughtai, Prachi Agarwal, Jean W. Kuriakose, Smita Patel, Jun Wei, Ella A. Kazerooni, Univ. of Michigan Health System (United States)

We are developing an automated registration method for coronary arterial trees from multiple-phase cCTA to build a best-quality tree to facilitate detection of stenotic plaques. Cubic B-spline with fast localized optimization (CBSO) is designed to register the initially segmented left and right coronary arterial trees (LCA or RCA) separately in adjacent phase pairs where displacements are small. First, the corresponding trees in phase 1 and 2 are registered. The phase 3 tree is then registered to the combined tree. Similarly the trees in phases 4, 5, and 6 are registered. An affine transform with quadratic terms and nonlinear simplex optimization (AQS) is designed to register the trees between phases with large displacements, namely, registering the combined tree from phases 1, 2, and 3 to that from phases 4, 5, and 6. Finally, CBSO is again applied to the AQS registered volumes for final refinement. The costs determined by the distances between the vessel centerlines, bifurcation points and voxels of the trees are minimized to guide both CBSO and AQS registration. The registration performance was evaluated on 22 LCA and 22 RCA trees on 22 CTA scans with 6 phases from 22 patients. The average distance between the centerlines of the registered trees was used as a registration quality index. The average distances for both the LCA and RCA registration for 6 phases and 22 patients were 1.5 pixels. This study demonstrates the feasibility of using automated method for registration of coronary arterial trees from multiple cCTA phases.

8671-1, Session 1

Technician-free system for image-guided bronchoscopy

Rahul Khare, The Pennsylvania State Univ. (United States); Rebecca Bascom, Penn State Hershey (United States); William E. Higgins, The Pennsylvania State Univ. (United States)

Previous studies have shown that bronchoscopy guidance systems improve accuracy and reduce skill variation among physicians during bronchoscopy. However, most of these bronchoscopy guidance systems suffer from one or more of the following limitations: 1) an attending technician must carefully keep the system position synchronized with the bronchoscope position during the live procedure; 2) extra bronchoscope tracking hardware may be required; 3) guidance cannot take place in real time and human studies have not been attempted; 4) the guidance system is unable to detect and correct faulty bronchoscope maneuvers; and 5) a re-synchronization procedure must be followed after adverse events such as patient cough or dynamic airway collapse. Here, we propose an image-based system for technician-free bronchoscopy guidance that relies on two features. First, our system precomputes a guidance plan that suggests natural bronchoscope maneuvers at every bifurcation leading toward a region of interest (ROI). Second, our system enables bronchoscope position verification that relies on a global-registration algorithm to establish the global bronchoscope position and, thus, provide the physician with updated navigational information during bronchoscopy. The system can handle general navigation to an ROI, as well as adverse events, and is directly controlled by the physician by a foot pedal. Guided bronchoscopy results using airway-tree phantoms and human cases demonstrate the efficacy of the system.

8671-2, Session 1

Robust feature tracking for endoscopic pose estimation and structure recovery

Stefanie Speidel, Karlsruhe Institut für Technologie (Germany); Sebastian Krappe, Fraunhofer-Institut für Integrierte Schaltungen (Germany); Sebastian Röhl, Sebastian Bodenstedt, Karlsruhe Institute of Technology (KIT) (Germany); Beat-Peter Müller-Stich, Univ. Hospital of Heidelberg (Germany); Rüdiger Dillmann, Karlsruhe Institut für Technologie (Germany)

Minimally invasive surgery is a highly complex medical discipline with several difficulties for the surgeon. To alleviate these difficulties, augmented reality can be used for intraoperative assistance. For visualization, the endoscope pose must be known which can be acquired using only the endoscopic images with a SLAM (Simultaneous Localization and Mapping) approach. In this paper we focus on feature tracking for SLAM in minimally invasive surgery. Robust feature tracking and minimization of false correspondences is crucial for localizing the endoscope. As sensory input we use a stereo endoscope and evaluate different feature types in a developed SLAM framework. The accuracy of the endoscope pose estimation is validated with synthetic and ex vivo data. Furthermore we test the approach with in vivo image sequences from da Vinci interventions.

8671-4, Session 1

Image guidance system for flexible endoscopes considering tissue deformation

Rainer Hoffmann, Michael Figl, Amar Bhatia, Marcus Kaar, Wolfgang Birkfellner, Medizinische Univ. Wien (Austria); Andreas Püspök, Alfred Kratochwil, Medizinische Univ Wien (Austria); Johann B. Hummel, Medizinische Univ. Wien (Austria) and Community Hospital Wilhelminen (Austria)

This paper describes a navigation system for flexible endoscopes equipped with ultrasound scan heads. In contrast to similar systems additional abdominal 3D ultrasound images are used to achieve the required image fusion. A 3D US scan which is tracked with an optical tracking system, has to be taken preoperatively before the CT scan. The CT is calibrated by means of the optical tracking system and the transformation between CT and the calibrated 3D US can be calculated without image registration. Immediately before intervention, a pre-interventional 3D US tracked with an electromagnetic tracking system (EMTS) is acquired and registered intra-modal to the preoperative US. Therefore, we canreplace a direct 2D/3D registration from the endoscopic US to the pre-operative CT by an intra-modal USUS registration and tracker calibrations.

To consider tissue deformation we implemented an approach using leading points. First, the US images were pre-processed by calculating importance images. The whole information of the image is reduced to a set of expressive leading points calculated from the importance image. Once the vector field of corresponding leading points is found, a deformation field can be calculated.

We found a target registration error for the whole transformation chain from a US pixel to a CT voxel of 4.34 +/- 2.56 mm (ten targets) on a phantom without deformation.

8671-5, Session 1

Endoscopic laser range scanner for minimally invasive, image guided kidney surgery

Eric M. Friets, Jerry Bieszczad, David B. Kynor, Jesse A. Norris, Brynmor J. Davis, Lindsay V. Allen, Robert Chambers, Jacob A. Wolf, Creare Inc. (United States); Courtenay Glisson, S. Duke Herrell III, Robert L. Galloway, Vanderbilt Univ. (United States)

Image guided surgery (IGS) has led to significant advances in surgical procedures and outcomes. Endoscopic IGS is hindered, however, by the lack of suitable intraoperative scanning technology for registration with preoperative tomographic image data. This paper describes implementation of an endoscopic laser range scanner (eLRS) system for accurate, intraoperative mapping of the kidney surface, registration of the measured kidney surface with preoperative tomographic images, and interactive image-based surgical guidance for subsurface lesion targeting. The eLRS comprises a standard stereo endoscope coupled to a steerable laser, which scans a laser fan beam across the kidney surface, and a high-speed color camera, which records the laser-illuminated pixel locations on the kidney. Through calibrated triangulation, a dense set of 3D surface coordinates are determined. At maximum resolution, the eLRS acquires over 300,000 surface points in less than 15 seconds. Lower resolution scans of 27,500 points are acquired in one second. Measurement accuracy of the eLRS, determined through scanning of reference planar and spherical phantoms, is estimated to be 0.38 ± 0.27 mm at a range of 2-6 cm. Registration of the scanned kidney surface with preoperative image data is achieved using a modified iterative closest point algorithm. Surgical guidance is provided through graphical overlay of the boundaries of subsurface lesions, vasculature, ducts, and other renal structures labeled in the CT or MR images, onto the eLRS camera image. Depth to these subsurface targets is also displayed. Proof of clinical feasibility has been established in an explanted perfused porcine kidney experiment.

8671-73, Session 1

Towards designing an optical-flow based colonoscopy tracking algorithm: a comparative study

Jianfei Liu, National Institutes of Health (United States); Kalpathi R. Subramanian, The Univ. of North Carolina at Charlotte (United States); Terry S. Yoo, National Library of Medicine (United States)

Automatic co-alignment of optical and virtual colonoscopy images can supplement traditional endoscopic procedures, providing more complete information of clinical values to the gastroenterologist. In this work, we compare our optical flow based approach for colonoscopy tracking to current state of the art methods, with respect to accuracy, system stability, and computational efficiency.

Our optical-flow based colonoscopy tracking algorithm computes multi-scale dense and sparse optical flow fields to measure image displacements. Camera motion parameters are determined from optical flow fields by employing a Focus of Expansion(FOE) constrained egomotion estimation scheme. We evaluate the three design choices made in our algorithm: dense optical flow, sparse optical flow, and egomotion estimation. Brox's approach was chosen to evaluate our multiscale dense optical flow, SIFT and Harris-affine features were used to assess the multiscale sparse optical flow, and the FOE-constrained egomotion estimation was compared with collinear, image deformation, and image derivative based egomotion methods.

Two virtual colonoscopy image sequences with known camera parameters were used in the study. Dense optical flow results showed that Brox's method was superior to multiscale dense optical flow in estimating camera rotational velocities, however, the final tracking errors were comparable: 6mm vs. 8mm over a travel distance of 110mm. Our appproach was computationally more efficient, averaging 7.2 vs. 38s per frame. SIFT and Harris affine features resulted in tracking errors of up to 70mm, while our sparse optical flow error was 6mm. The comparison among egomotion estimation algorithms showed that our FOE-constrained egomotion estimation balances tracking accuracy and robustness well.

8671-6, Session 2

Evaluation of non-rigid constrained CT/CBCT registration algorithms for delineation propagation in the context of prostate cancer radiotherapy

Mathieu Rubeaux, Antoine Simon, Univ. de Rennes 1, LTSI (France) and INSERM UMR (France); Khemara Gnep, Jérémy Colliaux, Ctr. Eugène Marquis (France); Oscar Acosta, Univ. de Rennes 1, LTSI (France) and INSERM UMR (France); Renaud De Crevoisier, Univ. de Rennes 1, LTSI (France) and INSERM UMR (France) and Ctr. Eugène Marquis (France); Pascal Haigron, Univ. de Rennes 1, LTSI (France) and INSERM UMR (France)

Image-Guided Radiation Therapy (IGRT) aims at increasing the precision of radiation dose delivery. In the context of prostate cancer, a planning Computed Tomography (CT) image with manually defined prostate and organs at risk (OAR) delineations is usually associated with daily Cone Beam Computed Tomography (CBCT) follow-up images. The CBCT images allow to visualize the prostate position and to reposition the patient accordingly. They also should be used to estimate the difference between the planned dose and the one which is actually delivered. But this procedure requires to compute the dose locally accumulated. To do so, the first step is a prostate and OAR segmentation on the daily CBCTs, which is very time-consuming. To simplify this task, CT to CBCT non-rigid registration could be used in order to propagate the original CT delineations in the CBCT images. For this aim, we compared several non-rigid registration methods. They are all based on the Mutual Information similarity measure, and use a BSpline transformation model. But we add different constraints to this global scheme in order to evaluate their impact on the final results. These algorithms are tested on two real datasets which contains 38 and 32 CBCT, which represents a total of 70 registration procedures for each method. The evaluation is led using the Dice score as a quality criteria. The experiments show that a rigid penalty constraint added on the bones can improve the final registration result, providing high quality propagated delineations.

8671-7, Session 2

Refinement and expansion of matched vessel graphs for intraoperative deformable registration of hepatic CT and ultrasound

Matthias Keil, Alexander Kaisler, Cristina Oyarzun Laura, Stefan Wesarg, Fraunhofer-Institut für Graphische Datenverarbeitung (Germany)

Multimodal registration of intraoperative ultrasound and preoperative contrast enhanced computed tomography (CT) imaging is the basis for image guided percutaneous hepatic interventions. Currently, the surgeon manually performs a rigid registration using vessel structures and other anatomical landmarks for visual guidance. In the literature vessel based ultrasound and CT registration are limited by the number and quality of correspondences between the vessel structures. Therefore, only rigid registrations can be realized or the deformable registrations suffer from the non-uniqueness of the correspondences inside the vessels.

We have presented our approach for automation of the intraoperative registration based on the definition of bijective correspondences between the vessel structures using an automatic graph matching. This paper describes our method for refinement and extension of the matched vessel graphs. The presented method greatly increases the number of landmarks along the vessel centerlines while keeping the bijection of the correspondences. Our method finds additional correspondences in matching vessel segments which could not be found by the initial graph matching. Based on the landmarks, we could calculate a smooth deformation field and extend our method to a fully deformable registration. Our system was applied successfully on nine patients, which are studied in this paper. The number of corresponding vessel points could be raised from a mean of 9.6 points to 60.7 points, allowing for the computation of a smooth deformation field.

8671-8, Session 2

Fast radioactive seed localization in intraoperative cone beam CT for low-dose-rate prostate brachytherapy

Yu C. Hu, Jian-Ping Xiong, Gilad Cohen, Marco Zaider, Gikas Mageras, Michael Zelefsky, Memorial Sloan Kettering Cancer Ctr. (United States)

Purpose: To efficiently localize radioactive seeds in an intraoperative cone beam CT (CBCT) so that corrections, if needed, can be made during prostate implant surgery.

Method: A transrectal ultrasound (TRUS) prostate scan is acquired for intraoperative planning. A CBCT scan is acquired of the pelvis with the TRUS probe in situ for implant evaluation. Planning seed positions are transferred from TRUS to CBCT following registration of the CBCT to a CT template scan of the ultrasound probe, in which the probe and associated fiducials are pre-segmented and their positions in TRUS are known. The transferred planned seeds and probe in the CBCT are used as an atlas to reduce the search space. A threshold is selected based on the known seed intensity profile to find candidate seed voxels. 3D regions are grown from the candidate seed voxels and overlay regions are merged. Regions with volume and intensity close to the known seed profile are identified as seeds. Regions not meeting the criteria are flagged as likely seeds and sorted based on a score calculated from the

volume, intensity profile and distance to the closest planning seed. Likely seeds with approximately twice the seed volume are automatically split.

Result: Three clinical cases are tested. Without any manual correction, the method performed the localization in 6 seconds (excluding registration) for a 512x512x193 CBCT scan. The average precision rate is 97% and the recall rate is 96% for a total of 243 seeds. All false negative seeds are found among the likely seeds.

8671-9, Session 2

A dynamic dosimetry system for prostate brachytherapy

Nathanael Kuo, Johns Hopkins Univ. (United States); Ehsan Dehgan, Philips Research North America (United States); Anton Deguet, Danny Y. Song, Jerry L. Prince, Junghoon Lee, Johns Hopkins Univ. (United States)

The lack of dynamic dosimetry tools for permanent prostate brachytherapy causes otherwise avoidable problems in prostate cancer patient care. The goal of this work is to satisfy this need in a readily adoptable manner. Using the ubiquitous ultrasound scanner and mobile non-isocentric C-arm, we show that dynamic dosimetry is now possible with only the addition of an arbitrarily configured marker-based fiducial. Not only is the system easily configured from accessible hardware, but it is also simple and convenient, requiring little training from technicians. Furthermore, the proposed system is built upon robust algorithms of distortion correction, seed segmentation, fiducial detection, seed reconstruction, and image registration. All individual steps of the pipeline have been thoroughly tested, and the system as a whole has been validated on a study of 25 patients. The system has shown excellent results of accurately computing dose, and does so with minimal manual intervention. Such a system therefore shows promise for resolving the problem of dynamic dosimetry.

8671-10, Session 2

Fully automated prostate magnetic resonance imaging and transrectal ultrasound fusion via a probabilistic registration metric

Rachel E. Sparks, Rutgers, The State Univ. of New Jersey (United States); Ernest Feleppa, Riverside Research Institute (United States); B. Nicolas Bloch, Boston Medical Ctr. (United States); Dean Barratt, Univ. College London (United Kingdom); Anant Madabhushi, Rutgers, The State Univ. of New Jersey (United States)

In this work, we present a novel, automated, registration method for magnetic resonance imaging (MRI) and transrectal ultrasound (TRUS) fusion consisting of: (1) delineating the prostate on MRI, (2) building a probabilistic model of the prostate location on TRUS using intensity and texture features, and (3) alignment of MRI prostate segmentation to the TRUS probabilistic model. TRUS-guided needle biopsy is the current gold standard for prostate cancer (CaP) diagnosis. Up to 40% of CaP lesions appear isoechoic on TRUS, hence TRUS-guided biopsy cannot reliable target CaP lesions and is associated with a high false negative rate. MRI is better able to distinguish CaP from benign prostatic tissue, but, requires special equipment. MRI-TRUS fusion, where MRI is acquired pre-operatively and aligned to TRUS during biopsy procedure, allows information from both modalities to guide the biopsy. Previous work in MRI-TRUS fusion has aligned manually determined landmarks or prostate surfaces. The accuracy of these methods is dependent on the reader's ability to determine landmarks and/or prostate surfaces with minimal error, which is a difficult and time consuming task.
Our novel, fully automated MRI-TRUS fusion scheme represents a significant advancement over current state-of-the-art as it does not require any manual intervention during TRUS acquisition. All necessary preprocessing steps (i.e. delineation of the prostate) can be performed offline prior to the biopsy procedure. Our method aligns MRI to TRUS with a Root Mean Squared Error (RMSE) of 3.69 ± 0.98 mm for expertly selected landmarks across 7 patient studies.

8671-11, Session 2

Nonrigid liver registration for image-guided surgery using partial surface data: a novel iterative approach

Daniel C. Rucker, Yifei Wu, Janet E. Ondrake, Thomas S. Pheiffer, Amber L. Simpson, Michael I. Miga, Vanderbilt Univ. (United States)

In open abdominal liver surgery, image-guidance systems aim to accurately depict tool locations with respect to the anatomy while maintaining the workflow of the surgical team. Partial surface measurements can be obtained intraoperatively with relatively little impact on the surgical workflow, as opposed to other intraoperative imaging modalities. In previous research, partial surface data has been (1) used to drive a rigid registration of the preoperative CT image volume to physical OR space, and (2) combined with a tissue-mechanics-based organ model to drive a non-rigid registration, thus compensating for organ deformations. In this paper we present a novel approach for the latter by iteratively reconstructing the displacement field on the posterior side of the organ in order to optimize the surface fit. Experimental results with a phantom liver show a mean target registration error (TRE) of 4.1 mm in the prediction of 58 locations inside the phantom. This represents a 42% reduction in mean error over the prior non-iterative single-solve method of extrapolating boundary conditions via a surface Laplacian.

8671-12, Session 3

Cryo-Balloon Catheter Localization in Fluoroscopic Images

Tanja Kurzendorfer, Friedrich-Alexander-Univ. Erlangen-Nürnberg (Germany); Alexander Brost, Stanford Univ. (United States); Carolin Jakob, Friedrich-Alexander-Univ. Erlangen-Nürnberg (Germany); Philip W. Mewes, Siemens AG (Germany); Felix Bourier, Krankenhaus Barmherzige Brueder (Germany) and Stanford Univ. (United States); Martin W. Koch, Friedrich-Alexander-Univ. Erlangen-Nürnberg (Germany); Klaus Kurzidim, Krankenhaus Barmherzige Brueder (Germany); Joachim Hornegger, Friedrich-Alexander-Univ. Erlangen-Nürnberg (Germany); Norbert Strobel, Siemens AG (Germany)

Minimally invasive catheter ablation has become the preferred treatment option for atrial fibrillation. The standard option radio-frequency catheter still bears a certain risk for the patient. To tackle this problem, cryo-balloon catheters have even been reported to be more advantageous in certain cases. Ablation procedures are performed in electro-physiology labs equipped with modern C-Arm X-ray systems. Electro-anatomical mapping systems are likely to be present as well, but they do not support cryo-balloon ablation procedures. Methods to provide support for cryo-balloon catheters in fluoroscopic guided ablation procedures rely heavily on manual user interaction. To improve this, we propose a first method for automatic cryo-balloon catheter localization in fluoroscopic images based on a simple blob detection algorithm. Our method is evaluated on 25 clinical images from 19 patients. The method successfully detected the cryo-balloon in 21 out of 25 images, yielding a success rate of 84.0 %. The successful localization achieved an accuracy of 0.65 mm +/- 0.34 mm. Even though our methods currently fails in 16.0 % of the images available, the current methods supporting cryo-balloon procedures completely rely on manual interaction. The information obtained from a single detected point itself may not help the physician during his procedure, but our result is very likely to avoid manual initialization for other methods.

8671-13, Session 3

Respiratory motion influence on catheter contact force during radio frequency ablation procedures

Martin W. Koch, Friedrich-Alexander-Univ. Erlangen-Nürnberg (Germany); Alexander Brost, Stanford Univ. (United States); Joachim Hornegger, Friedrich-Alexander-Univ. Erlangen-Nürnberg (Germany); Norbert Strobel, Siemens AG (Germany)

Minimally invasive catheter ablation is a common treatment option for atrial fibrillation. Individual ablation points need to be placed around the ostia of the pulmonary veins, attached to the left atrium, to generate transmural lesions and thereby block electric signals. During radio frequency ablation, the tip of the catheter has to be stable with a sufficient tissue contact. Besides the steerable interface operated by the physician, the movement of the catheter is also influenced by the heart and breathing motion. Particularly during ablation, after wall contact has been established, the tip of the catheter is influenced by cardiac and respiratory motion present at this particular position inside the left atrium.

In this paper we investigate the influence of breathing motion on different areas of the endocardium during radio frequency ablation. To this end, we analyze the frequency spectrum of the continuous catheter contact force to identify areas with increased breathing motion using a classification method. The approach has been applied to clinical patient data acquired during three pulmonary vein isolation procedures. Initial findings show that motion due to respiration is more pronounced at the roof and around the right pulmonary veins.

8671-14, Session 3

Image-based Modeling and Characterization of RF Ablation Lesions in Cardiac Arrhythmia Therapy

Cristian A. Linte, Jon J. Camp, Maryam E. Rettmann, David R. Holmes III, Richard A. Robb, Mayo Clinic College of Medicine (United States)

In spite of significant efforts to enhance guidance for catheter navigation, very little has been done to consider the changes that occur in the tissue during ablation as useful feedback on the accuracy of therapy delivery. We propose a technique to visualize lesion progression and monitor effects of the RF energy delivery using a thermal ablation model. The model incorporates both physical and physiological tissue parameters, and uses heat transfer principles to estimate temperature distribution in the tissue and geometry of the generated lesion in near real time. The thermal ablation model has been calibrated and evaluated using ex vivo beef muscle tissue in a clinically relevant tissue ablation protocol. To validate the model, the predicted temperature distribution within the tissue was assessed against that measured directly using fiberoptic temperature probes inserted in the tissue. Moreover, the model-predicted lesions were compared to the lesions observed in the post-ablation digital images. Results showed an agreement within 5degrees C between the model-predicted and experimentally measured tissue temperatures at prescribed locations, as well as comparable predicted and observed lesion characteristics and geometry. The model provided updates on the tissue temperature and lesion progression every 0.7 seconds for each 1 second computational cycle, resulting in a less than one minute overall computational time for a 60 second ablation cycle. We believe this technique is capable of providing reasonably accurate and sufficiently fast representations of the tissue response to RF energy delivery, enabling the generation of thermal maps in near real time, which can be used to guide the placement of successive lesions to ensure continuous and effective and enduring suppression of the arrhythmic pathway.

8671-15, Session 3

Validation of 3D surface imaging in breath-hold radiotherapy for breast cancer - one central camera unit versus three camera units

Tanja Alderliesten, Anja Betgen, Corine van Vliet-Vroegindeweij, Peter Remeijer, The Netherlands Cancer Institute (Netherlands)

In this work we investigated the benefit of the use of two lateral camera units additional to a central camera unit for 3D surface imaging for image guidance in deep-inspiration breath-hold (DIBH) radiotherapy by comparison with cone-beam computed tomography (CBCT).

Ten patients who received DIBH radiotherapy after breast-conserving surgery were included. The performance of surface imaging using one and three camera units was compared to using CBCT for setup verification. Breast-surface registrations were performed for CBCT as well as for 3D surfaces, captured concurrently with CBCT, to planning CT. The resulting setup errors were compared with linear regression analysis. For the differences between setup errors an assessment of the group mean, systematic error, random error, and 95% limits of agreement was made.

Correlations between derived surface-imaging [one camera unit;three camera units] and CBCT setup errors were: R^2=[0.67;0.75], [0.76;0.87], [0.88;0.91] in left-right, cranio-caudal, and anterior-posterior direction, respectively. Group mean, systematic and random errors were slightly smaller (sub-millimeter differences) and the limits of agreement were 0.10 to 0.25cm tighter when using three camera units compared with one. For the majority of the data, the use of three camera units compared with one resulted in setup errors more similar to the CBCT derived setup errors for the cranio-caudal and anterior-posterior directions ($p<0.01$, Wilcoxon-signed-ranks test).

This study shows a better correlation and agreement between 3D surface imaging and CBCT when three camera units are used instead of one and further outlines the conditions under which the benefit of using three camera units is significant.

8671-16, Session 3

3D surface imaging for guidance in breast cancer radiotherapy - organs at risk

Tanja Alderliesten, Anja Betgen, Corine van Vliet-Vroegindeweij, Peter Remeijer, The Netherlands Cancer Institute (Netherlands)

Purpose: To evaluate the variability in heart position in deep-inspiration breath-hold (DIBH) radiotherapy for breast cancer when 3D surface imaging would be used for monitoring the depth of the breath hold during treatment.

Materials and Methods: Ten patients who received DIBH radiotherapy after breast-conserving surgery (BCS) were included. Retrospectively, heart-based registrations were performed for cone-beam computed tomography (CBCT) to planning CT and breast surface registrations were performed for a 3D surface (two different regions of interest [ROIs]), captured concurrently with CBCT, to planning CT. The resulting setup errors were compared with linear regression analysis and receiver operating characteristic (ROC) analysis was performed to investigate the prediction quality of 3D surface imaging for 3D heart displacement. Further, the residual setup errors (systematic [Σ] and random [σ]) of the heart were estimated relative to the surface registrations.

Results: When surface imaging [$ROI_{left\text{-}side}$;$ROI_{both\text{-}sides}$] would be used for monitoring, the residual errors of the heart position are in left-right: Σ=[0.36;0.12], σ=[0.16;0.14]; cranio-caudal: Σ=[0.54;0.54], σ=[0.28;0.31]; and in anterior-posterior: Σ=[0.18;0.14], σ=[0.20;0.19] cm. Correlations between setup errors were: R^2 = [0.23;0.73], [0.67;0.65], [0.65;0.73] in left-right, cranio-caudal, and anterior-posterior direction, respectively. ROC analysis resulted in an area under the ROC curve of [0.82;0.78].

Conclusion: The use of ROI_both-sides provided promising results. However, considerable variability in the heart position, particularly in

CC direction, is observed when 3D surface imaging would be used for guidance in DIBH radiotherapy after BCS. Planning organ at risk volume margins should be used to take into account the heart-position variability.

8671-17, Session 4

Robot-assisted intracranial hemorrhage evacuation: an experimental evaluation

Jessica Burgner, Philip J. Swaney, Ray A. Lathrop, Vanderbilt Univ. (United States); Kyle D. Weaver M.D., Vanderbilt Univ. Medical Ctr. (United States); Robert J. Webster III, Vanderbilt Univ. (United States)

We present a novel robotic approach for the rapid, minimally invasive treatment of Intracerebral Hemorrhage (ICH), in which a hematoma or blood clot arises in the brain parenchyma. We present a custom image-guided robot system that delivers a steerable cannula into the lesion and aspirates it from the inside. The steerable cannula consists of an initial straight tube delivered in a manner similar to image-guided biopsy (and which uses a commercial image guidance system), followed by the sequential deployment of multiple individual precurved elastic tubes. Rather than deploying the tubes simultaneously, as has been done in nearly all prior studies, we deploy the tubes one at a time, using a compilation of their individual workspaces to reach desired points inside the lesion. This represents a new paradigm in active cannula research, defining a novel procedure-planning problem. A design that solves this problem can potentially save many lives by enabling brain decompression both more rapidly and less invasively than is possible through the traditional open surgery approach. Experimental results include a comparison of the simulated and actual workspaces of the prototype robot, and an accuracy evaluation of the system.

8671-18, Session 4

Automatic segmentation of intra-cochlear anatomy in post-implantation CT

Fitsum A. Reda, Benoit M. Dawant, Vanderbilt Univ. (United States); Robert F. Labadie, Vanderbilt Univ. Medical Ctr. (United States); Jack H. Noble, Vanderbilt Univ. (United States)

A cochlear implant (CI) is a hearing aid that restores hearing by directly stimulating the auditory nerve with an electrode array. In CI surgery, the surgeon threads the electrode array into the cochlea, blind to internal structures. Recently, we developed algorithms for determining the position of CI electrodes relative to intra-cochlear anatomy using pre- and post-operative CT. We are currently using this approach to develop a CI programming assistance system that uses knowledge of electrode position to determine a patient-customized CI sound processing strategy. However, this approach cannot be used for the majority of CI users because acquisition of pre-operative CT is atypical. In this study we propose an approach that extends our techniques so that intra-cochlear anatomy can be segmented for CI users for which pre-implantation CT was not acquired. We propose to perform a landmark-based segmentation of the post-implantation CT using information from the contralateral ear, exploiting the intra-subject symmetry of cochlear anatomy across ears. In this abstract, we present preliminary results demonstrating that our proposed approach is viable.

8671-19, Session 4

Deformable registration for cone-beam CT guidance of robot-assisted, trans-oral base-of-tongue surgery

Sureerat Reaungamornrat, Wen P. Liu, Sebastian Schafer, Yoshito Otake, Sajendra Nithiananthan, Ali Uneri, Jeremy Richmon, Johns Hopkins Univ. (United States); Jonathon Sorger, Intuitive Surgical Inc. (United States); Jeffrey H. Siewerdsen, Russell H. Taylor, Johns Hopkins Univ. (United States)

Purpose: Accurate localization of the surgical target in trans-oral robotic surgery (TORS) can be challenged by the highly deformed intraoperative setup (neck flexed, mouth open, and tongue distended). We propose a deformable registration framework using intraoperative cone-beam CT (CBCT) for high-precision TORS.

Method: The deformable registration aligns preoperative images to intraoperative CBCT using two established approaches. First, a Gaussian mixture (GM) model is applied to surface point clouds for rigid transformation (GMRigid) and surface deformation (GMNonRigid). Second, distance map transforms of the GMNonRigid and CBCT volumes are deformably registered using the Demons algorithm. The framework was evaluated in cadaver studies emulating preoperative and intraoperative setups, and performance was assessed in terms of target registration error (TRE), surface distance error, and normalized mutual information (NMI).

Result: The TRE following the GMRigid, GMNonRigid, and Demons steps was 8.1, 3.0, and 2.6 mm, respectively. The respective surface distance errors were 2.7, 0.7, and 0.2 mm, and the NMI was 0.53, 0.72, and 0.80. Demons registration based on distance map transforms (invariant to imaging modality) performed similarly to the best-case scenario of registration using image intensities directly (CT-to-CBCT registration with accurate intensity correction).

Conclusions: A promising workflow for CBCT-guided TORS has been identified using a deformable registration framework that is invariant to imaging modality (allowing preoperative CT or MRI) and is robust against CBCT intensity variations and artifact. The approach could facilitate overlay of planning data directly in stereo-endoscopic video in support of safer, high-precision surgery.

8671-20, Session 4

Simulation of retraction for brain deformation compensation in image-guided neurosurgery

Xiaoyao Fan, Songbai Ji, Dartmouth College (United States); Alex Hartov, Dartmouth College (United States) and Dartmouth Hitchcock Medical Ctr. (United States); David W. Roberts, Dartmouth Hitchcock Medical Ctr. (United States) and Dartmouth Hitchcock Medical Ctr. (United States); Keith D. Paulsen, Dartmouth College (United States) and Dartmouth Hitchcock Medical Ctr. (United States)

In image-guided neurosurgery, intraoperative brain shift significantly degrades the accuracy of neuronavigation if preoperative magnetic resonance images (pMR) are used alone. To compensate for brain deformation and to maintain the accuracy of image guidance achieved at the start of surgery, biomechanical models have been developed to simulate brain deformation and to produce model-updated MR images (uMR). To-date, most studies have focused on brain shift compensation at early stages of surgery (i.e., updated images are only produced after craniotomy and durotomy). Simulating surgical events at later stages such as retraction and tissue resection are, perhaps, more clinically relevant because much larger magnitudes of brain deformation are typically involved. However, these surgical events are substantially more complex, which pose significant challenges in biomechanical simulation. In this study, we present initial investigation using our model-based image guidance system to simulate brain retraction, where a biomechanical finite element model is used to assimilate intraoperative data, estimate whole-brain deformation field, and to produce uMR in order to improve the accuracy in spatial correspondence with respect to the surgical scene. Specifically, intraoperative stereovision (iSV) is used to acquire intensity-encoded 3D surface profiles at the exposed cortical area before and after tissue retraction. Retraction-induced surface displacements are then derived by co-registering these surface profiles and are used to drive the model. With one patient case, we demonstrate that our technique is feasible to produce uMR that agrees

well with iSV images after retraction. The computational cost to simulate brain deformation is approximately 10 min. In addition, our approach introduces minimal interruption to the surgical workflow, suggesting the potential for its clinical application.

8671-21, Session 5

How a surgeon becomes superman by visualization of intelligently fused multi-modalities

Okan Erat, Olivier Pauly, Technische Univ. München (Germany); Simon Weidert, Ludwig-Maximilians-Univ. München (Germany); Peter Thaller, Ludwig-Maximilians-Univ. München (Germany) and Ludwig-Maximilians-Univ. München (Germany); Ekkehard Euler, Wolf Mutschler, Ludwig-Maximilians-Univ. München (Germany); Nassir Navab, Pascal Fallavollita, Technische Univ. München (Germany)

Motivation: The augmented reality (AR) fluoroscope creates an augmented visualization by overlaying an X-ray view on top of the optical image. During surgery, this X-ray view partially occludes part of the scene (e.g. surgical instruments), providing thereby poor cues for depth information and presents the anatomical information in a confusing way to clinicians.

Methodology: We propose a method extracting relevant information in both X-ray and optical images, to create an improved mixed visualization. First, anatomical information is extracted in the X-ray and overlaid on the patient skin in the video image. Second, we use Bayes classifier that evaluates the probability of a pixel in the video frames to belong either to patient skin or surgical tools. To provide improved depth visualization, the augmentation of anatomical information is performed only when pixels have a larger probability of belonging to skin class.

Results/Conclusions: We displayed the new Superman visuals to 2 surgeons and 1 medical student during three surgical workflow sequences of the interlocking of intramedullary nail procedure, namely: skin incision, center punching, and drilling. We asked them to assess our visualization when compared to the current alpha-blending overlay image produced by the AR fluoroscope. The participants all agreed (100%) that occlusion and instrument tip position detection were immediately improved with our visual. When asked if our visualization has potential to replace the existing overlay during interlocking procedures, all participants did not hesitate to suggest an immediate integration of the Superman visualization for the correct navigation and guidance of the procedures.

8671-22, Session 5

Non photorealistic rendering for minimally invasive procedures

Jens Raab, Friedrich-Alexander-Univ. Erlangen-Nürnberg (Germany); Alexander Brost, Stanford Univ. (United States); Henry Schäfer, Marc Stamminger, Friedrich-Alexander-Univ. Erlangen-Nürnberg (Germany); Marcus Pfister, Siemens AG (Germany)

Abdominal aortic aneurysms are a common disease of the aorta which are treated minimally invasive in about 33~% of the cases. Treatment is done by placing a stent graft in the aorta to prevent the aneurysm from growing any further. Guidance during the procedure is facilitated by fluoroscopic imaging. Unfortunately, due to low soft tissue contrast in X-ray images, the aorta itself is not visible without the application of contrast agent.

To overcome this issue, advanced techniques allow to segment the aorta from pre-operative data, such as CT or MRI. Overlay images are then subsequently rendered from a mesh representation of the segmentation and fused to the live fluoroscopic images with the aim to improve the visibility of the aorta during the procedure.

The current overlay images typically use forward projections of the mesh representation. This fusion technique shows deficiencies in both the 3-D information of the overlay and the visibility of the fluoroscopic image underneath. We present a novel approach to improve the visualization of the overlay images using non-photorealistic rendering techniques. Our method preserves the visibility of the devices in the fluoroscopic images while, at the same time, providing 3-D information of the fused volume. The evaluation by clinical experts shows that our method is preferred over current state-of-the-art overlay techniques. We compared three visualization techniques to the standard visualization. A silhouette approach was chosen by clinical experts with 67~%, clearly showing the superiority of the new approach.

8671-23, Session 5

Interactive 3D segmentation of the prostate in magnetic resonance images using shape and local appearance similarity analysis

Maysam Shahedi, Western Univ. (Canada) and Baines Ctr. for Translational Cancer Research (Canada) and Imaging Research Lab. Robarts Research Institute (Canada); Aaron Fenster, Derek W. Cool, Cesare Romagnoli, Imaging Research Lab., Robarts Research Institute (Canada) and Western Univ. (Canada); Aaron D. Ward, Baines Ctr. for Translational Cancer Research (Canada) and Western Univ. (Canada)

3D segmentation of the prostate in medical images is useful to prostate cancer diagnosis and therapy guidance, but is time-consuming to perform manually. Clinical translation of computer-assisted segmentation algorithms for this purpose requires a comprehensive and complementary set of evaluation metrics that are informative to the clinical end user. We have developed an interactive 3D prostate segmentation method for 1.5T and 3.0T T2-weighted magnetic resonance imaging (T2W MRI) acquired using an endorectal coil. We evaluated our method against manual segmentations of 36 3D images using complementary boundary-based (mean absolute distance; MAD), regional overlap (Dice similarity coefficient; DSC) and volume difference (?V) metrics. Our technique is based on inter-subject prostate shape and local boundary appearance similarity. In the training phase, we calculated a point distribution model (PDM) and a set of local mean intensity patches centered on the prostate border to capture shape and appearance variability. To segment an unseen image, we defined a set of rays – one corresponding to each of the mean intensity patches computed in training – emanating from the prostate centre. We used a radial-based search strategy and translated each mean intensity patch along its corresponding ray, selecting as a candidate boundary point with the highest normalized cross correlation along each ray. These boundary points were then regularized using the PDM. For the whole gland, we measured a mean±std MAD of 2.5±0.7 mm, DSC of 80±4%, and ?V of 1.1±8.8 cc. We also provided an anatomic breakdown of these metrics within the prostatic base, mid-gland, and apex.

8671-24, Session 5

Multi-atlas-based automatic 3D segmentation for prostate brachytherapy in transrectal ultrasound images

Saman Nouranian, Sara Mahdavi, The Univ. of British Columbia (Canada); Ingrid Spadinger, William J. Morris, British Columbia Cancer Agency (Canada); Septimiu E. Salcudean, Purang Abolmaesumi, The Univ. of British Columbia (Canada)

One of the commonly used treatment methods for early-stage prostate cancer is brachytherapy. The standard of care for planning this procedure is segmentation of contours from transrectal ultrasound (TRUS) images, which closely follow the prostate boundary. This process is currently

performed either manually or using semi-automatic techniques. This paper introduces a fully automatic segmentation algorithm which uses a priori knowledge of contours in a reference dataset of TRUS volumes. A non-parametric deformable registration method is employed to transform the atlas prostate contours to a target image coordinates. All atlas images are sorted based on their registration results and the highest ranked registration results are selected for decision fusion. A Simultaneous Truth and Performance Level Estimation algorithm is utilized to fuse labels from registered atlases and produce a segmented target volume. In this experiment, 50 patient TRUS volumes are obtained and a leave-one-out study on TRUS volumes is reported. We also compare our results with a state-of-the-art semi-automatic prostate segmentation method that has been clinically used for planning prostate brachytherapy procedures. We show similar accuracy and better precision within clinically acceptable runtime.

8671-25, Session 5

A statistical multi-vertebrae shape+pose model for segmentation of CT images

Abtin Rasoulian, Robert Rohling, Purang Abolmaesumi, Univ. of British Columbia (Canada)

Segmentation of the spinal column from CT images is a pre-processing step for a range of image guided interventions. Current techniques focus on identification and separate segmentation of each vertebra. Recently, statistical multi-object shape models have been introduced to extract common statistical characteristics between several anatomies. These models are also used for segmentation purposes and are shown to be robust, accurate, and computationally tractable. In this paper, we reconstruct a statistical multi-vertebrae shape+pose model and propose a novel technique to register such a model to CT images. We validate our technique in terms of accuracy of the multi-vertebrae segmentation of CT images acquired from 16 subjects. The mean distance error achieved for all vertebrae is 1.17 mm with standard deviation of 0.38 mm.

8671-26, Session 6

Estimating Periodic Organ Motions based on Inverse Kinematics using Tetrahedron Mesh Registration

Nahyup Kang, Ji-Yeon Kim, Samsung Group (Korea, Republic of); Kyung Hwan Kim, Hyong-Euk Lee, James D. K. Kim, Samsung Advanced Institute of Technology (Korea, Republic of)

Minimally/Non-invasive surgery has become increasingly widespread because of its therapeutic benefits such as less pain, less scarring, and shorter hospital stay. However, it is very difficult to eliminate the target cancer cells selectively without damaging nearby normal tissues and vessels since the tumors inside organs cannot be visually tracked in real-time with the existing imaging devices while organs are deformed by respiration and surgical instruments. Note that real-time 2D US imaging is widely used for monitoring the minimally invasive surgery such as Radiofrequency ablation, however, it is difficult to detect tumor except highly echogenic regions because of its noisy and limited field of view. To handle these difficulties, we present a novel framework for estimating organ motion and deformed shape during respiration from the available features of 2D US images, by means of inverse kinematics method utilizing 3D CT volumes at the inhale and exhale phases; First, we generate target organ, tumor surface meshes and center-lines of vessels at the two extreme phases considering surface correspondence. Then, the corresponding two tetrahedron meshes are generated by coupling the internal components for volumetric modeling. Finally, a deformed organ mesh at an arbitrary phase is generated from the 2D US feature points for estimating the organ deformation and tumor position. To show effectiveness of the proposed method, the liver images from real patient has been used, and the experimental result shows that the average errors are less than 3mm in terms of tumor position as well as the whole surface shape.

8671-27, Session 6

Sources of error in CEMRA-based CFD simulations of the common carotid artery

Muhammad O. Khan, Univ. of Toronto (Canada); Bruce A. Wasserman, Johns Hopkins Univ. (United States); David A. Steinman, Univ. of Toronto (Canada)

Magnetic resonance imaging is often used as a source for reconstructing vascular anatomy for the purpose of computational fluid dynamics (CFD) analysis. We recently observed large discrepancies in such “image-based” CFD models of the normal common carotid artery (CCA) derived from contrast enhanced MR angiography (CEMRA), when compared to phase contrast MR imaging (PCMRI) of the same subjects. A novel quantitative comparison of velocity profile shape of N=13 cases revealed an average 23% overestimation of velocities by CFD, attributed to a corresponding underestimation of lumen area in the CEMRA-derived geometries. We hypothesized that this was due to blurring of edges in the images caused by dilution of contrast agent during the relatively long elliptic centric CEMRA acquisitions, and confirmed this with MRI simulations. Rescaling of CFD models to account for the lumen underestimation improved agreement with the velocity levels seen in the corresponding PCMRI images, but discrepancies in velocity profile shape remained, with CFD tending to over-predict velocity profile skewing. This may be due to modelling assumptions, such as fully-developed inflow velocities or Newtonian rheology, shown to be reasonable for geometrically-dominated vessels like the carotid bifurcation, but possibly unreasonable for more mildly curved arteries like the CCA. In summary, our findings suggest that caution should be exercised when using elliptic-centric CEMRA data as a basis for image-based CFD modelling, and emphasize the importance of comparing image-based CFD models against in vivo data whenever possible.

8671-28, Session 6

A patient specific 4D MRI liver motion model based on sparse imaging and registration

Yolanda H. Noorda, Lambertus W. Bartels, Marijn van Stralen, Josien P. W. Pluim, Univ. Medical Ctr. Utrecht (Netherlands)

Image-guided minimally invasive procedures are becoming increasingly popular. Currently, High-Intensity Focused Ultrasound (HIFU) treatment of lesions in mobile organs, such as the liver, is under development. A requirement for such treatment is automatic motion tracking, such that the position of the lesion can be followed in real-time. We propose a 4D liver motion model, which can be used during planning of this procedure. During treatment, the model can serve as a motion predictor. In a similar fashion, this model could be used for radiotherapy treatment of the liver. The model is built by acquiring 2D dynamic sagittal MRI data at six locations in the liver. By registering these dynamics to a 3D MRI liver image, 2D deformation fields are obtained at every location. The 2D fields are ordered according to the position of the liver at that specific time point, such that liver motion during an average breathing period can be simulated. This way, a sparse deformation field is created over time. This deformation field is finally interpolated over the entire volume, yielding a 4D motion model. The accuracy of the model is evaluated by comparing unseen slices to the slice predicted by the model at that specific location and phase in the breathing cycle. The mean Dice coefficient of the liver regions was 0.90. The mean misalignment of the vessels was 1.9 mm. The model is able to predict patient specific deformations of the liver and can predict regular motion accurately.

8671-29, Session 6

Sensitivity analysis and automation for intraoperative implementation of the atlas-based method for brain shift correction

Ishita Chen, Amber L. Simpson, Kay Sun, Reid C. Thompson, Michael I. Miga, Vanderbilt Univ. (United States)

The use of biomechanical models to correct misregistration in image-guided neurosurgery has been a growing area of study. The misregistration is caused by non-rigid deformations of the brain caused by drugs, cerebrospinal fluid drainage, and surgical manipulation. In previous work, an atlas-based inverse model was developed to overcome this difficulty and has been validated quantitatively [1, 2]. Previous studies were retrospective and did not address questions about feasibility with respect to pre-operative computational time. The goal of this work is to evaluate techniques that allow the atlas-based inverse framework to become a 'time of surgery' setup procedure rather than a pre-operative computing strategy. In this work, strategies to reduce the pre-operative computational burden associated with creating a patient specific mesh and building the deformation atlas are explored. With the former, an automated segmentation technique is described for the dural septa to ease the preoperative setup burden. The shift correction results using this automated segmentation method were compared to those using manual segmentation. Overall, the automatic segmentation results did not change the shift correction results significantly as compared to the manual segmentation method. With the latter, the extent and distribution of the surgical parameters within the deformation atlas were evaluated by a sensitivity analysis using simulation experiments and clinical data. The results of the sensitivity analysis show that the atlas could be constructed by coarser sampling without substantial degradation in the shift reconstruction. In summary, the work supports that a more automated preoperative setup and a less-resolved atlas for the compensation technique will allow for a 'time of surgery' setup procedure without sacrificing the fidelity of the compensation.

8671-30, Session 6

Image based cardiac acceleration map using statistical shape and 3D+t myocardial tracking models; in-vitro study on heart phantom

Ali Pashaei, Gemma Piella, Xavier Planes, Univ. Pompeu Fabra (Spain); Nicolas Duchateau, Teresa M. de Caralt, Marta Sitges, Hospital Clínic, Univ. de Barcelona (Spain); Alejandro F. Frangi, The Univ. of Sheffield (United Kingdom)

It has been demonstrated that the acceleration signal has potential to monitor heart function and adaptively optimize Cardiac Resynchronization Therapy (CRT) systems. In this paper, we propose a non-invasive method for computation of the acceleration map on bi-ventricular heart using medical images and statistical shape models.

In this study statistical shape models were used for automatic construction of heart domain via atlas-based landmarking. This relies on establishing corresponding 3D Active Shape Models (ASM) via an automatic segmentation and volumetric non-rigid registration. The algorithm has been applied to a realistic physical heart phantom (DHP-01, Shelley Medical Imaging Technologies, London, ON, CA) images in which the displacement of some control regions was known. The segmentation was applied to time frames of images to extract the deformed shape model in each time frame. From the shape correspondence, the deformation map and related acceleration map was computed. Finite difference method was performed to compute myocardial accelerations.

Good correlation has been demonstrated between the displacement field of the shape model and phantom setup. Due to the low number of time frames, the acceleration signals of points are sparse. However acceleration map shows two peaks of acceleration, which is similar to the reports from in-vivo measurements.

The study suggests a non-invasive technique to measuring the cardiac acceleration that may be used to improve the monitoring of cardiac mechanics and optimization of CRT.

8671-31, Session 6

Measuring soft tissue material properties using stereovision and indentation: a proof-of-concept study

Songbai Ji, Xiaoyao Fan, Alex Hartov, Dartmouth College (United States); David W. Roberts, Dartmouth Hitchcock Medical Ctr. (United States); Keith D. Paulsen, Dartmouth College (United States)

Accurate measurement of soft tissue material properties is critical for characterizing its biomechanical behaviors but can be challenging especially for the human brain. Recently, we have applied stereovision to track motion of the exposed cortical surface noninvasively for patients undergoing open skull neurosurgical operations. In this paper, we conduct a feasibility study to evaluate its utility in measuring material properties of the human brain in vivo using a phantom. A block of soft tofu is prepared and placed on a sand paper. Black pepper is lightly sprinkled on the top surface to provide a random pattern for surface reconstruction via stereovision. A high-density tungsten disk is then placed on the top surface in the center. Stereovision images are recorded before and after indentation and the corresponding 3D surfaces are reconstructed and co-registered from which a complete 3D displacement field around the indenter disk is obtained. A corresponding finite element model of the tofu is created subjected to the indenter gravity. A hyperelastic material model is chosen for the tofu, and the material constants are determined though an optimization scheme that iteratively adjusts the parameters until the misfit between model-derived surface displacement field and that measured is minimized. The resulting material property constants are compared with reports found in the literature. We show that the simple stereovision and indentation techniques coupled with an FE model is feasible for in vivo measurement of the human brain material properties, and it may also be feasible for other soft tissues.

8671-32, Session 7

Patient and process specific imaging and visualization for computer assisted interventions *(Keynote Presentation)*

Nassir Navab, Technische Univ. München (Germany)

In this talk, I will focus on the need for development of novel imaging techniques for patient and process specific intra-operative imaging and present some of our latest results as exemplary cases. As such novel intra-operative and multi-modality imaging techniques provide the surgical crew with rich co-registered information, their appropriate visualization and their integration into surgical workflow, their validation and finally their full deployment are becoming active subjects of research in our community. I will in particular trace the Freehand SPECT and Camera Augmented Mobile C-arm (CAMC) from the early development of research ideas within our multi-disciplinary research laboratories to their deployment in different surgical suites. In addition, I will present our efforts in development and integration of novel ultrasound imaging techniques into various image guided procedures. I will finally focus on the needs for simulation and advanced visualization not only in computer assisted interventions, but also in medical education and training.

8671-33, Session 7

A video guided solution for screw insertion in orthopedic plate fixation

Jessica Magaraggia, Friedrich-Alexander-Univ. Erlangen-Nürnberg (Germany); Gerhard Kleinszig, Rainer Graumann, Siemens AG (Germany); Elli Angelopoulou, Joachim Hornegger, Friedrich-Alexander-Univ. Erlangen-Nürnberg (Germany)

In orthopedic and trauma surgery, metallic plates are used for reduction and fixation of bone fractures. In clinical practice, the intra-operative planning for screw fixation is usually based on fluoroscopic images. Screw fixation is then performed on a free-hand basis. As such, multiple attempts may be required in order to achieve the optimal positioning of the fixing screws. To help the physician insert the screws in accordance to the planned position, we propose a method for screw insertion guidance. Our method uses a small video camera, rigidly placed on the drill, and a set of small markers that are rigidly fixed on a variable angle drill sleeve. In order to investigate the achievable accuracy of our setup, we simulate the estimation of the drill point position considering two different marker configurations, planar and 3D, and different noise levels. In our setup, an intrinsic source of noise is the vibration of the drill itself. Further, we motivate our choices for marker design and position given the limited space available for marker positioning, the requirement for accurate position estimation of the drill point and the illumination changes that could affect the surgical site. We also describe our proposed marker detection and tracking pipeline. Our simulation results let us conclude that it is possible to achieve an accuracy of 1° and 1mm in the estimation of angular orientation and insertion depth of the drill point respectively, with our simple monocular setup, provided that we have accurate marker detection.

8671-34, Session 7

Model-based cone-beam CT reconstruction for image-guided minimally invasive treatment of hip osteolysis

Yoshito Otake, Joseph W. Stayman, Wojciech Zbijewski, Johns Hopkins Univ. (United States); Ryan J. Murphy, Kutzer D. Michael, Johns Hopkins Univ. Applied Physics Lab. (United States); Russell H. Taylor, Jeffrey H. Siewerdsen, Johns Hopkins Univ. (United States); Mehran Armand, Johns Hopkins Univ. Applied Physics Lab. (United States)

Accurate assessment of the size and location of osteolytic regions is essential in diagnosis and treatment planning of minimally invasive hip revision surgery. Moreover, image-guided robotic intervention for osteolysis treatment requires precise localization of implant components. However, high density metallic implants in the field-of-view make assessment by either 2D or 3D x-ray imaging difficult. This paper details the initial implementation and evaluation of an advanced model-based cone-beam CT (CBCT) reconstruction algorithm called Known Component Reconstruction (KCR) which incorporates knowledge about the shape and material of implants to precisely reconstruct surrounding anatomy while simultaneously estimating implant position. A simulation study involved a phantom generated from a CBCT scan of a cadaveric hip. Improvement of image quality was evaluated using normalized cross correlation (NCC) of two region-of-interests (ROIs) about the femoral and acetabular components. Registration accuracy was evaluated as translational and rotational error from the true registration. The study showed significant improvement in image quality over conventional filtered backprojection (FBP) and penalized-likelihood (PL) reconstruction. The NCC in the two ROIs improved from 0.74 and 0.81 (FBP) to 0.98 and 0.86 (PL) and >0.99 for KCR. The registration error was 0.01 mm in translation (0.02o in rotation) for the acetabular component, 0.01 mm (0.01o rotation) for the femoral component. The application of KCR to imaging hiposteolysis in the presence of the implant demonstrated improved image quality (metal artifact reduction), yielded a precise registration estimate of the implant, and offered a means for reducing radiation dose in intraoperative CBCT.

8671-35, Session 8

Automatic real-time tracking of fetal mouth in fetoscopic video sequence for supporting fetal surgeries

Rong Xu, Tianliang Xie, Jun Ohya, Bo Zhang, Waseda Univ. (Japan); Yoshinobu Sato, Osaka Univ. (Japan); Masakatsu G. Fujie, Waseda Univ. (Japan)

Recently, a minimally invasive surgery (MIS) called fetoscopic tracheal occlusion (FETO) is developed to treat severe congenital diaphragmatic hernia (CDH) via fetoscopy, by which a detachable balloon is placed into fetal trachea for preventing pulmonary hypoplasia through increasing the pressure of chest cavity. This surgery is so dangerous that a supporting system for navigating the surgeon is demanded. In this paper, to guide a surgical tool to be inserted into fetal trachea, an automatic approach that detects and tracks fetal face and mouth in fetoscopic video sequence is proposed. More specifically, AdaBoost algorithm is utilized as a classifier to detect fetal face based on Haar-like features, which calculate the difference between the sums of the pixel intensities in each adjacent region at a specific location in the detection window. Then, CamShift algorithm based on an iterative search in the color histogram is applied to track fetal face, and an ellipse is fitted to the contour of fetal mouth by an improved iterative randomized Hough transform method. The experimental results demonstrate that our proposed method can automatically detect and track fetal face and mouth accurately in real-time in fetoscopic video sequence, and can provide an effective and timely feedback for the robot control system of the surgical tool.

8671-36, Session 8

A knowledge-driven quasi-global registration of thoracic-abdominal CT and CBCT for image-guided interventions

Li Zhang, Christophe Chefd'hotel, Siemens Corporate Research (United States); Vincent Ordy, Siemens Corp. (United States); Jie Zheng, Xiang Deng, Siemens Ltd. (China)

A novel knowledge-driven quasi-global method has been developed for fast and robust registration of thoracic-abdominal CT and cone beam CT (CBCT) scans in this work. While the use of CBCT in operating rooms has become a common practice, there is an increasing demand on the registration of CBCT with pre-operative scans, in many cases, CT scans. One of the major challenges of thoracic-abdominal CT/CBCT registration is from the various fields of view (FOVs) of the two imaging modalities. The proposed approach utilizes a priori knowledge of anatomy to generate 2D anatomy targeted projection (ATP) images that surrogate the original volumes. The use of lower dimension surrogate images can significantly reduce the computation cost of similarity evaluation during optimization and make it practically feasible to perform global optimization based registration for image-guided interventional procedures. Another a priori knowledge about the local optima distribution on energy curves is further used to effectively select multi-starting points for registration optimization. With the combination of ATP images and multi-starting point selection, this approach has demonstrated its capability for fast and robust thoracic-abdominal CT/CBCT registration by validating with 20 clinical data sets. Target registration error (TRE) and maximum registration error (MRE) were used to compare the performance of the knowledge-driven quasi-global registration against a typical local-search based registration. The local search based registration failed on 60% cases, with an average TRE of 22.91mm and MRE of 28.10mm; the knowledge-driven quasi-global registration achieved satisfactory results for all the 20 data sets, with an average TRE of 3.45mm, and MRE of 2.57mm.

8671-37, Session 8

Significant acceleration of 2D-3D registration-based fusion of ultrasound and x-ray images by mesh-based DRR rendering

Markus Kaiser, Siemens AG (Germany) and Innovation Ctr. Computer Assisted Surgery (ICCAS) (Germany); Matthias John, Anja Borsdorf, Siemens AG (Germany); Peter Mountney, Razvan Ionasec, Siemens Corporate Research (United States); Alois Nöttling, Siemens AG (Germany); Philipp Kiefer, Jörg Seeburger, Univ. Leipzig (Germany); Thomas Neumuth, Innovation Ctr. Computer Assisted Surgery (ICCAS) (Germany)

For transcatheter-based minimally invasive procedures in structural heart disease ultrasound and X-ray are the two enabling imaging modalities. A live fusion of both real-time modalities can potentially improve the workflow and the catheter navigation by combining the excellent instrument imaging of X-ray with the high-quality soft tissue imaging of ultrasound. A recently published approach to fuse X-ray fluoroscopy with trans-esophageal echo (TEE) registers the ultrasound probe to X-ray images by a 2D-3D registration method which inherently provides a registration of ultrasound images to X-ray images. In this paper, we significantly accelerate the 2D-3D registration method in this context. The main novelty is to generate the projection images (DRR) of the 3D object not via volume ray-casting but instead via a fast rendering of triangular meshes. This is possible, because in the setting for TEE/X-ray fusion the 3D geometry of the ultrasound probe is known in advance and their main components can be described by triangular meshes. We show that the new approach can achieve a speed up factor of 65 and does not affect the registration accuracy when used in conjunction with the gradient correlation similarity measure. The improvement is independent of the underlying registration optimizer. Based on the results, a TEE/X-ray fusion can be performed with a higher frame rate and a shorter time lag towards real-time registration performance. The approach could potentially accelerate other applications of 2D-3D registrations, e.g. the registration of implant models with X-ray images.

8671-38, Session 8

Thin plate spline feature point matching for organ surfaces in minimally invasive surgery imaging

Bingxiong Lin, Yu Sun, Xiaoning Qian, Univ. of South Florida (United States)

Robust feature matching for images in Minimally Invasive Surgery (MIS) is a challenging task due to low texture and specular reflections in these images. This paper presents a new approach that can improve feature matching performance by exploiting the inherent geometric property of the organ surfaces. Recently, pixel based 2D tracking using Thin Plate Spline (TPS) model has been applied for stereo images to recover 3D surfaces of internal organs. Our approach first improves this 3D reconstruction method by considering both the feature correspondences and intensity information. Second, we generate simulated images from the reconstructed 3D surfaces under all potential view positions and orientations, and then extract feature points from these simulated images. The obtained feature points are then filtered and re-projected to the common reference image. The descriptors of the feature points under different view angles are stored to ensure that the proposed method can tolerate a large range of view angles. We evaluate the proposed method with two silicon phantoms and the experimental results show that our method is much more robust with respect to the view angle changes than other state-of-the-art methods.

8671-39, Session 8

3D-3D registration of partial capitate bones using spin-images

Ryan E. Breighner, David R. Holmes III, Mayo Clinic, Biomechanics Lab. (United States); Shuai Leng, Mayo Clinic (United States); Kai-Nan An, Mayo Clinic (United States) and Mayo Clinic, Biomechanics Lab. (United States); Cynthia McCollough, Mayo Clinic (United States); Kristin Zhao, Mayo Clinic, Biomechanics Lab. (United States)

It is often necessary to register partial objects in medical imaging. Due to limited FOV, the entirety of an object cannot always be imaged. This study presents a novel application of an existing registration algorithm to this problem. The spin-image algorithm creates pose-invariant representations of global shape with respect to individual mesh vertices. These 'spin-images,' are then compared for two different poses of the same object to establish correspondences and subsequently determine relative orientation of the poses. In this study, the spin-image algorithm is applied to 4DCT-derived capitate bone surfaces to assess the accuracy of registration with varying amounts of geometry excluded.

The limited longitudinal coverage under the 4DCT technique (38.4mm), results in partial views of the capitate when imaging wrist motions. This study assessed the ability of the spin-image algorithm to register partial bone surfaces by artificially restricting the capitate geometry available for registration. Under IRB approval, standard static CT and 4DCT scans were conducted on a patient. The capitate was segmented from the static CT and one phase of 4DCT in which the whole bone was available. Spin-image registration was performed between the static and 4DCT. Distal portions of the 4DCT capitate (10-70%) were then removed and registration was repeated. Registration accuracy was evaluated by angular errors and percentage of sub-resolution fitting. It was determined that 60% of the distal capitate could be omitted without appreciable effect on registration accuracy using the spin-image algorithm (angular error $\leq$ 1 degree, sub-resolution fitting > 98.4%).

8671-40, Session 8

A framework for measuring TRE at the tip of an optically tracked pointing stylus

Amber L. Simpson, Neal P. Dillon, Michael I. Miga, Vanderbilt Univ. (United States); Burton Ma, York Univ. (Canada)

The purpose of our work is to develop a framework for empirically determining the precision of an optical tracking system in terms of fiducial localization error (FLE) and target registration error (TRE) [1] so that theoretical models of the behavior of TRE [2-7] can be validated or refuted. In this report, we are primarily interested in describing the framework, reporting on the consistency of the measurements, and reporting the results of measuring TRE as a function of the angle between a tracked coordinate reference frame (CRF) and the viewing direction of the tracking system. Our approach relies on a robotic manipulator equipped with a spherical wrist to collect large amounts of tracking data from well defined paths. Fitting the tracking data to planes, circles, and spheres allows us to derive estimates of FLE and precisely localize target locations. Preliminary analysis of our data suggests that there is bias in the registered pointer tip location that depended on the tilt angle of the coordinate reference frame with respect to the tracking system. If further testing of our framework proves that our methods are sound, then we can study many other aspects of TRE behavior. For example, we can evaluate the effects of different configurations of markers, different number of markers, different passive marker types (such as the Northern Digital Radix Lens passive marker), active versus passive markers, and motion of the CRF. Other potential topics include validating models of TRE distribution and online prediction of FLE.

8671-42, Session 9

Percutaneous needle placement using laser guidance: a practical solution

Sheng Xu, Ankur Kapoor, Nadine Abi-Jaoudeh, Kimberly Imbesi, Cheng W. Hong, Dumitru Mazilu, Karun Sharma, Aradhana Venkatesan, Elliot Levy, Bradford J. Wood, National Institutes of Health (United States)

In interventional radiology, various navigation technologies have emerged aiming to improve the accuracy of device deployment and potentially the clinical outcomes of minimally invasive procedures. While these technologies' performance has been explored, their impact on daily clinical practice remains undetermined due to the additional cost and complexity, modification of standard devices (e.g. electromagnetic(EM) tracking), and different levels of experience among physicians. Taking these factors into consideration, a robotic laser guidance system for percutaneous needle placement is developed. The laser guidance system projects a laser guide line onto the skin entry point of the patient, helping the physician to align the needle with the planned path of the preoperative CT scan. To minimize changes to the standard workflow, the robot is integrated with the CT scanner via optical tracking. As a result, no registration between the robot and CT is needed. The robot can compensate for the motion of the equipment and keep the laser guide line aligned with the biopsy path in real-time. Phantom experiments showed that the guidance system can benefit physicians at different skill levels, while clinical studies showed improved accuracy over conventional freehand needle insertion. The technology is safe, easy to use, and does not involve additional disposable costs. It is our expectation that this technology can be accepted by interventional radiologists for CT guided needle placement procedures.

8671-43, Session 9

Software for MR image overlay guided needle insertions: the clinical translation process

Tamas Ungi, Paweena U-Thainual, Queen's Univ. (Canada); Jan Fritz, Johns Hopkins Univ. (United States); Aaron J. Flammang, Siemens Corporate Research (United States); Iulian Iordachita, John A. Carrino, Johns Hopkins Univ. (United States); Gabor Fichtinger, Queen's Univ. (Canada)

PURPOSE: Needle guidance software using augmented reality image overlay was translated from the experimental phase to support preclinical and clinical studies. Major functional and structural changes were needed to meet clinical requirements. We present the process applied to fulfill these requirements, and selected features that may be applied in the translational phase of other image-guided surgical navigation systems. METHODS: We used an agile software development process for rapid adaptation to unforeseen clinical requests. The process is based on iterations of operating room test sessions, feedback discussions, and software development sprints. The open-source application framework of 3D Slicer and the NA-MIC kit provided sufficient flexibility and stable software foundations for this work. RESULTS: All requirements were addressed in a process with 19 operating room test iterations. Most features developed in this phase were related to workflow simplification and operator feedback. CONCLUSION: Efficient and affordable modifications were facilitated by an open source application framework and frequent clinical feedback sessions. Results of cadaver experiments show that software requirements were successfully solved after a limited number of operating room tests.

8671-44, Session 9

A fully actuated robotic assistant for MRI-guided prostate biopsy and brachytherapy

Gang Li, Worcester Polytechnic Institute (United States); Hao Su, Weijian Shang, Worcester Polytechnic Institute (United States); Junichi Tokuda , Nobuhiko Hata, Clare M. Tempany, Brigham and Women's Hospital (United States) and Harvard Medical School (United States); Gregory S. Fischer, Worcester Polytechnic Institute (United States)

Intra-operative medical imaging enables incorporation of human experience and intelligence in a controlled, closed-loop fashion. Magnetic resonance imaging (MRI) is an ideal modality for surgical guidance of diagnostic and therapeutic procedures, with its ability to perform high resolution, real-time, high soft tissue contrast imaging without ionizing radiation. However, for most current image-guided approaches only static pre-operative images are accessible for guidance, which are unable to provide updated information during a surgical procedure. The high magnetic field, electrical interference, and limited access of closed-bore MRI render great challenges to developing robotic systems that can perform inside a diagnostic high-field MRI while obtaining interactively updated MR images. To overcome these limitations, we are developing a piezoelectrically actuated robotic assistant for actuated percutaneous prostate interventions under real-time MRI guidance. Utilizing a modular design, the system enables coherent and straight forward workflow for various percutaneous interventions, including prostate biopsy sampling and brachytherapy seed placement, using various needle driver configurations. The unified workflow compromises: 1) system hardware and software initialization, 2) fiducial frame registration, 3) target selection and motion planning, 4) moving to the target and performing the intervention (e.g. taking a biopsy sample) under live imaging, and 5) visualization and verification. Phantom experiments of prostate biopsy and brachytherapy were executed under MRI-guidance to evaluate the feasibility of the workflow. The robot successfully performed fully actuated biopsy sampling and delivery of simulated brachytherapy seeds under live MR imaging, as well as precise delivery of a prostate brachytherapy seed distribution with an RMS accuracy of 0.98mm.

8671-45, Session 9

Design of a decoupeld MRI-compatible force sensor using fiber Bragg grating sensors for robot-assisted prostate interventions

Reza Monfaredi, Lab. for Computational Sensing and Robotics (LCSR), Johns Hopkins Univ. (United States); Reza seifabadi, Lab. for Computational Sensing and Robotics (LCSR), Johns Hopkins Univ. (United States) and Queen's Univ. (Canada); Gabor Fichtinger, Queens Univ. (Canada); Iulian Iordachita, Lab. for Computational Sensing and Robotics (LCSR), Johns Hopkins Univ. (United States)

During prostate needle insertion with straight trajectory, the gland rotates and displaces resulting in needle placement inaccuracy. To compensate for this error, we proposed master-slave needle steering under real-time MRI in a previous study. For MRI-compatibility and accurate motion control, the master (and the slave) robot uses piezo actuators. These actuators however, are non-backdrivable. To cope with this issue, force sensor is required. Force sensor is also required at the slave side to reflect the insertion force to the clinician's hand through the master robot. Currently, there is no MRI-compatible force sensor commercially available today. As the master (and slave) robot in this study requires a combination of linear and rotary motions to generate needle steering, this study is seeking to design a MRI-compatible 2DOF force/torque senor. Fiber Brag Grating (FBG) strain measuring sensors are used which are proved to be completely MRI-compatible. Except the active elements, all components are made of nonmetallic parts. The force and torque

measuring parts are designed to be entirely decoupled. The force and torque sensors are designed to measure +/-20N axial force with the resolution of 0.1 N, and the axial torque (torsion) of +/-200 Nmm with the resolution of 1 Nmm. The desired update frequency is 10Hz. Analytical and Finite Element (FE) analyses are performed to ensure the strains are within the measurable range of the FBG sensors while the sensitivity is maximized. The sensor is designed to be compact (diameter =15 mm, height =20 mm) and easy to handle and install.

8671-46, Session 10

Integration of intraoperative and model-updated images into an industry-standard neuronavigation system: initial results

Timothy J. Schaewe, Medtronic, Inc. (United States); Xiaoyao Fan, Songbai Ji, Alex Hartov, Thayer School of Engineering at Dartmouth (United States); Leslie Hiemenz Holton, Medtronic, Inc. (United States); David W. Roberts, Dartmouth Hitchcock Medical Ctr. (United States); Keith D. Paulsen, Thayer School of Engineering at Dartmouth (United States); David Simon, Medtronic, Inc. (United States)

Dartmouth and Medtronic Navigation have established an academic-industrial partnership to develop, validate, and evaluate a multi-modality neurosurgical image-guidance platform for brain tumor resection surgery that is capable of updating the spatial relationships between preoperative images and the current surgical field. Previous studies have shown that brain shift compensation through a modeling framework using intraoperative ultrasound and/or visible light stereovision to update preoperative MRI appears to result in improved accuracy in navigation. However, image updates have thus far only been produced retrospective to surgery in large part because of gaps in the software integration and information flow between the co-registration and tracking, image acquisition and processing, and image warping tasks which are required during a case. This paper reports the first demonstration of integration of a deformation-based image updating process for brain shift modeling with an industry-standard image guided surgery platform. Specifically, we have completed the first and most critical StealthLink® data transfer operation to transmit volumetric image data generated by the Dartmouth brain shift modeling process to the StealthStation®. StealthStation® comparison views, which allow the surgeon to verify the correspondence of the received updated image volume relative to the preoperative MRI, are possible, along with other displays of image data such as the intraoperative 3D ultrasound used to update the model. These views and data represent the first time that externally acquired and manipulated image data has been imported into the StealthStation® system through the StealthLink® portal and visualized on the StealthStation® display.

8671-47, Session 10

Ontology-based prediction of surgical events in laparoscopic surgery

Darko Katic, Karlsruhe Institut für Technologie (Germany); Anna-Laura Wekerle, Ruprecht-Karls-Univ. Heidelberg (Germany); Fabian Gärtner, Karlsruhe Institut für Technologie (Germany); Hannes Kenngott, Beat Peter Müller-Stich, Ruprecht-Karls-Univ. Heidelberg (Germany); Rüdiger Dillmann, Stefanie Speidel, Karlsruhe Institut für Technologie (Germany)

Context-aware technologies have great potential to help during laparoscopic surgeries. The underlying idea is to create systems which can adapt their assistance functions automatically to the situation in the OR, thus relieving surgeons from the burden of managing computer assisted surgery devices manually. To this purpose, a certain kind of understanding of the current situation in the OR is essential. Beyond that, anticipatory knowledge of incoming events is beneficial, e.g. for early warnings of imminent risk situations. To achieve the goal of predicting surgical events based on previously observed ones, we developed a language to describe surgeries and surgical events using Description Logics and integrated it with methods from computational linguistics. Using n-Grams to compute probabilities of follow-up events, we are able to make sensible predictions of upcoming events in real-time. The system was evaluated on professionally recorded and labeled surgeries and showed an average prediction rate of 80%.

8671-48, Session 10

Integration of 3D 1H-magnetic resonance spectroscopy data into neuronavigation systems for tumor biopsies

Berkay Kanberoglu, Arizona State Univ. (United States); Nina Z. Moore, Barrow Neurological Institute (United States); David H. Frakes, Arizona State Univ. (United States) and Arizona State Univ. (United States); Lina J. Karam, Arizona State Univ. (United States); Josef P. Debbins, Barrow Neurological Institute (United States) and Arizona State Univ. (United States); Mark C. Preul, Barrow Neurological Institute (United States)

Many important applications in clinical medicine can benefit from the fusion of spectroscopy data with anatomical images. For example, the correlation of metabolite profiles with specific regions of interest in anatomical tumor images can be useful in characterizing and treating heterogeneous tumors that appear structurally homogeneous. Such applications can build on the correlation of data from in-vivo Proton Magnetic Resonance Spectroscopy Imaging (1H-MRSI) with data from genetic and ex-vivo Nuclear Magnetic Resonance spectroscopy. To establish that correlation, tissue samples must be neurosurgically extracted from specifically identified locations with high accuracy. Toward that end, this paper presents new neuronavigation technology that enhances current clinical capabilities in the context of neurosurgical planning and execution. The proposed methods improve upon the current state-of-the-art in neuronavigation through the use of detailed three dimensional (3D) 1H-MRSI data. MRSI spectra are processed and analyzed, and specific voxels are selected based on their chemical contents. 3D neuronavigation overlays are then generated and applied to anatomical image data in the operating room. Without such technology, neurosurgeons must rely on memory and other qualitative resources alone for guidance in accessing specific MRSI-identified voxels. In contrast, MRSI-based overlays provide quantitative visual cues and location information during neurosurgery. The proposed methods enable a progressive new form of online MRSI-guided neuronavigation that we demonstrate in this study through phantom validation and clinical application.

8671-49, Session 11

Freehand ultrasound calibration: phantom versus tracked pointer

Mattea L. Welch, Jennifer Andrea, Tamas Ungi, Gabor Fichtinger, Queen's Univ. (Canada)

PURPOSE: Ultrasound-guided tracked navigation requires spatial calibration between the ultrasound beam and the tracker. We examined the reproducibility and accuracy of two popular calibration methods with a handheld linear ultrasound transducer. METHODS: A total of 10 calibrations were performed using (1) a double N-wire phantom with automatic image segmentation and registration; (2) and registration of landmark points collected with a tracked pointer. Reproducibility and accuracy were characterized by comparing the resulting transformation matrices, and by comparing ground truth landmark points. RESULTS: Transformation matrices calculated with N-wire phantom showed a variance of X: 0.02 mm (in the direction of sound propagation), Y: 0.03 mm (in the direction of transducer elements) and Z: 0.21 mm (in the

elevation direction). Transformation matrices obtained with tracked pointer had a variance of X: 0.10 mm, Y: 0.07 mm, and Z: 0.43 mm. Calibration accuracy was tested with ground truth cross wire points. The N-wire phantom provided a calibration with a distance from ground truth of X: 2.44 ± 1.44 mm, Y: 1.21 ± 0.88 mm, and Z: 1.12 ± 0.82 mm. Tracked pointer calibration had a distance from the ground truth of X: 0.23 ± 0.16 mm, Y: 0.62 ± 0.31 mm, and Z: 0.45 ± 0.33 mm. Distance from ground truth was significantly less ($p<0.01$) with the tracked pointer method in all directions. CONCLUSION: Calibration using a tracked pointer had a slightly greater variance, but it showed better accuracy over calibrations performed with N-wire phantoms.

8671-50, Session 11

Development of a 3D ultrasound-guided system for thermal ablation of liver tumors

Hamid Sadeghi Neshat, Robarts Research Institute (Canada); Derek W. Cool, Western Univ. (Canada); Kevin Barker, Lori Gardi, Robarts Research Institute (Canada); Nirmal Kakani, Western Univ. (Canada); Aaron Fenster, Robarts Research Institute (Canada)

Two-dimensional ultrasound (2D US) imaging is commonly used for diagnostic and intraoperative guidance of interventional abdominal procedures including percutaneous thermal ablation of focal liver tumors with radiofrequency (RF) or microwave (MW) ablation. However, 2D US in many situations may not provide enough anatomical detail and guidance information. Therefore intra-operative CT is used in many centers for guidance purposes that is costly and can only be utilized to confirm tool placement rather than guiding the insertion. Three-dimensional ultrasound (3D US) has been introduced to address these issues at different levels. In this work, we present our integrated solution to provide 3D US images using a newly developed mechanical transducer with a large field-of-view and without the need for external tracking devices to combine diagnostic and planning information of different modalities with intraoperative guidance. The system provides tools to segment the target(s), plan the ablation and detect the ablation applicators during the procedure for guiding purposes. Some of our pre-clinical experiments to ensure accurate measurements with the developed system as well as our early clinical results are presented that show 3D US used for focal liver ablation can provide a more reliable planning and guidance tool compared to 3D US only, and in many cases offers comparable measurements to intro-operative CT with lower cost and faster time.

8671-51, Session 11

Geometric reconstruction using tracked ultrasound strain imaging

Thomas S. Pheiffer, Amber L. Simpson, Janet E. Ondrake, Michael I. Miga, Vanderbilt Univ. (United States)

The accurate identification of tumor margins during neurosurgery is a primary concern for the surgeon in order to maximize resection of malignant tissue while preserving normal function. The use of preoperative imaging for guidance is standard of care, but tumor margins are not always clear even when contrast agents are used, and so margins are often determined intraoperatively by visual and tactile feedback. Ultrasound (US) strain imaging creates a quantitative representation of tissue stiffness which can be used in real-time. The information offered by strain imaging can be placed within a conventional image-guidance workflow by tracking the US probe and calibrating the image plane, which facilitates interpretation of the data by placing it within a common coordinate space with preoperative imaging. Tumor geometry in strain imaging is then directly comparable to the geometry in preoperative imaging. This paper presents a tracked US strain imaging system capable of co-registering with preoperative tomograms and also of reconstructing a 3D surface using the border of the strain lesion. In a preliminary study using a phantom with a subsurface tumor, tracked strain imaging was registered to a preoperative image volume and then a tumor surface was reconstructed using contours extracted from strain image slices. The volume of the phantom tumor in CT was 1.2 cm^3, compared to a volume of 1.5 cm^3 observed in the strain volume. Future work will be done to robustly characterize the reconstruction accuracy of the system.

8671-52, Session 12

Quantitative evaluation of treatment related changes on multi-parametric MRI after laser interstitial thermal therapy of prostate cancer

Satish E. Viswanath, Case Western Reserve Univ. (United States); Dan Sperling M.D., New Jersey Institute of Radiology (United States); Herbert Lepor M.D., New York Univ. Langone Medical Ctr. (United States); Jurgen Futterer M.D., Radboud Univ. Nijmegen Medical Ctr. (Netherlands); Anant Madabhushi, Case Western Reserve Univ. (United States)

Laser interstitial thermal therapy (LITT) has recently shown great promise as a treatment strategy for localized, low-grade, organ-confined prostate cancer. Additionally, LITT is highly compatible for use in conjunction with multi-parametric magnetic resonance imaging (MP-MRI). This enables (1) high resolution, accurate localization of ablation zones (prostate cancer extent) in vivo prior to LITT, and (2) real-time monitoring of temperature changes in vivo during LITT. A third, lesser explored application of MP-MRI is in the context of treatment-related changes in vivo post-LITT. Currently, short-term treatment-related change and outcome are evaluated via qualitative examination of post-LITT MP-MRI; the subjective nature of this process makes it highly error-prone. A second possibility, thus far unexplored, is whether certain MP-MRI imaging markers may be predictive of long-term patient outcome. In this work, we present preliminary results of developing a quantitative framework to evaluate treatment-related changes post-LITT on a per-voxel basis (high resolution), via construction of an integrated MP-MRI signature. Preliminary results on 2 patients showed that diffusion-weighted and T2-weighted MRI were most illustrative of treatment-related changes post-LITT; the resulting weighted MP-MRI difference map was highly indicative of short-term successful treatment outcome (major change specific to the ablation zone on MRI). Quantitative evaluation of pre- and post-LITT MP-MRI may hence allow for identification of non-invasive imaging markers which are prognostic of long- and short-term patient outcome.

8671-53, Session 12

A flexure-based wrist for needle-sized surgical robots

Philip J. Swaney, Jessica Burgner, Robert J. Webster III, Vanderbilt Univ. (United States)

We present a novel flexure-based wrist design for needle-sized robotic manipulators. It may be mounted at the tip of a traditional surgical needle, deployed through an endoscope working channel, or attached to the tip of a concentric tube robot. In all these applications, the wrist enables dexterity in very small spaces. The wrist consists of two stacked flexure joints that are actuated by thin pull wires, and is particularly useful in devices having diameters of 1 mm or less. In this paper we present the design of the wrist and experimental evaluation of its usefulness in an example motivating surgical scenario, endonasal skull base surgery.

8671-54, Session 12

Real-time 3D Fourier-domain optical coherence tomography guided microvascular anastomosis

Yong Huang, Johns Hopkins Univ. (United States); Zuhaib Ibrahim, Wei-Ping A. Lee, Gerald Brandacher, Johns Hopkins Univ. School of Medicine (United States); Jin U Kang, Johns Hopkins Univ (United States)

Vascular and microvascular anastomosis is considered to be the foundation of plastic and reconstructive surgery, hand surgery, transplant surgery, vascular surgery and cardiac surgery. In the last two decades innovative techniques, such as vascular coupling devices, thermo-reversible poloxamers and suture-less cuff have been introduced. Such procedures could benefit from using an innovative surgical imaging technique that provides in-depth view and 3D imaging during the surgery. Optical coherence tomography (OCT) is a non-invasive high-resolution (micron level), high-speed, 3D imaging modality that has been adopted widely in biomedical and clinical applications. In this work we performed a proof-of-concept evaluation study of OCT as an assisted intraoperative and poster operative imaging modality for microvascular anastomosis in the limb of mice model. The OCT imaging modality we used has an imaging range of 3x3x1.6 mm3 (XxYxZ-depth) with 12 μm lateral resolution, 3.0 μm axial resolution in air and 1 volume/s imaging speed, which could provide the surgeon with clearly visualized vessel lumen wall and suture needle position relative to the vessel during intraoperative imaging. These information could help surgeons reduce the risk of accidentally punching the needle through the back wall of blood vessel. Such risk significantly increases with smaller microvasculature diameter less than 0.5 mm. Phase-resolved Doppler OCT (PRDOCT) imaging of the surgical site was performed as a poster-operative evaluation of the surgical outcome to visualize the blood flow and thrombosis status in connected vessels.

8671-55, Session 12

Towards cone-beam CT thermometry

Ming Li, Nadine Abi-Jaoudeh, Ankur Kapoor, National Institutes of Health (United States); Samuel Kadoury, Philips Research North America (United States); Sheng Xu, National Institutes of Health (United States); Niels Noordhoek, Alessandro Radaelli , Bart Carelsen, Philips Healthcare (Netherlands); Bradford J. Wood, National Institutes of Health (United States)

Purpose.

Monitoring of the temperature and extent of an ablation zone during a cone-beam CT (CBCT) guided ablation can prevent overtreatment and under-treatment. We propose a new image-based method to detect tissue changes in sequential CBCT images acquired during an ablation procedure and explore the possibility of using this method to generate a thermometry map from CBCT images, which can be used as an input function for ablation treatment planning.

Methods.

The novel method uses a baseline and an intermittent CBCT scan, which are routinely acquired to confirm the needle position and monitor the progress of the ablation. A Wronskian change detector algorithm is applied on the compensated images to obtain a difference image between two scans. Finally, a thermal map created by applying a calibration determined experimentally is used to obtain the corresponding temperature at each pixel or voxel.

Results.

We tested the temperature mapping on a gel phantom with thermocouple data recorded for ground truth comparison. Results show our method can detect the ablation zone and predict temperature with sufficient accuracy (2.3±1.4°C difference to ground truth). A CBCT thermometry experiment performed on a pig shoulder show encouraging results for real tissue with temperature changes correlating with the ablation zones, within a 5°C margin.

Conclusion.

The preliminary experimental results show that CBCT thermometry is possible and promising, but preprocessing steps, such as deformable registration for compensating possible motion between the baseline and intermittent scans, as well as quantitative evaluations have to be conducted for validation prior to clinical assessment and translation.

8671-56, Session 12

Fast deformable registration for soft organs with large motion in HIFU treatment

Edward X. Huang, The Hospital for Sick Children (SickKids) (Canada)

In noninvasive high intensity focused ultrasound (HIFU) treatment, we often need to register MR images acquired with different patient positioning or at different respiratory instances. In these scenarios, the abdominal organs such as the liver exhibit a large motion in different images. In our previous work, we proposed a fast neuro-fuzzy technique for deformable registration with small motion/rotation. In this study, based on elastic solid mechanics, we extend our previous results to deformation with large motion which is often the case for soft tissues in HIFU treatment. The proposed method involves minimizing strain energy of soft tissues which is constrained by 3D curves of blood vessels and point marks. It provides fast and robust deformable match for internal structures such as blood vessels, and eliminate local minima. Furthermore, the strain energy constraint provides good generalization properties, prevents the issue of overfitting (for example, physically impossible deformation), and leads to physically consistent deformable registration results. We have demonstrated the effectiveness of our deformable technique in registering MR liver images. Validation shows a target registration error of 2.31 mm and an average centerline distance error of 2.30 mm. This technique has the potential to significantly improve registration capability and the quality of intra-operative image guidance in HIFU procedures.

8671-3, Session PSWed

A graph-based approach for local and global panorama imaging in cystoscopy

Tobias Bergen, Thomas Wittenberg, Christian Münzenmayer, Fraunhofer-Institut für Integrierte Schaltungen (Germany); Chi Chiung Grace Chen M.D., Gregory D. Hager, Johns Hopkins Univ. (United States)

Inspection of the urinary bladder with an endoscope (cystoscope) is the usual procedure for early detection of bladder cancer. The very limited field of view provided by the endoscope makes it challenging to ensure, that the interior bladder wall has been completely examined. Panorama imaging techniques can be used to assist the surgeon and provide a larger view field. Different approaches have been proposed, but generating a panorama image of the entire bladder from real patient data is still up for further research. We propose a graph-based and hierarchical approach to assess this problem to first generate several local panorama images, followed by a global textured three-dimensional reconstruction of the organ. In this contribution, we address details of the first level of the approach including a graph-based algorithm to deal with the challenging condition of in-vivo data. This graph strategy gives rise to a robust relocalization strategy in case of tracking failure, an effective keyframe selection process as well as the concept of building locally optimized sub-maps, which lay the ground for a global optimization process. Our results show the successful application of the method to four in-vivo data sets. We are currently acquiring further data sets and aim at validating the approach on several dozens of patients.

8671-41, Session PSWed

Experimental platform for intra-uterine needle placement procedures

Yashar Madjidi, PerkLab - Queen's Univ. (Canada); Tamás Haidegger, Budapest Univ. of Technology and Economics (Hungary); Wolfgang Ptacek, Austrian Ctr. for Medical Innovation and Technology (Austria); Daniel Berger, Christian Kirisits, Medizinische Univ. Wien (Austria); Gernot Kronreif, Austrian Ctr. for Medical Innovation and Technology (Austria); Gabor Fichtinger, PerkLab - Queen's Univ. (Canada)

A framework has been investigated to enable a variety of comparative studies in the context of needle–based gynaecological brachytherapy. Our aim was to create an anthropomorphic phantom–based platform. The three main elements of the platform are the organ model, needle guide, and needle drive. These have been studied and designed to replicate the close environment of brachytherapy treatment for cervical cancer. Key features were created with the help of collaborating interventional radio–oncologists and the observations made in the operating room. A phantom box, representing the uterus model, has been developed considering available surgical analogies and operational limitations, such as organs at risk. A modular phantom–based platform has been designed and prototyped with the capability of providing various boundary conditions for the target organ. By mimicking the female pelvic floor, this framework has been used to compare a variety of needle insertion techniques and configurations for cervical and uterine interventions. The results showed that the proposed methodology is useful for the investigation of quantifiable experiments in the intra-abdominal and pelvic regions.

8671-57, Session PSWed

Patient-specific port placement for laparoscopic surgery using atlas-based registration

Andinet Enquobahrie, Vikas Shivaprabhu, Stephen Aylward, Julien Finet, Kitware, Inc. (United States); Kevin Cleary, Children's National Medical Ctr. (United States); Ron Alterovitz, The Univ. of North Carolina at Chapel Hill (United States)

Laparoscopic surgery is a minimally invasive surgical approach, in which abdominal surgical procedures are performed through trocars via small incisions. Patients benefit by reduced post-operative pain, shortened hospital stays, improved cosmetic results, and faster recovery times. Optimal port placement can improve surgeon dexterity and avoid the need to move the trocars, which would cause unnecessary trauma to the patient. We are building an intuitive open source visualization system to help surgeons identify ports. Our methodology is based on an intuitive port placement visualization module and atlas-based registration algorithm to transfer port locations to individual patients. The methodology follows three steps:1) Use a port placement visualization module to manually place ports in an abdominal organ atlas. This step generates port-augmented abdominal atlas. This is done only once for a given patient population. 2) Register the atlas data with the patient CT data, to transfer the prescribed ports to the individual patient 3) Review and adjust the transferred port locations using the port placement visualization module. Tool maneuverability and target reachability can be tested using the visualization system. Our methodology would decrease the amount of physician input necessary to optimize port placement for each patient case. In a follow up work, we plan to use the transferred ports as starting point for further optimization of the port locations by formulating a cost function that will take into account factors such as tool dexterity and likelihood of collision between instruments.

8671-58, Session PSWed

Patient-specific liver deformation modeling for tumor tracking

Young-Taek Oh, Youngkyoo Hwang, Jung-Bae Kim, Won-Chul Bang, James D. K. Kim, ChangYeong Kim, Samsung Advanced Institute of Technology (Korea, Republic of)

We present a new method for patient-specific liver deformation modeling for tumor tracking. Our method focuses on deforming two main blood vessels of the liver -- hepatic and portal vein -- to utilize them as features. A novel centerline editing algorithm based on ellipse fitting is also introduced for vessel deformation. Centerline-based blood vessel model and various interpolation methods are often used when generating a deformed model at specific time t. However, when models used in interpolation are not consistent, it may introduce artifacts. One of main reason of this inconsistency is the location of bifurcation points differs from each image. To solve this problem, our method generates a base model from one of patient's CT images. Next, we apply a rigid Iterative Closest Point (ICP) method to the base model with centerlines of other images. Because the transformation is rigid, the length of each vessel's centerline is preserved while some part of the centerline is slightly deviated from centerlines of other images. We resolve this mismatch using our centerline editing algorithm. Lastly, we interpolate three deformed models of liver, blood vessels, tumor using quadratic Bezier curves. We demonstrate the effectiveness of the proposed approach with the real patient data.

8671-59, Session PSWed

Fully automated needle detection in transrectal ultrasound series for repeated prostate biopsies

Ethan Y. Leng, Rice Univ. (United States); Sheng Xu, Peter A. Pinto, Bradford J. Wood, National Institutes of Health (United States)

Needle identification in transrectal ultrasound (TRUS) guided prostate biopsy is important for documenting the positions of tissue samples, which can help physicians reach missed tumors in repeated biopsies. Due to the inherent high signal-to-noise ratio of ultrasound and the frequent occurrence of out-of-plane needle insertions that present indistinctly on TRUS images, robust needle identification is difficult. In this paper, we describe a novel method for the automatic detection and distance measurement of biopsy needles in TRUS that uses the concept of support vector machines (SVMs). Recorded frames are first retrospectively analyzed based on a series of quantifiable characteristics, and then a set of training examples are formed from both frames with insertions and those without. Using the training set, our algorithm is able to determine whether a given prospective frame contains a needle insertion. The algorithm has been evaluated retrospectively on TRUS video data with a total of more than 70,000 frames and 161 needle insertions, and detected needle deployments with sensitivity and specificity of 98.8% and >99.9%, respectively. Furthermore, given the nature of an SVM model, the algorithm can be easily adapted for real-time applications.

8671-60, Session PSWed

3D deformable organ model based liver motion tracking in ultrasound videos

Jung-Bae Kim, Youngkyoo Hwang, Young-Taek Oh, Won-Chul Bang, Heesae Lee, James D. K. Kim, ChangYeong Kim, Samsung Advanced Institute of Technology (Korea, Republic of)

This paper presents a novel method of using 2D ultrasound (US) cine

images during image-guided therapy to accurately track the 3D position of a tumor even when the organ of interest is in motion due to patient respiration. Tracking is possible thanks to a 3D deformable organ model we have developed. The method consists of three processes in succession. The first process is organ modeling where we generate a personalized 3D organ model from high quality 3D CT or MR data sets captured during three different respiratory phases. The model includes the organ surface, vessel and tumor, which can all deform and move in accord with patient respiration. The second process is registration of the organ model to 3D US images. From 133 respiratory phase candidates generated from the deformable organ model, we resolve the candidate that best matches the 3D US images according to vessel centerline and surface. As a result, we can determine the position of the US probe. The final process is the real-time tracking using 2D US cine images captured by the same US probe. We determine the respiratory phase by tracking the diaphragm on the image. Then the 3D model is deformed according to respiration phase and is fitted to the image by considering the positions of the vessels. The tumor's 3D positions are then inferred based on respiration phase. We have tested our method on real patient data. During tracking, the accuracy of the 3D position is within 3.79mm and processing time is 5.4ms.

8671-61, Session PSWed

Real-time tumor tracking in B-mode images using respiratory signal and deformed liver models

Youngkyoo Hwang, Young-Taek Oh, Jung-Bae Kim, Won-Chul Bang, Heesae Lee, James D. K. Kim, ChangYeong Kim, Samsung Advanced Institute of Technology (Korea, Republic of)

Respiratory signal is highly correlated with the movement of organs such as the lungs and liver. Thus, it is typical to find location of the cancers in the organs by respiratory monitoring systems. There are two main kinds of respiratory monitoring technologies: respiratory gating and tumor tracking. Respiratory gating applies a beam only periodically during the gating window. It result in a longer treatment time than tracking based treatments. Furthermore, gating requires that the respiratory motion is periodic and that the tumor moves in a similar fashion. If the patient fails to keep periodic respiration, it will result in inaccurate treatment. The tumor is tracked by monitoring either implanted fiducial markers within the body or on the surface of the chest or abdomen. However, in addition to being painful and uncomfortable to the patient, the technique is inaccurate because it estimates the tumor motion indirectly from abdominal movement.

In this paper, we propose a novel method to track a liver tumor in real time by monitoring respiratory signals directly from B-mode images and using a deformed liver model generated from CT images of the patient. Our method has several advantages. 1) There is no additional radiation dose and is cost effective due to use of an ultrasound device. 2) A high quality respiratory signal can be directly extracted from 2D images of the diaphragm. 3) Using a deformed liver model to track a tumor's 3D position, our method has an accuracy of 3.79mm in tracking error.

8671-62, Session PSWed

Surface-based prostate registration with biomechanical regularization

Wendy J. M. van de Ven, Radboud Univ. Nijmegen Medical Ctr. (Netherlands); Yipeng Hu, Univ. College London (United Kingdom); Jelle O. Barentsz, Nico Karssemeijer, Radboud Univ. Nijmegen Medical Ctr. (Netherlands); Dean Barratt, Univ. College London (United Kingdom); Henkjan J. Huisman, Radboud Univ. Nijmegen Medical Ctr. (Netherlands)

Adding MR-derived information to standard transrectal ultrasound (US) images for guiding prostate biopsy is of substantial clinical interest. A tumor visible on MR images can be projected on US by using MR-US registration. A common approach is to use surface-based registration. We hypothesize that using biomechanical modeling will better control deformation inside the prostate than a regular surface-based registration method. We developed a novel method using a surface-based registration and extended it with finite element (FE) simulation to predict internal deformation of the prostate. For each patient, a tetrahedral mesh was constructed from the manual prostate segmentation. Next, the internal prostate deformation was simulated using the derived radial surface displacement as boundary condition. The deformation field within the gland was calculated using the predicted FE node displacements and thin-plate spline interpolation. We tested our method on MR guided MR biopsy imaging data as landmarks can easily be identified on MR images. For evaluation of the registration accuracy we used 45 landmarks located in all regions of the prostate. Our results show that the median target registration error of a surface-based registration with biomechanical regularization is 1.88 mm, which is significantly different from 2.61 mm without biomechanical regularization. We can conclude that biomechanical FE modeling has the potential to improve the accuracy of multimodal prostate registration when comparing it to regular surface-based registration.

8671-63, Session PSWed

Transorbital target localization in the porcine model

Michael P. DeLisi, Louise A. Mawn, Robert L. Galloway, Vanderbilt Univ. (United States)

Current pharmacological therapies for the treatment of chronic optic neuropathies such as glaucoma are often inadequate due to their inability to directly affect the optic nerve and prevent neuron death. While drugs that target the neurons have been developed, existing methods of administration are not capable of delivering an effective dose of medication along the entire length of the nerve. We have developed an image-guided system that utilizes a magnetically tracked flexible endoscope to navigate to the back of the eye and administer therapy directly to the optic nerve. We demonstrate the capabilities of this system with a series of targeted surgical interventions in the orbits of live pigs. Target objects consisted of NMR microspherical bulbs with a volume of 18 µL filled with either water or diluted gadolinium-based contrast, and prepared with either the presence or absence of a visible coloring agent. A total of 6 pigs were placed under general anesthesia and two microspheres of differing color and contrast content were blindly implanted in the fat tissue of each orbit. The pigs were scanned with T1-weighted MRI, image volumes were registered, and the microsphere containing gadolinium contrast was designated as the target. The surgeon was required to navigate the flexible endoscope to the target and identify it by color. For the last three pigs, a 2D/3D registration was performed such that the target's coordinates in the image volume was noted and its location on the video stream was displayed with a crosshair to aid in navigation. The surgeon was able to correctly identify the target by color, with an average intervention time of 20 minutes for the first three pigs and 3 minutes for the last three.

8671-64, Session PSWed

Image guidance could aid performance of atraumatic cochlear implantation surgical techniques

Jack H. Noble, Vanderbilt Univ. (United States); Robert F. Labadie, George B. Wanna M.D., Vanderbilt Univ. Medical Ctr. (United States); Benoit M. Dawant, Vanderbilt Univ. (United States)

It is widely believed that a major factor in achieving atraumatic insertion of the electrode array into the cochlea in cochlear implant (CI) surgery is selection of the entry point and angle of insertion. Our group is interested

in developing an image guidance (IG) system for electrode insertion if IG can improve outcomes. Thus, in this work we conducted the first study evaluating whether IG could aid atraumatic electrode insertion. To do this, we measured the performance of experienced surgeons when tasked to select CI insertion trajectories in virtual surgical field-of-view rendering software. This software was designed to simulate views through the surgical microscope and allow a user to manually select a preferred insertion trajectory in one of two modes: (a) where the traditional approach is simulated and sub-surface anatomy is not visible; and (b) where an IG approach is simulated and the surgical view is augmented with rendering of subsurface intra-cochlear structures. We used this software to compare two surgeons' performance in selecting insertion trajectories with and without IG. Our results show that selection of insertion trajectories by both surgeons improves when using virtual IG and that the two surgeons choose more similar insertion trajectories when using virtual IG. These results suggest that IG could indeed aid performance of atraumatic cochlear implantation techniques.

8671-65, Session PSWed

Robotically adjustable microstereotactic frames for image-guided neurosurgery

Louis Kratchman, Michael Fitzpatrick, Vanderbilt Univ. (United States)

Stereotactic frames are a standard tool for neurosurgical targeting, but are uncomfortable for patients and obstruct the surgical field. Microstereotactic frames are more comfortable for patients, provide better access to the surgical site, and have grown in popularity as an alternative to traditional stereotactic devices. However, clinically available microstereotactic frames require either lengthy manufacturing delays or expensive image guidance systems. We introduce a robotically-adjusted, disposable microstereotactic frame for deep brain stimulation surgery that eliminates the drawbacks of existing microstereotactic frames. Our frame can be automatically adjusted in the operating room using a preoperative plan in less than five minutes. A validation study shows that our approach provides the required accuracy for DBS surgery.

8671-66, Session PSWed

Marker detection evaluation by phantom and cadaver experiments for C-arm pose estimation pattern

Teena Steger, Stefan Wesarg, Fraunhofer-Institut für Graphische Datenverarbeitung (Germany); Martin Hoßbach, Fraunhofer-Institut für Graphische Datenverarbeitung (Germany)

C-arm fluoroscopy is used for guidance during several clinical exams, e.g. in bronchoscopy to locate the bronchoscope inside the airways. Unfortunately, these images provide only 2D information. However, if the C-arm pose is known, it can be used to overlay the intrainterventional fluoroscopy images with 3D visualizations of airways, acquired from preinterventional CT images. Thus, the physician's view is enhanced, guiding him during bronchoscopy and facilitating the location of the instrument at the correct position inside the bronchial tree. We present a novel method for C-arm pose estimation introducing a marker-based fiducial, which is placed on the patient table. The steel markers form a pattern, allowing to deduce the C-arm pose by use of the projective invariant cross-ratio. Simulations show that the C-arm pose estimation is reliable and accurate for translations inside an imaging area of 30cm x 50cm and rotations up to 30deg. Mean error values are 0.33mm in 3D space and 0.48px in the 2D imaging plane. First tests on C-arm images resulted in similarly compelling accuracy values and high reliability in an imaging area of 30cm x 42.5cm. Even in the presence of interfering structures, tested both with anatomy phantoms and a turkey cadaver, high success rates over 90% and fully satisfying execution times below 4sec for 1024px x 1024px images could be achieved.

8671-67, Session PSWed

Pose estimation quality assessment for intra-operative image guidance systems

Adrian Egli, Gerhard Kleinszig, Adrian John, Siemens AG (Germany); Alberto Fernandez, Juan Cardelino, ICUC GmbH (Uruguay)

In trauma and orthopedic surgery screw assessment and trajectory prediction using two-dimensional X-ray images is very difficult due to projected 3D information. However screw assessment can be done with multiple X-ray images. If the X-ray image contains the projected implant geometry it can be used as global coordinate reference. Thereby multiple independent X-ray images can be synchronized by estimating the implant pose in each single image. Consequently high accuracy pose estimation is fundamental. To measure the outcome quality an evaluation process has been designed. The evaluation process investigates in its first step several clinical intra-operative anterior-posterior (AP) and medio-lateral (ML) X-ray images which have been analyzed using a manual pose estimation method. With the manual method the six 3D parameters of the implant pose are estimated. These parameters define as well the camera pose relative to the implant. Based on the pose parameters of all clinical cases the capturing range for typical AP and ML images is statistically defined. The implant was attached to a phantom with 16 steel balls which allows to calculate the ground truth pose. Afterwards several X-ray images of the phantom are taken within the statistically defined capturing range. With the known ground truth different pose estimation methods can be compared. For each method the estimation quality can be calculated. In addition this error calculation can be used to adjust the initial manually determined capturing range. This paper explains the error evaluation process and describes how to validate pose estimation methods for clinical applications.

8671-68, Session PSWed

Intraoperative imaging for patient safety and QA: detection of intracranial hemorrhage using high-quality C-arm cone-beam CT

Sebastian Schafer, Adam S. Wang, Yoshito Otake, Joseph W. Stayman, Wojciech Zbijewski, Johns Hopkins Univ. (United States); Gerhard Kleinszig, Siemens AG (Germany); Gary L. Gallia, Jeffrey H. Siewerdsen, Johns Hopkins Univ. (United States)

Intraoperative imaging could improve patient safety and quality assurance (QA) via the detection of subtle complications that are otherwise found hours after surgery and thereby reduce the need for additional intervention. Among the severe adverse events that could be reduced by high-quality intraoperative imaging is acute intracranial hemorrhage (ICH), conventionally assessed using post-operative CT. A mobile C-arm capable of high-quality cone-beam CT (CBCT) in combination with advanced image reconstruction techniques is reported as a means of detecting ICH in the operating room. The system employs an isocentric C-arm with a flat-panel detector in dual gain mode, correction of x-ray scatter and beam-hardening, and a penalized likelihood (PL) iterative reconstruction method. Performance in ICH detection was investigated using a quantitative phantom focusing on (non-contrast-enhanced) blood/brain contrast, an anthropomorphic head phantom, and a pig model with injected fresh blood bolus, with ICH visibility characterized in terms of contrast-to-noise ratio (CNR) and qualitative evaluation of images by a neurosurgeon. Across a range of dose and ICH simulations, the CNR increased from ~2.2-3.7 for conventional filtered backprojection (FBP) to ~3.9-5.4 for PL at equivalent spatial resolution. The porcine model demonstrated superior ICH detectability for PL. The results support the role of high-quality mobile C-arm CBCT employing advanced reconstruction algorithms for detecting subtle complications in the operating room at lower radiation dose and lower cost than intraoperative CT scanners and/or fixed-room

C-arms. Such capability could present a potentially valuable aid to patient safety and QA.

8671-69, Session PSWed

Quantitative evaluation of multi-parametric MR Imaging marker changes post-laser interstitial ablation therapy (LITT) for epilepsy

Pallavi Tiwari, Rutgers Univ. (United States); Shabbar Danish, Stephen Wong, Univ. of Medicine & Dentistry of New Jersey (United States); Anant Madabhushi, Rutgers, The State Univ. of New Jersey (United States)

Laser-induced interstitial thermal therapy (LITT) has recently emerged as a new, less invasive alternative to craniotomy for treating epilepsy; which allows for focused delivery of laser energy monitored in real time by MRI, for precise removal of the epileptogenic foci. Despite being minimally invasive, the effects of laser ablation on the epileptogenic foci (reflected by changes in MR imaging markers post-LITT) are currently unknown. In this work, we present the first-of-its-kind framework that qualitatively characterizes voxel-by-voxel basis imaging marker changes across different multi-parametric MR imaging (MP-MRI) protocols, to identify imaging markers that change most-dramatically post-LITT, and hence may serve as candidate markers for treatment response. A cohort of patients were monitored at different time-points post-LITT via MP-MRI involving T1-w, T2-w, T2-GRE, T2-FLAIR, and apparent diffusion coefficient (ADC) protocols. Post-affine registration of individual MRI protocols to a reference MRI protocol pre-LITT, a weighted MP-MRI difference map is generated by combining differences in individual MR intensities across protocols, where weights of each protocol are differentially optimized based on their ability in accurately capturing treatment changes. A time-dependent MP-MRI profile corresponding to successful (seizure-free) or unsuccessful (seizure recurrence) treatment can then be created that optimally quantifies contributions of each protocol at different time points. Preliminary results via MP-MRI profiles of two patients reflect that, (a) optimally weighted MP-MRI maps may be more informative in accurately identifying treatment related changes compared to individual protocols, and (b) ADC, T1, and T2-w are relatively more contributory in identifying post-LITT treatment changes, compared to T2-GRE, and T2-FLAIR. The current framework thus serves as an important precursor to a comprehensive treatment evaluation system that can be used to identify markers corresponding to patient's response (seizure-free or seizure recurrence), with an ultimate objective of making prognostic predictions about patients outcome post-LITT.

8671-70, Session PSWed

Physiologically gated micro-beam radiation therapy using electronically controlled field emission x-ray source array

Pavel Chtcheprov, The Univ. of North Carolina at Chapel Hill (United States); Michael Hadsell, The Univ. of North Carolina at Chapel Hill (United States); Laurel Burk, The Univ. of North Carolina at Chapel Hill (United States); Rachel Ger, The Univ. of North Carolina at Chapel Hill (United States); Lei Zhang, The Univ. of North Carolina at Chapel Hill (United States); Hong Yuan, Yueh Z. Lee, The Univ. of North Carolina at Chapel Hill (United States); Sha Chang, Jianping Lu, Otto Z. Zhou, The Univ. of North Carolina at Chapel Hill (United States)

Micro-beam radiation therapy (MRT) uses parallel planes of high dose narrow (10-100 um in width) radiation beams separated by a fraction of a millimeter to treat cancerous tumors. This experimental therapy method based on synchrotron radiation has been shown to spare normal tissue at up to 1000Gy of entrance dose while still being effective in tumor eradication and extending the lifetime of tumor-bearing small animal models. Motion during the treatment can results in significant movement of micro beam positions resulting in broader beam width and lower peak to valley dose ratio (PVDR), and thus can reduce the effectiveness of the MRT. Recently we have developed the first bench-top image guided MRT system for small animal treatment using a high powered carbon nanotube (CNT) x-ray source array. The CNT x-ray source can be electronically synchronized to an external triggering signal to enable physiologically gated firing of x-ray radiation to minimize motion blurring. Here we report the results of phantom study of respiratory gated MRT. A simulation of mouse breathing was performed using a servo motor. Preliminary results show that without gating the micro beam FWTM can increase by 70% and PVDR can decrease up to 50%. But with proper gating, both the beam width and PVDR changes can be negligible. Future experiments will involve irradiation of mouse models and comparing histology stains between the controls and the gated irradiation.

8671-71, Session PSWed

Patient-specific model of a scoliotic torso for surgical planning

Rola Harmouche, Farida Cheriet, École Polytechnique de Montréal (Canada); Hubert Labelle M.D., CHU Sainte-Justine (Canada); Jean Dansereau , École Polytechnique de Montréal (Canada)

A method for the construction of a patient-specific model of a scoliotic torso for surgical planning via inter-patient registration is presented. Magnetic Resonance Images (MRI) of a generic model are registered to surface topography (TP) and X-ray data of a test patient. A partial model is first obtained via thin-plate spline registration between TP and X-ray data of the test patient. The MRIs from the generic model are then fit into the test patient using articulated model registration between the vertebrae of the generic model's MRIs in prone position and the test patient's X-rays in standing position. A non-rigid deformation of the soft tissues is performed using a modified thin-plate spline constrained to maintain bone rigidity and to fit in the space between the vertebrae and the surface of the torso. Results show average DICE values of $0.975pm0.012$ between the MRIs following inter-patient registration and the surface topography of the test patient, which is comparable to the average value of $0.976pm 0.009$ previously obtained following intra-patient registration. The results also show a significant improvement compared to rigid inter-patient registration. Future work includes validating the method on a larger cohort of patients and incorporating soft tissue stiffness constraints. The method developed can be used to obtain a geometric model of a patient including bone structures, soft tissues and the surface of the torso which can be incorporated in a surgical simulator in order to better predict the outcome of scoliosis surgery, even if MRI data cannot be acquired for the patient.

8671-72, Session PSWed

Effect of landmark configuration on target registration error for vertebra: a phantom study

Marzieh Ershad, Alireza Ahmadian, Nassim Dadashi, Hooshang Saberi, Fatemeh Nazem, Tehran Univ. of Medical Sciences (Iran, Islamic Republic of); Keyvan Amini Khoiy, Sharif Univ. of Technology (Iran, Islamic Republic of)

The configuration of landmarks is an important issue in minimizing the target registration error (TRE). In this paper the effect of different landmark configurations on the accuracy of pedicle screw placement during image guided spine surgery (IGSS) is investigated. Since the spine is deformed in intra- operative conditions compared to the preoperative situation, an accurate alignment of each vertebra is crucial to compensate for the deformation. CT compatible markers are placed over anatomical landmarks which are feasible and routinely used in

surgical procedures. The TRE is obtained directly for the markers which are placed on the right and left pedicle of the vertebra. The estimated TRE values are also calculated using Fitzpatrick's TRE estimation formula. Optimum selections of landmarks are proposed for different number of landmarks, according to the minimum TRE values in different configurations.

The approach uses feasible anatomical landmarks, is able to become adaptive to constraints that may be imposed by surgeons during surgical procedure and it is reasonably robust to outliers. The proposed configurations are then used as initial conditions for surface registration. After removing the markers, the corresponding points in CT images and physical space are aligned using singular value decomposition. Then, ICP algorithm is applied to perform surface registration of the vertebra. The results indicate that registration accuracy is highly affected by the number of landmarks used in the initial point based registration as well as their arrangement. According to the results an improvement of 40% in the TRE for the best possible configuration of landmark is obtained.

8671-74, Session PSWed

Automatic generation of digital anthropomorphic phantoms from simulated MRI acquisitions

Clifford Lindsay, Michael A. Gennert, Worcester Polytechnic Institute (United States); Arda Konik, Univ. of Massachusetts Medical School (United States); Paul K. Dasari, Univ. of Massachusetts Medical School (United States) and Worcester Polytechnic Institute (United States); Michael A. King, Univ. of Massachusetts Medical School (United States)

In SPECT imaging, motion from patient respiration and body movement can reduce image quality by introducing motion-related artifacts. Simulation studies using numerical phantoms with precisely known motion can help to develop and evaluate motion correction algorithms. Previous methods for evaluating motion correction algorithms used either manual or semi-automated segmentation of MRI studies to produce patient models in the form of XCAT Phantoms, from which one calculates the transformation and deformation between MRI study and patient model. Both XCAT Phantom generation methods require expertise in human anatomy, with the semi-automated method requiring up to 30 minutes and the manual method requiring up to eight hours. Although faster than manual segmentation, the semi-automated method still requires a significant amount of time, is not repeatable, and is subject to errors due to the difficulty of aligning and deforming anatomical shapes in 3D. We propose a new method for matching patient models to MRI that extends the previous semi-automated method by alleviating the manual non-rigid transformation. Our method requires no user supervision and therefore does not require expert knowledge of human anatomy to align the NURBs to anatomical structures in the MR image. Our contribution is employing the SIMRI MRI simulator to convert the XCAT NURBs to a voxel-based representation that is amenable to automatic non-rigid registration. Then registration is used to transform and deform the NURBs to match the anatomy in the MR image. We show that our automated method generates XCAT Phantoms more robustly and significantly faster than the previous semi-automated method.

8671-75, Session PSWed

Estimation of lung's tissue incompressibility variation throughout respiration for accurate tumor targeting in lung radiotherapy

Zahra Shirzadi, Abbas Samani, The Univ. of Western Ontario (Canada)

A novel technique is proposed to characterize lung tissue incompressibility variation during respiration. Lung tissue incompressibility variation stems from significant air content variation throughout respiration. Considering this variation, hence its estimation is critical for computer assisted tumor motion tracking. Continuous tumor motion is a major challenge in lung cancer treatment by external beam radiotherapy. If not accounted for, this motion leads to areas of radiation over or/and under dosage for lung normal tissues and tumors, respectively. Since no effective imaging modality is available for real-time lung tumor tracking, computer based modeling which has the capability for accurate tissue deformation estimation can be a good alternative. Lung tissue deformation estimation can be made using the lung Finite Element (FE) model where its accuracy depends on input tissue biomechanical properties including incompressibility parameter. In this research, an optimization algorithm is proposed to estimate the incompressibility parameter function in terms of respiration cycle time. In this algorithm, the incompressibility parameter and lung pressure values are varied systematically until optimal values, which result in maximum similarity between acquired and simulated 4D CT images of the lung, are achieved for each respiration time point. The simulated images are constructed using a reference image in conjunction with the deformation field obtained from the lung's FE model in each respiration time increment. We demonstrated that utilizing the calculated function along with respiratory system FE modeling leads to accurate tumor targeting hence potentially improving lung radiotherapy outcome.

8671-76, Session PSWed

Experimental assessment of error in an electromagnetically-tracked ultrasound-guided needle navigation system

Irene Ayukawa, Tamas Ungi, Keyvan Hashtrudi-Zaad, Gabor Fichtinger, Parvin Mousavi, Queen's Univ. (Canada)

Purpose: Electromagnetic (EM)-tracked ultrasound (US)-guided needle navigation systems have potential use in spinal interventions; however, an assessment of the accuracy of these systems is required. Analysis of these systems involves examining the overall error of the system and the error of its components. The purpose of this study is to estimate the error components in an EM-tracked US-guided needle navigation system, and to determine the relationships between them, specifically for evaluation of US probe calibration. Methods: The main parts of the experimental setup are the US probe, the tracker, and the needle. The system error is examined by imaging the tracked needle with the US probe. The positional tracking error is tested for multiple needle, probe and reference sensors using a 7x9 grid with 4 cm spacing between points. Needle calibration error is evaluated by pivot calibration. An upper bound for the probe calibration error is then estimated using a series of transformations between the tracker and the needle tip position. Results: For all experiments, the mean error and its standard deviation increase as a function of distance from the tracker. The upper-bound of the US probe calibration error is estimated to be 1.81 mm. Conclusion: Operating distance has significant impact on component error, and the optimal operating distance for the presented setup has been shown. Although US probe calibration error cannot be measured directly, its upper-bound has been estimated by assessing the errors in other components of the system.

8671-77, Session PSWed

Phantom-based comparison of the accuracy of point clouds extracted from stereo cameras and laser range scanner

Ankur N. Kumar, Thomas S. Pheiffer, Amber L. Simpson, Reid C. Thompson, Michael I. Miga, Benoit M. Dawant, Vanderbilt Univ. (United States)

Using computational models, images acquired pre-operatively can be updated to account for intraoperative brain shift in image-guided surgical (IGS) systems. An optically tracked laser range scanner (LRS) furnishes the 3D coordinates of cortical surface points (3D point clouds) over the

surgical field of view and provides a correspondence between these and the pre-operative MR image. However, integration of the LRS acquired data into a clinically acceptable system has been limited. This is because acquiring the LRS data requires moving the scanner in and out of the surgical field, thus limiting the number of acquisitions. Large differences between acquisitions caused by tumor resection and tissue manipulation make it difficult to establish correspondence and estimate brain motion. An alternative to the LRS is to use feature-rich stereo surgical video data provided by the operating microscope to reconstruct the cortical surface in 3D in less than a second and continuously update the IGS system. This paper compares the accuracy of the 3D point clouds extracted from the stereo video system and the LRS for phantom objects in order to understand the tradeoffs between these approaches as input to an IGS system.

8671-78, Session PSWed

Accurate pose estimation using single marker single camera calibration system

Sarthak Pati, Okan Erat, Lejing Wang, Technische Univ. München (Germany); Simon Weidert, Ludwig-Maximilians-Univ. München (Germany); Euler Ekkehard, Ludwig-Maximilians-Univ. München (Germany) and Ludwig-Maximilians-Univ. München (Germany); Nassir Navab, Pascal Fallavollita, Technische Univ. München (Germany)

Visual marker based tracking is one of the most widely used tracking techniques in Augmented Reality (AR) applications. Generally, multiple square markers are needed to perform robust and accurate tracking. Various marker based methods for calibrating relative marker poses have been already been proposed. However, the calibration accuracy of these methods relies on the order of the image sequence and pre-evaluation of pose-estimation errors, making the method offline. Several studies have shown that the accuracy of pose estimation for an individual square marker depends on camera distance and viewing angle. We propose a method to accurately model the error in the estimated pose and translation of a camera using a single marker using an online method based on the Scaled Unscented Transform (SUT). Thus, the pose estimation for each marker can be estimated with highly accurate calibration results independent of the order of image sequences compared to cases when this knowledge is not used. This removes the need for having multiple markers and an offline estimation system to calculate camera pose in an AR application.

8671-79, Session PSWed

Template-based CTA X-ray angio rigid registration of coronary arteries in frequency domain

Timur Aksoy, Sabanci Univ. (Turkey); Stefanie Demirci, Technische Univ. München (Germany); Muzaffer Degertekin, Yeditepe Univ. Hospital (Turkey); Nassir Navab, Technische Univ. München (Germany); Gozde Unal, Sabanci Univ. (Turkey)

This study performs a segmentation-based 3D to 2D rigid registration of pre-operative CTA coronary arteries with a single segmented intra-operative X-ray Angio frame for real-time Angiography interventions by C-arm flouroscopy. Most of the work on rigid registration in literature required a close initialization of poses and/or positions because of the abundance of local minima and high complexity that searching algorithms face. This study avoids such setbacks by transforming the projections into translation-invariant Fourier domain which estimates the 3D pose. First, template DRRs as candidate poses of 3D vessels of segmented CTA are produced by rotating the camera (image intensifier) around the DICOM angle values with a wide range as in C-arm setup. We have applied 3 methods in Fourier magnitude, Fourier phase and Fourier polar domains for comparing the 3D poses of template DRRs with the real X-ray after equalizing the scales (due to disparities in focal length distances) in frequency domain. The best pose candidate was chosen by one of the similarity measures returned by these methods. It has been noted in literature that these methods are robust against noise and occlusion which was also validated by our results. Translation of the volume was then recovered by distance-map based BFGS optimization well suited to convex structure of our objective function without local minima by the help of distance maps. Final results were evaluated in 2D projection space rather than with actual values in 3D due to lack of ground truth, ill-posedness of the problem and ambiguity in Euler angles which we intend to address in future.

8671-80, Session PSWed

Interactive initialization for 2D/3D intra-operative registration using the Microsoft Kinect

Ren-Hui Gong, Oezgur Gueler, Ziv R. Yaniv, Children's National Medical Ctr. (United States)

The majority of 2D/3D registration algorithms are iterative, requiring a sufficiently good initial pose of the 3D data to start the process. Current initialization methods are not viable in the sterile OR environment due to various constraints. In this work we use the Microsoft Kinect device to allow the surgeon to interactively initialize the registration process. A Kinect sensor is used to simulate the mouse-based operations in a conventional manual initialization approach, obviating the need for physical contact with an input device. Different gestures from both arms are detected by the sensor in order to set or switch the required working contexts. 3D hand motion provides the six degrees of freedom controls for manipulating the pre-operative data in the 3D space. We evaluated our method using a CT of a distal radius fracture, and compared it with a conventional mouse-based approach. Preliminary results show that, with initial target registration errors of 25.9±7.3 mm the Kinect-based approach was able to achieve final errors of 3.0±0.5 mm within 151±60 sec, compared to 1.6±0.5 mm and 98±50 sec for the mouse-based approach. These initial results are sufficiently accurate for registration initialization, but reflect the learning curve associated with the Kinect interface.

8671-81, Session PSWed

Detection of the spatial accuracy of an O-arm in the region of surgical interest

Tapani Koivukangas, Univ. of Oulu (Finland); Jani P. Katisko, Oulu Univ. Hospital (Finland); John P. Koivukangas, Univ. of Oulu (Finland) and Oulu Univ. Hospital (Finland)

For image-guided surgical (IGS) procedures, medical images are the main source of diagnostic and spatial information. IGS procedures rely on the obtained image data to provide differentiation between normal and abnormal tissues. The image data also needs to provide accurate spatial representation of the anatomy of the patient.

This research has concentrated on the concept of the accuracy assessment of IGS devices to meet the needs of quality assurance in the hospital environment. For this purpose, two precision engineered accuracy assessment phantoms and an assessment protocol have been developed as advanced materials and methods for the community. The phantoms were designed to mimic the volume of the human head as the region of surgical interest (ROSI).

This paper introduces the utilization of the phantoms in the spatial accuracy assessment of a commercial surgical 3D CT scanner, the O-Arm. Special attention was given to the detection of possible geometrical distortions in the region of surgical interest.

Significant image distortions were detected when scanning the phantom with imaging parameters commonly used in clinical procedures. When the parameters were optimized for the phantoms, the O-Arm produced

images with minimal distortions and spatial accuracy within 1 mm. The study demonstrates the importance of optimizing the imaging parameters for the particular physical characteristics of each scanned region of surgical interest.

8671-82, Session PSWed

Deformable image registration with content mismatch: a demons variant to account for added material and surgical devices in the target image

Sajendra Nithiananthan, Ali Uneri, Sebastian Schafer, Daniel J. Mirota, Yoshito Otake, Joseph W. Stayman, Wojciech Zbijewski, A J. Khanna, Douglas D. Reh M.D., Gary L. Gallia, Jeffrey H. Siewerdsen, Johns Hopkins Univ. (United States)

Purpose: Fast, accurate, deformable image registration is an important aspect of image-guided interventions. Among the factors that can confound registration is the presence of additional material in the intraoperative ("target") image - e.g., contrast bolus, fat, or a surgical implant - that was not present in the prior ("moving") image. We present a variant of the Demons algorithm to accommodate such content mismatch.

Method: The approach combines segmentation of mismatched content with deformable registration featuring an extra pseudo-spatial dimension representing a reservoir from which material can be drawn into the moving image. The method was tested in phantom studies in the context of intraoperative cone-beam CT with three examples of content mismatch: a variable-diameter bolus (contrast injection); a layer of fat (weight gain); and surgical devices (pedicle screws). Registration accuracy was assessed in terms of difference images and normalized cross correlation (NCC).

Results: Conventional Demons exhibited spurious distortion about the region of content mismatch (often the region of interest). The extra-dimensional Demons (XDD) method reduced such distortion and improved NCC - e.g., for a (2x2x2) cm3 bolus, increasing NCC from 0.90 to 0.98. Similarly for fat and implants, conventional Demons exhibited unrealistic distortion, while XDD improved accuracy and robustness.

Conclusions: Difficulties faced by traditional registration algorithms when materials (e.g., contrast bolus or implants) are introduced between image acquisitions can be resolved by a combined segmentation and extra-dimensional registration process. The method maintains flexibility and speed associated with conventional Demons and could improve registration accuracy in a spectrum of interventions.

8671-83, Session PSWed

Fuzzy-model-based body-wide anatomy recognition in medical images

Jayaram K. Udupa, Dewey Odhner, Monica Matsumoto, Yubing Tong, Medical Image Processing Group , Univ. of Pennsylvania (United States); Krzysztof C. Ciesielski, Medical Image Processing Group , Univ. of Pennsylvania (United States) and West Virginia Univ. (United States); Pavithra Vaideeswaran, Victoria Ciesielski, Babak Saboury, Drew Torigian, Medical Image Processing Group , Univ. of Pennsylvania (United States)

To make Quantitative Radiology a reality in routine radiological practice, computerized automatic anatomy recognition (AAR) becomes essential. As part of this larger goal, in previous years of this conference, we presented a fuzzy object modeling strategy for AAR. Advances have been made in several directions in this project including streamlined and consistent definition of open-ended anatomic objects, extension to multiple imaging modalities, and demonstration of the same AAR approach on multiple body regions. The proposed AAR approach consists of the following steps: (a) Collecting image data for a specific population group G and body region B. (b) Delineating in these images the objects in B to be modeled. (c) Building Fuzzy Object Models (FOMs) for B. (d) Recognizing individual objects in a given image of B by using the models. (e) Delineating the recognized objects. (f) Implementing the computationally intensive steps in GPU. (g) Deriving quantitative descriptions. Image data are collected for B and G from our existing patient image database. For model building, objects are delineated following a strict object definition protocol. Fuzzy models for the individual objects are built and then assembled into a model of B as per a chosen hierarchy of the objects in B. First a global recognition strategy determines the approximate pose of the whole model assembly within B, Then, following a dual recognition-delineation strategy and the object hierarchy, pose is refined and delineation is performed. Based on three body regions tested utilizing both CT and MR imagery, global recognition places the models within about 12 mm of the true position with a scaling error of about 0.02.

8671-84, Session PSWed

Optimal hierarchy for fuzzy object models

Monica M. S. Matsumoto, Jayaram K. Udupa, Univ. of Pennsylvania (United States)

In radiologic clinical practice, the analysis underlying image examinations are qualitative, descriptive, and to some extent subjective. Quantitative radiology (QR) is valuable in clinical radiology. Computerized automatic anatomy recognition (AAR) is an essential step towards that goal. AAR is a body-wide organ recognition strategy. The AAR framework is based on fuzzy object models (FOMs) wherein the models for the different objects are encoded in a hierarchy. We investigated ways of optimally designing the hierarchy tree while building the models. The hierarchy among the objects is a core concept of AAR. The parent-offspring relationships have two main purposes in this context: (i) to bring more understanding and knowledge about the form, geography, and relationships among objects, and (ii) to foster guidance to object recognition and object delineation.

In this approach, the relationship among objects is represented by a graph, where the vertices are the objects (organs) and the edges connect all pairs of vertices into a complete graph. Each pair of objects is assigned a weight described by the spatial distance between them, their intensity profile differences, and their correlation in size, all estimated over a population. The optimal hierarchy tree is obtained by the shortest-path algorithm as a spanning tree. To evaluate the optimal hierarchies, we have performed some preliminary tests involving the subsequent recognition step. The body region used for initial investigation was the thoracic region. The FOMs were built using 20 subject clinical CT scan, and the recognition with another 10 subject CT scan data.

8671-85, Session PSWed

Segmentation of left atrial intracardiac ultrasound images for image guided cardiac ablation therapy

Maryam E. Rettmann, Mayo Clinic (United States); Trevor Stephens, Brigham Young Univ. (United States); David R. Holmes III, Cristian A. Linte, Douglas L. Packer, Richard A. Robb, Mayo Clinic (United States)

Intracardiac echocardiography (ICE), a technique in which structures of the heart are imaged using a catheter navigated inside the cardiac chambers, is an important imaging technique for guidance in cardiac ablation therapy. Automatic segmentation of these images is valuable for guidance and targeting of treatment sites. In this paper, we describe an approach for segmentation of ICE images by generating an empirical model of blood pool and tissue intensities. Gaussian, Weibell, Gamma, and Generalized Extreme Value (GEV) distributions are fit to histograms of tissue and blood pool pixels from a series of ICE scans. The validity of the statistical model is assessed by evaluating the ability to classify

blood and tissue pixels within homogenous regions using a generalized likelihood ratio test (GLRT) across neighborhood sizes ranging from 1 to 23. Lowest misclassification rates were found at the larger neighborhood sizes, and blood was classified with higher accuracy (approximately 4-6%) than tissue (approximately 15-22%). The GEV distribution is most accurate for tissue classification and the Gaussian distribution was most accurate for blood classification. Next, the model was used to automatically segment ICE images into blood and tissue regions. Each pixel is classified using the GLRT across neighborhood sizes ranging from 1 to 23. Automatic segmentation results were compared against manual segmentations across 160 images. The GEV distribution using a neighborhood size of 13 was found to be the most accurate with a misclassification rate of approximately 17%. As expected, the majority of misclassified pixels were located near the boundaries between tissue and blood pool regions.

8671-86, Session PSWed

Automatic probe artifact detection in MRI-guided cryoablation

Xinyang Liu, Kemal Tuncali, William M. Wells, Gary P. Zientara, Brigham and Women's Hospital (United States) and Harvard Medical School (United States)

Probe or needle artifact detection in 3D scans gives an approximate location for the tools inserted, and is thus crucial in assisting many image-guided procedures. Conventional automatic needle artifact localization algorithms often start with cropped images, where the borders and unwanted parts of raw scans are cropped either manually or by applying pre-defined masks. In cryoablation, however, the number of probes used, the placement and direction of probe insertion, and the portions of abdomen scanned differs significantly from case to case, and probes are often constantly being adjusted during the Probe Placement Phase. These features greatly reduce the practicality of approaches based on image cropping.

In this work, we present a fully Automatic Probe Artifact Detection method, APAD, that works directly on uncropped raw 3D MRI images, taken during the Probe Placement Phase in MRI-guided cryoablation. The key idea of our method is to first locate an initial 2D line strip which approximates the position and direction of the 3D probes bundle, noting that cryoprobes create a signal void (black) artifact in MRI with a bright cylindrical border. With the initial 2D line strip, standard approaches to detect line structures such as the 3D Hough Transform can be applied to quickly detect each probe's axis as well as its corresponding artifact. By comparing with manually labeled probes artifacts, the analysis of 5 patient treatment cases of kidney cryoablation with varying probe placements shows that our algorithm to detect the initial 2D line strip is accurate and robust.

8671-87, Session PSWed

Reconstruction method for curvilinear structures from two views

Matthias Hoffmann, Friedrich-Alexander-Univ. Erlangen-Nürnberg (Germany); Alexander Brost, Stanford Univ. (United States); Carolin Jakob, Martin W. Koch, Friedrich-Alexander-Univ. Erlangen-Nürnberg (Germany); Felix Bourier, Klinik für Herzrhythmusstörungen, Krankenhaus Barmherzige Brüder (Germany) and Stanford Univ. (United States); Klaus Kurzidim, Klinik für Herzrhythmusstörungen, Krankenhaus Barmherzige Brüder (Germany); Joachim Hornegger, Friedrich-Alexander-Univ. Erlangen-Nürnberg (Germany); Norbert Strobel, Siemens AG (Germany)

Minimally invasive interventions often involve tools of curvilinear shape like catheters and guide-wires. Knowing the camera parameters of a fluoroscopic system, a 3-D reconstruction of corresponding points can be computed by triangulation. Identification of point correspondences is time consuming, but there exists a method that automatically selects corresponding points of curvilinear structures. A previous evaluation of this method using clinical data yielded promising results. For that evaluation, however, no 3-D ground truth data was available such that the error could only be estimated using the reprojection of the reconstruction. In this paper, we now present a more extensive evaluation of this method based on both clinical and phantom data. For the evaluation using clinical images, 36 datasets and two different catheters were used. The mean error found when reconstructing the circumferential mapping catheter was 0.1mm ± 0.1mm and the mean error for the ablation catheter was again 0.1mm ± 0.1mm. Images of the 3-D phantom were acquired from 13 different angulations. For the phantom, 3-D information had been available such that an evaluation of the error in the 3-D space was possible. The evaluation yielded an average error of 1.2mm ± 1.2mm for the circumferential mapping catheter and 1.3mm ± 1.0mm for the ablation catheter.

8671-88, Session PSWed

Efficacy of a novel IGS system in atrial septal defect repair

Fuad N. Mefleh, Clemson Univ. (United States); George H. Baker, Medical Univ. of South Carolina (United States); David M. Kwartowitz, Clemson Univ. (United States) and Medical Univ. of South Carolina (United States)

Congenital heart disease occurs in 107.6 out of 10,000 live births, with Atrial Septal Defects (ASD) accounting for 10% of these conditions. Historically, ASDs were treated through resection of the outer wall of one of the atria, followed by placing a patch over the defect. In 1976, King et al demonstrated use of a transcatheter occlusion procedure, thus reducing the invasiveness of ASD repair. Catheter localization during procedures traditionally has relied on bi-plane fluoroscopy; more recently trans-esophageal ultrasound (TEE) and intra-vascular ultrasound (IVUS) have been used to navigate these procedures. Although there is a high success rate using the transcatheter occlusion procedure, fluoroscopy poses radiation dose risk to both patient and clinician. The impact of this dose to the patients is enormous as many of those undergoing this procedure are children. The combination of a child's small size and the likelihood of future interventions requiring fluoroscopy make the population receiving ASD repair at greater risk of future radiation effects.

Image-guided surgery (IGS) uses pre-operative and intra-operative images to guide surgery or an interventional procedure. Central to every IGS system is a software application capable of processing and displaying patient images, registration between multiple coordinate systems, and interfacing with a tool tracking system. We have developed a novel image-guided surgery framework called Kit for Navigation by Image Focused Exploration (KNIFE). In this work we assess the efficacy of this image-guided navigation system for ASD repair using a series of mock clinical experiments designed to simulate ASD repair device deployment.

8671-89, Session PSWed

Accuracy evaluation of a 3D ultrasound-guided biopsy system

Walter Wooten III, Emory Univ. (United States) and Emory Univ. (United States); Jonathan A. Nye, David M. Schuster, Peter T. Nieh, Viraj A. Master, John R. Votaw, Baowei Fei, Emory Univ. (United States)

Early detection of prostate cancer is critical in maximizing the probability of successful treatment. Current systematic biopsy approach takes 12 or more core tissue within the prostate and can have a high potential, especially with early disease, for a false negative diagnosis. The purpose

of this study is to determine the accuracy of a 3D ultrasound-guided biopsy system. Testing was conducted on prostate phantoms created from an agar mixture which had embedded markers. The phantoms were created in a manner which ensured adequate contrast for both ultrasound and CT imaging. The phantoms were scanned and the 3D ultrasound system was used to direct the biopsy. Each phantom was analyzed with a CT scan to obtain needle deflection measurements. The deflection experienced throughout the biopsy process was dependent on the depth of the biopsy target. The results for markers at a depth of less than 20 mm, 20-30 mm, and greater than 30 mm were 3.26 mm, 4.72 mm, and 6.20 mm, respectively. This measurement encapsulates the entire biopsy process, from the scanning of the phantom to the firing of the biopsy needle. Increased depth of the biopsy target did cause a greater deflection from the intended path in most cases which was due to an angular incidence of the biopsy needle and these deflections are likely to miss many prostate cancers that have a volume of 1 cc. Although some deflection was present, this system exhibits a clear advantage in the targeted biopsy of prostate cancer and has the potential to reduce the number of false negative biopsies for large lesions.

8671-90, Session PSWed

Evaluation of three 3D US calibration methods

Johann B. Hummel, Medizinische Univ. Wien (Austria) and Community Hospital Wilhelminen (Austria); Marcus Kaar, Rainer Hoffmann, Medizinische Univ. Wien (Austria); Amon Bhatia, Medizinische Univ. Wien (Austria) and Meduni Wien (Austria); Wolfgang Birkfellner, Medizinische Univ. Wien (Austria); Michael Figl, Medizinische Univ. Wien (Austria)

With the introduction of 3D US image devices the demand for accurate and fast 3D calibration methods arose. We implemented three different methods including a multi-spheres phantom (MS), a feature based model (FM) and a membrane model (MM) and compared the calibrations results in terms of fiducial registration errors (FRE) and target registration errors (TRE).

With respect to the MS method a simple point-to-point registration was applied. For the feature based model we employed a phantom consisting of spheres, pyramids and cones. These objects were imaged from different views and a 3D3D registration was then applied for all possible image combinations. The last method was accomplished by imaging a simple membrane which allows for calculation of the calibration matrix. For a first evaluation we computed the FREs for each method. To assess the calibration success on real patient data we used ten 3D3D registrations between images of the prostate area to calculate a TRE.

The FRE for the MS amounted to 1.40 mm, for the FM to 1.05 mm and with respect to the MM to 1.12 mm. The deviations arising from ten 3D3D patient registration were 3.44 mm (MS), 2.93 mm (FM) and 2.84 (MM) mm.

The MM revealed to be the most accurate of the evaluated procedures while the MS has shown significant higher errors. The results from FM were close to those from MM and also significantly better than the results with the MS. Between FM and MM no significant difference was detected.

8671-91, Session PSWed

Java multi-histogram volume rendering framework for medical images

Justin Senseney, National Institutes of Health (United States); Alexandra Bokinsky, Geometric Tools, Inc. (United States); Ruida Cheng, Matthew J. McAuliffe, National Institutes of Health (United States)

This work extends the multi-histogram volume rendering framework proposed by Kniss to provide rendering results based on the impression of overlaid triangles on a graph of image intensity versus gradient magnitude. The developed method of volume rendering allows for greater emphasis to boundary visualization while avoiding issues common in medical image acquisition. For example, partial voluming effects in computed tomography and intensity inhomogeneity of similar tissue types in magnetic resonance imaging introduce pixel values that will not display accurately when a standard transfer function is applied to an intensity histogram. This new framework uses developing technology to improve upon the Kniss multi-histogram framework by using Java, the GPU, and MIPAV, a free medical image processing application, to allow multi-histogram techniques to be widely disseminated. The OpenGL view-aligned texture rendering approach suffered from performance setbacks, inaccessibility, and usability problems. Rendering results can now be interactively compared with other rendering frameworks, surfaces can now be extracted for use in other programs, and file formats that are widely used in the field of biomedical imaging can be visualized using this multi-histogram approach. OpenCL and GLSL are used to produce this new multi-histogram approach, leveraging texture memory on the graphics processing unit of desktops to provide a new interactive method for visualizing biomedical images. Performance results for this method are generated and qualitative rendering results are compared. The resulting framework provides the opportunity for further applications in medical imaging, both in volume rendering and in generic image processing.

8671-92, Session PSWed

3-D examination of dental fractures with minimum user intervention

Andre Souza, Carestream Health, Inc. (United States); Alexandre X. Falcão, Univ. Estadual de Campinas (Brazil); Lawrence Ray, Carestream Health, Inc. (United States)

Cone-beam computed tomography (CBCT) is an X-ray imaging modality capable of acquiring three-dimensional (3-D) information of the human anatomy with a substantially lower radiation dose to patients as compared to conventional medical computed tomography (CT) systems. The use of CBCT as a diagnostic tool for endodontics has increased the need for better image quality and the ability to display very low-contrast tissue regions, usually associated with fractures within the tooth structure. In addition, recent clinical findings have reported the tremendous potential use of CBCT in the management of endodontic problems (e.g., during root canal therapy). A vertical root fracture (VRF) is a severe form of tooth fracture that results in root pain caused by infection and inflammation, which leads to tooth extraction. VFRs' diagnosis remains a challenge, but supporting evidence indicates that CBCT has the superior ability to detect VRFs, as compared to periapical radiographs. We developed segmentation and visualization algorithms for 3-D examination of root fracture from minimum user intervention. The application computes and displays the best 3-D cutting plane on a selected tooth by placing at least two splines (inside and outside of the tooth) in just one slice of the volume. Next, it allows the user to scroll through the volume, slice by slice, in parallel to the plane, or to examine the tooth by changing the plane's normal vector to different orientations. Both the root canal and the root fracture are highlighted during the examination phase. Doctors (end users) are in control to quickly and confidently examine the root fractures in 3-D for any given oblique orientation, without worrying about missing the selected tooth. We have designed and implemented these algorithms using the image-foresting transform (IFT) technique and Multi-Scale Parameter Search techniques.

8672-2, Session 1

Peripheral quantitative CT (pQCT) using a dedicated extremity cone-beam CT scanner

Abdullah Muhit, Yifu Ding, Sugandha Arora, Mizuha Ogawa, Wojciech Zbijewski, Joseph W. Stayman, Johns Hopkins Univ. (United States); Gaurav Thawait, Johns Hopkins Univ. (United States) and Johns Hopkins Medical Institutions (United States); Nathan Packard, Robert A. Senn, Dong Yang, John Yorkston, Carestream Health, Inc. (United States); Clifton Bingham, Johns Hopkins Medical Institutions (United States); Kenneth Means, MedStar Union Memorial Hospital (United States); John A. Carrino, Johns Hopkins Medical Institutions (United States); Jeffrey H. Siewerdsen, Johns Hopkins Univ. (United States)

Purpose: This paper provides initial technical assessment of quantitative imaging capabilities using a cone-beam CT (CBCT) scanner dedicated to musculoskeletal extremity imaging for peripheral quantitative CT (pQCT). The aim is to acquire accurate quantitative information relating to bone and joint morphology from information acquired automatically with each CBCT scan, thereby reducing the need for a separate pQCT exam.

Methods: A prototype CBCT scanner providing isotropic, sub-millimeter spatial resolution and soft-tissue contrast reso-lution comparable or superior to standard multi-detector CT (MDCT) has been developed for extremity imaging, includ-ing weight-bearing and multi-mode (radiography, fluoroscopy, and volumetric) capabilities. Assessment of quantitative imaging performance included measurement of bone mineral density (BMD), morphometric parameters of bone and trabecular structure, and joint space analysis. Measurements employed phantoms, cadavers, and patients imaged with the CBCT prototype (at various acquisition, calibration, and reconstruction techniques) and MDCT (using pQCT protocols).

Results: The CBCT extremity scanner yielded BMD measurement within ±2-3% error in both lower and upper extremi-ties. Cancellous bone micro-architecture (bone volume fraction, trabecular thickness, degree of anisotropy, and structural model index) exhibited good correlation with MDCT at matched voxel size (5-10%). Joint space analysis demonstrated the potential for sensitive 3D mapping beyond that of radiographic scores in application to sitting vs weight-bearing lower extremities and in arthritis/trauma cases.

Conclusion: The CBCT extremity scanner demonstrated promising results in accurate pQCT analysis with each scan. Future studies will include improved scatter and reconstruction techniques that could further improve accuracy and ex-panded correlation of pQCT metrics to known pathology.

8672-3, Session 1

Comparative studies of collimator performance in DaTscan (Ioflupane I-123) striatal SPECT

Andrzej Krol, Mary A. McGrath, Brian T. Carey, David H. Feiglin, SUNY Upstate Medical Univ. (United States)

Purpose: To determine optimal collimator and gamma camera combination for Ioflupane I-123 (DaTscan) striatal SPECT

Methods: Anthropomorphic basal ganglia phantom was used. The striatal chambers (caudate and putamen chambers, a total of 6 cc) and the large chamber (a total of 1200 cc) simulating nonspecific background activity in the remainder of the brain were filled with I-123 with the specific activity ratio 7.7. SPECT data were acquired in 128 ? 128 matrix, 120 views, 30 s/view using triple-head gamma camera (THGC) with fan-beam low-energy ultra high-resolution (LEUR) collimators (3.1 M counts), with dual-head gamma camera with parallel-beam low-energy high-resolution (LEHR) collimators (3.3 M counts) and medium-energy general purpose (MEGP) collimators (2.1 M counts). Data were acquired at 159 keV with a 20% window, with I-123 and Tc-99m flood table for THGC and DHGC, respectively. The images were reconstructed using OSEM algorithm with resolution modeling and uniform attenuation correction and Butterworth postfilter, 5th order and 0.5, 0.7 and 1.0 Ny for LEUR, LEHR, and MEGP, respectively.

Results: The best image quality was obtained with fan-beam LEUR. The MEGP and LEHR produced similar quality images with slightly better contrast-to-noise ratio for MEGP. The measured specific ratio of mean activity in striatal chambers to the remainder of the brain was more biased for LEUR, and similar for MEGP and LEHR.

Conclusions: Based on phantom DaTscan striatal SPECT, the THGC with fan-beam LEHR collimators is preferable. If DHGC is used LEHR and MEGP collimators provide similar image quality. More studies are needed to determine whether MEGP are preferable over LEHR collimators.

8672-4, Session 1

Fibrosis detection in renal artery stenosis mice model using magnetization transfer MRI

Behzad Ebrahimi, Bruce E. Knudsen, Slobodan I. Macura, Joseph P. Grande, Lilach O. Lerman, Mayo Clinic (United States)

Renal artery stenosis (RAS) promotes fibrosis by excessive and irreversible collagen deposition which may lead to end stage renal failure. Currently, invasive tissue biopsy is the main tool to assess fibrosis. Magnetization transfer imaging (MTI) is a MR-based technique that is sensitive to the interaction of macromolecules (e.g. collagen) and water. The characteristics of these interactions are notoriously organ and tissue dependent. This study tested the hypothesis that using MTI renal fibrosis in RAS can be detected.

MTI was applied in mice (n=4) with unilateral RAS induced by partial occlusion of the renal artery at a 16.4T MR system. Offset frequency, RF pulse power and bandwidth optimization for off-resonance MTI (FLASH sequence, TR, 50ms, TE, 2.3ms) was performed to achieve largest contrast between the fibrotic and non-fibrotic tissue. Moreover, water exchange rate (k) and the fraction of restricted-to-free water (F), two markers of tissue molecular change, were estimated using steady-state free precession, on-resonance MTI (TRUE-FISP, TR, 13ms, TE, 6.5ms, Flip-Angles, 0-70º).

The optimal contrast for visual differentiation was achieved at offset frequency, RF pulse power, and effective bandwidth of 6.6kHz, 10μT, and 300Hz, respectively. On-resonance MT demonstrated that F tended ($p=0.09$) to be and k was significantly ($p<0.01$) different in the stenotic vs. the contra-lateral kidneys. Additionally, significant correlation between k and the fibrosis quantification from trichrome staining was observed ($R2=0.56$ and $p=0.03$).

Therefore, off-resonance MT can differentiate the fibrotic from the non-stenotic kidneys. Furthermore, k and potentially F may serve as biomarkers for kidney morphological changes caused by RAS.

8672-5, Session 1

Quantification of microfluidic dye mixing using front line tracking in curvature scale space

Stephan Jonas, RWTH Aachen (Germany) and Yale Univ. (United States); Elaine Zhou, Brendan Huang, Michael A. Choma M.D., Yale Univ. (United States); Thomas M. Deserno, RWTH Aachen (Germany)

Microfluidic mixing or mixing at low Reynolds number is dominated by viscous forces that prevent turbulent flow. It therefore differs from conventional mixing (e.g., stirring milk into coffee), as it is driven primarily by diffusion. Diffusion is in turn dependent on (i) the concentration gradient along the interface between two fluids (dye front line) and (ii) the extent of the interface itself. Previously, we proposed an in vivo method to microscopically monitor the mixing interface using Shannon information entropy as mixing indicator and explored the use of length of dye front line as an indirect measure of mixing efficiency. In this work we present a robust image processing chain supporting quantitative measurements. Based on data from ciliated surfaces mixing dye and water, the dye-water interface front line is extracted automatically using the following processing steps: (i) noise reduction (average filtering) and down sampling in time to reduce compression artifacts; (ii) subtraction imaging with key reference frames in RGB color space to remove background; (iii) segmentation of dye based on color saturation in HSV color space; (iv) extraction of front line; (v) curve smoothing in curvature scale space (CSS) with an improved Gaussian filter adaptive to the local concentration gradient; and (vi) extraction of length. Evaluation is based on repeated measurements. The length of front line is assessed appropriately and this parameter is a reproducible measurement in unaltered animals. Future work will include a more comprehensive evaluation and the application to datasets with multiple classes.

8672-77, Session 1

A multimodal (MRI/Ultrasound) cardiac phantom for imaging experiments

Vahid Tavakoli, Michael Kendrick, Mostafa Shakeri, Univ. of Louisville (United States); Motaz Alshaher, Marcus F. Stoddard, Univ. of Louisville Hospital (United States); Amir A. Amini, Univ. of Louisville (United States) and Univ. of Louisville (United States)

A dynamic cardiac phantom can play a significant role in the evaluation and development of ultrasound and cardiac magnetic resonance (MR) motion tracking and registration methods. A four chamber multimodal cardiac phantom has been designed and built to simulate normal and pathologic hearts with different degrees of “infarction” and “scar tissues”. In this set up, cardiac valves have been designed and modeled as well. The four-chamber structure can simulate the asymmetric ventricular, atrial and valve motions. Poly Vinyl Alcohol (PVA) is used as the principal material since it can simulate the shape, elasticity, and MR and ultrasound properties of the heart. The cardiac shape is simulated using a four-chamber mold made of polymer clay. An additional pathologic heart phantom containing stiff inclusions has been manufactured in order to simulate an infracted heart. The stiff inclusions are of different shapes and different degrees of elasticity and are able to simulate abnormal cardiac segments. The cardiac elasticity is adjusted based on freeze-thaw cycles of the PVA cryogel for normal and scarred regions. Ultrasound and MRI markers were inserted in the cardiac phantom as landmarks for validations. To the best of our knowledge, this is the first multimodal phantom that models a dynamic four-chamber human heart including the cardiac valve.

8672-6, Session 2

Assessments from Intravascular OCT

David L. Wilson, Zhao Wang, Hong Lu, David Prabhu, Hiram G. Bezerra, Marco A. Costa, Andrew M. Rollins, Case Western Reserve Univ. (United States)

At CWRU, we are developing computer image analysis methods for making important clinical assessments of atherosclerotic disease and therapy from intravascular OCT (iOCT). Here we describe two major applications: characterization of thin-cap fibroatheroma (TCFA) and coronary artery stents. Data sizes overwhelm manual analysis with >200 images in a pullback. For example, our Cardiovascular Imaging Core Lab has manually analyzed (@6-16hrs/stent) iOCT image data from >20 international clinical stent trials including >2000 stents. To meet this need, we have developed highly automated methods for image analysis. Advanced image processing techniques (machine learning, graph search, etc.) give robust, accurate results with few manually tuned parameters. Meaningful validations are done against clinical data. Using a dynamic programming method, we segmented thin-cap fibroatheroma (TCFA) to aid determination of plaque vulnerability. Over 323 images from 14 lipid rich lesions, automatic segmentation of cap thickness gave minimum thicknesses, a measure of vulnerability, within manually determined values. In addition, 3D TCFA assessments by iOCT are compared to those from independent 3D cryo-imaging on cadaver samples. Unlike conventional visual determination of the thinnest part of a TCFA, the automated method is reproducible and gives 3D TCFA morphology and heat maps of vulnerability. Using machine learning and graph search, stent strut detection and area measurements have been created and validated. With comprehensive image analysis of iOCT, it is believed that one will be able to determine vulnerability of a second or third plaque, plan the stent implant, prove proper implantation by detecting any malapposed struts, and obtain follow up images to ensure proper tissue coverage of stents so as to avoid late stage stent thrombosis.

8672-7, Session 2

Porcine pulmonary artery distension during static pressure inflation

Yik Ching Lee, Alys R. Clark, Auckland Bioengineering Institute (New Zealand); Matthew K. Fuld, Susan Haynes, Abhay A. Divekar, Eric Hoffman, Univ. of Iowa (United States); Merryn H. Tawhai, Auckland Bioengineering Institute (New Zealand)

We utilized an in vivo CT imaging-based approach to quantify the influence of static intravascular pressure change on pulmonary arterial geometry to improve the geometrical and mechanical basis for studies of the porcine arterial bed. The cross-sectional area and distance from the inlet of pulmonary arteries of two porcine subjects were measured over a range of static inflation pressure (7 cmH2O - 25 cmH2O (0.69 kPa – 2.45 kPa)). Vessels with diameter range of 0.5 mm to 4.5 mm at airway inflation pressure of 25 cmH2O (2.45kPa) were considered. The results suggest that the porcine pulmonary arteries are distensible; inflation stretches the vessels laterally. Mean perimeter distensibility of 0.028/mmHg ± 0.028/mmHg (0.210/kPa ± 0.210/kPa) and mean diameter distensibility 0.015/mmHg ± 0.012/mmHg (0.113/kPa ± 0.090/kPa) of porcine pulmonary arteries are found similar with data of Krenz and Dawson, 2003, which compared several of these studies and concluded that pulmonary blood vessel distensibility was independent of species and approximately 0.02/mmHg (1.5/kPa). This similar observation suggested that a virtually constant distensibility coefficient can be utilized to correlate and represent both inter-species and inter-subject data over several orders of vessel diameter size from the main pulmonary to distal arteries.

8672-8, Session 2

MRI-based hemodynamical analysis in patients with surgically treated aortic coarctations

Michael Delles, Manuela Noe, Yoo-Jin Jeong, Karlsruhe Institute of Technology (Germany); Sebastian Ley, UniversitätsKlinikum Heidelberg (Germany) and Univ. of Toronto (Canada); Hendrik von Tengg-Kobligk, UniversitätsKlinikum Heidelberg (Germany) and German Cancer Research Ctr. (Germany); Hans-Ulrich Kauczor, UniversitätsKlinikum Heidelberg (Germany); Rüdiger Dillmann, Roland Unterhinninghofen, Karlsruhe Institute of Technology (Germany)

In management of cardiovascular diseases, information about the

patient-specific behavior of blood flow and pressure can be essential. In the human aorta, velocity-encoded magnetic resonance imaging (MRI) is the only method capable of measuring complete time-resolved three-dimensional vector fields of the blood flow velocities. Additionally, computations of relative blood pressure from this data source have been presented in recent years. Thus, velocity-encoded MRI can be a valuable measurement technique for both blood flow and blood pressure values in diagnostics and therapy control of aortic diseases. In the last years, we have developed a software framework for cardiovascular diagnostics based on MRI acquisitions. In this article, we apply our in-house developed software framework for a MRI-based hemodynamical analysis in five patients with surgically treated aortic coarctations. We compared our results to a control group of five healthy volunteers. The study included the measurement of blood flow velocities by phase-contrast MRI and the subsequent computation of relative blood pressure values. We generated a set of suitable visualizations for flow and pressure and created centerline diagrams of the cross-sectional area, flow and mean relative blood pressure. Additionally, characteristic values were computed from the centerline diagrams for every subject. In the vast majority of the visualization and quantification techniques of our software framework, we observed significant effects of the treated aortic coarctations. Therefore, we draw the conclusion that this kind of MRI-based hemodynamical analysis can be a valuable tool for diagnostics and therapy control of aortic coarctations.

8672-9, Session 2

Comparison of cartesian, UTE radial, and spiral Phase-Contrast MRI in measurement of blood flow in extracranial carotid arteries: normal subjects

MJ Negahdar, Mo Kadbi, Vahid Tavakoli, Jens Heidenreich, Univ. of Louisville (United States); Andrea Yancey, Robley Rex VA Medical Ctr. (United States); Amir A. Amini, Univ. of Louisville (United States)

Use of Phase contrast (PC) MRI in measurement of blood flow has significant clinical importance. In this paper, we compare the accuracy of the conventional approach to flow imaging to two de novo approaches in 3 normal subjects in the common, internal, and external carotid arteries and demonstrate that all three approaches have the capability to quantify the normal Carotid flow waveforms with high accuracy.

The conventional PC sequence adopts a Cartesian read-out in k-space and requires longer acquisitions but exhibits flow artifacts in the setting of stenotic and turbulent jets. Spiral PC collects k-space data using a spiral readout and is capable of reducing the TR and TE in order to minimize total imaging time. However, in the single shot mode, this technique suffers from off-resonance and inconsistent data artifacts. We counter this issue by covering k-space through use of multiple short spiral arms. Ultra short TE (UTE) PC MRI is a novel technique which adopts a radial trajectory and provides improvements to the standard radial acquisition by reducing the echo time to less than 1 ms through combination of flow encoding and slice select gradients and by immediate sampling of the FID during readout. The ultra short echo times, improves on intravoxel spin dephasing due to fluid mixing observed in imaging of disturbed flow and stenotic jets. Radial UTE however in general is hindered by longer acquisition times and phase corruption errors. We mitigate this by a novel 3-D acquisition which includes a phase correction step.

8672-10, Session 2

Cardiac deformation analysis using 3D SinMod from 3D CSPAMM tagged MRI

Hui Wang, Amir A. Amini, Univ. of Louisville (United States)

Magnetic resonance tagging techniques have been widely used for measuring cardiac motion. We propose a novel 3D sine wave modeling (3D SinMod) approach to automatic analysis of cardiac deformations. An accelerated 3D complementary spatial modulation of magnetization (CSPAMM) tagging technique as used to modulate the myocardial tissue and to acquire 3D MR data sets of the whole-heart including three orthogonal tags within three breath-holds. Each tag set is able to assess the motion along a direction perpendicular to the tag lines. With the application of CSPAMM, the effect of tag fading due to T1 relaxation is mitigated and tag deformations can be visualized for the entire cardiac cycle, including diastolic phases. In the proposed approach, the environment around each voxel in the 3D volume is modeled as a moving sine wavefront with local frequency and amplitude. The entire framework, from data acquisition to data analysis is in 3D domain, which permits quantification of both the in-plane and through-plane motion components. The accuracy and the effectiveness of the proposed method has been validated using both simulated and in vivo data.

8672-11, Session 2

Improved cardiac motion detection from ultrasound images using TDIOF: a combined B-mode/ tissue Doppler approach

Vahid Tavakoli, Motaz Alshaher, Marcus F. Stoddard, Amir A. Amini, Univ. of Louisville (United States)

The quantitative cardiac motion analysis of echocardiography images helps clinicians in the diagnosis and therapy of patients suffering from cardiac disease. Quantitative analysis is usually based on TDI (Tissue Doppler Imaging) or speckle tracking. These methods are based on two partly independent techniques – the Doppler Effect and image registration, respectively. In order to increase the accuracy of the speckle tracking technique and cope with the angle dependency of TDI, a combined approach dubbed TDIOF (Tissue Doppler Imaging Optical Flow) is proposed. TDIOF is formulated based on the combination of B-mode and Doppler energy terms minimized using algebraic equations and is validated on simulated, physical cardiac phantom, and in-vivo data. It is shown that the additional Doppler term is able to increase the accuracy of speckle tracking.

8672-12, Session 3

Texture-based CT Image analysis of asthma

Harishwaran Hariharan, Sally Wenzel, Bin Zheng, Bruce Whiting, Jiantao Pu, David Gur, Joseph K. Leader, Univ. of Pittsburgh (United States)

This study was motivated by anecdotal reports from our clinicians that the lung parenchyma appears “different” (more heterogeneous) in asthmatics compared to non-asthmatics. We investigated whether traditional texture features were different between severe asthmatics and non-asthmatics. CT examinations from 76 subjects classified as “severe asthma” (n = 51) and “normal control” (n = 25) based on Severe Asthma Research Program (SARP) criteria were used in this study. The CT exams were performed on a 64-detector or 16-detector GE scanner at a radiation exposure of 96.6 (±30.7) mAs. The CT images were reconstructed at 0.625 or 1.25 mm thickness using either GE’s “standard” or “detail” kernels. Air trapping was computed as the percentage of voxels with a value less than -856 HU. Gray level co-occurrence matrices (GLCM) were computed from the CT images, and 15 Haralick texture descriptors were computed from the GLCM. Air trapping was significantly greater in the severe asthma subjects compared to the normal control subjects. Seven of the 15 texture features were significantly different between the severe asthma and normal control subjects. Our findings provide some validity to anecdotal reports of differences between the parenchyma of asthmatic and non-asthmatics. The significant texture features may ultimately be used to classify individuals as asthmatic or non-asthmatic, which should improve the limited performance of air trapping alone.

8672-13, Session 3

Quantitative measurement of MR cortical atrophy: MR Brain Surface Intensity Model (BSIM) and group and individual cortical thinning studies

Zhongmin Lin, Gopal Avinash, Kathryn McMillan, Litao Yan, Saad Sirohey, GE Healthcare (United States); Satoshi Minoshima, Univ. of Washington (United States)

A novel Brain Surface Intensity Model (BSIM) has been developed for use as a potential imaging biomarker for neurodegenerative diseases. BSIM technique extracts MR intensity profiles perpendicular to the white matter surface at predefined reference points, fits that profile to BSIM, and computes cortical thickness. A 3D visualization tool has been developed to evaluate intensity extraction and model calculation. 29 normal subjects aged from 70 to 80 from ADNI database were used to generate normal references and measure individual Z-score cortical thinning. 30 age-matched AD subjects were used to study thinning patterns. Significant cortical thinning ($p < 0.0001$) was found for AD group. 95% confidence interval of the cortical thinning in subjects diagnosed with AD was from 0.17 to 0.23 mm. The cortical thinning of the individual AD patients showed distinct features that differentiate AD patients from normal controls. The thickness measurements of 29 normal controls were validated by comparing with results from literature ($p = 0.94$). BSIM technique avoids complicated 3D segmentation of brain gray and white matters, uses local MR intensity profiles to compute cortical thickness. BSIM technique greatly simplifies the thickness calculation, reduces the influences from the image noise, inhomogeneity, partial volume effects, and the intensity overlap of the white and gray matters.

8672-14, Session 3

Statistical texture analysis based MRI quantification in a canine model of Duchenne muscular dystrophy

Jiahui Wang, Zheng Fan, The Univ. of North Carolina at Chapel Hill (United States); Krista Vandenborne, Glenn A. Walter, Univ. of Florida (United States); Yael Shiloh-Malawsky, Hongyu An, The Univ. of North Carolina at Chapel Hill (United States); Joe N. Kornegay, Texas A&M Univ. (United States); Martin A. Styner, The Univ. of North Carolina at Chapel Hill (United States)

Golden retriever muscular dystrophy (GRMD) is a canine model of Duchenne muscular dystrophy (DMD) that has been increasingly used in both pathogenetic and therapeutic pre-clinical studies. Recent studies have shown that MRI can be used to non-invasively detect changes in both DMD and GRMD. In this study, we developed a statistical texture analysis based MRI quantification framework for GRMD. Our system was applied to a database of 43 MRI scans from 8 normal and 10 GRMD dogs in a natural history study. The dogs were longitudinally scanned at 3, 6 and 9 months of age. We first segmented six proximal limb muscles of each dog using a semi-automatic, interpolation-based method and then automatically measured the 3D first-order histogram and novel 3D high-order run-length matrix based texture features within each segmented muscle region. Our results indicated that MRI texture features has the ability to distinguish the normal and GRMD muscles at each age. With respect to longitudinal changes across time, the run-length matrix texture feature of long-run emphasis (LRE) showed significant difference between normal and GRMD muscles. Our experimental results demonstrated the potential of MRI texture measurements to serve as biomarkers to distinguish normal and muscular dystrophic muscles, quantify longitudinal disease progression and measure therapeutic effects in DMD patients.

8672-15, Session 3

Development of a method to image blood flow beneath the skull or tissue using ultrasonic speckle reflections

Jeff Sadler, Zaki Ahmed , Institute for Diagnostic Imaging Research (Canada); Kiyanoosh Shapoori, Tessonics Corp. (Canada); Adrian Wydra , Institute for Diagnostic Imaging Research (Canada); Eugene V. Malyarenko, Tessonics Corp. (United States); Elena Maeva, Dept. of Physics (Canada); Roman G. Maev, Institute for Diagnostic Imaging Research (Canada)

The focus of this work is on developing an ultrasonic imaging method for the visualization of flowing liquids surrounded by inhomogeneous media. The particular interest of our study is the in-vivo transcranial visualization of the blood flow without removal of the skull. Here the strong attenuation, scattering, and distortion by the skull bones (or other tissues) make it difficult to use currently existing methods.

Similar to many popular techniques, blood flow can be detected by using the ultrasonic speckle reflections from the blood cells and platelets (or contrast agents) moving with the blood A methodology is created to analyze the temporal changes in this speckle signal over multiple exposures. The methodology specifically targets this speckle property, creating an algorithm which both enhances the random (speckle) properties of the scan and eliminates the static properties. This process analyzed over multiple exposures allows an image of the blood flow to be obtained, even with negative acoustic effects of the skull in play.

Experimental results show this methodology is able to produce both 2D and 3D images of the flowing region, while eliminating those regions of static acoustic sources. Measurements of the cross-section of flowing region are found to agree with the physical size of the vessel analogues, and a qualitative measure on the amount of flow through the vessels is also obtained. While our earliest results use a modified acoustical microscope, our newest results show great promise using array based systems.

8672-16, Session 3

MR-guided conformal microwave imaging for enhanced inclusion detection within irregularly shaped volumes

Neil R. Epstein, Paul M. Meaney, Keith D. Paulsen, Dartmouth College (United States)

Approximately 1 in 8 women will develop breast cancer in their lifetime. Estimates suggest 230,500 new cases of invasive breast cancer in 2011, resulting in approximately 40,000 deaths. Traditional screening technologies, such as X-ray mammography use ionizing radiation, and suffer from high false-positive and false-negative rates. Due to the high contrast that exists between the dielectric properties of normal and abnormal breast tissue, microwave-imaging spectroscopy has proven an attractive breast cancer imaging modality. We have shown that the incorporation of a volume's internal structural information into our image reconstruction algorithm can increase the accuracy of recovered dielectric properties. Additionally, image reconstruction has benefited from the use of a custom reconstruction mesh generated from the imaged volume's perimeter boundary. This information is used in a conformal microwave image (CMI) reconstruction process, and has increased the accuracy of recovered high contrast regions within the volume's perimeter, without the use of prior internal spatial information. In simulation and phantom experiments with regular geometries, boundary information is obtained through spatial measurements. For irregularly shaped boundaries, alternative means are necessary for accurate boundary extraction. In this paper we demonstrate the MR-guided CMI reconstruction process for an irregularly shaped boundary; boundary information extracted from MR images will be used to generate a custom boundary-derived mesh for image reconstruction. Results from images

reconstructed using the MR-guided CMI reconstruction process will be compared with uniformly reconstructed images, highlighting the increased accuracy of high contrast features within the volume without the use of prior internal spatial information.

8672-17, Session 4

Introducing anisotropic Minkowski Functionals and quantitative anisotropy measures for local structure analysis in biomedical imaging

Axel Wismueller, Titas De, Univ. of Rochester Medical Ctr. (United States); Eva-Marie Lochmueller, Felix Eckstein, Institute of Anatomy and Musculoskeletal Research, Paracelsus Medical University Salzburg (Austria); Mahesh B. Nagarajan, Univ. of Rochester Medical Ctr. (United States)

The ability of Minkowski Functionals to characterize local structure in different biological tissue types has been demonstrated in a variety of medical image processing tasks. We introduce Anisotropic Minkowski Functionals (AMFs) as a novel variant that captures the inherent anisotropy of the underlying gray-level structures being analyzed. To quantify the anisotropy characterized by our approach, we further introduce a method to compute a quantitative measure motivated by a technique utilized in MR diffusion tensor imaging, namely fractional anisotropy. We showcase the applicability of our method in the research context of characterizing the local structure properties of trabecular bone micro-architecture in the proximal femur as visualized on multi-detector CT. To this end, AMFs were computed locally for each pixel of ROIs extracted from the head, neck and trochanter regions. Fractional anisotropy measure was then used to quantify the local anisotropy of the trabecular structures found in these ROIs and to compare its distribution in ROIs from different anatomical regions. Our results suggest a significantly greater concentration of anisotropic trabecular structures in the head and neck regions when compared to the trochanter region ($p < 0.0001$). We conclude that such anisotropic Minkowski Functionals can capture valuable information regarding directional attributes of local structure being analyzed, which may be useful in a wide scope of biomedical imaging applications.

8672-18, Session 4

Fuzzy object models for newborn brain MR image segmentation

Syoji Kobashi, Univ. of Pennsylvania (United States) and Univ. of Hyogo (Japan); Jayaram K. Udupa, Univ. of Pennsylvania (United States)

Newborn brain MR image segmentation is a challenging problem because of variety of size, shape and MR signal although it is the fundamental study for quantitative radiology in brain MR images. Because of the large difference between the adult brain and the newborn brain, it is difficult to directly apply the conventional methods for the newborn brain.

Inspired by the original fuzzy object model introduced by Udupa et al. at SPIE Medical Imaging 2011, called fuzzy shape object model (FSOM) here, this paper introduces fuzzy intensity object model (FIOM), and proposes a new image segmentation method which combines the FSOM and FIOM into fuzzy connected (FC) image segmentation. The fuzzy object models are built from training datasets in which the cerebral parenchyma is delineated by experts. After registering FSOM with the evaluating image, the proposed method roughly recognizes the cerebral parenchyma region based on a prior knowledge of location, shape, and the MR signal given by the registered FSOM and FIOM. Then, FC image segmentation delineates the cerebral parenchyma using the fuzzy object models.

The proposed method has been evaluated using 9 newborn brain MR images using the leave-one-out strategy. The revised age was between -1 and 2 months. Quantitative evaluation using false positive volume fraction (FPVF) and false negative volume fraction (FNVF) has been conducted. Using the evaluation data, a FPVF of 0.75% and FNVF of 3.75% were achieved. More data collection and testing are underway.

8672-19, Session 4

The ANTs cortical thickness processing pipeline

Nicholas J. Tustison, Univ. of Virginia (United States); Brian B. Avants, Philip A. Cook, Gang Song, Sandhitsu Das, Univ. of Pennsylvania (United States); Niels van Strien, Norwegian Univ. of Science and Technology (Norway); James R. Stone, Univ. of Virginia (United States); James C. Gee, Univ. of Pennsylvania (United States)

Numerous studies have explored the relationship between cortical structure and brain development, cognitive function, and functional connectivity. The highly convoluted cortical topography makes manual measurements arduous and often impractical given the population sizes necessary for sufficient statistical power. Computational techniques have permitted large-scale studies as they provide robust and reliable localized measurements characterizing the cortex with little or no human intervention. Particularly useful to the neuroscience community are publicly available tools, such as the popular surface-based Freesurfer, which facilitate the testing and refinement of

hypotheses. In this paper, we introduce the volume-based Advanced Normalization Tools (ANTs) cortical thickness automated pipeline comprising well-vetted components such as SyGN (multivariate template construction), SyN (image registration), N4 (bias correction), Atropos (n-tissue segmentation), and DiReCT (cortical thickness) all developed as part of the ANTs open science effort. Complementing the open source aspect of ANTs we demonstrate its utility using the publicly available IXI data set.

8672-20, Session 4

CT image feature analysis in distinguishing radiation fibrosis from tumour recurrence after stereotactic ablative radiotherapy (SABR) for lung cancer: a preliminary study

Sarah A. Mattonen, Western Univ. of Health Sciences (Canada); David A. Palma M.D., Western Univ. of Health Sciences (Canada) and London Regional Cancer Program (Canada); Cornelis J. A. Haasbeek M.D., Suresh Senan M.D., VU Univ. Medical Ctr. (Netherlands); Aaron D. Ward, Western Univ. of Health Sciences (Canada)

Radiation induced lung injury (RILI) is a common finding following lung radiotherapy and results in radiographic changes on computed tomography (CT). Stereotactic ablative radiotherapy (SABR) treats the tumour to a highly conformal dose with large doses/fraction, which can result in benign, tumour-mimicking radiographic changes. Our purpose was to determine the ability of quantitative measures of post-SABR radiographic changes to distinguish the subject groups (recurrence vs. RILI) at several time points. Two regions were manually contoured on each follow-up CT: consolidative changes and ground glass opacity (GGO). A peri-tumoural region of GGO was also taken around the consolidative changes. At 9 months, patients with recurrence had significantly denser consolidative areas compared to patients with RILI ($p=.046$) and significantly increased variability of CT densities in the GGO areas ($p=.0078$). The variability of CT density in a peri-tumoural region of 4 mm radius was also significant at 9 months post-treatment ($p=.0499$). Our preliminary study of classification accuracy based on

these measures showed that variability of the GGO CT density was the best predictor with a cross validation error of 26.1%, demonstrating that further refinement of the features and classifier may soon lead to a clinically useful computer-aided diagnosis tool. These results suggest the future potential to distinguish patients with recurrence from those RILI at 9 months post-SABR based on appearance characteristics within the consolidative, GGO, and peri-tumoural regions. This could potentially allow for earlier salvage of patients with recurrence, and result in fewer investigations of benign RILI.

8672-21, Session 4

Lateral ventricle morphology analysis via mean latitude axis

Beatriz Paniagua, Amanda Lyall, Jean-Baptiste Berger, The Univ. of North Carolina at Chapel Hill (United States); Clement Vachet, The Univ. of Utah (United States); Robert Hamer, Sandra Woolson, Weili Lin, John Gilmore, Martin A. Styner, The Univ. of North Carolina at Chapel Hill (United States)

Purpose: Statistical shape analysis has emerged as an insightful method for evaluating brain structures in neuroimaging studies, however most shape frameworks are surface based and thus directly depend on the quality of surface alignment. In contrast, medial descriptions employ thickness information as alignment-independent shape metric. We propose a joint framework that computes local medial thickness information via a mean latitude axis from the well-known spherical harmonic (SPHARM-PDM) shape framework. In this work, we applied SPHARM derived medial representations to the morphological analysis of lateral ventricles in neonates.

Mild ventriculomegaly (MVM) subjects are compared to healthy controls to highlight the potential of the methodology. Data: Lateral ventricles were obtained from MRI scans of neonates (9-144 days of age) from 30 MVM subjects as well as age- and sex-matched normal controls (60 total). Methods: SPHARM-PDM shape analysis was extended to compute a mean latitude axis directly from the spherical parameterization. Local thickness and area was straightforwardly determined. MVM and healthy controls were compared using local MANOVA and compared with the traditional SPHARM-PDM analysis. Results: Both surface and mean latitude axis findings differentiate successfully MVM and healthy LV morphology. LV in MVM neonates show enlarged shapes in tail and head. Mean latitude axis is able to find significant differences all along the LV shape, demonstrating that local thickness analysis provides significant insight over traditional SPHARM-PDM. Conclusions: This study is the first to precisely quantify 3D lateral ventricle morphology in MVM neonates using shape analysis.

8672-22, Session 4

Influence of different sources of noise on epileptic spike EEG source localization

Yazdan Shirvany, Xinyuan Chen, Prathamesh Sharad Dhanpalwar, Chalmers Univ. of Technology (Sweden); Mahdieh Mir Hashemi, Chalmers University of Technology (Sweden); Fredrik Edelvik, Fraunhofer-Chalmers Research Centre, Chalmers Science Park (Sweden); Mikael Persson, Chalmers Univ. of Technology (Sweden)

Spike EEG source localization result is influenced by different errors and approximations, e.g., head-model complexity, EEG signal noise, tissue conductivity noise and electrode misplacements. For accurate interpretation of source localization it is crucial to understand the influence of these errors on the source localization results. In this paper the influence of these sources of noise on the EEG source localization were examined in details. Six finite element head models were selected for head-model complexity study. A reference head model was used to create synthetic EEG signals by placing the dipole source inside the model to mimic the epileptic spike signal. For the inverse source localizations an exhaustive search method was used to estimate the best dipole parameters with the EEG signals. Results showed that the inverse problem is significantly influenced by the head-model complexity. A head model with more tissues has better localization results as compared with one with fewer tissues. Moreover, CSF layer plays an important role to achieve an accurate source localization results. To understand the influence of other sources of noise on the EEG source localization, different level of noises were added to EEG signals, tissue conductivities and electrode positions, independently. Simulation results showed that source localization is very sensitive to the tissue conductivity noises. 4% noise on conductivities cause approximately 13mm localization error. Moreover, an electrode misplacement error makes approximately 17% relative error and 8mm localization error for 1cm electrode misplacements. The EEG signal with SNR equal to 6 and higher had an acceptable localization error.

8672-23, Session 5

Fusing functional magnetic resonance image and electrophysiological data on face processing using joint independent component analyses

Xueqian Yang, Xiaojie Zhao, Li Yao, Changming Wang, Beijing Normal Univ. (China)

The functional magnetic resonance imaging (fMRI) research on face processing have found that the significant activation by face stimuli mainly localized at the occipital temporal lobe especilly the fusiform gyrus. However, fMRI cannot reflect the face processing as time changes. Event-related potential (ERP) can record electrophysiological changes induced by neuronal activity in time, but spatial information is not well localized. Fusing fMRI and ERP data can perform that how the fMRI activation changes as time move at each ERP time point. Although most of fuse methods perform to analysis by constraint ERP or fMRI data, joint independent component analysis (jICA) method can equally use the ERP and fMRI data and simultaneously examine electrophysiologic and hemodynamic response. In this paper, we use jICA method to analysis two modalities in common data space in order to examine the dynamics of face stimuli response. The results showed that the ERP component N170 response associated with middle occipital gyrus, fusiform gyrus, inferior occipital gyrus, superior temporal gyrus and parahippocampa gyrus for face. Likewise, for non-face, the N170 component was mainly related to parahippocampa gyrus, middle occipital gyrus and inferior occipital gyrus. Further studying on the correlation of the localized ERP response and corresponding average ERP, it was also concluded that the spatial activations related to N170 response induced by face stimulus located in fusiform gyrus, and that induced by non-face stimulus located in parahippocampa gyrus. From the result, fusing fMRI and ERP data by jICA not only provides the time information on fMRI and the spatial source of ERP component, but also reflects spatiotemporal change during face processing.

8672-24, Session 5

Real-time independent component analysis of fMRI using spatial constraint

Zhi Wang, Beijing Normal Univ. (China); Hang Zhang, Peking Univ. (China); Xia Wu, Li Yao, Zhiying Long, Beijing Normal Univ. (China)

Real-time functional magnetic resonance imaging (fMRI) is a useful tool that researchers can monitor and assess dynamic brain activity in real time and train individuals to actively control over their brain activation by using neurofeedback. Independent Component Analysis (ICA) is a data-driven method which can recover a set of independent sources from data without using any prior information. Since ICA was firstly proposed to be applied to fMRI data by Mckeown (1998), it has become more and more

popular in offline fMRI data analysis. However, ICA was seldom used in real-time fMRI studies due to its large time cost. Although Esposito(2005) proposed a real-time ICA (rtICA) framework by combining FastICA with a sliding-window approach, it was only applied to analyze single-slice data rather than full-brain data and was not stable. The semi-blind rtICA (sb-rtICA) method proposed by Ma (2011) can reduce the computation time and improve stability by adding regularization of certain estimated time course using the experiment paradigm information to rtICA. However, the target independent component (IC) cannot be extracted as the first component in all sliding windows by sb-rtICA, which still adds computation time to some extent. The constrained ICA proposed by Lu (2005) can eliminate the ICA's indeterminacy on permutation. In this study, we proposed a real-time Constrained Independent Component Analysis (rtCICA) method by combining CICA with the sliding-window technique to improve the performance of rtICA. The basic idea of rtCICA is to induce spatial prior information as constraints into ICA so that the target IC can be always automatically extracted as the first one. Both simulated and real-time fMRI experiments demonstrated that rtCICA outperforms rtICA greatly in the stability and the computational time.

8672-25, Session 5

Motor execution and imagery: a comparison of the functional network based on ICA and hierarchical integration

Mingqi Hui, Hang Zhang, Ruiyang Ge, Li Yao, Zhiying Long, Beijing Normal Univ. (China)

Neuroimaging studies have revealed that motor imagery (MI) shared similar neural substrates with motor execution (ME) though there are some differences in the activation pattern. Most previous studies generally focused on voxel-wise based analysis. However, the congruence and difference in functional brain network relevant to MI and ME task has been rarely investigated. In this study, independent component analysis (ICA) was applied to characterize the functional brain networks underlying MI and ME. Conjunction analysis and paired-T test were used separately to detect the regions showing the commonalities and differences between MI and ME. Results shows that the brain networks underlying MI and ME shared similar brain regions consisted of supplementary motor area (SMA), premotor area (PMA), posterior parietal lobule (PPL), and cerebellum. However, the ME task induced stronger activities in SMA-proper, bilateral primary sensorimotor area (M1/S1) and cerebellum while the MI task produced greater acitivites in preSMA, right cerebellum, bilateral PMA, parietal cortex and striatum. These findings are in accordance with the model proposed by Hikosaka (2002) that includes the parietal–prefrontal cortical loops for a spatial sequence and the motor cortical loops for a motor sequence. Moreover, the functional connectivity within the MI/ME-relevant network was evaluated using hierarchical integration that can quantify the total amount of interaction within the network and further assess the information exchanges within/between sub-networks. Results of hierarchical integration further indicate that parietal-prefrontal areas contributes more to the integration of MI network than that of ME network while motor cortical areas contributes more to the integration of ME network than that of MI network.

8672-26, Session 5

Motor execution and imagination: a comparison of functional connectivity based on connection strength

Lele Xu, Beijing Normal Univ. (China); Hang Zhang, Peking Univ. (China); Mingqi Hui, Zhiying Long, Li Yao, Beijing Normal Univ. (China); Yijun Liu, Peking Univ. (China)

Motor tasks, in our daily life, could be performed through execution and imagination. The brain response underlying these movements has been investigated by many studies. Neuroimaging studies have reported that both execution and imagination could activate several brain regions including supplementary motor area (SMA), premotor area (PMA), primary sensorimotor area (M1/S1), posterior parietal lobe (PPL), striatum, thalamus and cerebellum. These findings were based on the regional activation, and brain regions have been indicated to functionally interact with each other when performing tasks. Therefore further investigation in these brain regions with functional connectivity measurements may provide new insights into the neural mechanism of execution and imagination. As a fundamental measurement of functional connectivity, connection strength of graph theory has been used to identify the key nodes of connection and their strength-priorities. Thus, we performed a comparative investigation between execution and imagination tasks with functional magnetic resonance imaging (fMRI), and further explored the key nodes of connection and their strength-priorities based on the results of functional activations. Our results revealed that bilateral SMA, contralateral PMA, thalamus and M1/S1 were involved in both tasks as key nodes of connection. These nodes may play important roles in motor control and motor coordination during execution and imagination. Notably, the strength-priorities of contralateral PMA and thalamus were different between the two tasks. Higher strength-priority was detected in PMA for imagination, implicating that motor planning may be more involved in the imagination task.

8672-27, Session 5

Exploring the relationship between N170's amplitudes and the activation of the picture visual stimuli using general linear model

Xian Zheng, Xiaojie Zhao, Li Yao, Changming Wang, Beijing Normal Univ. (China)

Many studies have reported that discrete cortical areas in the ventral temporal cortex of humans are correlated with the perception of pictures visual stimuli. Moreover, event-related potentials caused by different kinds of picture stimuli show different amplitude levels of N170 which is maximal over occipito-temporal electrode sites. However, the phenomenon which is mentioned above may be correlated with some local bold signal change, and where is the change happened is still unclear. Recently, research for EEG-fMRI has been widely performed through General Linear Model (GLM) to find the relationship between some feature of the ERP component and the activation of local brain area. In our study, we dealt with the simultaneously recorded EEG-fMRI data of picture stimuli to find the correlation between the change of the N170's amplitudes and the BOLD signal. The amplitudes of the N170 component from the average ERPs of 4 different kinds of picture stimuli were extracted from the EEG data and the activation map for the same stimuli was provided based on the fMRI data.GLM model was performed including regressors that could represent the change of the N170's amplitude. Our result showed that fusiform and occipital gyrus were activated by the parametric design and were overlapped by the activation map of the common fMRI design. Thus we might conclude that these regions had relationship with the change of the amplitudes of N170. Our research may contribute to location of the source of N170 and bring a new approach for the parameter design of the fMRI signal in EEG-fMRI analysis.

8672-28, Session 6

Characterizing and utilizing fMRI fluctuations, patterns, and dynamics *(Keynote Presentation)*

Peter A. Bandettini, National Institutes of Health (United States)

On first impression, the sluggishness and messiness of the hemodymamic-based fMRI signal suggests that it is a rather blunt instrument for the study of neuroscience. Nevertheless, a wide range of methods have been developed over the years that have been able to extract exquisitely detailed neuronal information as well as correlates to extremely subtle behavior.

Currently, the fMRI methods community is struggling with several over-

riding issues in fMRI processing that range from artifact elimination to the derivation of robust subject-specific biomarkers to furthering the spatial resolution, temporal resolution, and sensitivity. In this talk I highlight these issues and discuss some relevant contributions of our lab.

With regard to work from our lab, I will first focus on our unique approach to “cleaning up” the resting state fMRI signal using multi-echo EPI, and then create individual whole-brain functional connectivity maps that are consistent and correspond well with specific task-activated networks. I will also show how this multi-echo approach minimizes the problem of motion in resting state fMRI. Secondly, I will discuss our characterization of how the resting state signal changes over time, what the most and least variable networks are, and how we characterize specific mental states as they change over time.

With regard to task-activated signal, I will show that with massive averaging of the signal and with a less-restrictive model of the expected hemodynamic response, virtually the whole brain becomes activated with even simple task. Lastly, I will describe our latest efforts in the rapidly advancing field of fMRI decoding. Here I show preliminary data on simultaneously decoding 100ms timing differences between ocular dominance columns with up to 90% accuracy. I also demonstrate our unique paradigm for extracting subjective “yes” and “no” responses, also with 90% accuracy, independent of whether the subject is being truthful or not in their answers.

Overall, I will hopefully demonstrate that this temporally and spatially variable hemodynamic responds is a highly sensitive and consistent marker of neuronal activity that will continue to provide new information as our tools become more sophisticated.

8672-29, Session 6

Statistical bias in optimized VBM

Nicholas J. Tustison, Univ. of Virginia (United States); Brian B. Avants, Philip A. Cook, James C. Gee, Univ. of Pennsylvania (United States); James R. Stone, Univ. of Virginia (United States)

The recent discovery of methodological flaws in experimental design and analysis in neuroscience research has raised concerns over the validity of certain techniques used in routine analyses and their corresponding findings. Such concerns have centered around selection bias whereby data is inadvertently manipulated such that the resulting analysis produces falsely increased statistical significance, i.e. type I errors. This has been illustrated recently in fMRI studies, with excessive flexibility in data collection, and general experimental design issues. Current work from our group has shown how this problem extends to generic voxel-based analysis (and certain technique derivatives such as tract-based spatial statistics) using fractional anisotropy images derived from diffusion tensor imaging. In this work, we demonstrate how this circularity principle can potentially extend to the well-known optimized voxel-based morphometry technique cite{Good2001} for assessing cortical density differences whereby the principal cause of experimental corruption is due to normalization strategy. Specifically, the popular sum-of-squared-differences (SSD) metric explicitly optimizes statistical findings potentially inflating type I errors. Additional experimentation demonstrates that this problem is not restricted to the SSD metric but extends to other commonly used metrics such as mutual information, neighborhood cross correlation, and Demons.

8672-30, Session 6

3D of brain shape and volume after cranial vault remodeling surgery for craniosynostosis correction in infants

Beatriz Paniagua, Omri Emodi, Jonathan Hill, The Univ. of North Carolina at Chapel Hill (United States); James Fishbaugh, The Univ. of Utah (United States); Luiz Pimenta, The Univ. of North Carolina at Chapel Hill (United States); Stephen Aylward, Andinet Enquobahrie, Kitware Inc. (United States); Guido Gerig, The Univ. of Utah (United States); John Gilmore, John van Aalst, Martin A. Styner, The Univ. of North Carolina at Chapel Hill (United States)

Description of purpose: The skull of young children is made up of bony plates that enable growth. Craniosynostosis is a birth defect that causes one or more sutures on an infant’s skull to close prematurely. Corrective surgery focuses on cranial and orbital rim shaping to return the skull to a more normal shape. Functional problems caused by craniosynostosis such as speech and motor delay can improve after surgical correction, but a post-surgical analysis of brain development in comparison with age-matched healthy controls is necessary to assess surgical outcome. Data: Full brain segmentations obtained from pre- and post-operative computed tomography (CT) scans of 8 patients with single suture sagittal (n=5) and metopic (n=3), non-syndromic craniosynostosis from 41 to 452 days-of-age were included in this study.

Age-matched controls obtained via 4D acceleration-based regression [1] of a cohort of 402 full brain segmentations from healthy controls magnetic resonance images (MRI) were also used for comparison (ages 38 to 825 days). Method(s): 3D point-based models of patient and control cohorts were obtained using SPHARM-PDM shape analysis tool [2]. From a full dataset of regressed shapes, 240 healthy regressed shapes between 30 and 588 days-of-age (time step = 2.34 days) were selected. Volumes and shape metrics were obtained for craniosynostosis and healthy age-matched subjects. Results: Volumes and shape metrics in single suture craniosynostosis patients were larger than age-matched controls for pre- and post-surgery.

Conclusions: The use of 3D shape and volumetric measurements show that brain growth is not normal in patients with single suture craniosynostosis.

1. Estimation of smooth growth trajectories with controlled acceleration from time series shape data. Fishbaugh J, Durrleman S, Gerig G. Med Image Comput Comput Assist Interv. 2011;14(Pt 2):401-8.

2. M Styner, I Oguz, S Xu, C Brechbuhler, D Pantazis, J Levitt, M Shenton, G Gerig: Framework for the Statistical Shape Analysis of Brain Structures using SPHARM-PDM, Open Science Workshop at MICCAI 2006, Kopenhagen, published at Insight Journal DSpace link: http:// hdl.handle.net/1926/215

8672-31, Session 6

Altered hemodynamic oscillations of resting-state networks in mesial temporal lobe epilepsy

Xiaopeng Song, College of Engineering, Peking Univ. (China); Yi Zhang, School of Life Sciences and Technology, Xidian Univ. (China); Hang Zhang, Qijun Xie, College of Engineering, Peking Univ. (China); Shuyan Song, Huazhong Univ. of Science and Technology (China); Haibo Xu, Union Hospital of Huazhong, Univ. of Science and Technology (China); Yijun Liu, College of Engineering, Peking Univ. (China) and Univ. of Florida (United States)

Mesial-temporal lobe epilepsy (mTLE), a neurological disorder characterized by abnormal synchronous discharges in a large cell population, affects the hemodynamic activities of functional networks remote from the epileptogenic zone and causes widespread deficits in brain functions. Although a number of resting-state fMRI studies have found altered spatial patterns in the canonical resting-state networks (RSNs) in patients with mTLE, including the default mode network (DMN), dorsal lateral attention network (DAN), auditory network (AUN), somatosensory network (SMN) and visual network (VIN), none of these studies has addressed the question whether the frequencies of hemodynamic oscillations in these RSNs were altered. In the present study, we have proposed a method to characterize the resting hemodynamic activity of a large-scale functional network. First, the RSNs were identified in healthy controls as well in the left mTLE patients using independent component analysis (ICA). Then, a time course representing the hemodynamic activity of each RSN was extracted by

counting the number of the voxels that were activated simultaneously at each time point within the network. Finally, the power spectral density (PSD) of the time course was estimated. Our results have demonstrated significant differences in the frequency profiles of the SMN, VIN and left DAN between the patients and controls: the peaks of these spectra shifted toward a lower frequency in the patients, while more power was distributed over higher frequency bands in the healthy controls. However, no significant difference has been found in the AUN, DMN and right DAN. These features might serve as biomarkers to differentiate the patients from controls.

8672-32, Session 7

Multiscale, multimodal fusion of histological and MRI lung volumes for characterization of airways

Mirabela Rusu, Haibo Wang, Thea Golden, Andrew Gow, Anant Madabhushi, Rutgers State Univ. of New Jersey (United States)

Mouse lung models facilitate the investigation of various pulmonary diseases such as acute and chronic inflammation. Various imaging modalities may be integrated to generate a multi scale-mouse lung model. Some, for example in vivo MRI, are non-invasive and capture macroscopic information, while others, e.g. histological specimens, depict detailed structures on ex vivo samples. Registering such multi-modal data to the same spatial coordinates will allow the construction of a comprehensive 3D model to enable the multi-scale study of diseases. Moreover, it may facilitate the identification of imaging signatures for diseases and pathologic processes in vivo. The registration of multi-modal data is typically challenging due to 1) different level of detail of the acquired images, 2) deformations induced by other organs, and 3) artifacts caused by the sample preparation. We introduce a framework to integrate in vivo MR images of the entire mouse with ex vivo MRI and ex vivo histology of the lung alone. First, we align the MR images by registering the in vivo and ex vivo MRI lungs. Then we reconstruct the 3D volume of the histological specimen by efficient groupwise registration of the 2D sections. The resulting 3D histologic volume is subsequently registered to the MRI volumes, directly to the ex vivo MRI, and implicitly to in vivo MRI. A preliminary study was conducted to investigate chronic and acute inflammation in a diseased mouse. We anticipate that our integrated framework will identify in vivo imaging signatures of inflammation.

8672-33, Session 7

Longitudinal assessment of treatment effects on pulmonary ventilation using 1H/3He MRI multivariate templates

Nicholas J. Tustison, Benjamin Contrella, Talissa A. Altes, Univ. of Virginia (United States); Brian B. Avants, Univ. of Pennsylvania (United States); Eduard E. de Lange, John P. Mugler III, Univ. of Virginia (United States)

The utility of pulmonary functional imaging techniques, such as hyperpolarized 3He MRI, has encouraged their inclusion in research studies for longitudinal assessment of disease progression and the study of treatment effects. We present methodology for performing voxelwise statistical analysis of ventilation maps derived from hyperpolarized 3He MRI which incorporates multivariate template construction using simultaneous acquisition of 1H and 3He images. Additional processing steps include intensity normalization, bias correction, 4-D longitudinal segmentation, and generation of expected ventilation maps prior to voxelwise regression analysis. Analysis is demonstrated on a cohort of eight individuals with diagnosed cystic fibrosis (CF) undergoing treatment imaged five times every two weeks with a prescribed treatment schedule.

8672-34, Session 7

Using CT imaging to quantify differences between young and elderly healthy lungs

Karthik Subramaniam, Merryn H. Tawhai, Auckland Bioengineering Institute (New Zealand); Eric Hoffman, Univ. of Iowa (United States)

Volumetric computed tomography (CT) imaging provides a method of acquiring a 3-Dimensional view of lung soft tissue. The data captured in these images allows several methods of assessing the state of health of the lung. This information can prove valuable in early diagnosis of conditions where lung tissue is damaged, before external symptoms are expressed. The imaging data is also necessary for modeling lung tissue mechanics. This paper presents some analysis techniques for lung soft tissue, and uses these techniques to compare lungs of young and elderly subjects, all of whom are classified as healthy, in order to establish a baseline study.

The data we used was acquired at two different lung inflations, and information such as tissue density distributions and heterogeneity are extracted from these images. This data is then used to test various hypotheses about how lung tissue characteristics change with age and BMI. The results of these tests are presented in the paper, along with a discussion of the challenges faced in lung imaging and data extraction.

8672-35, Session 7

Graph-based segmentation of the pediatric trachea in MR images to model growth

Richard Amendola, Joseph Reinhardt, Univ. of Iowa (United States); Yutaka Sato, Univ. of Iowa (United States) and Univ. of Iowa (United States); Miriam B Zimmerman, University of Iowa (United States); Henry Diggelmann, Deborah Kacmarynski, Univ. of Iowa (United States)

The upper airways are a major site of congenital and acquired pediatric airway obstruction. Airway size information can be used for pre-surgical planning and post-treatment assessment. The aim of this research is to develop a greater understanding of the growth and variation of the normal pediatric airway to assist a surgeon in optimizing the outcomes for patients by increasing efficiency and accuracy. The standard imaging tool for measuring airway geometry has been computed tomography, but to eliminate the risks of radiation exposure during prospective studies, we have developed an image analysis system to measure airway geometry in MR images of the upper airway. Six adult patients that had CT and MR images of a normal airway were used as the training set to optimize the segmentation cost function to find the appropriate 3D surface. 25 normal pediatric subjects were segmented and measured and then compared to the segmentations of three experts. Dice similarity coefficient and boundary point distances were used for comparison metrics. The automated segmentations correlated well and were not significantly different from those from the group of experts. The measurements were plotted against age, weight, height and body mass index and fit to a 2nd degree polynomial. In an attempt to model growth, cross-sectional area showed a significant correlation with age or height of the individual. This work demonstrates that MR imaging can be used for measuring the pediatric upper airway and to develop growth models to assist in pre-surgical planning.

8672-36, Session 7

Stochastic tracking of small pulmonary vessels in human lung alveolar walls using synchrotron radiation micro CT images

Yoshiki Kawata, Noboru Niki, Univ. of Tokushima (Japan); Keiji

Umetani, Japan Synchrotron Radiation Research Institute (Japan); Yasutaka Nakano, Shiga Univ. of Medical Science Hospital (Japan); Hironobu Ohamatsu, National Cancer Ctr. Hospital East (Japan); Noriyuki Moriyama, National Cancer Ctr. Research Ctr. for Cancer Prevention and Screening (Japan); Harumi Itoh, Univ. of Fukui (Japan)

The small pulmonary vessel network (arteriole and venule) provides a significant insight into understanding the alveolated structure in the human acinus. However, automatic extraction of small pulmonary vessels is challenging due to the presence of abundant complexities in the networks. We thereby introduced a stochastic framework, a particle filter, to track small vessels running inside alveolar walls in human acinus using synchrotron radiation micro CT (SR?CT) images. We formulated vessel tracking using a non-linear sate space which captures both smoothness of the trajectories and intensity coherence along vessel orientations. In the particle filter scheme, we computed the proposal distribution by using the orientation distribution function (ODF), which is estimated as the combination of three different profiles; appearance, directional, and medialness profiles. To model the posterior distribution, we obtained voxels inside cylindrical tube which encapsulated a local vessel part. We constructed the prior distribution using the von Mises-Fisher (vMF) distribution on a unit sphere. At the same time, we detected branches of a vessel by analyzing the dominance of local vessel orientations through the vMF mean shift algorithm. Given a seed point, the method is able to locate the optimal vessel networks inside alveolar walls. Applying the method to the SR?CT images of the human lung acini, we demonstrate its potential usefulness to extract the trajectories of small pulmonary vessels running inside the alveolar walls.

8672-37, Session 7

From imaging to functional outcome in pulmonary embolism

Alys R. Clark, Auckland Bioengineering Institute (New Zealand); Kelly S. Burrowes, Univ. of Oxford (United Kingdom); David G. Milne, Margaret L. Wilsher, Auckland City Hospital (New Zealand); Merryn H. Tawhai, Auckland Bioengineering Institute (New Zealand)

The interaction between mechanical obstruction and outcome in pulmonary embolism (PE) is not well quantified. Therefore a simple prognostic tool that can be used quickly in the clinical setting remains elusive. Several scoring systems have been proposed to address this problem. However, they are unable to adequately capture the functional outcomes in PE so have not been adopted widely clinically. Here we present an image-based computational model that correlates very well with measures of RV dysfunction. The model extracts the geometric features of the lung, airways, blood vessels and emboli from CTPA (computed tomography pulmonary angiogram) imaging and simulates function (perfusion, ventilation and gas exchange) within these geometries. This results in subject-specific predictions of function in 9 patients with acute PE. There is a high correlation between model results and indicators of right heart dysfunction ($p=0.001$ in the case of the ratio between right and left ventricular volumes and $p<0.03$ in the case of systolic pulmonary artery pressure estimated from echocardiography). An existing scoring system that accounts only for the mechanical obstruction of capillary bed performs less well than the model ($p=0.04$ in the case of the ratio between right and left ventricular volumes and $p=0.23$ in the case of systolic pulmonary artery pressure estimated from echocardiography). This suggests that the functional impact of occlusion must be accounted to construct useful PE scoring systems.

8672-38, Session 7

Strain as a novel index of regional pulmonary function from thoracic 4D CT images: in-vivo validation with tomographic SPECT ventilation and perfusion

Mohammadreza Negahdar, Neal Dunlap, Albert Zacarias, Shiao Y. Woo, Amir A. Amini, A. Cahid Civelek, Univ. of Louisville (United States)

Since many diseases or injuries can cause biomechanical or structural property changes that can alter lung function, there is great interest in measuring regional lung function by measurement of regional mechanical changes. To date, the most prevalent approach for assessing regional lung function from 4-D X-ray CT data has been a measure of Jacobian of deformation. However, although the Jacobian describes regional volume changes of the lung during deformation, it lacks any consideration of directional changes of local compressions and expansions during respiration. Herein, we propose the use of strain as a measure of regional lung function from 4-D thoracic CT and we perform correlation of principal strains of calculated deformation by s recently proposed 3-D optical flow technique (MOFID) computed from radiotherapy treatment planning 4-D X-ray CT data sets collected in seven subjects suffering from non-small cell primary lung cancer. In addition to 4-D CT data, both SPECT ventilation (V_SPECT), and SPECT perfusion (Q_SPECT) data were acquired in all subjects. For each subject, we performed voxel-wise statistical correlation of the Jacobian as well as principal strains of deformation (CT-derived pulmonary function images) with both ventilation and perfusion SPECT. For all subjects, the maximum principal strain resulted in a higher correlation with both SPECT ventilation and SPECT perfusion than other indices including the previously established Jacobian metric.

8672-39, Session 8

Automated 3-D region-based volumetric estimation of optic disc swelling in papilledema using spectral-domain optical coherence tomography

Jui-Kai Wang, Mohammad Saleh Miri, The Univ. of Iowa (United States); Randy H. Kardon, Mona K. Garvin, The Univ. of Iowa (United States) and Veterans Administration Hospital (United States)

The six-stage Frisén scale is a qualitative and subjective method for assessing papilledema (optic disc swelling due to raised intracranial pressure) using fundus photographs. The recent introduction of spectral-domain optical coherence tomography (SD-OCT) presents a promising alternative to enable the 3-D quantitative estimation of papilledema. In this work, we propose an automated region-based volumetric estimation of the degree of papilledema from SD-OCT. After using a graph-based approach to segment the surfaces of the swollen optic nerve head, the volumes of the nasal, superior, temporal, and inferior regions are computed. Using a dataset of 70 SD-OCT optic-nerve-head (ONH) SD-OCT scans, the Spearman rank correlation coefficients between expert-defined Frisén scale grades and the total retina volume, nasal, superior, temporal, inferior regions were 0.737, 0.752, 0.747, 0.770 and 0.758, respectively. Also, a fuzzy k-nearest-neighbor (k-NN) algorithm was used to predict Frisén scale grades (in a leave-one-subject-out fashion); using multiple features rather than just the total retina volume made the resulting mean difference between the expert-defined grades 0.4 (down from 0.7).

8672-40, Session 8

In vivo detection of near infrared transferrin using FRET tomography imaging in breast cancer cells

Ken Abe, Albany Medical College (United States); Lingling Zhao, Rensselaer Polytechnic Institute (United States); Vivek Venugopal, Beth Israel Deaconess Medical Ctr., Harvard Medical School (United States); Xavier Intes, Rensselaer Polytechnic Institute (United States); Margarida Barroso, Albany Medical College (United States)

The dimeric nature of transferrin receptors on cells allows the use of Förster Resonance Energy Transfer (FRET) based detection methods to determine receptor-bound, fluorophore labeled Tfn donor and acceptor pairs. We report the use of near infrared (NIR)-FRET tomographic imaging to detect this internalization of transferrin based on the reduction of donor fluorophore lifetime using a multispectral time resolved fluorescence molecular tomography (FMT) based imaging system to identify these events within mice. We further apply this technique to distinguish between T47D breast cancer cells from normal human mammary epithelial cells (HMECs). T47D and other cancer cells have elevated TFR expression levels and more rapid uptake of transferrin molecules compared to HMECs. Concomitantly, we are also able to show that internalization is increased in cancer vs. non-cancerous cells with co-localization to early endosome 1 (EEA1) positive markers, therefore validating internalization of transferrin into the cytoplasm. T47D cells show increased FRET percent (E%) at higher intensity thresholds of the acceptor molecules using confocal microscopic analysis. Similarly, using NIR-FRET FMT, we are able to demonstrate a positive linear correlation of quenched donor fractions with increased acceptor to donor ratios, indicating a detection of FRET events and thus the presence of tumors using approximately 1x104 cells, a number well below current clinical detection capabilities. We thus show proof-of-principle detection of NIR FRET in animal tissues in which these detectable signals could be a powerful and non-invasive tool in identifying the presence of tumors in vivo.

8672-41, Session 8

Evaluation of embolic deflection devices using optical particle tracking

Ciprian N. Ionita, Daniel R. Bednarek, Stephen Rudin, Toshiba Stroke and Vascular Research Ctr. (United States)

Trans-aortic valve replacement (TAVR) is a new endovascular procedure which has started to be routinely used in cardiac suites. During such procedures a stent containing new aortic valves is place over the damaged ones, causing calcifications dislocation and possible stroke. To prevent such events, new devices are being developed to provide distal protection to brain supplying arteries. To evaluate reproducibly the efficacy of such devices, we propose a method based on particle optical tracking. We simulated TAVR using two porous screens (150 and 200 μm pore size) which were placed in an arterial bifurcation phantom connected to a clinically relevant flow loop. A mask image was acquired and gold embolic particles (100-300 μm) were injected at a steady rate using a motorized injector. Optical images with 2 ms exposure were acquired at 30 fps. Images were subtracted, thresholded and filtered using a 5x5 median filter. ROI's were drawn over the main and bifurcating arteries and a particle counting algorithm was used to estimate particle flow rates in each artery for each run. An unprotected and two protected cases were evaluated. For the unprotected case the particle flow rate was 40 % of the main artery. After the filter placement the particle flow rate in the protected branch was 0.5% or 0.05% of the particle flow rate in the main artery. We are thus able to assess the efficacy of such diversion devices using this optical method.

8672-42, Session 8

Cryo-Imaging: providing the answer to 'Where did my cells go?'

David L. Wilson, Patiwet Wuttisarnwattana, Case Western Reserve Univ. (United States); Wouter V. Hof, Athersys, Inc. (United States); Mohammed Qutaish, Case Western Reserve Univ. (United States); Madhusudhana Gargesha, Sasidhar Katari, BioInVision, Inc. (United States); Zhenghong Lee, Horst Von Recum, Case Western Reserve Univ. (United States); Debashish Roy, BioInVision, Inc. (United States); Kenneth Cooke M.D., Case Western Reserve Univ. (United States)

We applied cryo-imaging(CryoVizTM,www.bioinvision.com) with single cells sensitivityto assess stem cell biodistribution, homing, and engraftment. The system sections and images repeatedly to obtain tiled microscopic ana¬tomical bright field and molecular fluorescence image volumes. Cryo-imaging fulfills an unmet need to map cells within a 3D anatomical context over volumes 106 times larger than confocal or 2-photon, at a resolution/sensitivity much better than in vivo. Stem cells were fluorescently labeled with quantum dots, dyes, and/or gene reporters. Machine learning algorithms were created, and rigorously validated to detect stem cells. We developed specialized image analysis algorithms to obtain cell counts in specific organs (kidney, lung, spleen, liver, bone marrow, etc.). In addition, we have developed very specialized visualization approaches allowing one to probe the enormous (150+GB) image volumes. For example, at the computer screen, one can examine the entire mouse in 3D with and without stem cells visible; zoom to an organ and, for example, see the 3D distribution of cells within the kidney; compute cell densities in regions of interest; and zoom even further and examine single cells in bone marrow within an exact anatomical context. The technology has been applied in multiple stem cell applications including MultiStemTM distribution in a GVHD model, MSC homing in heart therapy, and safety studies of embryonic stem cells. Dual/triple reporters enable in vivo imaging with SPECT, PET, bioluminescence, etc., followed by cryo-imaging with single cell sensitivity. Finally, multispectral imaging enables identification of multiple cell types and/or differentiation reporters. We will describe the technology, illustrate applications, and invite vigorous discussion of potential applications.

8672-43, Session 8

Biodistribution study of nanoparticle encapsulated photodynamic therapy drugs using multispectral imaging

Luma V. Halig, Dongsheng Wang, Xulei Qin, Emory Univ. (United States); Andrew Y. Wang, Ocean NanoTech (United States); Georgia Z. Chen, Baowei Fei, Emory Univ. (United States)

The therapy uses a drug called a photosensitizer that is excited by irradiation with a laser light of a particular wavelength, which generates reactive singlet oxygen that damages the tumor cell. The photosensitizer and light are inert; therefore, systemic toxicities are minimized in photodynamic therapy (PDT). The synthesis of novel PDT drugs and the use of nanosized carriers for photosensitizers may improve the efficiency of photodynamic deliverance and function. In this study, we formulated two nanoparticles with and without a targeting ligand to encapsulate phthalocyanines 4 (Pc 4) molecule and compared their biodistributions. Metastatic human head and neck cancer cells (M4e) were transplanted into nude mice. After 2-3 weeks, the mice were injected with Pc 4, Pc 4 encapsulated into iron oxide (IO-Pc 4), and IO-Pc 4 conjugated with a fibronectin-mimetic peptide (FMP-IO-PC 4) which binds specifically to integrin ?1. The mice were imaged using a hyperspectral camera. Using hyperspectral images, a library of spectral signatures was created and the signal per pixel of each tumor was calculated, in a grayscale representation of the unmixed signal of each drug. An enhanced biodistribution of nanoparticle encapsulated PDT drugs compared to non-formulated Pc 4 was observed. Furthermore, specific

targeting nanoparticles conjugated Pc 4 has a quicker delivery time and accumulation than the non- specific nanoparticle. The nanoparticle-conjugated PDT drug can have variety potential applications in cancer imaging and treatment.

8672-44, Session 9

Single-sided magnetic particle imaging: magnetic field and gradient

Ksenija Gräfe, Mandy Grüttner, Timo F. Sattel, Matthias Graeser, Thorsten M. Buzug, Univ. zu Lübeck (Germany)

The first Magnetic Particle Imaging (MPI) scanner has been presented by Gleich and Weizenecker in 2005. Recently, a variety of innovations in coil design, particle excitation sequences, and particle synthesis have been introduced. For example, in 2009, a proof-of-concept for a single-sided MPI scanner has been published by Sattel et al.. For the imaging process in MPI, super-paramagnetic iron oxide nanoparticles (SPIONs) are applied as tracer material. The physical property of these nanoparticles is the nonlinear magnetisation of the iron oxide particle core. When the particles are excited by a sinusoidal signal (drive field), a voltage is induced in receive coils. This signal contains the excitation frequency and – due to the nonlinearity of the magnetisation - its harmonics. For the spatial encoding a static gradient field (selection field) overlays the excitation field. Due to the selection field the particles are in saturation almost everywhere and the magnetisation is near constant. In this case, no signal is induced into the receive coil. A field-free point (FFP) is established at the zero crossing of the gradient field. The FFP is important for the imaging process, because only the SPIONs at the FFP or in direct neighbourhood to the FFP contribute to the receive signal. To enable imaging, it is necessary to move the FFP in space.

This contribution presented simulated magnetic fields of a single-sided scanner which were evaluated based on measured magnetic fields. Moreover, the quality of the gradient strength was analysed, thus image resolution is directly linked to the gradient strength.

8672-45, Session 9

System matrices for field of view patches in magnetic particle imaging

Mandy Grüttner, Timo F. Sattel, Florian Griese, Thorsten M. Buzug, Univ. zu Lübeck (Germany)

The new imaging modality Magnetic Particle Imaging develops further, continuously.

To determine its spatial distribution superparamagnetic iron-oxide nanoparticles are excited with oscillating magnetic fields. The change in magnetization is recorded with receive coils.

Spatial encoding is achieved with a superimposed gradient field featuring a field-free point.

Particles not located in the vicinity of this point are in saturation and therefore do not induce a signal. Image reconstruction is often performed via a system matrix, which is very accurate on the one hand, but time consuming on the other hand. Recently, a method was introduced that images several small patches instead of one large field of view. This contribution applies this approach and additionally suggests to reusing the system matrix of one patch for the reconstruction of all patches. We will motivate this idea with symmetry characteristics of the magnetic fields applied in Magnetic Particle Imaging and perform a simulation study on homogeneous as well as inhomogeneous fields to show the potential of the approach.

8672-46, Session 9

Scanner setup and reconstruction for three-dimensional magnetic particle imaging

Thilo Wawrzik, Christian Kuhlmann, Frank Ludwig, Meinhard Schilling, Technische Univ. Braunschweig (Germany)

Magnetic particle imaging (MPI) is a promising new imaging method capable of determining the spatial distribution of magnetic nanoparticle tracers in real-time. By means of a time-varying magnetic field the non-linear response of the nanoparticle tracer is observed. Under constraints of an additional gradient field an image is reconstructed from the resulting spectrum.

Our magnetic particle imaging (MPI) scanner covers a field of view of 25x25x15 mm. It features a bore size of 30mm, large enough to fit a ventilated mouse under laboratory conditions. The selection field gradient of 3 to 6 T/m is created by a combination of NdFeB permanent magnets and Maxwell coils. For drive field generation three coils in Helmholtz-type or Solenoid configuration are used. The orthogonal drive fields are operated by an audio power amplifier, followed by resonating filter stages tuned to frequencies around 10 kHz, with maximum amplitudes of 30 mT. The coil system is water-cooled for stable long-term operation. The read-out signal from the induction coil sensors passes a higher-order bandstop filter for supression of the drive field frequency before it is fed into an ultra low noise amplifier.

By imaging plastic or bio-compatible phantoms we were studying the properties of the MPI system function and its dependence on components of the imaging system and particle dynamics. In progress towards three-dimensional imaging, two-dimensional imaging results of phantoms obtained with the scanner are presented.

8672-47, Session 9

Langevin equation simulation of Brownian magnetic nanoparticles with experimental and model comparisons

Daniel B. Reeves, Dartmouth College (United States); Jurgen Weizenecker, Karlsruhe Institute of Technology (Germany); John B. Weaver, Dartmouth College (United States)

Magnetic nanoparticles (mNPs) are extremely useful in medical applications because they interact with biology on a cellular level. Studying the dynamics of magnetic particles may lead to advances in imaging through enhanced MRI contrast or directly in magnetic particle imaging (MPI). Moreover, understanding dynamic properties is essential for mNP sensing or counting as in magnetic spectroscopy of Brownian motion (MSB). Lastly, therapeutic techniques like hyperthermia require information about particle dynamics for safe and reliable use in the clinic. To that end, we have developed a stochastic dynamical model of rotating Brownian mNPs from a Langevin equation approach. This matches the current analytical models in three regimes. With a static applied field, the equilibrium magnetization of mNPs agrees with the Langevin function of the Boltzmann distribution approach while the relaxation time toward equilibrium satisfies Einstein's Brownian relaxation. At high frequency or low amplitude driving fields, the model exhibits behavior characteristic of the Debye approximation. In higher field regimes where saturation occurs, the magnetization shapes and harmonics compare well with the effective field model. Currently the model is being benchmarked against experimental results and has successfully demonstrated that harmonics of the magnetization carry enough information to detect environmental parameters.

8672-48, Session 9

Magnetic red blood cells as new contrast agents for MRI applications

Antonella Antonelli, Carla Sfara, Univ. degli studi de Urbino Carlo Bo (Italy); Elisabetta Manuali, Sonia Salamida, Lab. of Histopathology and Clinical Chemistry (Italy) and Experimental Zooprofilactic Institute of Umbria and Marche (Italy); Gaelle Louin, Guerbet Research Group (France); Mauro Magnani, Univ. degli studi de Urbino Carlo Bo (Italy)

Superparamagnetic iron oxide (SPIO) nanoparticles have been produced and used successfully as potent contrast agents for Magnetic Resonance Imaging (MRI). However, a significant challenge associated with the biological application of SPIO-tracer agents is their behavior in vivo since their efficacy is often compromised due to a rapid recognition and clearance by the reticuloendothelial system (RES) which limits the applicability of such compounds in MRI.

The advances in nanotechnology and molecular cell biology had lead to improve stability and biocompatibility of these nanoparticles, but despite a number of efforts, the SPIO half-life in blood circulation is very short. In this contest, the potential of red blood cells (RBCs) loaded with SPIO nanoparticles as a tracer material for MRI has been investigated in order to realize a blood pool tracer with longer blood retention time. Previously, we have proposed the encapsulation into RBCs of superparamagnetic iron oxide nanoparticles carboxydextran coated, such as Resovist contrast agent.

This approach led to a nanoparticle reduction in uptake by the RES, increasing the blood circulation half-life of nanoparticles. Recently, the loading procedure was applied to a new contrast agent, the P904 ultrasmall superparamagnetic iron oxide (USPIO) nanoparticles coated by hydrophilic derivatives of glucose, recently developed by Guerbet Laboratories. The results evidenced that this nanomaterial can be efficiently loaded into human and murine RBCs at concentrations ranging from 1.5 to 12 mM Fe. In vivo experiments performed in mice have showed an increased survival in the mouse vascular system of P904 encapsulated into RBCs respect to free P904 sample intravenously injected at the equivalent amounts.

8672-49, Session 9

Interstitial detection of gold nanoparticles in deep tissues with optical radiance using porcine phantom

Serge Grabtchak, Univ. of Prince Edward Island (Canada); Elena Tonkopi, QEII Health Sciences Centre (Canada) and Dalhousie Univ. (Canada); William M. Whelan, Univ. of Prince Edward Island (Canada)

We have applied an optical radiance technique to map localized inclusions of gold nanoparticles in a porcine phantom. Our goal was to show that combined spectroscopic and angular snapshots of phantoms allow obtaining information that is relevant for prostate cancer diagnostics and treatment. A combination of the point radiance spectroscopy and white light spectroscopy was used to measure angular resolved light distribution in 600-950 nm spectral range inside a porcine phantom that mimics prostate geometry. Optical radiance defines a variation in the angular density of photons impinging on a selected point in the tissue from various directions. To obtain radiance data, a specially constructed optical probe with a well-defined angular detection window must be rotated along its axis. Characteristic spectro-angular snapshots of the phantom alone and with the localized inclusion of gold nanoparticles were obtained. The inclusions were formed by either immersing a capillary filled with gold nanoparticles into selected areas in the phantom or directly injecting the equivalent volume with nanoparticles inside the phantom. The distribution of particles in both cases was monitored with CT. For phantoms with gold inclusions, the approach allows isolation of the spectroscopic signatures of the inclusions from the background and identification of locations of the inclusions in the angular domain. A detection of ~1x1012 particles up to 20 mm deep in porcine tissue was demonstrated. These encouraging results indicate a promising potential of radiance spectroscopy in prostate treatment and diagnostics with gold nanoparticles.

8672-50, Session 10

A consistent pre-clinical/clinical elastography approach for assessing tumor mechanical properties in therapeutic systems

Jared A. Weis, Thomas E. Yankeelov, Samantha A. Munoz, Vanderbilt Univ. (United States); Rahul A. Sastry, Stanford Univ. (United States); Stephanie L. Barnes, Lori R. Arlinghaus, Xia Li, Michael I. Miga, Vanderbilt Univ. (United States)

Unlike many other experimental imaging methods, elastography has enjoyed a strong link to the standard diagnostic and interventional evaluation technique of soft tissue palpation. As a result, the initial excitement about elastography quickly translated to clinical use (e.g., [1-3]) which now includes commercially available ultrasound and magnetic resonance (MR) elastography products. However, despite these advances, understanding what these macroscopic clinical-scale tissue measurements indicate with respect to the underlying cellular and tissue-matrix scale phenomena is largely unclear. In this work, we present preliminary data towards a more systematic study of the elasticity biomarker in characterizing cancer for therapeutic design and monitoring. In addition, we demonstrate that we can conduct these studies with techniques that are consistent across both pre-clinical (i.e., mouse) and clinical length scales. The elastography method we use is called modality independent elastography (MIE) and can be described as a highly translatable model-based inverse image-analysis method that reconstructs elasticity images using two acquired image volumes in a pre-post state of deformation. Quantitative phantom results using independent testing methods report an elastic property contrast between the inclusion and background as a 14.9 to 1 stiffness ratio with MIE reconstructing the ratio as 13.1 to 1. Preliminary elasticity reconstructions in murine and human systems are reported and are consistent with literature findings. Finally, the results suggest that MIE may accurately and reliably monitor disease/therapy-induced changes to breast cancer tissue architecture systems and as a result become an important therapeutic design tool and prognosticator.

8672-51, Session 10

A mechanically coupled reaction diffusion model of breast tumor response during neoadjuvant chemotherapy

Jared A. Weis, Michael I. Miga, Xia Li, Lori R. Arlinghaus, A. Bapsi Chakravarthy, Vandana Abramson, Richard G. Abramson, Jaime Farley, Thomas E. Yankeelov, Vanderbilt Univ. (United States)

There is currently a paucity of reliable techniques for predicting the response of breast tumors to neoadjuvant chemotherapy. The standard approach is to monitor gross changes in tumor size as measured by physical exam and/or conventional imaging, but these methods generally do not show whether a tumor is responding until the patient has received multiple treatment cycles. One promising approach to address this clinical need is to integrate quantitative in vivo imaging data into biomathematical models of tumor growth in order to predict eventual response based on early measurements during therapy. One approach is to use contrast enhanced and diffusion weighted magnetic resonance imaging data acquired before and after the first cycle of therapy to calibrate a patient-specific response model which could subsequently be used to predict patient outcome. In this work, we illustrate a mathematical modeling approach to optimize key model parameters

for the calibration of a patient-specific mechanically coupled reaction-diffusion model of response. We apply the approach to patient data in which tumors were either responsive or non-responsive to neoajuvant chemotherapy and demonstrate changes to the patient-specific model which result in altered growth patterns. Additionally, we show that reconstructed parameter maps exhibit drastic differences between patients with different tumor burden outcomes at the conclusion of therapy, in this case, a 10-fold increase in proliferative capacity is found for a non-responsive patient versus its responsive counterpart. Finally, we show that the mechanically coupled reaction-diffusion growth model, when projected forward, more accurately predicts residual tumor burden than the uncoupled model.

8672-52, Session 10

Supplying a-priori spatial information using soft prior regularization in non-linear inversion MR elastography

Matthew D. McGarry, Adam J. Pattison, Dartmouth College (United States); Elijah Van Houten, Univ. of Sherbrooke (Canada); John B. Weaver, Dartmouth Hitchcock Medical Ctr. (United States); Keith D. Paulsen, Dartmouth College (United States)

Magnetic resonance elastography (MRE) looks to image the mechanical properties of soft tissue for diagnosis and monitoring of disease. To date, most MRE studies use averaging of properties over large spatial regions to produce a single quantitative mechanical property value. Anatomical information is readily available in any MRE exam from other established sequences. This work investigates supplying spatial information using a soft prior regularization scheme in a subzone based non-linear inversion MR elastography algorithm. Soft prior regularization promotes homogeneous properties over pre-defined spatial regions. A term penalizing intra-regional variation of properties is added to the function that is minimized during solution of the elastographic inverse problem. Phantom experiments show that smooth images with the correct contrast in both storage modulus and damping ratio are produced when the segmentation is correct, however, segmentation errors can lead to bias in the results. Careful choice of regularization weighting can mitigate segmentation errors, however some bias still remains. When the segmentation is correct, regional mechanical property estimates are stable over a range of soft prior weightings spanning 2 orders of magnitude.

8672-53, Session 10

Stable automated segmentation of liver MR elastography images for clinical stiffness measurement

Bogdan Dzyubak, Sudhakar Venkatesh, Kevin Glaser, Meng Yin, Jayant Talwalkar, Jun Chen, Armando Manduca, Richard L. Ehman, Mayo Clinic (United States)

Magnetic Resonance Elastography (MRE) is an MRI-based technique that is used for clinical diagnosis and staging of liver fibrosis by quantitatively measuring the stiffness of the liver. The image analysis can be complex and subjective, however, potentially leading to significant variability between readers. An algorithm has been developed to segment an appropriate ROI from MRE data and perform the measurements in a fully automated manner.

Automated segmentation of MRE images is quite challenging, and to be able to process large numbers of clinical cases, the algorithm needs to be highly stable with respect to patient anatomy, signal dropout, inhomogeneity, and motion artifact. The initialization of the segmentation uses an adaptive threshold based on peaks fitted to the intensity histogram. An active contour based on intensity and edge information, with morphology used to implicitly enforce smoothness, is used to find the final liver shape. Blood vessels are found by excluding outliers from the liver mask and running an active contour driven by the reconstructed stiffness image to adjust the ROI shape.

The algorithm showed better agreement with the more experienced of two readers in a set of 88 cases than the readers did with each other. The segmentation was run on an additional 200 cases and the final ROIs on those cases were rated by a radiologist. Now that the algorithm has been shown to produce accurate results under a wide range of conditions, it can be evaluated as a quality control tool for clinical MRE.

8672-54, Session 10

Characterizing healthy and osteoarthritic knee cartilage on phase contrast CT with geometric texture features

Mahesh B. Nagarajan, Univ. of Rochester Medical Ctr. (United States); Paola Coan, Ludwig-Maximilians-Univ. München (Germany) and European Synchrotron Radiation Facility (France); Markus B. Huber, Univ. of Rochester Medical Ctr. (United States); Paul C. Diemoz, European Synchrotron Radiation Facility (France); Christian Glaser, Ludwig-Maximilians-Univ. München (Germany); Axel Wismueller, Univ. of Rochester Medical Ctr. (United States)

The current approach to evaluating cartilage degeneration at the knee joint requires visualization of the joint space on radiographic images where indirect cues such as joint space narrowing serve as markers for osteoarthritis. A recent novel approach to visualizing the knee cartilage matrix using phase contrast CT imaging (PCI) was shown to allow direct examination of chondrocyte patterns and their subsequent correlation to osteoarthritis. This study aims to characterize chondrocyte cell patterns in the radial zone of the knee cartilage matrix in the presence and absence of osteoarthritic damage through texture analysis. Statistical features derived from gray-level co-occurrence matrices (GLCM) and geometric features derived from the Scaling Index Method (SIM) were extracted from 404 regions of interest (ROI) annotated on PCI images of healthy and osteoarthritic specimens of knee cartilage. These texture features were then used in a machine learning task to classify ROIs as healthy or osteoarthritic. A fuzzy k-nearest neighbor classifier was used and its performance was evaluated using the area under the Receiver Operating Characteristic (ROC) curve (AUC). The best classification performance was observed with high-dimensional geometrical feature vectors derived from SIM and GLCM correlation features. With the experimental conditions used in this study, both SIM and GLCM achieved a high classification performance (AUC value of 0.98) in the task of distinguishing between healthy and osteoarthritic ROIs. These results show that such quantitative analysis of chondrocyte patterns in the knee cartilage matrix can distinguish between healthy and osteoarthritic tissue with high accuracy.

8672-55, Session 11

Predicting the biomechanical strength of proximal femur specimens through high dimensional geometric features and support vector regression

Chien-Chun Yang, Univ. of Rochester Medical Ctr. (United States) and Univ. of Rochester (United States); Mahesh B. Nagarajan, Univ. of Rochester Medical Ctr. (United States); Markus B. Huber, Univ. of Rochester Medical Ctr. (United States) and Univ. of Rochester (United States); Julio Carballido-Gamio, Univ. of California, San Francisco (United States); Jan S. Bauer, Thomas Baum, Institut Für Röntgendiagnostik, Technische Univ. München (Germany); Felix Eckstein, Eva Lochmüller, Institute of Anatomy and Musculoskeletal Research (Austria); Sharmila Majumdar,

Thomas M. Link, Univ. of California, San Francisco (United States); Axel Wismüller, Univ. of Rochester Medical Ctr (United States) and Univ. of Munich (Germany)

Estimating local trabecular bone quality for purposes of femoral bone strength prediction is important for improving the clinical assessment of osteoporotic hip fracture risk. In this study, we explore the ability of geometric features derived from the Scaling Index Method (SIM) in predicting the biomechanical strength of proximal femur specimens as visualized on multi-detector computed tomography (MDCT) images. MDCT scans were acquired for 50 proximal femur specimens harvested from human cadavers. An automated volume of interest (VOI)-fitting algorithm was used to define a consistent volume in the femoral head of each specimen. In these VOIs, the non-linear micro-structure of the trabecular bone was characterized by statistical moments of its BMD distribution and by local scaling properties derived from SIM. Linear multi-regression analysis and support vector regression with a linear kernel (SVRlin) were used to predict the Failure Load (FL) from the feature sets; the predicted FL was compared to the FL values determined through biomechanical testing. The prediction performance was measured by the root mean square error (RMSE) for each image feature on independent test set. The best prediction result was obtained from the SIM feature set with SVRlin, which had the lowest prediction error (RMSE = 0.842 ± 0.209) and which was significantly lower than the conventionally used mean BMD (RMSE = 1.103 ± 0.262, , $p<0.005$). Our results indicate that the biomechanical strength prediction can be significantly improved in proximal femur specimens on MDCT images by using high-dimensional geometric features derived from SIM with support vector regression.

8672-56, Session 11

Cortical bone microstructure in human osteogenesis imperfecta (OI) assessed by synchrotron radiation

John R. Jameson, Marquette Univ. (United States) and Advanced Light Source, Lawrence Berkeley National Lab. (United States) and Orthopaedic & Rehabilitation Engineering Ctr. (United States); Carolyne Albert, Marquette Univ. (United States) and Orthopaedic & Rehabilitation Engineering Ctr. (United States) and Shriners Hospitals for Children (United States); Peter Smith, Orthopaedic & Rehabilitation Engineering Ctr. (United States) and Shriners Hospitals for Children (United States); Gerald Harris, Marquette Univ. (United States) and Orthopaedic & Rehabilitation Engineering Ctr. (United States) and Shriners Hospitals for Children (United States)

Osteogenesis imperfecta (OI) is a genetic disorder leading to increased bone fragility. Coupled with a lack of sufficient testing techniques, the small size and reduced availability of human OI bone samples has limited biomechanical studies to date. The current study represents one of the first attempts to characterize the 3-D microstructure of cortical bone in OI. Bone fragments from routine orthopaedic procedures were machined into rectangular beams and loaded to failure in 3-point bending. Both longitudinal and transverse beams were tested, where the direction refers to the orientation of the beam with respect to the long axis of the bone. Each beam was then imaged by micro-computed tomography with a synchrotron light source (SRμCT) for several microstructural parameters including porosity (Ca.V/TV), canal surface to tissue volume (Ca.S/TV), canal diameter (Ca.Dm), and canal spacing (Ca.Sp). The canal network was defined as the combination of all non-Haversian, Haversian, and Volkmann canals. Architectural properties including the number of canal intersections and the connectivity density (Ca.ConnD) were also determined. Results indicated elevated Ca.V/TV, Ca.S/TV, and Ca.Dm in samples taken from patients with severe (type III) OI versus mild (type I) and moderate (type III/IV) OI. These properties were also correlated with the flexural strength (?bend) assessed by 3-point bending. Cortical bone in the transverse orientation showed a greater than 80% decrease in bending strength versus the longitudinal direction. These results suggest that the size, amount, and orientation of pores in OI bone contribute greatly to its reduced strength.

8672-57, Session 11

Assessment and characterization of in situ rotator cuff biomechanics

Erika A. Trent, Clemson Univ. (United States); Lane Bailey, Proaxis Therapy (United States) and Univ. of South Carolina (United States); Fuad N. Mefleh, Vipul Raikar, Clemson Univ. (United States); Ellen Shanley, Charles A. Thigpen, Proaxis Therapy (United States); Delphine E. Dean, David M. Kwartowitz, Clemson Univ. (United States)

Rotator cuff disease is a degenerative disorder that is a common, costly, and often debilitating, ranging in severity from partial thickness tear, which may cause pain, to total rupture, leading to loss in function. Currently, clinical diagnosis and determination of disease extent relies primarily on subjective assessment of pain, range of motion, and possibly X-ray or ultrasound images. The final treatment plan however is at the discretion of the clinician, who often bases their decision on personal experiences, and not quantitative standards.

The use of ultrasound for the assessment of tissue biomechanics is established, such as in ultrasound elastography, where soft tissue biomechanics, typically in the breast, are measured. Few studies have investigated the use of ultrasound elastography in the characterization of musculoskeletal biomechanics. To assess tissue biomechanics we have developed a device, which measures the force applied to the underlying musculotendentious tissue while simultaneously obtaining the related ultrasound images. Validation and preliminary measurements using this device have been performed. We aim better stage the extent and location of damage to the rotator cuff tissue, through the in situ analysis of subsurface biomechanics.

8672-58, Session 11

Non-invasive quantitative assessment of scoliosis spinal surgery outcome

Lama Seoud, Farida Cheriet, Ecole Polytechnique de Montréal (Canada) and Sainte Justine Hospital Research Ctr. (Canada); Hubert Labelle M.D., Stefan Parent M.D., Sainte Justine Hospital Research Ctr. (Canada)

Improving the appearance of the trunk is an important goal of scoliosis surgical treatment, mainly in patients' eyes. Unfortunately, existing methods for assessing postoperative trunk appearance are rather subjective as they rely on a qualitative evaluation of the trunk deformity. In this paper, an objective method is proposed to quantify the changes in trunk shape after surgery. Using a non-invasive optical system, the whole trunk surface is acquired and reconstructed in 3D. Trunk shape is described by two functional measurements spanning the trunk length: the lateral deviation and the axial rotation. To measure the pre and postoperative differences, a correction rate is computed for both measurements. On a cohort of 36 scoliosis patients with the same spinal curve type who underwent the same surgical approach, surgery achieved a very good correction of the lateral trunk deviation (median correction of 76%) and a poor to moderate correction of the back axial rotation (median correction of 19%). These results demonstrate that after surgery, patients are still confronted with residual trunk deformity, mainly a persisting hump on the back. That can be explained by the fact that current scoliosis assessment and treatment planning are based solely on radiographic measures of the spinal deformity and do not take trunk deformity into consideration. It is believed that with our novel quantitative trunk shape descriptor, clinicians and surgeons can now objectively assess trunk deformity and postoperative shape and think of possible new treatment strategies that could better address patients' concern about their appearance.

8672-59, Session 12

A full inversion unconstrained ultrasound elastography technique for prostate cancer assessment

Seyed Reza Mousavi, Abbas Samani, The Univ. of Western Ontario (Canada)

Prostate cancer can be cured, if it is detected at early stage. This implies that prostate cancer detection at early stage is very critical for desirable treatment outcome. Among different imaging modalities, ultrasound elastography is emerging as an effective clinical tool for prostate and breast cancer diagnosis. Current clinical ultrasound elastography utilises strain imaging where tissue strain images are generated to approximate the tissue elastic modulus distribution. While strain images can be generated in real-time fashion, they lack the accuracy necessary for having high sensitivity and specificity. To improve strain imaging, researchers developed full inversion based elastography techniques. The drawback of these techniques is that they are computationally intensive hence are not suitable for real-time imaging. Among these techniques, a constrained elastography technique was developed which showed promising results as long as the tumor geometry can be obtained accurately from the imaging modality used in conjunction with elastography. This requirement is not easy to fulfill, especially with ultrasound imaging. To address this issue, we present an unconstrained full inversion prostate elastography method in conjunction with ultrasound imaging where knowledge of tissue geometry is not necessary. The proposed reconstruction technique is iterative where each iteration involves tissue stress computation using Finite Element Method (FEM) followed by Young's modulus updating of each finite element using Hooke's law. The method was validated with in silico and tissue mimicking prostate phantom studies. Results indicate that this technique is reasonably accurate and robust.

8672-60, Session 12

Development of a poroelastic dynamic mechanical analysis technique for biphasic media

Adam J. Pattison, Matthew D. McGarry, Dartmouth College (United States); John B. Weaver, Keith D. Paulsen, Dartmouth College (United States) and Dartmouth Hitchcock Medical Ctr. (United States)

Magnetic resonance elastography is a technique where mechanical properties of materials are estimated by fitting a mechanical model to an MRI-acquired displacement field. Mechanical models have been primarily limited to viscoelasticity and linear elasticity, and only recently has poroelasticity been utilized as an applied model. To validate these estimates, the same material is measured via an independent dynamic mechanical analysis device. However, these devices only apply viscoelastic models. In some cases, there is a model mismatch if a viscoelastic mechanical analysis is being compared to a poroelastic model in elastography. Thus, a poroelastic dynamic mechanical analysis technique is needed to properly measure porous media and compare the results with the elastography technique. A technique was implemented on a TA-Q800 Dynamic Mechanical Analysis machine using a finite element technique similar to the algorithm used in the corresponding MR elastography method. An optimization technique was used to estimate shear modulus and hydraulic conductivity by fitting the predicted force with the acquired force from the device. A series of three different tofu materials were used and gave promising results. The shear modulus followed the expected trend ('extra firm' is stiffest, 'soft' is softest), where hydraulic conductivity followed the opposite trend. This shows great promise in the ability to measure poroelastic properties of certain tissues.

8672-62, Session PSMon

Enzymatic glucose detection using ZnO nanorods modified gate graphene transistor

Sheng Chun Hung, National Central Univ. (Taiwan)

ZnO nanorod-gated graphene transistors are demonstrated for the detection of glucose. A ZnO nanorod array was selectively grown on the gate area using low temperature hydrothermal decomposition to immobilize glucose oxidase (GOx). The one-dimensional ZnO nanorods provide a large effective surface area with high surface-to-volume ratio and provide a favorable environment for the immobilization of GOx. Graphene transistors are made by graphene grown by chemical vapor deposition (CVD) transferred on a glass covered with a thin SiO2 layer on the gate area. The ZnO nanorod matrix on the gate area provides a microenvironment for immobilizing negatively charged GOx while retaining its bioactivity, and passes charges produce during the GOx and glucose interaction to the graphene transistor. Further details will be discussed in the conference.

8672-63, Session PSMon

Abdominal adiposity quantification at MRI via fuzzy model-based anatomy recognition

Yubing Tong, Jayaram K. Udupa, Dewey Odhner, Medical Image Processing Group, Univ. of Pennsylvania (United States); Sanghun Sin, Raanan Arens, Children's Hospital at Montefiore (United States)

In studying Obstructive Sleep Apnea Syndrome (OSAS) in obese children, the quantification of obesity through MRI has been shown to be useful. For large-scale studies, interactive or manual segmentation strategies become inadequate. Our goal is to automate this process to facilitate high throughput and precision and to eliminate subjectivity in quantification. In this paper, we demonstrate the adaptation, to this application, of a general body-wide Automatic Anatomy Recognition (AAR) system that is being developed separately. The AAR system is developed based on existing clinical CT image data (of 50-60 male subjects) and is based on fuzzy models of the form, geography, and inter-relationships of the objects in each body region. The individual object models are arranged in a hierarchy that is specific to each body region. In adapting this system to our application, which deals with only 3 objects (skin boundary, subcutaneous adipose region, and visceral adipose region) and MRI as the image modality (subjects being 8-17 year-old females), compared to the tens of objects and CT as the modality in the body-wide model, the new hierarchy and the objects in the hierarchy are to be specified. The model is then automatically modified to tailor to the application and can be used to perform AAR. Our preliminary tests based on MRI of 14 obese subjects indicate a recognition accuracy of about 15 mm for both types of adipose regions. This seems quite adequate in terms of the initialization of model-based graph-theoretic delineation algorithms.

8672-64, Session PSMon

Which schematic eye is most appropriate when developing biomedical instrumentation or vision science research?

Luis A. Carvalho, Univ. de São Paulo (Brazil) and Wavetek LLC (United States) and Escola Paulista de Medicina, UNIFESP, Sao Paulo (Brazil)

Current eye-care industry and universities develop a wide range experiments and researches towards new surgical or diagnostic techniques. Nevertheless, the correct or most appropriate schematic eye when designing the optical portion of the project is never an easy

question. Moreover, product development and research for the eye-care professional has reached very high standards, since there is nowadays software available to design and simulate practically any mechanical or optical characteristic of the product before it is thrown into the production line. In order to answer this question, we have used a commercial optical design software (Zemax), and implemented computer simulations of 5 well-known schematic eyes available in the literature. These models were the Helmholtz-Laurance, Gullstrand, Emsley, Greivenkamp and Liou & Brennan. Comparisons between the MTF (Modulation Transfer Function), spot diagrams and Streh Ratio showed the difference in image quality between eye models. A careful comparison between the different models showed that the first four schematic eyes have better optical quality than what is expected for the general and healthy emmetropic in vivo eye. Liou & Brennan schematic eye is the one that most closely resembles the in vivo biological eye. Therefore, in applications, such as research or product development which requires high quality images of the retina, or which will be used to simulate customized optical corrections, we recommend this latter model; for applications that do not require refraction-limited performance, most of the other models should be a good approximation.

8672-65, Session PSMon

A novel approach for real-time monitoring Akt/PKB activity in vitro

Duanwen Shen, Washington Univ. in St. Louis (United States); Mingfeng Bai, Univ. of Pittsburgh (United States); Rui Tang, Washington Univ. in St. Louis (United States); Baogang Xu, Washington Univ. in St. Louis (United States); Xiaoming Ju, Kimmel Cancer Ctr., Thomas Jefferson Univ. (United States); Richard G. Pestell, Thomas Jefferson Univ. (United States); Samuel Achilefu, Washington Univ. School of Medicine in St. Louis (United States)

We applied a new PKB substrate Cypate-di-Serine, LS456, to real-time image phosphorylation activity of Akt/PKB in MCF-7 breast cancer cells in vitro. We observed more than100-fold dichromic fluorescence signal enhancement for 700/800 nm fluorescence signal ratio by 150 nM insulin activation. This signal enhancement was completely blocked by 10 μM phosphatidylinositol 3-kinases (PI3Ks) inhibitor Wortmannin and 50 μM of Akt/PKB specific inhibitor Perifosine, and was totally abolished in PKB/Akt-deficient cells. Kinetic study of activated Akt with LS 456 and anti-phosphorylated Akt (residue 473Ser) suggests high specificity between LS456 and activated Akt. To our best knowledge, Cypate-di-Serine is a new Akt substrate that has been firstly successfully applied in monitoring Akt enzymatic activity in cells.

8672-66, Session PSMon

Quantitative Analysis of the effect of Phosphorylated Tau on Cellular Microfilament Networks

Deborah Sturm, Alejandra Alonso, Christopher Corbo, Isaac Osores, Cynthia Murillo, College of Staten Island (United States)

The purpose of this study is to analyze the effect of site-specific tau phosphorylation on cellular microtubule networks. We examined cell images to study tau's interaction with microtubules in both wild type and P-tau transfected cells. A custom ImageJ plugin was developed to provide quantitative analysis of the immunofluorescence data. Using histograms of the pixel intensities of images (with user-defined thresholds), the code calculates the integrated densities and creates an output image to visualize the considered areas (those outside the thresholds are displayed as well). The visualization helped reveal some image acquisition anomalies. The results should help to further understand the mechanism of cellular degeneration induced by hyper-phosphorylated tau.

8672-67, Session PSMon

Classifying spatial patterns of fMRI activity for object category based on information mapping

Xin OuYang, CaiFeng Yan, School of Information Science and Technology, Beijing Normal Univ. (China); Li Yao, Xiaojuan Guo, School of Information Science and Technology, Beijing Normal Univ. (China) and State Key Lab. of Cognitive Neuroscience and Learning, Beijing Normal Univ. (China)

Multi-voxel pattern analysis (MVPA) has been widely used in the object category classification of functional MRI data. Feature selection is an essential operation in pattern classification. Searchlight, based on information mapping, is one method of feature selection. In contrast with traditional methods based on activation, searchlight has more sensitivity and then provides higher statistical power. In this study, we applied two different feature selection methods, searchlight and activation, combined with linear support vector machine (SVM) classifier, to investigate the classification effect in classifying 4-category objects on fMRI data. We found that the average classification accuracies of searchlight were 0.8095 (house vs. face), 0.7240 (house vs. car), 0.7247 (house vs. cat), 0.6980 (face vs. car), 0.5982 (face vs. cat) and 0.6860 (car vs. cat). For house vs. car, the average classification accuracy based on searchlight was better than that based on activation (0.7240 vs. 0.7143). Specially, searchlight method performs better than activation for some subjects. The results showed that object category classification of fMRI data based on information mapping were significantly reliable. Our findings suggest that information mapping can be applied in pattern classification in future work.

8672-69, Session PSMon

A visualization platform for high-throughput, follow-up, co-registered multi-contrast MRI rat brain data

Artem Khmelinskii, Leids Univ. Medisch Ctr. (Netherlands); Luam Mengler, In-vivo-NMR Lab., Max Planck Institute for Neurological Research (Germany); Pieter Kitslaar, Marius Staring, Leids Univ. Medisch Ctr. (Netherlands); Mathias Hoehn, In-vivo-NMR Lab., Max Planck Institute for Neurological Research (Germany); Boudewijn P. F. Lelieveldt, LKEB-LUMC (Netherlands)

Multi-contrast MRI is a frequently used imaging technique in preclinical brain imaging. In longitudinal cross-sectional studies exploiting and browsing through this high-throughput, heterogeneous data can become a very demanding task. The goal of this work was to build an intuitive and easy to use, dedicated visualization and side-by-side exploration tool for heterogeneous, co-registered multi-contrast, follow-up cross-sectional MRI data. The registration by-products were used: the deformation field was used to automatically link the same voxel in the displayed datasets of interest. Its determinant of the Jacobian (detJac) was used for a faster and more accurate visual assessment and comparison of brain deformation between the follow-up scans. This was combined with an efficient data management scheme. We investigated the functionality and the utility of our tool in the neuroimaging research field by means of a case study evaluation based on the principles and terminology set out by R. K. Yin, with three experienced domain scientists, using longitudinal, cross-sectional multi-contrast MRI rat brain data. Based on the performed case study evaluation we can conclude that the proposed tool improves the visual assessment of high-throughput cross-sectional, multi-contrast, follow-up data and can further assist in guiding quantitative studies.

8672-70, Session PSMon

An automated method for registration and perfusion analysis of pulmonary CT data for evaluating response to radiotherapy in patient with non small cell lung cancer

YuTzu Lee, Chi-Hsuan Tsou, Institute of Biomedical Engineering, National Taiwan Univ. (Taiwan); Yeun Chung Chang, National Taiwan Univ. Hospital and College of Medicine (Taiwan); Chung-Ming Chen, Institute of Biomedical Engineering, National Taiwan Univ. (Taiwan)

Perfusion computed tomography (PCT) has been widely used to assess the response of lung cancer treatment. However, the respiratory motion has become the major obstacle to the pixel-based time-series analyses. To minimize the effect of respiratory motion and to investigate the feasibility of perfusion CT for prediction of tumor response and prognosis of non–small cell lung cancer, an image registration framework is proposed by unifying a virtual 3-D local rigid alignment and 3-D global non-rigid alignment. The basic idea is to use the perfusion CT data and routine whole-lung CT data, respectively. To realize this idea, maximum intensity projection (MIP) of the time series perfusion CT images is first generated, followed by decomposing the MIP image into region of interest (ROI), ROI is located on a lung nodule. For the ROI, affine transformation model based on mutual information is performed to estimate the virtual three dimensional linear deformations. Following that, the 3-D thin plate spline (TPS) is carried out to establish the pixel correspondence for paired volumetric CT data. The control points for the TPS are global feature points chosen from the boundary of whole lung, which are automatically derived by using the iterative closest point (ICP) matching Algorithm. The proposed algorithm has been evaluated both qualitatively and quantitatively on real lung perfusion CT datasets. From the time-intensity curves and perfusion parameters, the experiment results suggest that the findings of perfusion CT images obtained after treatment may be considered as a significant predictor of lung cancer.

8672-71, Session PSMon

Multiparametric prediction of acute ischemic stroke tissue outcome using CT perfusion datasets

Nils Daniel Forkert, Jens Fiehler, Susanne Siemonsen, Andre Kemmling, Univ. Medical Ctr. Hamburg-Eppendorf (Germany)

Acute ischemic strokes are a major cause for death and severe neurologic deficits in the western hemisphere. The prediction of tissue outcome in case of an acute ischemic stroke is an important variable for treatment decision. An estimation of the expected outcome is typically obtained by thresholding a single perfusion parameter map, which is calculated from a perfusion CT dataset. However, cerebral perfusion is complex and the severity of perfusion impairment is not consistent within the penumbra of an acute ischemic stroke. Therefore, the application of only one parameter for acute stroke tissue outcome prediction may oversimplify the given problem. The aim of this study was to develop and evaluate the feasibility of a multiparametric approach for estimating tissue outcome in acute ischemic stroke patients using 15 CT perfusion datasets. For this purpose, perfusion parameter maps of cerebral blood flow, cerebral blood volume and mean transit time were calculated based on the concentration time curves derived from perfusion CT datasets. The parameter maps of ten patients were employed for a voxel-wise training of a support vector machine using ground-truth final infarct segmentations, whereas the remaining five patient datasets were used for evaluation of the voxel-wise prediction of tissue outcome using the trained support vector machine. Furthermore, tissue outcome was also predicted by optimal thresholding of corresponding time-to-peak (TTP) maps for comparison purposes. Both predictions were compared to ground-truth final infarct lesions for the five datasets used for evaluation. The proposed multiparametric tissue outcome prediction lead to superior prediction results in all cases. More precisely, the multiparametric prediction lead to a mean Dice coefficient of 0.556, while optimal thresholding of TTP maps lead to an average Dice-coefficient of 0.444 compared to the ground-truth infarct lesions. In conclusion, the evaluation results of the proposed method suggest that a multiparametric tissue outcome prediction may be feasible for CT perfusion datasets but needs to be evaluated in more detail.

8672-72, Session PSMon

Realistic comparison between aneurysmal wall shear stress vector and blood rheology in patient-specific computational hemodynamic models

Marcelo A. Castro, CONICET - Univ. Tecnologica Nacional - Facultad Regional Buenos Aires (Argentina); Maria C. Ahumada Olivares, Univ. Favaloro, Facultad de Ingenieria, Ciencias Exactas y Naturales (Argentina); Christopher M. Putman, INOVA Fairfax Hospital (United States); Juan R. Cebral, George Mason Univ. (United States)

Wall shear stress plays an important role in the development of intracranial aneurysms. Blood flow numerical simulations have been widely used to investigate associations between flow characteristics and aneurysm initiation, growth and rupture. Newtonian rheology is commonly used for the numerical simulations. However, there is no consent about the impact of the rheology on the wall shear characteristics and aneurysm processes. High resolution patient-specific models containing large aneurysms with multiple lobulations and blebs were created to perform unsteady finite element blood flow simulations and investigate hemodynamic differences for both rheologies.

8672-73, Session PSMon

Intracranial aneurysm wall motion and wall shear stress from 4D computerized tomographic angiography images

Marcelo A. Castro, CONICET - Univ. Tecnologica Nacional - Facultad Regional Buenos Aires (Argentina); Maria C. Ahumada Olivares, Univ. Favaloro - Facultad de Ingenieria, Ciencias Exactas y Naturales (Argentina); Christopher M. Putman, INOVA Fairfax Hospital (United States); Juan R. Cebral, George Mason Univ. (United States)

Based on the assumption that damaged regions of the endothelium have different mechanical properties, regions with differentiated wall displacement amplitudes are expected within an intracranial aneurysm sac. An extended methodology is presented to measure those displacements from four dimensional computerized tomographic angiography images. Unsteday finite element blood flow simulations were performed to search for associations between wall motion and wall shear stress distribution.

8672-74, Session PSMon

Automated 3D mouse lung segmentation from CT Images for extracting quantitative tumor progression biomarkers

Ran Ren, The Univ. of Southern California (United States); Sangeetha Somayajula, Merck Research Labs., IT-Informatics (United States); Raquel Sevilla, Amy Vanko, Merck Research Labs., Imaging (United States); Matthew Wiener, Belma Dogdas,

Merck Research Labs., IT-Informatics (United States); Weisheng Zhang, Merck Research Labs., Imaging (United States)

Imaging of lung cancer through micro-computed tomography (uCT) enables longitudinal in vivo evaluation of tumor burden. This work demonstrates the use of uCT imaging and image segmentation techniques in large population phenotyping studies of transgenic mouse models of lung cancer. We studied 8 genotypes of KRAS mice with 99 subjects imaged at 4 time points. We developed (1) a high throughput image acquisition technique that acquires 60 subjects in 3 hours at an isotropic resolution of 100 um, and (2) an automated segmentation algorithm to compute tumor and vasculature volume (TVV), a previously validated biomarker for lung cancer progression. TVV is computed as the difference between whole lung and functional lung (air space within lung) volumes. We automatically compute TVV by determining (1) lung region of interest (ROI) by using the rib cage, (2) functional lung volume by thresholding within the lung ROI, and (3) whole lung volume by iteratively performing morphological hole-fill, bridge, and image close operations on the functional lung. We compare the automated results with that of manual analysis. Automated functional lung volume results were highly correlated to manual results ($R2 \geq 0.95$) at all the time points. Whole lung volume was well-correlated to manual measurements ($R2 \geq 0.8$ up to 2nd time point), but required some manual correction at later time points when the tumors almost filled the lung. Overall this approach provided about 66% time saving compared to manual analysis. Our innovative workflow with high throughput acquisition and automated segmentation enabled efficient phenotyping studies to aid drug development.

8672-75, Session PSMon

Optimization of automated segmentation of monkeypox virus-induced lung lesions from normal lung CT images using hard C-Means algorithm

Marcelo A. Castro, CONICET - Univ. Tecnologica Nacional - Facultad Regional Buenos Aires (Argentina); David Thomasson, National Institutes of Health - National Institute of Allergy and Infectious Diseases (United States); Nilo Avila, Veterans Affairs Medical Ctr. Radiology Service (United States) and NHLBI, National Institutes of Health (United States); Jennifer Hufton, National Institutes of Health - National Institute of Allergy and Infecious Diseases (United States); Justin Senseney, National Institutes of Health - Ctr. for Information Technology (United States); Reed F. Johnson, National Institutes of Health - National Institute of Allergy and Infectious Diseases (United States); Julie Dyall, National Institutes of Health - National Institute of Allergy and Infecious Diseases (United States)

Monkeypox virus is an emerging zoonotic pathogen that results in up to 10% mortality in humans. Given the limited capability to study monkeypox disease in humans, characterization of the disease in animal models is required. In this work we extended techniques used in computer-aided detection of lung tumors to identify inflammatory lesions from monkeypox virus infection using CT images before inoculation and after disease progression. Automated estimation is in close agreement with manual segmentation.

8672-78, Session PSMon

Reduced centrality of Wernicke's area in autism

Caspar J. Goch, Bram Stieltjes, Deutsches Krebsforschungszentrum (Germany); Romy Henze, UniversitätsKlinikum Heidelberg (Germany); Jan Hering, Hans-Peter Meinzer, Klaus H. Fritzsche, Deutsches Krebsforschungszentrum (Germany)

Symptoms of autism spectrum disorders may include social deficits, communication difficulties and ritualistic or repetitive behavior. While not all of these are necessarily present the impairment of communication facility is one of the most common.

We present an analysis of the role of speech related areas of interest within the large scale network, by assessing the betweenness centrality of the corresponding areas for healthy subjects and those suffering from autism spectrum disorders.

To validate our approach we also evaluate a motor area unrelated to speech impairment or other usual symptoms of autism spectrum disorders. We show that the reduced capacity for comprehension of language is reflected in the reduced importance of Wernicke 's area for the large scale brain network.

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8673-1, Session 1

Optimizing visual search: How does the brain do it? *(Keynote Presentation)*

Miguel Eckstein, Univ. of California, Santa Barbara (United States)

Even with the great advances in computer vision, it is fair to say that for most tasks, humans are still unsurpassed by computers in their ability to visually search. Yet, human searches are not error free. What limits human search performance? And what are the strategies and mechanisms the brain uses to achieve efficient search and minimize errors? I will review the visuo-cognitive limitations degrading search performance and findings spanning the fields of visual psychophysics, computational vision, neuroscience and medical image perception identifying strategies fundamental to successful visual search. The strategies include utilization of knowledge about the targets, distracters, background statistical properties, location probabilities, contextual cues, scene context, rewards, target prevalence and eye movement plans. I will discuss studies using monkey cell electrophysiology, human functional magnetic resonance imaging (fMRI) and electroencephalography (EEG) which have led to progress in our understanding of the underlying brain areas involved in these strategies. The hope is that a better understanding of the computational and neural basis of human visual search might lead to improvements of human performance in life-critical search tasks and advances in our comprehension of what differentiates an expert proficient searcher from a poorly performing searcher.

8673-2, Session 1

Investigating the association of eye gaze pattern and diagnostic error in mammography

Frank M. Pinto Jr., Virginia State Univ. (United States); Sophie Voisin, Oak Ridge National Lab. (United States); Garnetta Morin-Ducote, Kathy Hudson, Univ. of Tennessee Medical Ctr. (United States); Songhua Xu, Georgia Tourassi, Oak Ridge National Lab. (United States)

The objective of this study was to investigate the association between eye-gaze patterns and the diagnostic accuracy of radiologists for the task of assessing the likelihood of malignancy of mammographic masses. Six radiologists (2 expert breast imagers and 4 Radiology residents of variable training) assessed the likelihood of malignancy of 40 biopsy-proven mammographic masses (20 malignant and 20 benign) on a computer monitor. Eye-gaze data were collected using a commercial remote eye-tracker. Upon reviewing each mass, the radiologists were also asked to provide their assessment regarding the probability of malignancy of the depicted mass as well as a rating regarding the perceived difficulty of the diagnostic task. The collected data were analyzed using established algorithms and various quantitative metrics were extracted to characterize the recorded gaze patterns. The extracted metrics were correlated with the radiologists' diagnostic decisions and perceived complexity scores. Results showed that the visual gaze pattern of radiologists varies substantially, not only depending on their experience level but also among individuals. However, some eye gaze metrics appear to correlate with diagnostic error and perceived complexity more consistently. These results suggest that although gaze patterns are generally associated with diagnostic error and the human perceived difficulty of the diagnostic task, there are substantially individual differences that are not explained simply by the experience level of the individual performing the diagnostic task.

8673-3, Session 1

High throughput screening for mammography using a human-computer interface with rapid serial visual presentation (RSVP)

Chris I. Hope, Annette Sterr, Premkumar Elangovan, Nicholas Geades, David Windridge, Univ. of Surrey (United Kingdom); Kenneth C. Young, National Co-ordinating Ctr. for the Physics of Mammography (United Kingdom); Kevin Wells, Univ. of Surrey (United Kingdom)

The steady rise of the breast cancer screening population, coupled with data expansion produced by new digital screening technologies (tomosynthesis/CT) motivates the development of new, more efficient image screening processes. Rapid Serial Visual Presentation (RSVP) is a new fast-content recognition approach which uses electroencephalography to record brain activity elicited by fast bursts of image data. These brain responses are then subjected to machine classification methods to reveal the expert's 'reflex' response to classify images according to their presence or absence of particular targets. The benefit of this method is that images can be presented at high temporal rates (~10 per second), faster than that required for fully conscious detection, facilitating a high throughput of image (screening) material. In the present paper we present the first application of RSVP to medical image data, and demonstrate how cortically coupled computer vision can be successfully applied to breast cancer screening. Whilst prior RSVP work has utilised multi-channel approaches, we also present the first RSVP results demonstrating discriminatory response on a single electrode with a ROC area under the curve of 0.66 using a simple Fisher discriminator for classification. This can increase to 0.71 when three electrodes are used in combination.

8673-4, Session 2

Influence of a-priori information on the visibility of target object

Santosh Singh, Ankur Gupta, Siemens Information Systems Ltd. (India)

Humans have great and exceptional ability to recognize an object in the worst conditions if they have good a-priori information about the objects. In most of the cases, the goal of quality assessment research is to design algorithms for objective evaluation of quality in a way that is consistent with subjective human evaluation [1]. In this work our task is to find out how a-priori information influences the detectability of a target object and in certain conditions even a "bad" looking image can be perceived as a "good" image. By "bad image" we mean less information about the target object and by "good image" we mean that humans can perceive the target object clearly based on the a-priori information about the target object.

Over the years, number of researchers have contributed significant research in designing different algorithms based on the concept of Just Noticeable Difference (JND) which is supposedly the core theoretical concept behind how and when humans starts perceiving the shapes and objects. A lot of experimental studies have been preformed to understand and validate the quality assessment algorithms. There is a lot of experimental work has been done on the memory retention [survey paper. Still there is not enough experimental work has been preformed to understand as how human brain behaves in different conditions and based on the a-priori information humans can perceive the information which is not clearly visible.

A lot of efforts have been made to come with solutions for reduction in x-ray dosage. The main problem with the reduction in x-ray dosage,

the image quality suffers. There are different cases and scenarios where the image quality has its own impact. For example, when analyzing any particular disease or case, it is always important to have a good quality image to avoid any kind of miss diagnosis, where as there are certain scenarios where the poor image quality is acceptable. Now the question comes as how poor quality will be considered as acceptable or unacceptable. For example, when angioplasty procedure is being preformed, and the cardiologist is placing the stunt for removal of the blockage, during the procedure, cardiologist will keep acquiring the fluoroscopic images. The main motivation for such continuous acquisition of fluoroscopic images to keep a track of the guide wire along with the placement of the stunt at the proper position. When analyzing such fluoroscopic images, an interesting observation from these images is, if these images are shown in isolation then it becomes hard to see whether the guide wire is present in certain parts of the image or not. At the same time if these images are shown to a human observer as a sequence of images, then guide wire visibility is perceived for the images where the guide wire was not visible when seen in isolation.

In this experimental work, our main aim is to understand, how human observer perceive the guide wire in fluoroscopic images even if the guide wire is not clearly visible and is buried under different types of noises? The main advantage by performing such an experiment will help is some way defining the acceptability of the poor quality of fluoroscopic images. Such an experiment will also help in understanding the optimum x-ray dose usage while acquiring such fluoroscopic images during the surgical procedure. In this particular scenario, the main objective is to provide an visibility index which will represent the different measures of the image quality preferred by individual doctors. In this whole concept, we are dealing with human perception and humans tend to behave and assess each and everything in their own individual way. Although, coming up with the standards for the usage of x-ray dosage is a much bigger theoretical task, but at least such experiments will be a step forward in validating the theoretical concepts.

8673-5, Session 2

A novel graphical user interface for high-efficacy modeling of human perceptual similarity opinions

James Kress, Boise State Univ. (United States); Songhua Xu, Georgia Tourassi, Oak Ridge National Lab. (United States)

We present a novel graphical user interface (GUI) that facilitates high-efficacy collection of perceptual similarity opinions of a user in an effective and intuitive manner. The GUI is based on a hybrid mechanism that combines ranking and rating. Namely, it presents a base image for rating its similarity to seven peripheral images that are displayed simultaneously following a circular layout. The user is asked to report the base image's pairwise similarity to each peripheral image on a fixed scale while preserving the relative ranking among all peripheral images. The collected data are then used to predict the user's subjective opinions regarding the perceptual similarity of images. We tested this new approach against two methods commonly used in perceptual similarity studies: (1) a ranking method that presents triplets of images for selecting the image pair with the highest internal similarity and (2) a rating method that presents pairs of images for rating their relative similarity on a fixed scale. We aimed to determine which data collection method was the most time efficient and effective for predicting a user's perceptual opinions regarding the similarity of mammographic masses. Our study was conducted with eight individuals. By using the proposed GUI, we were able to derive individual user profiles that were 41.4% to 46.9% more accurate than those derived with the other two data collection GUIs. The accuracy improvement was statistically significant.

8673-6, Session 2

BREAST: a novel method to improve the diagnostic efficacy of mammography

Kriscia A. Tapia, Patrick C. Brennan, Univ. of Sydney (Australia); Warwick B. Lee, BreastScreen NSW (Australia); John Ryan, Ziltron (United States)

High quality breast imaging and accurate image assessment are critical to the early diagnoses, treatment and management of women with cancer. The Breast Screen Reader Assessment Strategy (BREAST) provides a platform accessible by researchers and clinicians world-wide, which will contain image data bases, algorithms to assess reader performance and on-line systems for image evaluation. The BREAST platform will contribute to the diagnostic efficacy of breast imaging in Australia and beyond on two fronts: reducing errors in mammography, and transforming our assessment of novel technologies and techniques.

Mammography is the primary diagnostic tool for detecting breast cancer with over 800,000 women X-rayed each year in Australia, however, it fails to detect 30% of breast cancers, with a number of missed cancers being visible on the image [1-6]. BREAST will monitor the mistakes, identify reasons for mammographic errors and facilitate innovative solutions to reduce error rates.

The BREAST platform has the potential to enable expert assessment of breast imaging innovations, anywhere in the world where experts or innovations are located. Currently, innovations are often being assessed by limited numbers of individuals who happen to be geographically located close to the innovation, resulting in equivocal studies with low statistical power. BREAST will transform this current paradigm by enabling large numbers of experts to assess any new method or technology using our embedded evaluation methods.

We are confident that this world-first system will play an important part in the future and efficacy of breast imaging.

8673-7, Session 2

Perception in screening mammography: Can insertion of obvious cases enhance cancer detection?

Sarah Lewis, Mariusz W. Pietrzyk, Robert Nurthen, Mark F McEntee, The Univ. of Sydney (Australia); Michael G Evanoff, The American Board of Radiology (United States); Warwick B Lee, The Univ. of Sydney (Australia) and Cancer Institute of NSW (Australia); Patrick C. Brennan, Warren M. Reed, The Univ. of Sydney (Australia)

Purpose – To determine whether a strategy of inserting obvious cancers can improve the detection of subsequent abnormal cases screening mammography sets.

Method – Eight experienced breast imaging radiologists were asked to interpret 40 mammography cases in two sittings and localise any malignancies present. Two differing conditions were presented to participants. In Set 1/Condition 1, there were 36 normal images interspersed with 4 abnormal cases determined to be of medium to high difficulty. Set B/Condition 2 differed in that two normal cases were replaced with two new malignant cases determined to be of a low difficulty. These two obvious cases were placed shortly before two of the subtle malignancies. In both sittings, participants were told they were viewing a screening mammography set.

Results –Radiologists performed equally over the two sets with no statistical difference in location sensitivity. There was decreased overall specificity of normal cases in Set B/Condition 2. No correlation was found between reader experience and performance.

Conclusion – Initial findings suggest that the insertion of more easily observed abnormal cases into image sets may have no defined effect on reader performance. With continuing analysis and examination of

participant eye-positions, information regarding the nature of their search may offer some explanation of our findings.

8673-8, Session 2

Is Grandma like a lichen planus? The problem of image perception and knowledge retention in pathology

Claudia R. Mello-Thoms, Elizabeth Legowski, Eugene Tseytlin, Rebecca S. Crowley, Univ. of Pittsburgh (United States)

Medicine is the science of acquiring a lot of obscure knowledge and the art of knowing when to apply it, even if only once in a physician's lifetime. Although medical experts seem to have it all figured out, being significantly better and faster than trainees, many studies have suggested that it is not only the amount of knowledge – which comes with experience – that differentiates the experts, but it is also how the knowledge is structured in memory. To acquire new knowledge, trainees will first encode both 'surface' (i.e., irrelevant) and 'structural' (relevant) features, and repeated presentations of the material will allow for dismissal of the unimportant elements from memory. However, just because knowledge has been encoded it does not mean that it is safely guarded in the physician's memory; as with any information, if it is not tended to, it will slowly decay, and eventually it may be completely forgotten. In this study we investigated knowledge retention in a specific sub-domain of Pathology which is rarely, if ever, used by trainees. We wanted to determine the relationship between the way long-term memory is accessed (i.e., through recognition or recall) and trainee performance. We also sought to determine whether access to long-term memory through either mechanism led to better transfer of newly acquired knowledge to never before seen cases.

8673-9, Session 2

Characterization of human observer detection in 2-AFC volumetric detection tasks

Ivan Diaz, François O. Bochud, Francis R. Verdun, Ctr. Hospitalier Univ. Vaudois (Switzerland); Sabine K. Kobbe-Schmidt, Ctr. Hospitalier Univ. Vaudois (Switzerland)

Model observers applied on 3D images should take into account the speed at which the frames are displayed. We explore the temporal aspects of signal detection in lung CT images with the aid of an EyeLink 1000 eye tracker. From at set of lung CTs sseries of small lung nodules (4-6mm of diameter each) were extracted from positive cases where the nodule was not surrounded by any vessels. Volumetric backgrounds were taken from negative cases. For each set, 21 slices were extracted measuring 128 x 128 pixels. It was not possible to extract volumes without the lung boundary present in one of the slices. Two of the signals were then embedded in the backgrounds and the realism of the final signal-present images was checked by a radiologist. The center of the signal was located in the middle slice, number 10.We performed a series of 3D 2-AFC (Alternative Forced Choice) detection tasks. We studied the way radiologists and naïve observers look through volume sets at three fixed speeds: 5, 14, and 24 frames per second. Since the signal was always located in the middle and the performance was too high in pre-trials, the observers were allowed to see through the volume sets only once. The same experiment was repeated in a free scrolling mode.. We were able to determine a histogram of scrolling speeds in frames per second. The scrolling speed at the moment the signal was detected was estimated at 20 fps. This was higher than that reported by the radiologists.

8673-10, Session 3

The impact of using a JAFROC or ROC approach on the conclusions of a typical observer performance study

Mohammad A. Rawashdeh, The Univ. of Sydney (Australia); Warwick B. Lee, NSW Cancer Institute (Australia); Mariusz W. Pietrzyk, Roger Bourne, Elaine Ryan, Warren M. Reed, Patrick C. Brennan, The Univ. of Sydney (Australia)

Purpose: The current study aims to compare the ROC with the JAFROC method to determine how the choice of available analytical approaches in radiology can impact upon study conclusions. The current paper is part of a larger work looking at the impact of reader characteristics on diagnostic efficacy.

Methods and materials: A total of 129 readers independently reviewed 60 mammographic cases, 20 of which were biopsy proven cases (abnormal) and 40 normal cases. Each case consisted of the four standard caudal-cranial and medial-lateral oblique projections. Readers were asked to interpret and locate any presence of cancer, and levels of confidence were scored on a scale of 1-5. Radiology workstations containing 5MP diagnostic monitors supported with full image manipulation tools were used to display all images. JAFROC and ROC methodologies were employed and figure of merit and Az values respectively were correlated against key reader characteristics such as experience, qualifications, breast reading activities and physical characteristics using Spearman techniques.

Results: Correlation analysis between JAFROC analysis demonstrated that four key characteristics were linked to performance: years of qualification as radiologist (p=0.05, r= 0.18), years reading mammogram (p=0.01, r=0.24), number of mammograms reading per year (p=0.001, r=0.24), and hours reading mammogram per week (p=0.04, r= 0.19). The ROC method indicated that determinants of performance were confined to years reading mammogram (p=0.02, r = 0.2), and number of mammograms reading per year (p=0.04, r=0.23).

Conclusion: This work demonstrates the practical impact on conclusions when different image evaluation methodologies are used. The location sensitivity approach employed and statistical power with JAFROC, would suggest that the findings from this approach should be prioritized.

8673-11, Session 3

One parameter contaminated binormal model (CBM) for analysis of difficult-to-fit ROC data

Kevin S. Berbaum, Kevin M. Schartz, Univ. of Iowa (United States)

Introduction. Perception experiments collecting rating method ROC data sometimes result in operating points at only relatively high specificities for some treatment-reader combinations. In the extreme, no operating points are internal to the feasible space of many parametric models (i.e. for all points, FP = 0). Dorfman & Berbaum (2000) developed a contaminated binormal model (CBM) to account for ROC data that have few false-positive reports even though many healthy subjects are sampled. Unfortunately, CBM can give very different ROC curve shapes for similar ROC points and when there are no internal operating points, the ROC curve shape will often differ substantially from that obtained when there are internal operating points.

Materials and Methods. We eliminate the CBM limiting case by adding a small constant to each cell of the rating data matrix (Agresti, 1990; Dorfman & Berbaum, 1995) and to set μ, the difference between the visible signal and noise distributions, to the same high value for all conditions (Dorfman & Berbaum, 2000).

Results. We illustrate the resulting ROC curves using an example dataset from Schartz et al. (2012). All observed ROC points become internal. The fitted ROC curves are similar to those of the limiting CBM and empirical ROC, but all curves using the same μ have the same shape and never

cross. ROC accuracy parameters such area, partial area, and sensitivity at any fixed specificity correspond perfectly.

Conclusions. Constraining the CBM to a fixed large μ provides a more effective way to apply it to difficult-to-fit data.

8673-12, Session 3

Statistical properties of a utility measure of observer performance compared to area under the ROC curve

Craig K. Abbey, Univ. of California, Santa Barbara (United States); Frank W. Samuelson, Brandon D. Gallas, U.S. Food and Drug Administration (United States); John M. Boone, UC Davis Medical Ctr. (United States); Loren T. Niklason, Hologic, Inc. (United States)

The receiver operating characteristic (ROC) curve has become the standard for evaluating diagnostic imaging technologies, and the primary endpoint of such evaluations is area under the curve (AUC). Because it integrates sensitivity over the entire false positive range, AUC may be influenced by regions of the ROC curve that have little relevance to clinical practice. The expected utility (EU) figure of merit has some known benefits in terms of focusing on the relevant region of the ROC curve as well as resolving crossing or otherwise ambiguous ROC curves.

However if this measure is to be used it must also have desirable statistical properties. In this work we evaluate effect size and variability for EU and AUC. We use two observer performance studies recently submitted to the FDA to compare effect sizes and variability between the EU and AUC endpoints. The studies were conducted using the multi-reader multi-case methodology in which all readers score all cases in all modalities. ROC curves from the study were used to generate both the AUC and EU values for each reader and modality. The EU measure was computed assuming an iso-utility slope of 1.03.

We find mean effect sizes, the reader averaged difference between modalities, to be roughly twice as big for EU as AUC. The standard deviation across readers is roughly 1.5 times as large, suggesting better statistical properties for the EU endpoint. Specifically, relative utility required 40% fewer readers for equivalent power, although this preliminary analysis does not account for case variability.

8673-13, Session 3

The equivalence of a human observer and an 'ideal' observer in binary diagnostic tasks: perception as Bayesian inference through rationality encouragement

Xin He, U.S. Food and Drug Administration (United States); Frank W. Samuelson, U.S. Food and Drug Administration (United States); Brandon D. Gallas, Berkman Sahiner, U.S. Food and Drug Administration (United States); Kyle J. Myers, U.S. Food and Drug Administration (United States)

The Ideal Observer (IO) is "ideal" for a given data population. In the image perception process, as the raw images are degraded by factors such as display and eye optics, there is an equivalent IO (EIO). The EIO uses the statistical information that survives the perception/cognitive degradations as the data. We hypothesize that a human observer behaves as if he is an EIO. To measure the likelihood ratio (LR) distributions of an EIO, we formalize experimental design principles that encourage rationality based on von Neumann and Morgenstern's (vNM) axioms. We present examples to show that many observer study design refinements, although motivated by empirical principles explicitly, implicitly encourage rationality. Our conjecture is supported by a recent review paper on ROC curve convexity by Pesce, Metz, and Berbaum. We also provide additional evidence based on a database of observer performance studies in medical imaging and evidence from neuroscience. EIO theory puts the measurement of observer performance, a non-physical quantity, on the same footing as the measurement of physical quantities by providing a truth model, a measurement model, and a noise model. In addition, EIO theory shows that the "sub-optimal" performance of a human observer can be mathematically formalized in the form of an EIO, and measured through rationality encouragement. EIO theory provides a different perspective to the approach of regarding perception as Bayesian inference.

8673-14, Session 3

A nonparametric approach for statistical comparison of results from alternative forced choice experiments

Frederic Noo, Adam Wunderlich, Dominic Heuscher, Zhicong Yu, Katharina Schmitt, The Univ. of Utah (United States)

Task-based image quality assessment is a valuable methodology for development, optimization and evaluation of new image formation processes in x-ray computed tomography (CT). A simple way to perform such an assessment is through the use of two (or more) alternative forced choice (AFC) experiments. In this paper, we are interested in drawing statistical inference from outcomes of multiple AFC experiments that are obtained using multiple readers as well as multiple cases. We present a non-parametric covariance estimator for this problem. Then, we illustrate its usefulness with a practical example involving x-ray CT simulations. The task for this example is classification between presence or absence of one lesion with unknown location within a given object.

8673-15, Session 4

Two complementary model observers to evaluate reconstructions of simulated micro-calcifications in digital breast tomosynthesis

Koen Michielsen, Katholieke Univ. Leuven (Belgium); Federica Zanca, Nicholas W. Marshall, Hilde Bosmans, UZ Leuven (Belgium); Johan Nuyts, Katholieke Univ. Leuven (Belgium)

New imaging modalities need to be properly evaluated before being introduced in clinical practice. The gold standard is to perform an observer experiment with experienced readers. Unfortunately this is not feasible during development or optimization of new reconstruction algorithms due to their many degrees of freedom.

Our goal is to design a set of model observers to evaluate the performance of newly developed reconstruction methods on visualization of micro-calcifications in digital breast tomosynthesis. The model observers need to evaluate both detection and classification of micro-calcifications. A channelized Hotelling observer was created for the detection task and a Hotelling observer working on an extracted feature vector was implemented for the classification task. These observers were evaluated on their ability to predict the results of human observers.

Results from a previous observer study were used as reference to compare performance between human and model observers. This study evaluated detection of small micro-calcifications (100 – 200 μm) by a free search task in a power law filtered noise background and classification of two types of larger micro-calcifications (200 – 600 μm) in the same background. Scores from the free search study were evaluated using the weighted JAFROC method and the classification scores were analyzed using the DBM MRMC method. The same analysis methods were applied to the model observer scores.

Results of the detection model observer were related linearly with the human observer results with a correlation coefficient of 0.962. The correlation coefficient for the classification task was 0.959 with a power law non-linear regression.

8673-16, Session 4

Integration of spatio-temporal contrast sensitivity with a multislice channelized Hotelling observer

Ali Avanaki, Kathryn Espig, Barco, Inc. (United States); Cédric Marchessoux, Barco N.V. (Belgium); Elizabeth A. Krupinski, The Univ. of Arizona (United States); Predrag R. Bakic, The Univ. of Pennsylvania Health System (United States); Tom Kimpe, Barco N.V. (Belgium); Andrew Maidment, University of Pennsylvania (United States)

Barten's model of spatio-temporal contrast sensitivity function of human visual system is embedded in a multi-slice channelized Hotelling observer. This is done by 3D filtering of the stack of images with the spatio-temporal contrast sensitivity function and feeding the result (i.e., the perceived image stack) to the multi-slice channelized Hotelling observer. The proposed procedure of considering spatio-temporal contrast sensitivity function is generic in the sense that it can be used with observers other than multi-slice channelized Hotelling observer. Detection performance of the new observer in digital breast tomosynthesis is measured in a variety of browsing speeds, at two spatial sampling rates, using computer simulations. Our results show a peak in detection performance in mid browsing speeds. We compare our results to those of a human observer study reported earlier (I. Diaz et al. SPIE MI 2011). The effects of display luminance, contrast and spatial sampling rate, with and without considering foveal vision, are also studied. Reported simulations are conducted with real digital breast tomosynthesis image stacks, as well as stacks from an anthropomorphic software breast phantom (P. Bakic et al. Med Phys. 2011). Lesion cases are simulated by inserting single micro-calcifications or masses. Limitations of our methods and ways to improve them are discussed.

8673-17, Session 4

Exact confidence intervals for channelized Hotelling observer performance

Adam Wunderlich, Frederic Noo, Marta Heilbrun, The Univ. of Utah (United States)

Task-based assessments of image quality constitute a rigorous, principled approach to the evaluation of imaging system performance. To conduct such assessments, it has been recognized that mathematical model observers are very useful, particularly for purposes of imaging system development and optimization. One type of model observer that has been widely applied in the medical imaging community is the channelized Hotelling observer (CHO). In the present work, we address the need for reliable confidence interval estimators of CHO performance. Specifically, we observe that a procedure proposed by Reiser for interval estimation of the Mahalanobis distance can be applied to obtain confidence intervals for CHO performance. In addition, we find that these intervals are always well-defined with theoretically-exact coverage probabilities, which is a new result not proved by Reiser. The confidence intervals are tested with Monte Carlo simulation and demonstrated with an example comparing x-ray CT reconstruction strategies.

8673-18, Session 4

Objectively measuring signal detectability, contrast, blur and noise in medical images using channelized joint observers

Bart Goossens, Hiep Luong, Univ. Gent (Belgium); Ljiljana Plati?a, Univ. Gent (Belgium); Wilfried Philips, Univ. Gent (Belgium)

To improve imaging systems and image processing techniques, objective image quality assessment is essential. Model observers adopting a task-based quality assessment strategy by estimating signal detectability measures, have shown to be quite successful to this end. At the same time, costly and time-consuming human observer experiments can be avoided. However, optimizing images in terms of signal detectability alone, still allows a lot of freedom in terms of the imaging parameters. More specifically, fixing the signal detectability defines a manifold in the imaging parameter space on which different "possible" solutions reside. In this article, we present measures that can be used to distinguish these possible solutions from each other, in terms of image quality factors such as signal blur, noise and signal contrast. Our approach is based on an extended channelized joint observer (CJO) that simultaneously estimates the signal amplitude, scale and detectability. As an application, we use this technique to design k-space trajectories for MRI acquisition. Our technique allows to compare the different spiral trajectories in terms of blur, noise and contrast, even when the signal detectability is estimated to be equal.

8673-19, Session 4

Model Mismatch and the Ideal Observer in SPECT

Michael Ghaly, Jonathan M. Links, Yong Du, Eric C. Frey, Johns Hopkins Univ. (United States)

SPECT acquisition parameters can be optimized using the Ideal Observer (IO) applied to projections. The IO implicitly has perfect knowledge of the image formation process, and thus its performance reflects the best achievable with perfect compensation. However, SPECT images are often reconstructed with imperfect or no compensation. This mismatch between the reconstruction and IO can give rise to suboptimal performance when human observers interpret SPECT images.

In this study, we investigated the importance of including 'model mismatch' (MM) in the IO in the context of myocardial perfusion SPECT for a signal known exactly/background known statistically (SKE/BKS) task. We optimized the energy window using the IO with and without MM.

We evaluated IO performance when the observer had (1) a perfect and (2) no or (3) an approximate analytic model of scatter. We used an anthropomorphic observer (AO) as a benchmark for human observer performance and compared optimal energy windows. IO performance was relatively insensitive to energy window settings for case 1. Performance for case 2 was significantly worse than for 1, and the optimal window width was 13%. For case 3, performance was similar to case 1. Performance for the AO was similar to cases 2 and 3 when scatter compensation was or was not, respectively, included in the reconstruction.

Incorporating MM into the IO is a new approach for improving agreement of the IO with human observers. This allows optimization of acquisition and instrumentation parameters in the presence of non-ideal compensation methods more efficiently than reconstructed-image-domain AOs.

8673-20, Session 4

Tests of a 3D visual-search model observer for SPECT

Howard C. Gifford, Univ. of Houston (United States)

Observer studies with single 2D images can bias assessments of diagnostic technologies, as physicians usually have access to an entire image volume presented as multiple slices in multiple views. Previously, we introduced a scanning model observer for detection-localization tasks with multislice-multiview (or volumetric) display, but comparisons against human data were disappointing. The current work continues our investigation with tests of a 3D visual-search (VS) model observer. The VS framework amounts to an initial holistic search that identifies suspicious locations for analysis by a statistical observer. Our VS model uses a scanning observer for the analysis. The VS model was evaluated

against the scanning and human observers in a localization ROC study of mass detection in SPECT lung imaging. The study compared two iterative reconstruction strategies that applied different combinations of corrections for attenuation, scatter, and distance-dependent system resolution. In our earlier work, the scanning and human observers ranked the strategies in opposite order of performance. The ranking from the VS observer matched that of the humans.

8673-21, Session 5

Identification of depth information with stereoscopic mammography using different display methods

Takamitsu Morikawa, Yoshie Kodera, Nagoya Univ. School of Medicine (Japan)

With the advance of digital imaging, novel breast imaging technology such as stereomammography and breast tomosynthesis have been developed. As stated above, the benefits of stereoscopic imaging have been attracted attention again, so we expect three-dimensional (3D) monitors would come into medical field for viewing these imaging stereoscopically. However the quantitative and sufficient evaluation of three-dimensional monitors has not done yet. Therefore, we evaluated capacity to identify the depth information with stereoscopic mammography comparing using 3D monitor to viewing with naked-eye stereoscopic method.

Acryl steps (1-10mm / 10 steps) with pillars arranged on the top and under the bottom of each step that were used as a phantom and we exposed at some different angles (1°/4°/7°/10° from normal line) on the left and right.

We got observers to view stereoscopically these imaging under two different display methods, naked-eye method and using 3D monitor method, and answer the direction of pillar which they could feel at the top. We calculated the percentage of correct answers (PCAs) from their responses.

The results (PCAs of each angles) showed PCAs rise from 1 to 7 degrees and down from 7 to 10 degrees. PCAs of 7 degree got the highest PCAs under both of display method. All PCAs accomplished getting more than 85% in all situations (4 angles ? 2 methods).

We found that using 3D monitor method have more capacity to identify the depth information than naked-eye method.

8673-22, Session 5

Assessment of visual-spatial skills in medical context tasks when using monoscopic and stereoscopic visualization

Marisol Martinez-Escobar, Iowa State Univ. (United States); Bethany Juhnke, Iowa State University (United States); Kenneth Hisley, Touro University (United States); Eliot Winer, Iowa State Univ. (United States); David Eliot, Touro University (United States)

With increasing medical procedures utilizing cameras, such as minimally invasive surgery, it is critical to understand how people complete spatial tasks under different visual conditions. This paper details a study performed to isolate the benefits between monoscopic and stereoscopic displays while conducting a spatial task inside of a 3D medical volume. The participants were 35 medical school students who had at least one year of gross anatomy classes completed. The study consisted of a pre-survey, a set of visual-spatial baseline tests, and ended with a set of relative position judgment tasks within a medical volume. The pre-survey and baseline tests were used to identify a participant's skills for correlation with their results. For example, does a correlation exist between video game playing and correctly completing the tasks? The spatial tasks consisted of three colored cylinders (red, green, blue) placed at varying distances apart inside a 3D medical volume representation. By changing the view orientation, a total of 40 tasks were generated where each participant had to assess whether the blue or green cylinder was closest to the red. The participants were randomly assigned to either a monoscopic or stereoscopic display. The time taken for each task was recorded and the selections were marked as correct, incorrect, or skipped. The stereoscopic group performed better in 17 out of the 35 tasks with six of these cases showing statistical significance.

8673-23, Session 5

Effect of image processing on detection of non-calcification cancers in 2D digital mammography imaging

Lucy M. Warren, The Royal Surrey County Hospital NHS Trust (United Kingdom) and Univ. of Surrey (United Kingdom); Julie Cooke, Jarvis Breast Screening and Diagnostic Ctr. (United Kingdom); Rosalind Given-Wilson, St. George's Healthcare NHS Trust (United Kingdom); Matthew G. Wallis, Cambridge Breast Unit (United Kingdom) and NIHR Cambridge Biomedical Research Ctr. (United Kingdom); Mark Halling-Brown, Alistair Mackenzie, The Royal Surrey County Hospital NHS Trust (United Kingdom); Dev P. Chakraborty, Univ. of Pittsburgh (United Kingdom); Hilde Bosmans, Univ. Hospitals Leuven (Belgium); David R. Dance, Kenneth C. Young, The Royal Surrey County Hospital NHS Trust (United Kingdom) and Univ. of Surrey (United Kingdom)

Image processing (IP) is the last step in the digital mammography imaging chain before diagnosis by a radiologist. Each manufacturer has their own IP algorithm(s) and the appearance of an image after IP can vary greatly depending upon the algorithm and version used. It is unclear whether these differences in visualisation affect cancer detection. This work investigates the effect of IP on the visibility and characterisation of non-calcification cancers by performing an observer study. Digital mammography images for 270 patients were collected from two screening centres using Hologic amorphous selenium detectors. Eighty of these cases contained non-calcification cancers. The images were processed using three versions of IP from Hologic - default, screen-film and low contrast. Four experienced observers inspected the images and marked the location of regions suspected to be non-calcification cancers, assigning scores for visibility and likelihood of malignancy. These lesion specific data were analysed using JAFROC analysis. The observers also scored the clinical interpretation of the entire case using the RCRBG classification scale. This was analysed using ROC analysis. IP did not have a significant effect on the radiologists judgement of the likelihood of malignancy of individual lesions ($p>0.05$). However, the visibility of non-calcification cancers was judged to be significantly higher with the default version when compared to the screen-film version ($p=0.01$) and the low contrast version ($p=0.005$). The clinical interpretation of the entire case was also significantly higher for default compared with low contrast version ($p=0.005$). It is possible that patient outcome could be affected by IP.

8673-24, Session 5

Can technical characteristics predict clinical performance in PET/CT imaging? A correlation study for thyroid cancer diagnosis

Maria Kallergi, Dimitrios Menychtas, Technological Educational Institute of Athens (Greece); Alexandros Georgakopoulos, Nikoletta Pianou, Marinos Metaxas, Biomedical Research Foundation of the Academy of Athens (Greece); Sofia Chatziioannou, National and Kapodistrian Univ. of Athens, Medical School (Greece)

PURPOSE: The purpose of this study was to determine whether technical characteristics could be used to predict the outcome of ROC studies in PET/CT imaging.

MATERIAL & METHODS: Patients suspected for recurrent thyroid cancer underwent a standard whole body (WB) examination and an additional high-resolution head-and-neck (HN) F18-FDG PET/CT scan. The value of the latter was determined with an ROC study, the results of which showed that the WB+HN combination was better than WB alone for thyroid cancer diagnosis. The technical characteristics of the two image sets were determined by measuring lesion diameter, area, and volume, histograms, minimum, maximum, and average gray values, tumor margins and contrast, and standard uptake values. Bivariate correlation and linear regression analysis was used to correlate features between scans and explore the relationship between ROC responses and image feature values.

RESULTS: The analysis of the images seems to support the clinical findings. The values of all parameters were significantly different between the WB and HN scans with low correlation coefficients, $\leq$0.3, in almost all data pairs. The regression coefficients of determination ranged from 0.60-0.85 suggesting that the predictive value of the HN image features could be significant and, more importantly, visually deciphered.

CONCLUSIONS: ROC studies are widely recognized as the method of choice for evaluating new imaging procedures and clinical protocols. They pose, however, major time and cost constraints. Our study provides initial evidence that clinical performance under new PET/CT imaging protocols could be predicted by image characteristics alone.

8673-25, Session 5

Enhancing reproducibility of ultrasonic measurements by new users

Manojit Pramanik, Indian Institute of Science (India); Madhumita Gupta, GE Healthcare (India); Kajoli B. Krishnan, GE Global Research (India)

Perception of operator influences ultrasound image acquisition and processing. Lower costs are attracting new users to medical ultrasound. Anticipating an increase in this trend, we conducted a study to quantify the variability in ultrasonic measurements made by novice users and identify methods to reduce it. We designed a protocol with four presets and trained four new users to scan and manually measure the head circumference of a fetal phantom with an ultrasound scanner. In the first phase, the users followed this protocol in seven distinct sessions. They then received feedback on the quality of the scans from an expert. In the second phase, two of the users repeated the entire protocol aided by visual cues provided to them during scanning. We performed off-line measurements on all the images using a fully automated algorithm capable of measuring the head circumference from fetal phantom images. The ground truth (198.1±1.6 mm) was based on sixteen scans and measurements made by an expert. Our analysis shows that: (1) the inter-observer variability of manual measurements was 5.5 mm, whereas the inter-observer variability of automated measurements was only 0.6 mm in the first phase (2) consistency of image appearance improved and mean manual measurements was 4-5 mm closer to the ground truth in the second phase (3) automated measurements were more precise, accurate and less sensitive to different presets compared to manual measurements in both phases. Our results show that visual aids and automation can bring more reproducibility to ultrasonic measurements made by new users.

8673-26, Session 6

Test set readings predict clinical performance to a limited extent: preliminary findings

BaoLin Pauline Soh, The Univ. of Sydney (Australia); Warwick B. Lee, BreastScreen NSW (Australia); Peter L. Kench, Warren M. Reed, Mark F. McEntee, Patrick C. Brennan, The Univ. of Sydney (Australia)

Aim: To investigate the level of agreement between laboratory screen read test sets and actual clinical reading

Background: Standardised mammographic screen read test sets are currently used to describe the performance of screen readers in detecting breast cancer. Previous studies have provided little evidence that performance as assessed by test sets are strongly correlated to performance in clinical reading.

Methods: Five clinicians from BreastScreen New South Wales participated in this study. Each clinician was asked to read 200 de-identified reader-specific mammographic examinations gathered from the BreastScreen NSW Digital Imaging Library. All test sets were designed with specific numbers of true positive, true negative, false positive and false negative examinations from the previous clinical reads specific to each reader. A prior mammogram examination for comparison (when available) was provided for each case.

Results: Preliminary analyses have shown that there is a moderate level of agreement (Kappa between 0.424 to 0.556, $p<0.001$) between laboratory test sets and clinical reading. In addition, a mean increase of 38% in sensitivity in the laboratory test sets as compared to their actual clinical readings was demonstrated along with specificity which appears to be on average similar between the two settings. Further results will be presented at the meeting.

Conclusion: This study demonstrate a moderate level of agreement between actual clinical reading and test set reading, which suggests that test sets have reflected clinical performance to a certain extent.

8673-27, Session 6

A comparison of image interpretation times in full field digital mammography and digital breast tomosynthesis

Susan M. Astley, Sophie J. Connor, The Univ. of Manchester (United Kingdom); Yit Yoong Lim, Univ. Hospital of South Manchester (United Kingdom); Catriona Tate, The Univ. of Manchester (United Kingdom); Helen Entwistle, Univ. Hospital of South Manchester (United Kingdom); Julie Morris, Sigrid Whiteside, Jamie Sergeant, The Univ. of Manchester (United Kingdom); Mary Wilson, Ursula Beetles, Caroline Boggis, Univ. Hospital of South Manchester (United Kingdom); Fiona J. Gilbert, Univ. of Cambridge (United Kingdom)

Purpose: Digital Breast Tomosynthesis (DBT) provides three-dimensional images of the breast that enable radiologists to discern whether densities are due to overlapping structures or lesions. To aid assessment of the cost-effectiveness of DBT for screening, we have compared the time taken to interpret DBT images and the corresponding two-dimensional Full Field Digital Mammography (FFDM) images.

Method: Four Consultant Radiologists experienced in reading FFDM images (4 years 8 months to 8 years) with training in DBT interpretation but more limited experience (137-407 cases in the past 6 months) were timed reading between 24 and 32 two view FFDM and DBT cases. The images were of women recalled from screening for further assessment and women under surveillance because of a family history of breast cancer. FFDM images were read before DBT, according to local practice.

Results: The median time for readers to interpret FFDM images was 17.0 seconds, with an interquartile range of 12.3-23.6 seconds. For DBT, the median time was 66.0 seconds, and the interquartile range was 51.1-80.5 seconds. The difference was statistically significant ($p<0.001$). Reading times were significantly longer in family history clinics ($p<0.01$).

Conclusions: Although it took approximately four times as long to interpret DBT than FFDM images, the cases were more complex than would be expected for routine screening, and with higher mammographic density. The readers were relatively inexperienced in DBT interpretation and may increase their speed over time. The difference in times between clinics may be due to increased throughput in assessment clinics, or decreased density.

8673-28, Session 6

Same task, same observers, different values: the problem with visual assessment of breast density

Jamie Sergeant, Lani Walshaw, The Univ. of Manchester (United Kingdom); Mary Wilson, Univ. Hospital of South Manchester (United Kingdom); Sita Steed, The Univ. of Manchester (United Kingdom); Nicky Barr, Ursula Beetles, Caroline Boggis, Sara Bundred, Soujanya Gadde, Yit Yoong Lim, Sigrid Whiteside, Gareth Evans, Anthony Howell, Univ. Hospital of South Manchester (United Kingdom); Susan M. Astley, The Univ. of Manchester (United Kingdom)

Purpose: The proportion of radio-opaque fibroglandular tissue in a mammographic image of the breast is a strong and modifiable risk factor for breast cancer. Subjective, area-based estimates made by expert observers provide a simple and efficient way of measuring breast density within a screening programme, but the degree of variability may render the reliable identification of women at increased risk impossible. This study examines the repeatability of visual assessment of percent breast density by expert observers.

Methods: Six consultant radiologists and one breast physician, all with at least two years' experience in mammographic density assessment, were presented with 100 digital mammogram cases for which they had estimated density at least 12 months previously. Estimates of percent density were made for each mammographic view and recorded on a printed visual analogue scale. The level of agreement between the two sets of estimates was assessed graphically using Bland-Altman plots.

Results: All but one observer had a mean difference of less than 6 percentage points, while the largest mean difference was 14.66 percentage points. The narrowest 95% limits of agreement for the differences were -2.46 to 17.02 and the widest were -14.50 to 40.98.

Conclusions: Although visual assessment of breast density has been shown to be strongly associated with cancer risk, the lack of agreement shown here between repeat assessments of the same images by the same observers questions the reliability of using visual assessment to identify women at high risk or to detect moderate changes in breast density over time.

8673-29, Session 6

The impact of mammographic density and lesion location on detection

Dana Al Mousa, Elaine Ryan, The Univ. of Sydney (Australia); Warwick B. Lee, BreastScreen NSW (Australia); Carolyn Nickson, The Univ. of Melbourne (Australia); Mariusz W. Pietrzyk, Warren M. Reed, Ann Poulos, Yanpeng Li, Patrick C. Brennan, The Univ. of Sydney (Australia)

The aim of this study is to examine the impact of breast density and lesion location on detection. A set of 55 mammographic images (23 abnormal images with 26 lesions and 32 normal images) were examined by 22 expert radiologists. The images were classified by an expert radiologist according to the Royal Australian and New Zealand College of Radiologists (RANZCR) breast density classification to low density (D1: 0-25% glandular and D2: 25-50% glandular) and high density (D3: 50-75% glandular and D4: 75-100% glandular), as well as by a semi-automated thresholding (Cumulus) method. The observers freely examined the images and located any malignancy using a 5-point confidence. Performance was defined using the following metrics: sensitivity, location sensitivity, specificity, receiver operating characteristic (ROC Az) curves and jackknife free-response receiver operator characteristics (JAFROC) figures of merit. Significant increases in sensitivity (p= 0.0174) and ROC (p=0.0001) values were noted for the higher density compared with lower density images according to RANZCR classification. Using the Cumulus method, specificity (p=0.0001), ROC (p<0.0001) and JAFROC (p=0.0014) scores were higher in the high compared with low density images. No differences were seen in radiologists' performance between lesions within or outside the fibroglandular region. In conclusion, analysis of our data suggests that radiologists performed better in higher density breasts without any improvement in lesion localisation. Lesion location whether within or outside the fibroglandular region appeared to have no impact on detection abilities suggesting that if a masking effect is present the impact is minimal. Eye-tracking analyses are ongoing.

8673-30, Session 6

Does routine breast screening practice over-ride display quality in reporting enriched test sets?

Alastair G. Gale, Yan Chen, Loughborough Univ. (United Kingdom); Michael G. Evanoff, The American Board of Radiology (United States)

The performance of a group of 16 American breast screening radiologists in interpreting a number of cases from a recent PERFORMS self -assessment case set which had been carefully selected to exclude small calcifications, using sub-mammographic resolution displays, as compared to a UK group using mammographic displays has previously been reported. It was found that the UK group performed better, detecting more cancers with the Americans recalling less. These results were interpreted as due to differences in the displays employed by each group as well as routine screening differences between the two countries. This study extended that work with 12of these experienced American breast screening radiologists interpreting 20 PERFORMS mammographic cases using a suitable mammographic workstation. The PERFORMS cases were selected so as to show a range of normal, benign and abnormal appearances. Data from these radiologists were compared to their earlier performance on different displays. Their data were also compared to that of UK radiologists reading the same cases on clinical workstations. Data are still being analysed but indications are that overall the American group identified as many cancers as the UK participants did but still recalled more cases. The previously reported differences between the two groups were again largely found reflecting differences in screening practices and not due to differences in display quality.

8673-31, Session 6

Difficulty of mammographic cases in the context of resident training: preliminary experimental data

Maciej A. Mazurowski, Duke Univ. (United States)

We are currently developing an intelligent data-driven educational system for mammography. Since our system attempts to predict which cases will be difficult to the trainees, it is important to better understand the concept of case difficulty. While the concept of difficulty is central to our efforts on adaptive education, it is also an important concept in radiology education in general as well as image perception research. In in this study, we tested some, we believe important, hypotheses that relate to difficulty. Specifically, we performed a reader study to evaluate relationship between the error rate (which could be considered a more objective measure of difficulty), individual assessment of case difficulty by a resident and expert's assessment of case difficulty (subjective measures of difficulty). Furthermore, we investigated the relationship between individual and expert's assessment of difficulty and time that the residents took to interpret the case. The analysis of the results showed that the individual assessment of difficulty made by a resident relates well to the rate of false positives errors but not to the rate of false negative errors. Interestingly, the expert's assessment of difficulty predicted the rate of false negative errors but not the false positive errors. Time taken to interpret a case by a resident related well to the individual assessment

of difficulty but not to the expert's assessment of difficulty. These interesting results offer additional guidance in our efforts to construct an adaptive education system as well as provide insight into important aspects of radiology education in general.

8673-32, Session 7

Analysis of individual variability and habituation in stereoscopic radiography

Yasuko Y. Unno, Takao Kuwabara, FUJIFILM Corp. (Japan); Nobutaka Natsui, Kazuo Ishikawa, Tokyo Polytechnic Univ. (Japan)

From previous research, stereoscopic (3D) radiographs are easier to identify target objects than two dimensional (2D) radiographs, however, it is found out that the visual and mental fatigues is equivalent. It has been reported that some percent of people have difficulty in viewing stereoscopic images and no sufficient analysis has been implemented. Hence, the personal variability for easiness of stereoscope vision was demonstrated and the habituation for the stereoscope vision was studied in this research.

Simulated images containing calcifications were prepared at the parallactic angles between ± 2 and 15 degrees and the heights of the object from 40 to 80mm, and the images were displayed on stereoscopic 3D display. Seven readers judged the ability of the stereoscope vision on each calcifications, and the response rates were measured. Stereoscopic cursor was pointed at a space of 3D for the calcifications, and the accuracy rates of the depth pointing were evaluated. Subsequently, there-examination was implemented after the training on 3D visual training system for 15 to 20 minutes a day for 2 weeks and the response and the accuracy rates were measured.

It was approved that there were individual differences in the response rates. Moreover, the parallactic angles of the visible stereoscopic vision widened through training and the response rates were improved. Furthermore, the accuracy rates were improved. As the result, it was suggested that a reader who was weak in looking at stereoscopic vision could be trained to be a better at stereoscopic viewing.

8673-33, Session 7

Impact of bone suppression imaging improves on the detection of lung nodules in chest radiographs: analysis of multiple reading sessions.

Steven Schalekamp, Bram van Ginneken, Radboud Univ. Nijmegen Medical Ctr. (Netherlands); Cornelia M. Schaefer-Prokop, Radboud Univ. Nijmegen Medical Ctr. (Netherlands) and Meander Medisch Centrum (Netherlands); Nico Karssemeijer, Radboud Univ. Nijmegen Medical Ctr. (Netherlands)

Lung cancer is frequently overlooked in chest radiographs (CXR), often caused by overprojection of bone structures in the image. Bone suppression imaging (BSI) techniques could improve detection and interpretation of lung nodules. We investigated the effect of a new software product (Clearread BSI 2.4, Riverain Medical Group, Miamisburg, Ohio) that suppresses ribs and clavicles, on the detection of lung nodules. Eight observers, including five radiologists and three residents assessed radiographs of 111 patients with a CT proven solitary nodule and 189 controls. In a fully crossed study design observers assessed first radiographs without and with BSI sequentially. Secondly they scored radiographs independently having BSI available from the beginning. Five months later, the same readers scored the same cases again in an independent reading session, completing the three scorings for CXRs with BSI. Multi reader multi case (MRMC) receiver operating characteristics (ROC) were used for statistical analysis. DBM variance component estimates were calculated. Reading times were digitally recorded. Observer achieved a mean area under the curve (AUC) for unaided reading of 0.855. AUC increased to 0.883(p=0.002) with BSI in the sequential reading mode and to 0.874 (p=0.21) in the independent reading mode. In the second independent reading session after five months the AUC was 0.882 (p=0.20). Median reading times were 19s per case for the unaided CXR with another 10s for reading BSI sequentially. For the independent modes reading times were 19s and 18s. Total observer variance between sequential and independent reading design remained the same. A strong increase of uncorrelated components was found in the independent reading sessions, masking the ability to demonstrate differences in observer performance across modalities. In conclusion, bone suppression imaging improves lung nodule detection in CXR and does not prolong reading time. The independent study design has little power compared to the sequential study design due to a strong increase of uncorrelated variance components.

8673-34, Session 7

A preliminary comparison of different methods for human reader performance estimation

Francesc Massanes, Jovan G. Brankov, Illinois Institute of Technology (United States)

In this paper we compare different techniques to estimate the area under the receiver operation characteristic curve (AUC). AUC is accepted as a standard for human observer performance quality metrics in for a lesion detection task. We use five different The AUC is accepted as a standard for human observer performance quality metrics in for a lesion detection task. We use five different AUC estimation techniques, widely used in the literature, which include parametric and non-parametric methods. We compared each method by equivalence hypothesis testing using two data sets from a previously published human observer study. The first dataset is a multi-level detection task and the second dataset is a binary detection task, both in a signal-known-exactly paradigm. The preliminary results show that these methods cannot be differentiated if a small data set is used due to estimates large variance. For a larger dataset, these methods do not converge to the same values.

8673-35, Session 7

The variation of radiologists' performance over the course of a reading session

Markus Elze, Sian Taylor-Phillips, The Univ. of Warwick (United Kingdom); Claudia R. Mello-Thoms, Univ. of Pittsburgh (United States); Elizabeth A. Krupinski, The Univ. of Arizona (United States); Alastair G. Gale, Loughborough Univ. (United Kingdom); Aileen Clarke, The Univ. of Warwick (United Kingdom)

The radiologist's task of reviewing many cases successively is highly repetitive and requires a high level of concentration. Fatigue effects have, for example, been shown in studies comparing performance at different times of day. However, changes of performance during an individual reading session have, to our knowledge, not yet been investigated. During a reading session, the radiologist's performance may be affected by both fatigue and training effects. In this paper, we reanalyse 5 studies for changes in radiologist performance during a reading session. Studies feature 8-22 radiologists reading (assessing) 50-162 cases. As the studies were not designed for this analysis, study setups range from bone fractures to mammograms and randomisation varies between studies. Thus, they are analysed separately using mixed-effects models. There is some indication that, as time goes on, the performance for normal (non-malignant) cases increases (shown with $p<0.05$ for 2 out of 6 studies) while the performance for abnormal (malignant) cases decreases (shown with $p<0.05$ for 3 out of 6 studies). The difficulty of malignant and non-malignant cases typically differs (shown with $p<0.05$ for 4 out of 6 studies) and the experience of the reader may also be a significant factor (shown with $p<0.05$ for 2 out of 6 studies). These results suggest that

careful planning of breaks and session length may help optimise reader performance. Note that the overall results are still inconclusive and a targeted study to investigate fatigue and training effects within a reading session is recommended.

8673-36, Session 7

Investigating the feasibility of using partial least squares as a method of extracting salient information for the evaluation of digital breast tomosynthesis

George Zhang, U.S. Food and Drug Administration (United States) and Univ. of California, Berkeley (United States); Kyle J. Myers, Subok Park, U.S. Food and Drug Administration (United States)

Digital breast tomosynthesis (DBT) has shown promise for improving the detection of breast cancer, but it has not yet been fully optimized due to a large space of system parameters to explore. A task-based statistical approach is a rigorous method for evaluating and optimizing this promising imaging technique with the use of optimal observers such as the Hotelling observer (HO). However, high data dimensionality found in DBT has been the bottleneck for the use of the task-based approach in DBT evaluation. To reduce data dimensionality while extracting salient information for performing the given task, efficient channels have to be used for the HO. In the past few years, 2D Laguerre-Gauss (LG) channels, which are a complete basis for stationary backgrounds and rotationally symmetric signals, have been adopted for DBT evaluation. But since background and signal statistics from DBT data are neither stationary nor rotationally symmetric, LG channels may not be efficient in providing reliable performance trends as a function of system parameters. Recently, partial least squares (PLS) have been shown to generate efficient channels for the Hotelling observer in detection tasks involving random backgrounds and signals. In this study, we investigate the use of PLS as a method for extracting salient information from DBT in order to better evaluate the system.

8673-37, Session 7

Quantitative anatomical labeling of the anterior abdominal wall

Wade M. Allen, Zhoubing Xu, Andrew J. Asman, Benjamin K. Poulose, Bennett A. Landman, Vanderbilt Univ. (United States)

Ventral hernias (VHs) are abnormal openings in the anterior abdominal wall that are common side effects of surgical intervention. Repair of VHs is the most commonly performed procedure by general surgeons worldwide, but VH repair outcomes are not particularly encouraging (with recurrence rates up to 43%). A variety of open and laparoscopic techniques are available for hernia repair, and the specific technique used is ultimately driven by surgeon preference and experience. Despite routine acquisition of computed tomography (CT) for VH patients, little quantitative information is available on which to guide selection of a particular approach and/or optimize patient-specific treatment. From anecdotal interviews, the success of VH repair procedures correlates with hernia size, location, and involvement of secondary structures. Herein, we propose an image labeling protocol to segment the anterior abdominal area to provide a geometric basis with which to derive biomarkers and evaluate treatment efficacy. Based on routine clinical CT data, we are able to identify inner and outer surfaces of the abdominal walls and the herniated volume. This is the first formal presentation of a protocol to quantify these structures on abdominal CT. The intra- and inter rater reproducibilities of this protocol are evaluated on 4 patients with suspected VH (3 patients were ultimately diagnosed with VH while 1 was not). Mean surfaces distances of less than 2mm were achieved for all structures.

8673-38, Session 7

Observer performance in semi-automated microbleed detection

Hugo J. Kuijf, Manon Brundel, Jeroen de Bresser, Max A. Viergever, Geert Jan Biessels, Univ. Medical Ctr. Utrecht (Netherlands); Mirjam I Geerlings, University Medical Center Utrecht (Netherlands); Koen L. Vincken, Univ. Medical Ctr. Utrecht (Netherlands)

Cerebral microbleeds are small bleedings in the human brain and are associated with various vascular diseases and dementia. The number of studies involving microbleed detection is increasing rapidly. However, manual detection is a time-consuming process, especially at high-resolution 7.0T MR images, has limited reproducibility and is highly observer dependent. Recently, multiple techniques have been published for the semi-automated detection of microbleeds, attempting to overcome these problems.

In the present study, a 7.0T dual-echo gradient echo MR image was acquired in 18 participants with microbleeds. Two experienced observers identified 54 microbleeds in the participants, using a validated visual rating scale.

The radial symmetry transform (RST) is a technique for semi-automated detection of microbleeds in 7.0T MR images. The results of the RST have been assessed by two observers and 47 microbleeds were identified: 35 true positives and 12 extra positives (microbleeds that were missed during visual rating). A total number of 66 microbleeds was present in the 18 participants.

The use of the RST increased the sensitivity of individual observers from 51% and 67% to 70% and 67%. More importantly, inter-rater agreement (ICC and Dice's coefficient) increased from 0.85 and 0.64 to 0.98 and 0.96, respectively. Furthermore, the required rating time was reduced from 30 to 2 minutes per participant. By fine-tuning the RST, sensitivities up to 90% can be achieved, at the cost of extra false positives.

8673-39, Session PSMon

An investigation of the relationship between ambient lighting and image manipulation behavior

Shun Ming Lee, Rachel J. Toomey, Louise A. Rainford, Univ. College Dublin (Ireland); John Ryan, Ziltron (United States)

Purpose: This study examines the relationship between ambient lighting level and image manipulation. Method: Academic radiographers (n=10), with experience in observer performance studies, each assessed 70 postero-anterior projection radiographs of the wrist / scaphoid in both low (12.5 lux) and high (150 lux) ambient lighting. Half of the images featured one or more acute fractures and the remainder did not. Observers were encouraged to window the images to a level they felt was appropriate and, requested to rate their confidence that an acute fracture was present, marking the locations of any suspected acute fractures on the image. The images were displayed on a secondary-class monitor using Ziltron software, which recorded the adjustments to brightness and contrast made for each image. The images were presented in different orders for each lighting level to reduce potential memory effects. Results: Student's t-tests were applied to compare the mean brightness and contrast adjustments made to the images in each ambient lighting level. Tests were carried out to include all images, only positive cases, and only cases where observers elected to change the brightness and/or contrast. No statistically significant differences were noted except when images where no brightness/contrast adjustments were made were discounted. In that case, mean brightness levels were slightly higher in the high ambient light level (p=0.049). Conclusion: No convincing difference in adjustments of brightness and contrast between high and low ambient lighting levels, although further research is warranted.

8673-40, Session PSMon

The effect of viewing distance on observer performance in skeletal radiographs

Marie Louise Butler, Joanna Lowe, Rachel J. Toomey, Marion Maher, Univ. College Dublin (Ireland); Michael G. Evanoff, The American Board of Radiology (United States); John Ryan, Louise A. Rainford, Univ. College Dublin (Ireland)

A number of different viewing distances are recommended by international agencies, however none with specific reference to radiologist performance. The purpose of this study was to ascertain the extent to which radiologists' performance is affected by viewing distance on softcopy skeletal reporting. Eighty poster-anterior (PA) wrist radiographs, of which half feature one or more fractures, were viewed by seven readers at 2 viewing distances, 30cm and 70cm. Readers rated their confidence that the images contained a fracture on a scale of 1 to 5 and could mark multiple locations on the images when they visualised a fracture. Viewing distance was measured from the centre of the face plate to the outer canthus of the eye. The DBM MRM analysis showed no statistically significant differences between the area under the curve for the two distances (p = 0.482). The JAFROC analysis, however, demonstrated a statistically significantly higher area under the curve with the 30cm viewing distance than with the 70 cm distance (p = 0.035). This suggests that while readers were able to make decisions about whether an image contained a fracture or not equally well at both viewing distances, they may have been less reliable in terms of fracture localisation or detection of multiple fractures. The impact of viewing distance warrants further attention from both clinical and scientific perspectives.

8673-41, Session PSMon

Breast screening: understanding case difficulty and the nature of errors

Alastair G. Gale, Leng Dong, Yan Chen, Loughborough Univ. (United Kingdom)

In the UK all screeners undertake the PERFORMS scheme where they read annual sets of challenging cases. During this test, they give each case a confidence rating on whether it should be recalled. If they decide to recall a case, they also indicate the centre of any key mammographic features on a display of the relevant mammographic case view. Expert radiological opinion defines what the key abnormalities (targets) are in any case. Data can then be analysed using ROC and JAFROC approaches, and for the latter, accurate location is important. Using image pixel information alone it is possible to delineate correct localisation of an abnormality from an incorrect location by defining an area of interest around a target. However, an apparent incorrect location can be a correct localisation of another valid abnormal feature. Additionally, a participant may have already also correctly located and identified the key abnormality. To explore such location information in more detail, data from the last year of the scheme were reanalysed and the location responses for each of 624 participants on 120 screening cases examined. Additional expert radiological opinions were garnered for potential reasons for the marking of non-target areas. Results show that even when participants correctly recalled a case, not all of them marked the correct target location. Sometimes abnormalities were clearly missed and on other occasions other potential abnormality sites were marked. The underlying reasons for this and what makes a case particularly difficult are explored.

8673-42, Session PSMon

Immersive virtual reality for visualization of abdominal CT

Qiufeng Lin, Zhoubing Xu, Vanderbilt Univ. (United States); Bo Li, Vanderbilt Univ (United States); Rebeccah Baucom, Benjamin K. Poulose, Bennett A. Landman, Robert E. Bodenheimer, Vanderbilt Univ. (United States)

Immersive virtual environments use a stereoscopic head-mounted display and data glove to create high fidelity virtual experiences in which users can interact with three-dimensional models and perceive relationships at their true scale. This stands in stark contrast to traditional PACS-based infrastructure in which images are viewed as stacks of two-dimensional slices, or, at best, disembodied renderings. Although there has substantial innovation in immersive virtual environments for entertainment and consumer media, these technologies have not been widely applied in clinical applications. Here, we consider potential applications of immersive virtual environments for ventral hernia patients with abdominal computed tomography imaging data. Nearly a half million ventral hernias occur in the United States each year, and hernia repair is the most commonly performed general surgery operation worldwide. A significant problem in these conditions is communicating the urgency, degree of severity, and impact of a hernia (and potential repair) on patient quality of life. Hernias are defined by ruptures in the abdominal wall (i.e., the absence of healthy tissues) rather than a growth (e.g., cancer); therefore, understanding a hernia necessitates understanding the entire abdomen. Our environment allows surgeons and patients to view body scans at scale and interact with these virtual models using a data glove. This visualization and interaction allows users to perceive the relationship between physical structures and medical imaging data. The system provides close integration of PACS-based CT data with immersive virtual environments and creates opportunities to study and optimize interfaces for patient communication, operative planning, and medical education.

8673-43, Session PSMon

Altered resting-state functional connectivity in post-traumatic stress disorder: a perfusion MRI study

Baojuan Li, Fourth Military Medical Univ. (China); Jian Liu, College of Mechatronics and Automation, National Univ. of Defense Technology (China); Yang Liu, Hong-Bing Lu, Fourth Military Medical Univ. (China); Hong Yin, Xijing Hospital, Fourth Military Medical Univ. (China)

The majority of studies on PTSD so far have focused on delineating patterns of activations during cognitive processes. Recently, more and more researches start to investigate functional connectivity in PTSD subjects using BOLD-fMRI. Functional connectivity analysis has been demonstrated as a powerful approach to identify biomarkers of different brain diseases. This study aimed to detect resting-state functional connectivity abnormities in patients with PTSD using ASL fMRI. As a completely non-invasive technique, arterial spin labelling (ASL) allows quantitative estimates of cerebral blood flow (CBF). Compared with BOLD-fMRI, ASL fMRI can provide superior functional localization and is more suitable for the investigation of slow changes in neural activity. In the current study, ASL images were collected form 10 survivors in mining disaster with recent onset PTSD and 10 survivors without PTSD. Decreased regional CBF in the right inferior temporal gyrus was detected in the PTSD patients. Seed-based functional connectivity analysis was performed using an area in the right inferior temporal gyrus as region of interest. Compared with the non-PTSD group, the PTSD subjects demonstrated increased functional connectivity in the right precentral gyrus, left middle occipital gyrus and right middle occipital gyrus. Meanwhile, decreased functional connectivity in the right inferior parietal lobule, left superior frontal gyrus and right superior parietal lobule was found in the PTSD group. This is the first study attempt to investigate

resting-state functional connectivity in PTSD using ASL images. The results may provide new insight into the neural substrates of PTSD.

8673-44, Session PSMon

Does image reduction affect the diagnostic accuracy of digital mammograms?

Yumi Takane, Yusuke Kawasumi, Tsunemitsu Horie, Tadashi Ishibashi, Tohoku Univ. Graduated School of Medicine (Japan)

The aim of this study is to evaluate the influence of image reduction using bicubic interpolation method on diagnostic accuracy for detection of clustered microcalcifications (MCLs) and masses on digital mammograms.

A total of 194 digital mammograms of 97 subjects were retrospectively selected. They consisted of 47 patients with clustered MCLs or masses and 52 control subjects. All images were craniocaudal view and obtained by a Phase Contrast Mammography (PCM) System. The pixel size of the original PCM image was 25 ?m. The reduced images converted from the original images using bicubic interpolation method were 50 ?m in pixel size. Five observers independently interpreted the original images and the reduced images, and rated their confidence concerning the presence of the lesions on a continuous point scale from 0 to 100. A receiver-operating characteristic (ROC) analysis was performed with the jackknife method using the program LABMRMC. The differences in area under the curve (AUC) values based on the 95% confidence interval were evaluated.

The average AUC values on detection of masses were 0.8435 for the original images and 0.8646 for the reduced images. The difference between the average AUC values was not statistically significant (p=0.5855). And the average AUC values on detection of clustered MCLs were 0.9273 and 0.9574 for the original images and reduced images, respectively. The difference between the average AUC values was not statistically significant (p=0.1949).

Diagnostic performance for detection of masses and clustered MCLs on digital mammograms was not affected by image reduction using bicubic interpolation method.

8673-45, Session PSMon

Deviance statistics in model fit and selection in ROC studies

Tianhu Lei, Kyongtae T. Bae, UPMC Presbyterian (United States)

A general non-linear regression model-based Bayesian inference approach is used in our ROC (Receiver Operating Characteristics) study. In the sampling of posterior distribution, two prior models - continuous Gaussian and discrete categorical - are used for the scale parameter. How to judge Goodness-of-Fit (GOF) of each model and how to criticize these two models, Deviance statistics and Deviance information criterion (DIC) are adopted to address these problems.

Model fit and selection focus on the adequacy of models. Judging model adequacy is essentially measuring agreement of model and observations. Deviance statistics and DIC provide overall measures on model fit and selection. In order to investigate model fit at each category of observations, we find that the cumulative, exponential contributions from individual observations to Deviance statistics are good estimates of FPF (false positive fraction) and TPF (true positive fraction) on which the ROC curve is based.

This finding further leads to a new measure for model fit, called FPF-TPF distance, which is a Euclidean distance defined on FPF-TPF space. It combines both local and global fitting. Deviance statistics and FPF-TPF distance are shown to be consistent and in good agreement. Theoretical derivation and numerical simulations for this new method for model fit and model selection of ROC data analysis are included.

8673-46, Session PSMon

Visibility of single spiculations in breast tomosynthesis

Pontus A. Timberg, Magnus Dustler, Daniel Förnvik, Sophia Zackrisson, Scanias Univ. Hospital (Sweden)

Purpose: To investigate the visibility of single spiculations in breast tomosynthesis (BT). Method: Simulated spheres (6 mm diameter) with single spiculations were added to projection images acquired on a BT system (Mammomat Inspiration, Siemens). The spiculations had a cylindrical shape and were diagonally aligned (in four different positions: $\pm \pi/4$ and $\pm 3\pi/4$) at a plane parallel to the detector. They were assumed to consist of a fibroglandular tissue composition. The length of the spiculations was 5 mm while the diameter varied (0.08 mm, 0.12 mm, 0.16 mm, 0.20 mm, 0.24 mm and 0.28 mm). Reconstructed central slices were used in two 4-alternative forced choice (4AFC) human observer experiment, separated by insertions in fatty and dense breasts (300 images per observer and experiment). Six medical physicists participated and their task was to locate the spiculation in randomly presented images from the whole image set. Each experiment was divided into 50 trials (for each diameter), which were separated two weeks apart to reduce possible memory bias. The percent correct (PC) decision was determined in both fat and dense tissue for all spiculation diameters. Results: At a PC level of 92.5% the required diameter was 0.22 mm in dense tissue, and 0.20 mm in fatty tissue. Conclusions: The visibility of single spiculation was determined. The required diameter depends on tissue composition in BT. The result suggests a longer required diameter in dense tissue compared with fat tissue.

8673-47, Session PSMon

Assessment of image quality in orthopedic radiography with digital detectors: a visual grading analysis

Robin Decoster, Harrie Mol, Renaat Van den Broeck, Dirk Smits, Hogeschool-Univ. Brussel (Belgium)

Background: The introduction of digital detectors in the radiology predicted a dose reduc-tion. Due to the dynamic range, radiographies of sufficient quality can be produce with a lower detector air kerma. (DAK) However this reduction was not observed. Some authors indicate a creep towards higher DAK, explained by a better appreciation of the radiographs due to a higher contrast-to-noise ratio.

Methodology: To investigate the relation between the DAK and the appreciation of image quality by radiologists, 172 anterior-posterior (AP) radiographs of the knee and 152 radiographs of the pelvis where collected in 19 radiologic centres. A Visual Grading Analysis (VGA) with a five-point scale was used to judge the image quality of seven different anatomic structures. The mid-point of the scale was equalized to diagnostic image quality. Six experienced radiologists scored both datasets, in a controlled environment, with ViewDex®. Every observer received instruction and a training dataset. Moreover, twenty radio-graphs were repeated to determine intra-observer variability.

Results: The intra-observer variability was not significant ($p>0.05$) for both datasets. The knee AP obtained a VGAS score of 3.92, the pelvis AP obtained VGAS score of 3.71. In both cases, the inter-observer correlation is high and significant. The correlation between the VGAS and the DAK (0.41µGy – 6.18µGy) was not significant in either of cases. Neither did other analyses based on technical parameters.

Conclusion: The VGA revealed an image quality higher than diagnostic necessary. Based on the DAK an overexposure is suspected. The relation between DAK and the appreciation has to be investigated.

8673-48, Session PSMon

Model-based Bayesian inference for ROC data analysis

Tianhu Lei, Kyongtae T. Bae, UPMC Presbyterian (United States)

This paper presents a study of model-based Bayesian inference to Receiver Operating Characteristics (ROC) data. The model is a simple version of general non-linear regression model. Different from Dorfman model, it uses a probit link function with a covariate variable having zero-one two values to express binormal distributions in a single formula. Model also includes a scale parameter.

Bayesian inference is implemented by Markov Chain Monte Carlo (MCMC) method carried out by Bayesian analysis Using Gibbs Sampling (BUGS). Contrast to the classical statistical theory, Bayesian approach considers model parameters as random variables characterized by prior distributions. With substantial amount of simulated samples generated by sampling algorithm, posterior distributions of parameters as well as parameters themselves can be accurately estimated.

MCMC-based BUGS adopts Adaptive Rejection Sampling (ARS) protocol which requires the probability density function (pdf) which samples are drawing from be log concave with respect to the targeted parameters. Our study corrects a common misconception and proves that pdf of this regression model is log concave with respect to its scale parameter. Therefore, ARS's requirement is satisfied and a Gaussian prior which is conjugate and possesses many analytic and computational advantages is assigned to the scale parameter.

A cohort of 20 simulated data sets and 20 simulations from each data set are used in our study. Output analysis and convergence diagnostics for MCMC method are assessed by CODA package. Models and methods by using continuous Gaussian prior and discrete categorical prior are compared. Intensive simulations and performance measures are given to illustrate our practice in the framework of model-based Bayesian inference using MCMC method.

8673-49, Session PSMon

Development of a digital rectangular phantom for quality controls of medical primary B / W and CL monitors in RIS-PACS system

Alessia Mattacchioni, Marco Cristianini, Alessia Lo Bosco, Health Physics Service, AUSL RMH (Italy)

The purpose of this paper is to project and to support the use of rectangular digital phantoms (DI.RECTA. Phantoms) instead of the square phantoms usually used for quality control of the primary medical monitors.

The different types of primary monitors are included in a range between 2 and 5 Mp, with resolutions ranging between 1600x2560 and 1200 x 2048. The first approach for the evaluation of the quality of a monitor is represented by AAPM tests using the phantoms TG-18-CQ. In the second step, a DI.RECTA Phantom is designed to simulate typical radiological conditions to determine the presence of significant defects such as luminance, contrast, resolution, artefacts and distortion. The TG-18-QC Pattern is available in 2 sizes: 1024x1024 and 2048x2048 and the use of these phantoms require a correct monitor setup. Moreover, the difference between the resolution of the monitor and phantoms does not allow for a complete analysis of the entire system. This image device becomes especially important in contrastographyc exams where it is essential to guarantee the radiologist the same image quality at all points of the screen. There are proposed, therefore, digital rectangular phantoms compatible with the spatial resolution of most of the monitor on market.

The analysis of images in the peripheral regions of medical monitors can not be neglected, especially because of the possible legal implications. A simpler study of these areas can be done through the use of rectangular phantoms in place of square ones. Adequate procedures for setting the monitor is moreover necessary.

8673-50, Session PSMon

Prediction of near-term breast cancer risk using a Bayesian belief network

Bin Zheng, Pandiyarajan Ramalingam, Harishwaran Hariharan, Univ. of Pittsburgh (United States); Joseph K. Leader, UPMC Presbyterian (United States); David Gur, Univ. of Pittsburgh School of Medicine (United States)

Accurately predicting near-term breast cancer risk is an important prerequisite for establishing an optimal personalized breast cancer screening paradigm. In our previously studies we have investigated and tested the feasibility of developing a unique near-term breast cancer risk prediction model based on a new risk factor associated with the bilateral mammographic density asymmetry between the left and right breasts of the individual woman. Instead using a single feature, we in this study developed a multi-feature based Bayesian belief network (BBN) that combines bilateral mammographic density asymmetry with other three popular risk factors namely (1) woman's age, (2) family history, and (3) average breast density, to further increase the discriminatory power of our cancer risk model. A dataset involving "prior" negative mammography examinations of 348 women was used in the study. Among these women, 174 had breast cancer detected and verified in the next sequential screening examinations, and 174 remained negative (cancer-free). A BBN was applied to predict the risk of each woman having cancer detected 6 to 18 months later following the negative screening mammography. The prediction results were compared with those using single features. The results showed when using the BBN the prediction accuracy was significantly increased. The area under ROC curve was increased from AUC=0.70 to 0.84 ($p<0.01$), while the positive predictive value (PPV) and negative predictive value (NPV) are also increased from PPV=0.61 to 0.78 and NPV=0.65 to 0.75, respectively. This study that a multi-feature based BBN enables to more accurately predict the near-tern breast cancer risk.

8673-51, Session PSMon

A new assessment method for image fusion quality

Liu Li, Xuming Zhang, Wanying Jiang, Jing Li, Yuchi Ming, Mingyue Ding, Huazhong Univ. of Science and Technology (China)

Image quality assessment for the evaluation of image fusion quality plays a critically important role in the field of medical imaging. To evaluate the quality of different image fusion metrics, a lot of assessment methods have been proposed. Examples include mutual information (MI), root mean square error (RMSE), universal image quality index (UIQI). These image fusion assessment methods could not reflect the human visual inspection effectively.

To address this problem, we have proposed a novel image fusion assessment method which combines the nonsubsampled contourlet transform?NSCT? with the regional mutual information in this paper. In this proposed method, the source medical images are firstly decomposed into different levels by the NSCT. Then the maximum NSCT coefficients of the decomposed directional images at each level are obtained to compute the regional mutual information (RMI). Finally, multi-channel RMI is computed by the weighted sum of the obtained RMI values at the various levels of NSCT.

The advantage of the proposed method lies in the fact that the NSCT can present image information using multi-directions and multi-scales and therefore it conforms to the multi-channel characteristic of human visual system, leading to its outstanding image assessment performance. The experimental results using CT and MRI images demonstrate that the proposed assessment method outperforms such assessment methods as mutual information (MI) and universal image quality index (UIQI) based measure in evaluating image fusion quality and it can provide consistent results with human visual assessment.

8673-52, Session PSMon

Application of a computed tomography-based cystic fibrosis scoring system on chest tomosynthesis

Christina Söderman, Göteborg Univ. (Sweden); Åse Johnsson, Jenny Vikgren, Sahlgrenska Univ. Hospital (Sweden); Hans Rystedt, Jonas Ivarsson, Univ. of Gothenburg (Sweden); Lisbeth Denbratt, Rauni Rossi Norrlund, Lena Nyberg Andersson, Sahlgrenska Univ. Hospital (Sweden); Magnus Båth, Sahlgrenska Univ. Hospital (Sweden) and Univ. of Gothenburg (Sweden)

In the monitoring of progression of lung disease in patients with cystic fibrosis (CF), recurrent computed tomography (CT) examinations are often used. The relatively new imaging technique chest tomosynthesis (CTS) may be an interesting alternative in the follow-up of these patients due to its visualization of the chest in slices at radiation doses and costs significantly lower than is the case with CT. A first step to introducing CTS imaging in the diagnostics of CF patients is to establish a scoring system appropriate for evaluating the severity of CF pulmonary disease based on findings in CTS images. Previously, several such CF scoring systems based on CT imaging have been published. The purpose of the present study was to investigate the applicability of one of these existing CT scoring systems on CTS images. Three thoracic radiologists independently scored both CT and CTS images from five different CF patients using a CF scoring system designed specifically for CT. The agreement between the resulting scores for the two types of images was assessed. Preliminary results indicate that there is a need to modify the CT-based CF scoring system used in this study in order for it to be adapted to the interpretation of CTS images.

8673-53, Session PSMon

An initial investigation of radiologist eye movements in vascular imaging

Rachel J. Toomey, Univ. College Dublin (Ireland); Scott Hodgins, Acuity ETS (United Kingdom); Michael G. Evanoff, The American Board of Radiology (United States); Louise A. Rainford, Univ. College Dublin (Ireland)

Eye tracking has been used by many researchers to try to shed light on the perceptual processes involved in medical image perception. Despite a large volume of data having been published regarding radiologist viewing patterns for static images, and more recently for stacked imaging modalities, little has been produced concerning angiographic images, which commonly have substantially different characteristics. A study was performed in which 8 expert radiologists viewed a range of digital subtraction angiograms of the peripheral vascular system. Initial results are presented. The observers were free to control the rate at which they viewed the images. Eye position data was recorded for each participant using Tobii TX300 eyetrackers. Analysis was performed in Tobii Studio software and included qualitative analysis of gaze pattern and analysis of metrics including first and total fixation duration etc. for areas of clinical interest. Early results indicate that experts briefly fixate on lesions but do not dwell in the area, rather continuing to inspect the more distal vascular segments before returning. Total fixation duration was longest for abnormal areas. Some individual variation was noted. Further research is required and ongoing.

8673-54, Session PSMon

The value of the cranial-caudal mammographic view in breast cancer detection: a preliminary study

Phuong Dung Trieu, Patrick C. Brennan, The Univ. of Sydney (Australia); Warwick Lee, Screen New South Wales, Cancer Institute, Alexandria NSW 1435, Australia (Australia); Elaine Ryan, Discipline of Medical Radiation Sciences, Faculty of Heath Sciences, the University of Sydney (Australia); Warren Reed, Discipline of Medical Radiation Sciences, Faculty of Heath Sciences, the University of Sydney (Australia); Mariusz W. Pietrzyk, The Univ. of Sydney (Australia)

Mammography is considered a reliable modality in detecting early breast lesions with high level of sensitivity and specificity being demonstrated (3,7). Although a single medio-lateral oblique view used to be the routine protocol (3), there are many studies (5,6,8) indicating that two-view (cranio-caudal and mediolateral oblique) mammogram provides radiologists with more information to detect breast cancer. However, the value of cranio-caudal view in the diagnoses of breast cancers has never been established.

Materials and Methods

129 radiologists were asked to report 60 two-view mammograms of the left and right breasts (20 malignant lesions) and 55 radiologists assessed a set of 55 single cranio-caudal views (23 malignant lesions). Participants were asked to search for the presence of any breast lesions and provide confidence scores for their decisions. The sensitivity, specificity and localization sensitivity of each reader were analysed and JAFROC figure of merit and ROC Az values calculated.

Results

Two-view mammograms showed more effectiveness in detecting malignant nodules than single cranio-caudal view in terms of sensitivity (0.84 > 0.62; p<0.001), localized-sensitivity (0.6 > 0.5; p=0.006), ROC (0.82 > 0.64; p<0.001) and JAFROC (0.67 > 0.62; p =0.02). Nevertheless, the single CC view had a higher (non-significant) specificity (0.79) as compared to two-view mammography (0.72) (p=0.065).

Conclusions

Single view cranial-caudal mammogram reduces the ability of cancer detection in mammography; however its improved specificity may provide some benefit for low risk women having follow-up screening appointments.

8673-55, Session PSMon

Assessment of methods to extract the mid-sagittal plane from brain MR images

Hugo J. Kuijf, Univ. Medical Ctr. Utrecht (Netherlands); Alexander Leemans, Max A. Viergever, Koen L. Vincken, Image Sciences Institute (Netherlands)

Automatic detection of the mid-sagittal plane, separating both hemispheres of the brain, is useful in various applications. Several methods have been developed in the past years, applying different techniques to accurately estimate the position of the mid-sagittal plane.

These methods can be classified into three distinct classes: feature-based, global symmetry based, and local symmetry based methods. Feature-based methods use the shape or intensity of the interhemispheric fissure to extract the mid-sagittal plane. Global symmetry based methods reflect the entire image with respect to the sagittal axes and perform a rigid registration. Local symmetry based methods try to optimize a symmetry-measure in a small band covering the interhemispheric fissure.

From each class, one leading method has been implemented. The methods have been evaluated on the same dataset to allow a fair comparison. Manual delineations were made by two experienced human observers.

The results show that the examined methods perform similar to human observers. No significant differences were found between errors (defined as the angle and volume between planes) made by the methods and the inter-rater differences. Feature-based and local symmetry based methods have a low computation time of 1.8 and 0.5 seconds, respectively. The global symmetry based method has a higher computation time of 33.6

seconds, caused by the full 3D rigid registration.

The largest errors, both by the methods and observers, are made in participants with cerebral atrophy. These participants have a widened interhemispheric fissure, allowing many plane orientations and positions to result in a valid division of the hemispheres.

8673-56, Session PSMon

A study of the feasibility of using slabbing to reduce tomosynthesis review time

Magnus Dustler, Martin Andersson, Daniel Förnvik, Medical Radiation Physics, Lund Univ. (Sweden); Pontus A. S. Timberg, Diagnostic Radiology, Lund Univ. (Sweden); Anders Tingberg, Medical Radiation Physics, Lund Univ. (Sweden)

This study aimed to investigate whether decreasing the amount of slices in breast tomosynthesis (BT) image volumes reduce reading time. BT slices were combined into so-called slabs, by reconstructing thin slices and merging them into thicker slabs. Sets of slabs where created from 35 clinical BT volumes with malignant or benignant findings and from 50 BT volumes drawn from screening sets (without any prior review). The image sets were reviewed in two separate sessions while the review time was recorded. A total of five experienced radiologists were employed for the image review.

Additionally a VGA study was performed to compare slabbed images with the originals in order to ensure that the image quality was not significantly degraded. One set of 27 pathological cases (13 masses and 14 microcalcification clusters) and one of 22 subtle lesions that had been missed on digital mammography but detected on BT were presented to an experienced radiologist and 3 medical physicists who rated the quality of the slabbed versions relative to the originals.

The study could find no significant degradation in image quality when using 2 mm slabs instead of 1 mm slices. There was no significant decrease in reading time on pathological cases ($P = .133$), but on screening images there was a significant decrease of 7.1 ± 10.4 s from an average level of 33.8 ± 15.8 s ($P < .0001$). This suggests that increasing slab thickness can reduce the time radiologists spend studying non-pathological images by 20 %.

8673-57, Session PSMon

Comparing the Microsoft® Kinect™ and traditional mouse for adjusting viewed tissue density of three-dimensional anatomical structures

Bethany Juhnke, Iowa State Univ. (United States); Monica Berron, Univ. of Maryland, Baltimore County (United States); Adriana Philip, The Pennsylvania State Univ. (United States); Jordan Williams, Univ. of Maryland, Baltimore County (United States); Eliot Winer, Iowa State Univ. (United States); Joseph Holub, Iowa State University (United States)

Medical image visualization within virtual reality has advanced to enable volume-rendered images from computed tomography and magnetic resonance imaging scans. This area of research is well studied, however little work has been done to evaluate the usability of interaction devices preferred by users operating these software packages. A mouse and keyboard configuration has become the norm for interaction with medical data. These conventional methods limit the user to two-dimensional (2D) mouse movements of a three-dimensional (3D) on screen volume. New commercial off-the-shelf (COTS) interaction devices are allowing unique 3D interaction with six degrees of freedom (DOF) to more accurately map to the six DOF present in 3D medical volumes. By applying these cutting-edge interaction devices to medical technology, opportunities arise to expand the data and information available to doctors in special cases. For example, enabling a doctor to personally interact with volume-rendered medical data while maintaining a sterile operating room. This research explores the application of a cutting edge COTS device to interact with volume-rendered medical data, focusing on the usability and functionality amongst medical applications. The Kinect™ was selected to study user interaction to manipulate and interact with volume-rendered images. Participants focused on adjusting tissue densities to view pre-selected anatomical features.

8673-58, Session PSMon

Potential method for relieving fatigue in radiologists

Elizabeth A. Krupinski, The Univ. of Arizona (United States)

Radiologists moved to an environment in which they read digital images off of computer displays instead of film images off of light boxes. With film and light boxes they typically would read for about an hour (seated) and then take a break while the film librarian changed the images on the view box. With digital viewing off computers they tend to sit all day in front of the computers with far fewer breaks and opportunity to stand up and move around than with film. There is concern that this lack of activity not only contributes to back, shoulder and neck discomfort, but also contributes to increased fatigue which has been shown to impact reader performance. The goal of this study was to determine if there are differences in physiologic vital signs (heart rate and blood pressure) of radiologists as a function of whether they read images while seated or while standing up. Five subjects had their blood pressure and heart rate measured while seated and while standing reading cases in the normal clinical setting. For all three measures there was a statistically significant ($p < 0.0001$) difference between seated and standing measures with seated being lower than standing. The higher heart rate and blood pressure with standing suggests that the radiologists are more active in this position and thus potentially more attentive than while seated. This study will be followed up to determine impact on diagnostic performance of standing vs seated as well as subjective ratings of wakefulness and mood.

8673-59, Session PSMon

Availability of color calibration for consistent color display in medical images and optimization of reference brightness for clinical use

Daiki Iwai, Nagoya Univ. Graduate School of Medicine (Japan); Haruka Suganamis, Minoru Hosoba, Kazuko Ohno, Yutaka Emoto, Yoshito Tabata, Kyoto College of Medical Science (Japan); Norihisa Matsui, Shimadzu Corp. (Japan)

Color image consistency has not been accomplished yet except the DICOM Supplement 100 for implementing a color reproduction pipeline and device independent color spaces. However, there is no standardized guideline for quality control of color monitors. Thus, most healthcare enterprises could not check monitor degradation routinely.

To ensure color consistency in medical color imaging, we think color calibration is useful. We indicate some examples that usefulness of color calibration for color monitor in color imaging, Introducing simple color calibration device . Chromaticity of 120 colors included typical color (Red, Green, Blue, Green and White) is measured as device independent profile connection space value called Yxy before and after calibration. Moreover, clinical color images are displayed and visual difference are observed.

In color calibration, monitor brightness level is set to quite lower value 80 to 140cd/m2. Nowadays, maximum brightness of most color monitors for medical use have much higher brighteness than 140cd/m^2. It is not seemed to be appropriate to use 140cd/m^2 level for calibration. Thus, we propose that new brightness standard should be introduced while

maintaining the color representation in clinical use.

We evaluated effects of brightness to chromaticity experimentally. Brightness level is deliberately changed in two monitors from 80 to 270cd/m^2. Then, chromaticity value are compared with each brightness level. As a result, there is no significant differences in chromaticity diagram when brightness is changed.

In conclusion, chromaticity is close to theoretical value after color calibration. Moreover, chromaticity isn't moved when brightness is changed. The result indicate optimized reference brightness level for clinical use could be set at high brightness in current monitors .

8673-60, Session PSMon

Analysis of detectability loss through fan-beam x-ray computed tomography reconstruction

Adrian A. Sanchez, The Univ. of Chicago Medical Ctr (United States); Emil Y. Sidky, Xiaochuan Pan, The Univ. of Chicago Medical Ctr. (United States)

We consider detection of a small signal in fan-beam x-ray computed tomography (CT). In order to characterize the loss of intrinsic signal detectability from the projection data (sinogram) domain to the reconstructed image, we analyze the Hotelling observer SNR in each domain. Further, we characterize the loss of Hotelling observer SNR through decomposition into two components: loss of signal detectability which arises due to unequal variance in the noise of separate detector elements and loss of detectability arising from the fact that some noiseless signals have components which lie in the nullspace of a given reconstruction operator (reconstruction matrix). The relative significance of the two sources of detectability loss is evaluated by considering an uncorrelated Poisson-like noise model and a uniform uncorrelated Gaussian noise model for detector noise and comparing detectability after reconstruction. The proposed methodology is investigated for filtered back-projection (FBP) and the back-projection filtration (BPF) algorithm.

8673-61, Session PSMon

Study of CT systems low contrast detectability performance using mathematical model observers

Jiahua Fan, GE Healthcare (United States); Hsin-Wu Tseng, The Univ. of Arizona (United States) and GE Healthcare (United States); Guangzhi Cao, Paavana Sainath, GE Healthcare (United States); Matthew A. Kupinski, College of Optical Sciences, The Univ. of Arizona (United States)

Radiation dose on patient has become a major concern today for CT imaging in clinical practice. Various hardware and algorithm solutions have been designed to reduce dose. Among them, iterative reconstruction (IR) has been widely expected to be an effective dose reduction approach for CT. Different IR algorithms have been invented and introduced on commercial CT systems and have received very positive feedbacks from clinicians in terms of dose saving capabilities as well as image quality performance. However, there is no clear understanding on the exact amount of dose saving an IR approach can offer for various clinical applications. We know that quantitative image quality assessment should be task-based. This work applies mathematical model observer to study detectability performance of CT scan data reconstructed using advanced CT IR approach as well as the conventional FBP approach. The theory, validation and limitation of model observers on quantitative image quality assessment have been well established and understood. The purpose of this work is to establish a practical and robust approach for using model observers on CT IR detectability image quality assessment. LC objects imbedded in head size and body size phantoms are imaged multiple times with different dose levels. Independent signal present and absent pairs are generated for model observer training and testing. ROC curves and AUC values are calculated using CHO with LG channels. One-shot method is used to derive the variance of the AUCs. Results show approximately 4 times dose reduction is achieved using the IR method under study.

8673-62, Session PSMon

Cardiovascular CTA applications: patient-specific contrast formulae

Charbel Saade, American Univ. of Beirut (Lebanon) and The Univ. of Sydney (Australia); Roger Bourne, The Univ. of Sydney (Australia); Mark Wilkinson, Royal Prince Alfred Hospital (Australia); Patrick C. Brennan, The Univ. of Sydney (Australia)

Clear visualisation of the vertebral arteries are of substantial clinical importance, yet optimisation of contrast administration has not been developed in tandem with recent technological developments in computed tomography (CT). The current work involving 202 patients compares the value of a tailored contrast regiment based on patient dynamics and a craniocaudal scan acquisition, with the routine contrast protocol with a caudocranial scan. Attenuation characteristics within 20 arteries were calculated and diagnostic efficacy measured using DBM receiver operating characteristic (ROC) methods. The results demonstrated that the tailored regimen resulted in significantly higher attenuation values ($p<0.01$) and ROC Az values ($p=0.002$), along with better inter-observer agreement compared with the routine protocol and contrast volume was reduced by almost 50%. The data demonstrate that patient-specific strategies can result in significant diagnostic benefit.

8673-63, Session PSMon

A novel phantom system facilitating better descriptors of density within mammographic images

Yanpeng Li, Patrick C. Brennan, The Univ. of Sydney (Australia); Carolyn Nickson, The Univ. of Melbourne (Australia); Mariusz W. Pietrzyk, The Univ. of Sydney (Australia); Dana Al Mousa, The University of Sydney (Australia); Elaine Ryan, The Univ. of Sydney (Australia)

High mammographic density is a risk factor for breast cancer. As it is impossible to measure actual weight or volume of fibroglandular tissue evident within a mammogram, it is hard to know the correlation between measured mammographic density and the actual fibroglandular tissue volume. The aim of this study is to develop a phantom that represents glandular tissue within an adipose tissue structure so that correlations between image feature descriptors and the synthesised glandular structure can be accurately quantified. In this pilot phantom study, four different weights of fine steel-wool were put into gelatine to simulate breast structure. Image feature descriptors are investigated for both the whole phantom image and the dense areas. Descriptors included dense area, percentage density, mean intensity for the whole image and dense area, standard deviation of mean intensity, and integrated density which is the production of area and mean intensity. Whilst the model is still in its development stage, our early results are promising. The results show high level correlation between steel-wool weight and percentage density measured on mammograms ($r = 0.9344$), and the integrated density of dense area ($r = 0.9433$). The correlation is significant for mean intensity standard deviation for the whole phantom ($r = 0.9165$). The phantom study may help identify descriptors linked to mammographic density, thus facilitating better assessments of fibroglandular tissue appearances.

8673-64, Session PSMon

Use of an imaging colorimeter for image quality evaluation

Hans Roehrig, The Univ. of Arizona (United States)

The purpose of this study was to examine the influence of medical display types, monochrome or color at the same maximum luminance settings, on diagnostic performance. The focus was on the measurements of physical characteristics including spatial resolution and noise performance, which we believed could affect the clinical performance. Specifically, Modulation Transfer Function (MTF) and Noise Power Spectrum (NPS) were evaluated and compared at different digital driving levels (DDL) between two EIZO displays.

With the fast advancement of the color medical display technology, today they have been widely employed in almost every medical imaging application. Grayscale as well as color information, such as images from multi-modality systems, 3D image volumes, etc. can be naturally presented on a color medical display. However, studies have shown that the diagnostic performance on a color display was inferior to its monochrome peer [1]. But this difference is getting smaller with the technology advancement.

When we started the physical evaluation tasks for this project, we used a high-end monochrome CCD camera equipped with a color filter wheel to acquire images from displays. Calibration using a spectrometer was developed and implemented. Having realized that the accurate characterization of the color display cannot be possible without an imaging colorimeter system, especially for the tasks of MTF and NPS analysis, we employed an imaging colorimeter system PM-1423 from Radiant Imaging for data acquisition. MTF and NPS were derived using the data achieved.

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8674-1, Session 1

An evaluation system for electronic retrospective analyses in radiation oncology: implemented exemplarily for pancreatic cancer

Kerstin A. Kessel, UniversitätsKlinikum Heidelberg (Germany); Andreas Jäger, Deutsches Krebsforschungszentrum (Germany); Christian Bohn, CHILI GmbH (Germany); Daniel Habermehl, UniversitätsKlinikum Heidelberg (Germany); Lanlan Zhang, Deutsches Krebsforschungszentrum (Germany); Uwe Engelmann, UniversitätsKlinikum Heidelberg (Germany); Nina Bougatf, UniversitätsKlinikum Heidelberg Univ. Heidelberg (Germany); Rolf Bendl, Deutsches Krebsforschungszentrum (Germany); Jürgen Debus, Stephanie E. Combs, UniversitätsKlinikum Heidelberg (Germany)

To date, conducting retrospective clinical analyses is rather difficult and time consuming. Especially in radiation oncology, handling voluminous datasets from various information systems and different documentation styles efficiently is crucial for patient care and research. With the example of patients with pancreatic cancer treated with radio-chemotherapy, we performed a therapy evaluation by using analysis tools connected with a documentation system. A total number of 783 patients have been documented into a professional, web-based documentation system. Information about radiation therapy, diagnostic images and dose distributions have been imported. For 37 patients with disease progression after neoadjuvant chemoradiation, we designed and established an analysis workflow. After automatic registration of the radiation plans with the follow-up images, the recurrence volumes are segmented. Based on these volumes the DVH (dose-volume histogram) statistic is calculated, followed by the determination of the dose applied to the region of recurrence. All results are stored in the database and included in statistical calculations. The main goal of using an automatic evaluation system is to reduce time and effort conducting clinical analyses, especially with large patient groups. We showed a first approach and use of some existing tools, however manual interaction is still necessary. Further steps need to be taken to enhance automation. Already, it has become apparent that the benefits of digital data management and analysis lie in the central storage of data and reusability of the results. Therefore, we intend to adapt the evaluation system to other types of tumors in radiation oncology.

8674-2, Session 1

A distributed plugin based architecture for medical image processing

Eduardo Romero Castro, Juan C. Leon, Alexander Pinzon, Cesar Sanchez, Univ. Nacional de Colombia (Colombia)

Large volumes of data are common in medical imaging and require special applications that enable fast and reliable processing. High performance computing enables such processing by running applications in parallel.

This work presents a cluster architecture for the parallel processing of DICOM datasets, where the functionality is not specified by the application itself but rather by a set of plugins. Results show that processing times reduce with each added node while network latency is kept stable.

8674-3, Session 1

Robust inter-modality multi-atlas segmentation for PACS-based DTI quality control

Andrew J. Asman, Carolyn B. Lauzon, Bennett A. Landman, Vanderbilt Univ. (United States)

Anatomical contexts (spatial labels) are critical for interpretation of medical imaging content. Numerous approaches have been devised for segmentation, query, and retrieval within the Picture Archive and Communication System (PACS) framework. To date, application-based methods for anatomical localization and tissue classification have yielded the most successful results, but these approaches typically rely upon the availability of standardized imaging sequences. With the ever expanding scope of PACS archives — including multiple imaging modalities, multiple image types within a modality, and multi-site efforts, it is becoming increasingly burdensome to devise a specific method for each data type. To address the challenge of generalizing segmentations from one modality to another, we consider multi-atlas segmentation to transfer label information from labeled T1-weighted MRI data to unlabeled B_0 data collected in a diffusion tensor imaging (DTI) experiment. The label transfer approach is fully automated and enables a generalizable cross-modality segmentation method. Herein, we propose a multi-tier multi-atlas segmentation framework for the segmentation of previously unlabeled imaging modalities (e.g., B_0 images for DTI analysis). We show that this approach can be used to construct informed structure-wise noise estimates for fractional anisotropy (FA) measurements of DTI. Although this label transfer methodology is demonstrated in the context of quality control of DTI images, the proposed framework is applicable to any application where the segmentation of unlabeled modalities is limited due to the current collection of available atlases.

8674-4, Session 1

Integration of XNAT/PACS, DICOM, and research software for automated multimodal Image analysis

Yurui Gao, Institute of Imaging Science, Vanderbilt Univ. (United States) and Biomedical Engineering, Vanderbilt Univ. (United States); Scott S. Burns, Vanderbilt Kennedy Ctr., Vanderbilt Univ. (United States); Carolyn B. Lauzon, Institute of Imaging Science, Vanderbilt Univ. (United States) and Electrical Engineering and Computer Science, Vanderbilt Univ. (United States); Andrew E. Fong, Terry A. James, Blanchfield Army Community Hospital (United States); Joel F. Lubar, Southeastern Biofeedback Institute, Inc. (United States); Robert W. Thatcher, Applied Neuroscience, Inc. (United States); David A. Twillie, Michael D. Wirt, Marc A. Zola, Bret W. Logan, Blanchfield Army Community Hospital (United States); Adam W. Anderson, Biomedical Engineering, Vanderbilt Univ. (United States) and Institute of Imaging Science, Vanderbilt Univ. (United States) and Radiology and Radiological Sciences (United States); Bennett A. Landman, Biomedical Engineering, Vanderbilt Univ. (United States) and Institute of Imaging Science, Vanderbilt Univ. (United States) and Electrical Engineering and Computer Science, Vanderbilt Univ. (United States)

Traumatic brain injury (TBI) is an increasingly important public health concern. While there are several promising avenues of intervention, clinical assessments are relatively coarse and comparative quantitative analysis is an emerging field. Imaging data provide potentially useful

information for evaluating TBI across functional, structural, and microstructural phenotypes. Integration and management of disparate data types are major obstacles. In a multi-institution collaboration, we are collecting electroencephalogy (EEG), structural MRI, diffusion tensor MRI (DTI), and single photon emission computed tomography (SPECT) from a large cohort of US Army service members exposed to mild or moderate TBI who are undergoing experimental treatment options. We have constructed a robust informatics backbone for this project centered on the DICOM standard and eXtensible Neuroimaging Archive Toolkit (XNAT) server. Herein, we discuss (1) optimization of data transmission, validation and storage, (2) quality assurance and workflow management, and (3) integration of high performance computing with research software.

8674-5, Session 2

Region-based volumetric medical image retrieval

Antonio Foncubierta-Rodríguez, Univ. of Applied Sciences Western Switzerland (Switzerland); Henning Müller, Adrien Depeursinge, Univ. of Applied Sciences Western Switzerland (Switzerland) and Univ. and Univ. Hospitals of Geneva (HUG) (Switzerland)

Volumetric medical images contain an enormous amount of visual information that can discourage the exhaustive use of local descriptors for image analysis, comparison and retrieval.

Distinctive features and patterns that need to be analyzed for finding diseases are most often local or regional.

In this paper a novel method for detecting key--regions is introduced as a way of extending the concept of keypoints often used in 2D image analysis.

The region detection method is integrated into a platform--independent, web--based graphical interface for medical image visualization and retrieval in three dimensions.

These features make it easy to deploy on existing infrastructures in both small and large--scale clinical environments.

By including the region detection method into the interface, manual annotation is spared and time is saved,

making it possible to integrate the presented interface and methods into clinical routine and workflows analyzing image data at a large scale.

8674-6, Session 2

Computer-assisted identification and volumetric quantification of dynamic contrast enhancement in brain MRI: an interactive system

Shandong Wu, The Univ. of Pennsylvania Health System (United States); Nicholas G. Avgeropoulos, M.D. Anderson Cancer Ctr. Orlando (United States); David J. Rippe, Florida Hospital Zephyrhills (United States)

We present a dedicated segmentation system for tumor identification and volumetric quantification in dynamic contrast brain magnetic resonance (MR) scans. Our goal is to offer a practically useful tool at the end of clinicians in order to boost volumetric tumor assessment. The system is designed to work in an interactive mode such that maximizes the integration of computing capacity and clinical intelligence. We demonstrate the main functions of the system in terms of its functional flow and conduct preliminary validation using a representative pilot dataset. The system is inexpensive, user-friendly, easy to deploy and integrate with picture archiving and communication systems (PACS), and possible to be open-source, which enable it to potentially serve as a useful assistant for radiologists and oncologists. It is anticipated that in the future the system can be integrated into clinical workflow so that become routine available to help clinicians make more objective interpretations of treatment interventions and natural history of disease to best advocate patient needs.

8674-7, Session 2

How inaccurate is weight as a metric for patient size? Comparing patient weight to effective diameter for size-specific dose estimation

Tessa S. Cook, Seetharam C. Chadalavada, William W. Boonn, The Univ. of Pennsylvania Health System (United States)

One of the biggest challenges in dose monitoring is customization of CT dose estimates to the patient. Patient size remains a highly significant variable. One metric that has previously been used for patient size is patient weight, though this is often criticized as inaccurate. In this work, we compare patients' weight to their effective diameters obtained from a CT scan of the chest or the abdomen. 261 CT exams of the chest (133) and abdomen/pelvis (128) performed on adult patients in July 2012 were randomly selected for analysis. The effective diameter of the patient for each exam was determined using the central slice of the scan region for each exam using eXposure™ (Radimetrics, Inc., Toronto, Canada). In some cases, the same patient had both a chest and abdominopelvic CT, so effective diameters from both regions were analyzed. In this small sample size, there appears to be a linear relationship between patient weight and effective diameter when measured in the mid-chest and mid-abdomen of adult patients. However, for each weight, patient effective diameter can vary by 5 cm from the regression line in both the chest and the abdomen. A 5-cm difference corresponds to a difference of approximately 0.2 in the chest and 0.3 in the abdomen/pelvis for the correction factors recommended for size-specific dose estimation by the AAPM. This preliminary data suggests that weight-based CT protocoling may in fact be appropriate for some adults. However, more work is needed to identify those patients in whom weight-based protocoling is not appropriate.

8674-8, Session 2

A multimedia system for decision support in neurological classification of pain in spinal cord injury patients

Sneha K. Verma, The Univ. of Southern California (United States); Sophia Chun M.D., Veterans Affairs Clinic (United States); Brent J. Liu, The Univ. of Southern California (United States)

Pain is a common complication after spinal cord injury, which deeply affects a patient's lifestyle and well-being. For better treatment, accurate classification of pain becomes very important, which directly depends on the information provided by patients to the physicians. Currently, with the limited knowledge about pain related information, patients end up taking medications that are not suitable or required. We are presenting a multi-media system that provides decision support for the neurological classification of pain in spinal cord injury patients which includes a tool that will allow a patient to select multiple pain locations and group each individual pain according to various properties, such as severity of the pain, location of pain, frequency of the pain etc. The pain classifier acquires data from the patient through the use of specific input tools and then compares that data with three sets of classification layers. The first layer contains information about the general anatomical location, the second layer contains information about the joint or non-joint location, and the third layer contains information about the dermatome region which defines neurological pain. The computer-aided pain classifier can be extended to integrate different imaging modalities, so that if physicians want to compare the pain information given by patients with the X-rays or MRI of that patient, they can do it all at the same time. This

application is developed to run on IPads and Tablets as well as PC's and Laptops, which makes it very useful when data needs to be collected from different locations or directly captured by the patient prior to seeing the physician.

8674-9, Session 2

Integration of imaging informatics-based multiple sclerosis eFolder system for multisite clinical trials utilizing IHE workflow profiles

Kevin C. Ma, Nakul Reddy, Lilyana Amezcua, The Univ. of Southern California (United States); Brent J. Liu, The Univ. of Southern California (United States)

At last year's SPIE, we presented a multiple sclerosis (MS) eFolder as an integrated imaging-informatics based system to provide several functionalities to both clinical and research environments. The eFolder system combines patients' clinical data, radiological images and computer-aided lesion detection and quantification results to aid in longitudinal tracking, data mining, decision support, and other clinical and research needs.

To demonstrate how this system can be integrated in an existing imaging environment such as a large-scale multi-site MS clinical trial, we present a system infrastructure to streamline imaging and clinical data flow with postprocessing (CAD) steps. The system stores clinical and imaging data, provides CAD postprocessing algorithm and data storage, and a web-based graphical user interface (GUI) to view clinical trial data and monitor workflow. To evaluate the system infrastructure, the MS eFolder is set up in a simulated environment with workflow scenarios, including DICOM store, query, and retrieve, automatic CAD steps, and data mining based on CAD results. This project aims to discuss the methodology of setting up eFolder system simulation with a connection to a CAD server component, simulation performance and test results, and discussion of eFolder system deployment results.

8674-10, Session 2

The use of ultrasound structured reporting to shorten dictation time

Steven C. Horii M.D., The Univ. of Pennsylvania Health System (United States); Hanna Zafar, Univ. of Pennsylvania (United States); Jill Langer, Beverly Coleman, The Univ. of Pennsylvania Health System (United States)

Even with the use of speech recognition, the generation of radiology reports is still dependent on the radiologist dictating findings. For ultrasound, many of the elements of a report are measurements made on the ultrasound machine. Many of the ultrasound vendors can export these measurements as DICOM Structured Reporting elements, though few PACS can make use of them. With our ultrasound miniPACS vendor, we implemented a system to capture the structured reporting values, map them into dictation template fields, and automatically load them into our speech recognition system. Our initial experience is that we can reduce dictation time by between 10 – 20%. This may increase for reports that include many measurements (e.g., a carotid ultrasound).

8674-11, Session 3

Secured processing of medical data using Grid/Cloud computing

Andreas Thiel, OFFIS e.V. (Germany); Frank Hertel, Johannes Bernarding, Institute for Biometry and Medical Informatics, Univ. Magdeburg (Germany)

The power of Grid and Cloud computing enables the development of new telemedical services that can be offered using high-speed networks, which are increasingly available to hospitals in Germany. Currently the implementation of such new services is often prevented by hurdles such as heterogeneous IT infrastructure, data protection and safety considerations, and by the significant requirements in terms of transfer speed and computing power. The MedInfoGRID project, which is funded by the German Federal Ministry of Education and Research, is developing a virtual "documentation and information center" for the management of integrated distributed databases. This portal will enable researchers to gain access to relevant imaging, findings and therapies. Because of the large volumes of image data, the image distribution approach implemented in the project, based on DICOM, requires careful attention. For example, some of the post-processing algorithms used require a conversion of non-DICOM image sources including color-encoded pathology images to DICOM and their integration with other images sources. Also, data protection and more generally IT security are a highly relevant topic for the project. Different DICOM conformant data security concepts have been analyzed. First results include a concept for a DICOM conformant selective encryption of personal data (patient demographics etc.) that only requires the encryption of about 5% of the data to be transmitted, thus significantly reducing the speed penalty caused by encryption and decryption. The concept enables standard DICOM tools to correctly process the secure images if the processing algorithm does not depend on the personal data.

8674-12, Session 3

Image communication, storage and computing in e-science platform for translational biomedical imaging research

Jianguo Zhang, Tushen Wang, Yuanyuan Yang, Mingqing Wang, Shanghai Institute of Technical Physics, Chinese Academy of Sciences (China); Haibo Hu, School of Biomedical Engineering, Shanghai Jiao Tong Univ. (China)

Purpose:

A new imaging and informatics infrastructure and paradigm need to be developed to promote multiple disciplines of medical researchers, clinical physicians and biomedical engineers working together in a secured, efficient, and transparent cooperative environment, and image communication, storage and computing are important components in translational biomedical imaging research and clinical applications. We designed and developed an e-Science platform integrated with high performance image communication, storage and computing for biomedical imaging research and application cross multiple academic institutions and hospitals in Shanghai. In this presentation, we give preliminary design work on this novel platform and discuss about preliminary results, challenges and solutions in building this platform.

Materials and Methods:

The e-Science platform was designed with service-oriented architecture integrated with grid-based image communication, storage and high performance computing. A virtual organization mechanism with PI/Task oriented research information model (RIM) was presented to support collaborative research work flows defined by PI. MTOM/XOP Web Service, grid-based storage and CPU/GPU enabled high performance computing cluster (HPCC) were introduced to enable DICOM and non-DICOM biomedical image communication, distributed image storage and huge image data analysis and computation in this e-Science platform.

Results:

The developed e-Science system has deployed in Micro-PET/CT research center of Ruijing hospital, Med-X Research Institute of SJTU, and Chinese Academy of Science to support multi-disciplines translational biomedical imaging research cross healthcare enterprises and academic institutions.

New Technologies and Results to be Presented:

A novel image processing pipelines from image acquisition, communication, archiving, computation and presentation were developed

to support various kinds of translational biomedical imaging research work flows defined by PI.

Conclusions:

The preliminary testing results showed that this e-Science platform can provide powerful image communication, storage and computation capability for multiple disciplines of medical researchers, clinical physicians and biomedical engineers working together to execute their research works without barriers and difficulties.

8674-13, Session 3

Transmission of DICOM studies using multi-series DICOM format

Mahmoud M. Ismail, James F. Philbin, Johns Hopkins Univ. (United States)

The DICOM standard defines the application level network protocol used to send and receive medical images. DICOM is defined on top of TCP. DICOM addresses many issues associated with medical image transmission; however, sending and receiving large studies is inefficient because they are transmitted one object at a time. The Multi-Series DICOM (MSD) format has been introduced as a solution for the large study problem. It can store an entire study in a single object. The metadata information in the MSD object is free of repetition. In this work, the advantage of sending and receiving DICOM studies as MSD objects is investigated. A set of DICOM studies is stored in two formats, traditional Single Frame DICOM (SFD) and MSD. The time required to send the studies in both formats synchronously and asynchronously is monitored. The results show there is a significant reduction in the time required to synchronously send the studies in MSD format compared to SFD format and a small improvement sending asynchronously. Sending studies synchronously in SFD format results in a delay waiting for the acknowledgment for each DICOM instance sent before sending subsequent ones. In the asynchronous approach, the time reduction is a direct result of the difference in metadata size between SFD and MSD formats and the lower number of acknowledgments sent back from the received application entity to the sender. Both approaches show it is more efficient to send DICOM studies as MSD objects.

8674-14, Session 3

Image management and analysis in OpenClinica using web services

Thomas M. Deserno, Christian Samsel, Johan Gehlen, Daniel Haak, RWTH Aachen (Germany)

Although image-based measures have become an important surrogate for primary endpoints in controlled clinical trials, electronic data capture (EDC) insufficiently supports image and signal data files. In this paper, we suggest a simple extension of OpenClinica, the world's largest open source EDC system, to handle image data files, process image and signal data, and fill out the electronic case report forms (eCRF) accordingly. We use the web service server interface that is integrated with OpenClinica. The missing client component is substituted by JavaScript that is embedded into the eCRF definition. JavaScript is also used to display images within the OpenClinica interface. The counterpart system was developed using the Google Web Toolkit (GWT) and the Java application programming interface (API) for eXtensible Markup Language (XML) web services (JAX-WS). Image processing is implemented in Java using ImageJ libraries. We demonstrate the workflow for CRFs of a conjunctival provocation test, where two photographs of a human eye are captured, transferred into the eCRF, segmented and measured. The secure file transfer protocol (SFTP) is used to transfer the data files between the systems, and web services are used to fill the eCRFs, which also integrate resulting images generated by the analysis process. Both, images as well as computed measures are automatically displayed within the OpenClinica eCRFs and can be evaluated by the study nurse immediately after file upload. This allows re-capturing of images in case of evaluation failure, and avoids elaborative query management. In future, DICOM-based data transfer will be implemented.

8674-15, Session 3

Recommending images of user interests from the biomedical literature

Steven Clukey, The Univ. of Tennessee Knoxville (United States); Songhua Xu, Oak Ridge National Lab (United States)

Every year thousands of new biomedical images are published in thousands of different journals and conferences, this makes finding the subset of images that relates to one person's interests quite a daunting task. This vast amount of literature creates a need for simple and intelligent tools that can help researchers navigate through it all to find what is of interest to them. Currently there are tools available that allow searches based on topics and keywords, but this searching must be done manually, and is often very broad, so it can take quite some time to filter though all of the results. A better system is one that can automatically deliver relevant content to a researcher without their need to spend hours manually entering their interests or filtering extraneous results. This can be done with a system that determines a researcher's interests without consulting the researcher at all, and then recommending images to them that is similar to their interests. This system relates the relevance of images to the relevance of the document that contains the image, so that documents that are related to the researcher's interests can be found, and then the images contained in those documents are recommended. This technology will greatly improve a researcher's ability to stay up to date in their fields of study by allowing them to automatically and effortlessly search through the vast amounts of new academic literature to find images and documents that they will be interested in.

8674-16, Session 4

Storage and breast region segmentation for a non-distributed approach to clinical scale content-based image retrieval in mammography

Fumbeya Marungo, Paul Taylor, Univ. College London (United Kingdom)

The goal of the work to be presented is to lay the foundation for implementing a personal computer Content-Based Image Retrieval (CBIR) system that can search a clinical scale mammogram archive. For a system to be relevant to clinicians it must be able to search over the large number of mammograms a PACS stores. We therefore chose to use the largest publically available mammography dataset, the Digital Database for Screening Mammography (DDSM).

We modernized DDSM using the DICOM supported PNG image format to store the mammogram images and using a combination of an embedded database and compressed files to store the non-image data. In addition we performed image segmentation to extract the breast region on all 10,420 mammograms in the DDSM using a combination of thresholding and region growing. The resulting image masks are stored in compressed files. We then implemented ImageJ plug-ins to apply the image masks and DDSM regions of interest.

Generally mammography CBIR work, including interfaces with the DDSM, employs distributed approaches such as grid computing, client/server, or web services. Our work demonstrates that approaches using a single personal computer are now feasible due to the increases in computing power.

We found that the new dataset requires less than 256GB in storage. A single computer can perform automatic breast region segmentation in a mean time of 22.1 seconds per image while processing three images concurrently.

Due to the DDSM's inaccessibility often only a subset or a different, much smaller, dataset is used. Our work not only makes the entire DDSM accessible using of standard open-source technologies including ImageJ, and embedded SQL databases. We also believe that the approach used for the DDSM will be similar to the approaches for CBIR storage and processing in clinical PACS.

8674-17, Session 4

Determining the importance of figures in journal articles to find representative images

Henning Müller, Univ. of Applied Sciences Western Switzerland (Switzerland); Antonio Foncubierta-Rodríguez, Univ. of Applied Sciences Western Switzerland (Switzerland); Chang Lin, Fujian Medical Univ. (China); Ivan Eggel, Univ. of Applied Sciences Western Switzerland (Switzerland)

When physicians are searching for articles in the medical literature, images of the articles can help determining relevance of the article content for a specific information need.

The visual image representation can be an advantage in effectiveness (quality of found articles) and also in efficiency (speed of determining relevance or irrelevance) as many articles can likely be excluded much quicker by looking at a few representative images.

In domains such as medical information retrieval, allowing to determine relevance quickly and accurately is an important criterion.

This becomes even more important when small interfaces are used as it is frequently the case on mobile phones and tablets to access scientific data whenever information needs arise.

To get a clearer idea of image relevance in articles, a user test with a physician was performed who classified images of biomedical research articles into categories of importance that can subsequently be used to evaluate algorithms that automatically select images as representative examples.

The manual sorting of images of 50 journal articles of BioMedCentral with each containing more than 8 figures by importance also allows to derive several rules that determine how to choose images and how to develop algorithms for choosing the most representative images of specific texts.

This article describes the user tests and can be a first important step to evaluate automatic tools to select representative images for representing articles and potentially also images in other contexts, for example when representing patient records or other medical concepts when selecting images to represent RadLex terms in tutorials or interactive interfaces for example.

This can help to make the image retrieval process more efficient and effective for physicians.

8674-18, Session 4

Separating compound figures in journal articles to allow for subfigure classification

Ajad Chhatkuli, Univ. of Applied Sciences Western Switzerland (Switzerland) and Univ. of Burgundy, Le Creusot (France); Antonio Foncubierta-Rodríguez, Dimitrios Markonis, Univ. of Applied Sciences Western Switzerland (Switzerland); Fabrice Mériaudeau, Univ. de Bourgogne (France); Henning Müller, Univ. of Applied Sciences Western Switzerland (Switzerland) and Medical Informatics, Univ. Hospitals & Univ. of Geneva (Switzerland)

Images in scientific journals represent an important part of the knowledge stored in the medical literature.

Figure classification has received much attention as the information of the image types can be used in a variety of contexts to focus image search and filter out unwanted information or noise.

A major problem in figure classification is the fact that many figures in the biomedical literature are compound figures and do often contain more than a single modality.

Some journals separate sub-figures into several images but most journals require the separation of the compound figures using additional tools.

This article is based on a data set of manually annotated figures that was created for the ImageCLEF 2012 benchmark and contains over 3000 manually classified compound figures.

The total database of document figures actually contains over 300'000 images and of these over 5000 were manually classified with a compound figure rate of slightly above 50%.

This means that over 150'000 compound figures exist in the data set, leading to potential problems for image retrieval systems.

Manual analysis determined the separation lines of the sub--figures for a training set to test the system and then a test set to analyze its performance.

The automatic tools presented can reach a reasonable accuracy in separating compound figures.

Still, if very high accuracy is required the systems become complex as the variety and types of sub figures is extremely large.

The tools described in this article were tested on a database of approximately 150'000 compound figures from the biomedical literature making these images available for further research

and allowing to filter important information from them to increase content--based medical image retrieval.

8674-19, Session 4

Example-based segmentation for breast mass images

Qingying Huang, Sun Yat-sen Univ. (China); Songhua Xu, Oak Ridge National Lab. (United States); Xiaonan Luo, Sun Yat-sen University (China)

We propose a new example-based mass segmentation algorithm for breast mass images. The training examples used in our algorithm are prepared by three medical imaging professionals who manually outlined mass contours on 45 sample breast mass images. These manually segmented mass images are then partitioned into small regular grid units to be used as base reference units in our algorithm. Each time when our algorithm is applied to segment a previously unseen breast mass image, it first detects grid cell regions in the image that likely overlap with the underlying mass region. Upon identifying these broader candidate regions, our algorithm then locates the exact mass contour through an example based segmentation procedure. In this process, the algorithm retrieves, transfers, and re-applies the human expert knowledge regarding mass segmentation as encoded in the segmentation samples. The key advantage of our approach lies in its adaptability in tailoring to the skills and preferences of multiple experts through simply switching to a different corpus of human segmentation samples. To explore the effectiveness of our new approach, we comparatively evaluated the accuracy of our algorithm for mass segmentation against segmentation results produced both by several medical imaging professionals manually and by a state-of-the-art level set based method automatically. The comparison results demonstrate that our algorithm achieves a higher accuracy than the level set based peer method with statistical significance; with regard to the manual segmentation results, the automatic mass segmentation results generated by our method attains a very comparable visual quality.

8674-21, Session 4

Text- and content-based biomedical image modality classification

Daekeun You, National Library of Medicine (United States); Md

Mahmudur Rahman, National Library of Medicine (United States); Sameer Antani, Dina Demner-Fushman, George R. Thoma, National Library of Medicine (United States)

In this paper we present our methods for medical image modality classification and the results submitted to the medical image classification and retrieval track of ImageCLEF2012. Image modality detection is an important task toward achieving high performance in biomedical image and article retrieval by primarily reducing the search space to the set of relevant modalities. We participated in the competition and developed several modality classification methods using visual and textual features extracted from images and text data such as figure captions, article citations, and MeSH®, respectively. Our hierarchical classification method using multimodal (mixed textual and visual) and several class-specific features achieved the highest classification accuracy of 63.2% among our submitted methods and it was ranked within the submissions from the top three groups.

8674-22, Session 5

Extending the XNAT archive tool for image and analysis management in ophthalmology research

Andreas Wahle, Kyungmoo Lee, Adam T. Harding, The Univ. of Iowa (United States); Mona K. Garvin, The Univ. of Iowa (United States) and Veterans Affairs (United States); Meindert Niemeijer, Milan Sonka, The Univ. of Iowa (United States); Michael D. Abramoff, The Univ. of Iowa (United States) and Veterans Affairs (United States)

In ophthalmology, various modalities and tests are utilized to obtain vital information on the eye's structureand function. For example, optical coherence tomography (OCT) is utilized to diagnose (also mass screening) and aid treatment of eye diseases like macular degeneration or glaucoma. Such data are complemented by photographic retinal fundus images and functional tests on the visual field. DICOM isn't widely used yet,

though, and frequently images are encoded in proprietary formats. The Extensible Neuroimaging Archive Tool (XNAT) is an open-source NIH-funded framework for research PACS and is in use at the University of Iowa for neurological research applications. Its use for ophthalmology was hence desirable but posed new challenges due to data types thus far not considered and the lack of standardized formats. We developed custom tools for data types not natively recognized by XNAT itself using XNAT's low-level REST API. Vendor-provided tools can be included as necessary to convert proprietary data sets into valid DICOM. Clients can access the data in a standardized format while still retaining the original format if needed by specific analysis tools. With respective project-specific permissions, results like segmentations or quantitative evaluations can be stored as additional resources to previously uploaded datasets. Applications can use our abstract-level Python or C/C++ API to communicate with the XNAT instance. This paper describes concepts and details of the designed upload script templates, which can be customized to the needs of specific projects, and the novel client-side communication API which allows integration into new or existing research applications.

8674-23, Session 5

SuperRIVAM: software for the computation of the super-resolution of medical images and video

Aldo Camargo, Ingenia Technology Ltd. (Peru); Enzo Camargo, Engineering & Technology (Peru)

Super-resolution is the process to construct an image of better quality based on images of low quality. Super-resolution of medical images has been studied for many years, but there is not a software that computes it. Super-rivam is a software that is based in 6 different algorithms to compute the super-resolution. Two of them, use only one image to produce the super-resolution and four of them use two or more image to compute the super-resolution images (video). Two of these algorithms were developed by our team of researches.

The algorithms based on only one image are useful for X-ray , CT, Tomography, etc. The algortihms based on two or more images are useful for ecographies. The paper explains the algorithms and gives a comparison between them. The results shown are the summary of more than 200 different test to the algorithms.

8674-24, Session 5

Role of an imaging informatics-based DICOM-RT cancer registry in evaluating treatment parameters of IMRT for prostate cancer

Ruchi R. Deshpande, Alyssa Zhou, Jeffrey Zhang, The Univ. of Southern California (United States); John DeMarco, Univ. of California, Los Angeles (United States); Brent J. Liu, The Univ. of Southern California (United States)

Cancer registries are information systems that enable easy and efficient collection, organization and utilization of data related to cancer patients for the purpose of epidemiological research, evidence based medicine and planning of public health policies. Our research focuses on developing a web-based system which incorporates aspects of both cancer registry information systems and medical imaging informatics, in order to provide decision support and quality control in external beam radiation therapy. Integrated within this system is a knowledge base composed of retrospective treatment plan data sets of 100 patients, organized in a systematic fashion to aid query, retrieval and data mining. A major cornerstone of our system is the use of DICOM RT data sets as the building blocks of the database. This offers enormous practical advantages since it establishes a framework that can assimilate data from different treatment planning systems and across institutions by making use of a widely used standard – DICOM. Our tool will help clinicians to assess their dose volume constraints for prospective patients. This is done by comparing the anatomical configuration of an incoming patient's tumor and surrounding organs, to that of retrospective patients in the knowledge base. Treatment plans of previous patients with similar anatomical features are retrieved automatically for review by the clinician. The system helps the clinician decide whether his dose/volume constraints for the prospective patient are optimal based on the constraints of the matched retrospective plans. Preliminary results indicate that this small-scale cancer registry could be a powerful decision support tool in radiation therapy treatment planning in IMRT.

8674-25, Session 5

An imaging informatics-based multimedia electronic medical record (eMR) system for data management and decision support in rehabilitation research

Ximing Wang, Sneha K. Verma, Yi Qin, Josh Sterling, Alyssa Zhou, Jeffrey Zhang, Clarisa Martinez, Narissa Casebeer, Hyunwook Koh, Carolee Winstein, The Univ. of Southern California (United States); Brent J. Liu, The Univ. of Southern California (United States)

Rehabilitation engineering is the systematic application of engineering sciences to distribute technological solutions to problems confronted by individuals with disabilities. With the rapid development of science and

technology, large-scale rehabilitation centers and clinical rehabilitation trials usually involve a large volume of multimedia data. Moreover, due to the global aging crisis (e.g., U.S.'s 76 million baby boomers begin to retire), millions of new patients with age-related chronic diseases(such as Chronic Spinal Cord Injury) will produce huge amounts of data and contribute to soaring costs of medical care. Hence, a solution for effective data management and decision support will significantly reduce the expenditure and finally improve the patient life quality.

Inspired from the concept of the electronic medical record (eMR), we developed a system prototype for this field of rehabilitation engineering. The system is subject-oriented and customized for specific projects. The system components include data entry, multimedia data presentation and data retrieval. To process the multimedia data, the system includes a DICOM viewer with annotation tools and video/audio player. The system also serves as a platform for integrating decision-support tools and data mining tools.

Based on the prototype system, we developed two specific applications: 1) DOSE(a phase 1 randomized clinical trial to determine the optimal dose of therapy for rehabilitation of the arm and hand after stroke.); and 2) NEXUS project from the Rehabilitation Engineering Research Center(RERC, a NIDRR funded Rehabilitation Engineering Research Center).

Currently, the system is being evaluated in the context of the DOSE trial with a projected enrollment of 60 participants over 5 years, and will be evaluated by the NEXUS project with 30 subjects. By applying the eMR concept, we developed a system in order to improve the current research workflow, reduce the cost of managing data, and provide a platform for the rapid development of future decision-support tools.

8674-26, Session 5

Training system for digital mammographic diagnoses of breast cancer

Ricardo L. Thomaz, Marcela G. N. Crozara, Ana C. Patrocinio, Univ. Federal de Uberlândia (Brazil)

As the technology evolves, the analog mammography systems are being replaced by digital systems. The digital system uses video monitors as the display of mammographic images instead of the previously used screen-film and negatoscope for analog images. The change in the way of visualizing mammographic images may require a different approach for training the health care professionals in diagnosing the breast cancer with digital mammography. Thus, this paper presents a computational approach to train the health care professionals providing a smooth transition between analog and digital technology and also training to use the advantages of digital image processing tools to diagnose the breast cancer. This computational approach consists of a software where is possible to open, process and diagnose a full mammogram case from a database, which has the digital images of each of the mammographic views. The software communicates with a gold standard digital mammogram cases database. This database contains the digital images in Tagged Image File Format (TIFF) and the respective diagnoses according to BI-RADSTM, these files are read by software and shown to the user as needed. There are also some digital image processing tools that can be used to provide better visualization of each single image. The software was built based on a minimalist and a user-friendly interface concept that might help in the smooth transition. It also has an interface for inputting diagnoses from the professional being trained, providing a result feedback. This system has been already completed, but hasn't been applied to any professional training yet.

8674-27, Session 6

The digital operating room: towards intelligent infrastructures and processes *(Keynote Presentation)*

Heinz U Lemke, International Foundation for Computer Assisted Radiology and Surgery (Germany) and Innovation Center Computer Assisted Surgery (ICCAS) (Germany); Leonard Berliner, New York Methodist Hospital (United States)

Based on current research and development activities, a timeline with five stages of maturity levels for the development of the Digital Operating Room (DOR) during the first quarter of the twenty-first century will be outlined.

In particular, there are several areas of technology development for the DOR such as

(1) Devices, including signal detection and recording, robotics, navigation systems and simulation technologies, which allow more precision in the delivery of personalized interventional therapy;

(2) IT Infrastructure and Standards, including DICOM, IHE, EMR, and Therapy Imaging and Model Management System (TIMMS) infrastructure for the storage, integration, processing and transmission of patient specific data in and outside the operating room; and

(3) Functionalities, including patient specific modeling for selected interventional processes, optimization of surgical workflow as well as TIMMS engines and repositories for improving the overall quality of surgical interventions.

Patient specific modeling, work flow management and standards are key aspects for the development of DOR technologies. They will be the prerequisite for intelligent infrastructures and processes in the digital operating room of the future.

8674-28, Session 6

In memory of three pioneers: Ledley (Biomedical Imaging), Greenfield (Medical Physics) and Kangarloo (PACS and Informatics)

Han K. Huang, The Univ. of Southern California (United States)

In 2012, we lost three pioneers: Robert S. Ledley in Biomedical Imaging, Moses Greenfield in Medical Physics, and Hooshang Kangarloo in PACS and Informatics. They had their own respective background, interest, and contribution to science and technology which cemented certain cornerstones of today's Biomedical Imaging Informatics. Among other accomplishments, this memory focuses in their contributions related to medical imaging, medical physics, PACS and informatics. I was fortunate to have the opportunity to be mentored and worked with them during their progressive carrier paths.

8674-29, Session PSWed

An intelligent monitoring and management system for cross-enterprise biomedical data sharing platform

Tushen Wang, Yuanyuan Yang, Jianguo Zhang, Shanghai Institute of Technical Physics (China)

Materials and Methods:

The intelligent monitoring and management system for cross-enterprise biomedical data sharing platform comprises one or more center management module (CMM), many monitoring clients (MC) and consumer clients (CC). We designed a message communication framework based on XMPP (Extensible Messaging and Presence Protocol) which provides send-response and publish-subscribe communication pattern between CMM and MC. There are two type of Message in the monitoring system, one is status-type message which contains node resource and service status data, the other is control-type message which contains operative instruction such as process restart, node life cycle control. Each MC collects the status of system resources including CPU, memory, disk I/O and network I/O. It also collects status

of services, such as database, process, DICOM communication service and image routing service. These collected data is encapsulated as structural data, embedded into XMPP Message and then sent to CMM through XMPP channel. The CMM extracts data from receiving message and analyze it for resource statistic, performance estimation. When node failure or service unavailable occurs, CMM invokes rule engine with customized rule sets loading to diagnose and restore. As the rule engine is running, control-type message could be generated and sent to MC for executing. Besides, the CMM publishes services for CC to query the latest or even real-time monitoring data. The CC could be a browser which is used to display the historical and current status of whole system and customize workflow of diagnosis and restoring. It could also be an application which schedule the storage and computing resource considering load balance and quality of service.

Results:

The intelligent monitoring and management system for cross-enterprise biomedical data sharing platform were able to endure with the stress of monitoring more than 100 nodes concurrently, each monitoring client cost lower than 50MB memory and little CPU and network utilization rate, and doesn't cause obvious performance degradation of the system.

New Technologies and Results to be presented:

We designed a message communication framework based on XMPP (Extensible Messaging and Presence Protocol) which provide send-response and publish-subscribe communication pattern. We also adopt rule engine for diagnosis and restoring node failure. It helps promote the flexibility since it separates changeable business logic from code.

Conclusion:

The intelligent monitoring and management system for cross-enterprise biomedical data sharing platform integrated in our e-Science platform provides the function of quickly monitoring ,early failure detection and restoring, It promotes the robustness, reliability and service continuity of cross-enterprise biomedical data sharing platform.

8674-30, Session PSWed

3D segmentation and image annotation for quantitative diagnosis in lung CT images with pulmonary lesions

Suo Li, Shanghai Institute of Technology and Physics (China); Jianguo Zhang, Shanghai Institute of Technical Physics (China)

Pulmonary nodules, honeycombing and ground glass opacities are highly significant findings in high-resolution computed tomography (HRCT) of patients with COPD (Chronic Obstructive Pulmonary Disease). Currently, most of the studies have focused on two-dimensional quantitative analysis of these kinds of deceases. Compared to two-dimensional images, three-dimensional quantitative analysis can take full advantage of isotropic image data acquired by using thin slicing HRCT in space and has better quantitative precision for clinical diagnosis. This presentation gives an approach to segment 3D disease areas of nodules, honeycombing and ground glass opacities in lung CT images, and use AIML (Annotation and image makeup language) to annotate the segmented 3D pulmonary lesions which may provide more features and information to the radiologists in clinical diagnosis.

8674-31, Session PSWed

Rapid deployment of a Monte Carlo simulation system using diskless remote boot in Linux in a PACS environment

Yuan-Jen Chang, Central Taiwan University of Science and Technology (Taiwan); Yan-Lin Liu, Cheng-Ting Shih, National Tsing Hua Univ. (Taiwan); Shu-Jun Chang, Institute of Nuclear Energy Research (Taiwan); Jay Wu, China Medical Univ. (Taiwan)

Monte Carlo (MC) simulation has been widely used as the gold standard for interaction of radiation with matter in the fields of medical physics, radiation therapy, and nuclear medicine. However, it is time consuming and may require a lot of computational resources. Generally, a dedicated high performance computing cluster is use to improve the efficiency, but it is costly and lacks of the ability to run routine tasks. In this study, we proposed a method for rapid deployment of computing platform for MC simulation in the PACS environment using review workstations as computing nodes. The workstations were booted from the network and initialed a RAM disk as the boot sector. The simplified Linux operating system and the Monte Carlo N-Particle Transport Code Version 5 were transferred from a DRBL (Diskless Remote Boot in Linux) server to each computer automatically. The cluster computing environment can be established within 4 minutes. We compared a commercially available dedicated cluster (HyperCluster, Infowrap, Taiwan) with the DRBL cluster. The results show that the commercial cluster had slightly higher AF than the DRBL cluster. The simulation time of the commercial and DRBL clusters for 2.0x108 histories was 37,151 and 40,021 sec, respectively. When the number of rendezvous increased to 20, the maximum time differences between both clusters were 95 and 85 sec for the megabit and gigabit switches. We conclude that the DRBL cluster can be quickly deployed to the non-workloaded review workstations in the PACS. Thus, the MC technique could be broadly used for radiological research in the healthcare facility.

8674-32, Session PSWed

Integration of PACS and CAD systems using DICOMDIR and open-source tools

Jiaxin Huang, Alexander Ling M.D., Ronald M. Summers M.D., Jianhua Yao, National Institutes of Health (United States)

The advancements of the last 30 years have made picture archiving and communication systems (PACS) an indispensable technology to improve the delivery and management of clinical imaging services. Similarly, the maturation of algorithms and computer aided detection (CAD) systems has enhanced the interpretation and diagnosis of radiographical images. However, the lack of integration between the two systems inhibits the rate of development and application of these recent innovations in reaching the clinical users of PACS. We aim to enhance the clinical efficiency of CAD systems by developing an accessible, fully automated, user-friendly, and integrated linkage of CAD and PACS systems. This is the first integration initiative to take advantage of DICOMDIR file and its ability to index DICOM files, allowing images outside of PACS to be viewed within PACS. In this demonstration, the CAD system evaluates CT chest exams to detect lesions in the ribs and produces whole rib map images, screenshots, and detection report. A script executes the rib CAD system and creates a DICOMDIR file using 'DCMTK', an open-source DICOM toolkit. We evaluated our system on thirty 5mm slice thickness and thirty 2mm slice thickness image studies and demonstrated a time saving efficiency of 93s±14s and 221s±17s per exam, respectively, compared to the current non-integrated workflow of using CAD systems. The advantages of this system are that it is easy to implement, requires no additional workstation and training, and allows CAD results to be viewed in PACS without disrupting radiology workflow, while maintaining the independence of both technologies.

8674-33, Session PSWed

Teleradiology network system on cloud using the web medical image conference system with a new information security solution

Hitoshi Satoh, Tokyo Health Care Univ. (Japan)

Our method has the function of automatic backup. With automatic backup technology on cloud, if there is a failure in a single tally, there is redundant data already copied to other tally. Confidential information is preserved at an individual Data Center connected through internet because individual medical information cannot be decoded by using one tally at all. Therefore, even if one of the Data Centers is struck and information is damaged due to the large area disaster like the great earthquake of Japan, the confidential medical information can be decoded by using the tallies preserved at the data center to which it escapes damage. Moreover, by using tokenization, the history information of dividing the confidential medical information into two or more tallies is prevented from lying scattered by replacing the history information with another character string (Make it to powerlessness). As a result, information is available only to those who have rightful access it and the sender of a message and the message itself are verified at the receiving point. We propose a new information transmission method and a new information storage method?with a new information security solution.

8674-34, Session PSWed

Developing an interactive and MIRC-compliant radiology teaching file system

Marcelo dos Santos, Asa Fujino, Univ. de Sao Paulo (Brazil)

Purpose:

Currently, teaching files are present in many Radiology departments and they are useful, e.g. to illustrate pertinent teaching points. For many years, the teaching of Radiology had involved the use of case-based files presented in filmed images accompanied by relevant clinical data and a short write-up of the clinical condition. In this approach, problems exist with creating, maintaining, tracking, storing, and sharing cases in film-based systems. However, the popularization of digital – digitalized and film-less radiology, and increasing use and establishment of digital picture archiving and communication systems (PACS) – has presented good opportunities to design teaching file solutions.

Looking at the importance of images for Medicine teaching practice, the Radiological Society North America (RSNA) has worked on the development of the Medical Imaging Resource Center (MIRC). The MIRC initiative aims to facilitate the creation of repositories for medical images and related information, as well as to investigate and propose standards to be used in the development of teaching file and clinical dataset exchange.

By using experiences reported in other studies, in this work, an user-centered Radiology ETF system is developed such as an instance of MIRC compliant medical image database. The main focus has been on offering a set of user-centered application concerning the usage contexts.

8675-1, Session 3

Ultrasound strain imaging for quantification of tissue function: cardiovascular and muscle applications *(Keynote Presentation)*

Chris L. de Korte, Radboud Univ. Nijmegen Medical Ctr. (Netherlands)

With ultrasound Imaging, the deformation of tissue can be measured. When a force is applied on the tissue, the tissue is deformed. Quantification of tissue deformation can be used to assess the mechanical properties of tissue (elastography). If the tissue under interrogation is actively deforming, the deformation is directly related to the function of the structure (strain imaging). The first approach can be used for atherosclerotic plaques characterization while with the latter application the contractility of the heart or skeletal muscles can be assessed.

We developed radio frequency (rf) based ultrasound methods to assess the deformation at higher resolution and with higher accuracy than commercial methods using conventional image data (Tissue Doppler Imaging and 2D speckle tracking methods). However, this method is limited to measuring strain only along the ultrasound beam direction, so 1D. We further extended this method to multiple directions by using compounding of data acquired at multiple beam steered angles.

In arteries, the presence of vulnerable plaques may lead to acute events like stroke and myocardial infarction. Consequently, timely detection of these plaques is of great diagnostic value. Non-invasive ultrasound strain compounding is currently being evaluated as diagnostic tool to identify the vulnerability of plaques. In the heart, we determined the strain locally and at high resolution resulting in a local assessment in contrary to conventional global functional parameters like cardiac output or shortening fraction. In cleft lip patients we were able to quantify orbicular muscle function and correlate that with disability of the patients.

8675-2, Session 3

Pulmonary ultrasound elastography: a feasibility study with phantoms and ex-vivo tissue

Man Nguyen, Philips Research North America (United States) and Univ. of Southern California (United States); Hua Xie, Kamila Paluch, Doug Stanton, Bharat Ramachandran, Philips Research North America (United States)

Elastography has become widely used for minimally invasive diagnosis in many tumors as seen with breast, liver and prostate. Among different modalities, ultrasound-based elastography stands out due to advantages like being safe, real-time, and relatively low-cost. While lung cancer is the leading cause of cancer mortality among both men and women, the use of ultrasound elastography for lung cancer diagnosis has hardly been investigated due to the limitations of ultrasound in air. In this work, we investigate the use of static-compression endobronchial ultrasound elastography by a 3D trans-oesophageal echocardiography (TEE) transducer for lung cancer diagnosis. A water-filled balloon was designed to 1) improve the visualization of endobronchial ultrasound and 2) to induce compression via pumping motion inside the trachea and bronchiole. In a phantom study, we have successfully generated strain images indicating the stiffness difference between the gelatin background and agar inclusion. The strain ratio of 4:1 was confirmed with Philips ultrasound strain imaging product Elasto ®. For ex-vivo lung study, different tissue ablation methods were implemented to achieve tumor-mimicking tissue. Unlike in liver, RF ablation in lung was limited by the air content. On the other hand, stiff ablated lung tissue using direct heat was obtained and detected with our proposed method. These results suggest the feasibility of pulmonary elastography to differentiate stiff tumor tissue from normal tissue. Further studies, including temperature-controlled ablation and 3D elastography, are currently in progress.

8675-3, Session 4

Correlation-based discrimination between cardiac tissue and blood for segmentation of 3D echocardiographic images

Anne E. Saris, Maartje M. Nillesen, Radboud Univ. Nijmegen Medical Ctr. (Netherlands); Richard G. P. Lopata, Technical Univ. Eindhoven (Netherlands); Chris L. de Korte, Radboud Univ. Nijmegen Medical Ctr. (Netherlands)

Automated segmentation of 3D echocardiographic images in patients with congenital heart disease is challenging, because the boundary between blood and cardiac tissue is poorly defined in some regions. Cardiologists mentally incorporate movement of the heart, using temporal coherence of structures to resolve ambiguities. Therefore, we investigated the merit of temporal cross-correlation for automated segmentation over the entire cardiac cycle.

Optimal settings for maximum cross-correlation (MCC) calculation, based on a 3D cross-correlation based displacement estimation algorithm, were determined to obtain the best contrast between blood and myocardial tissue over the entire cardiac cycle. Resulting envelope-based as well as RF-based MCC-values were used as additional external force in a deformable model approach, to segment the left-ventricular cavity in entire systolic phase. MCC-values were tested against, and combined with, adaptive filtered, demodulated RF-data. Segmentation results were compared with manually segmented volumes using a 3D Dice similarity index (3DSI).

Results in 3D pediatric echocardiographic images sequences (n = 4) demonstrate that incorporation of temporal information improves segmentation. The use of MCC-values, either alone or in combination with adaptive filtered, demodulated RF-data, resulted in an increase of 3DSI in 75% of the cases (average 3DSI increase: 0.71 to 0.82). Results might be further improved by optimizing MCC-contrast locally, in regions with low blood-tissue contrast. Reducing underestimation of the endocardial volume due to MCC processing scheme (choice of window size) and consequential border-misalignment, could also lead to more accurate segmentations. Furthermore, increasing the frame rate will also increase MCC-contrast and thus improve segmentation.

8675-4, Session 4

3D segmentation and reconstruction of endobronchial ultrasound

Xiaonan Zang, The Pennsylvania State Univ. (United States); Mikhail Breslav, Boston Univ. (United States); William E. Higgins, The Pennsylvania State Univ. (United States)

State-of-the-art practice for lung-cancer staging bronchoscopy often draws upon a combination of endobronchial ultrasound (EBUS) and multidetector computed-tomography (MDCT) imaging. While EBUS offers real-time in vivo imaging of suspicious lesions and lymph nodes, its low signal-to-noise ratio and tendency to exhibit missing region-of-interest (ROI) boundaries complicate diagnostic tasks. Furthermore, past efforts did not incorporate automated analysis of EBUS images and a subsequent fusion of the EBUS and MDCT data. To address these issues, we propose near real-time automated methods for three-dimensional (3D) EBUS segmentation and reconstruction that generate a 3D ROI model along with ROI measurements. Results derived from

phantom data and lung-cancer patients show the promise of the methods. In addition, we present a preliminary image-guided intervention (IGI) system example, whereby EBUS imagery is registered to a patient's MDCT chest scan.

8675-5, Session 4

Statistical segmentation of carotid plaque neovascularization

Zeynettin Akkus, Johan G. Bosch, Erasmus MC (Netherlands); Gonzalo V. S. Ferrero, Valladolid Univ. (Spain); Diego D. B. Carvalho, Guillaume Renaud, Stijn C. H. van den Oord, Gerrit L. ten Kate, Arend F. L. Schinkel, Nico de Jong, Antonius F. W. van der Steen, Erasmus MC (Netherlands)

In several studies, intraplaque neovascularization (IPN) has been linked with plaque vulnerability. The recent development of contrast enhanced ultrasound enables to detect IPN, but an accurate quantification of IPN is a big challenge due to noise, subtle contrast response, blooming of contrast and artifacts. We present an algorithm that automatically estimates the location and amount of contrast within the plaque over time. Plaque pixels are initially labeled through an iterative expectation-maximization (EM) algorithm using information from neighboring pixels through a 3-by-3 smoothing kernel. The used algorithm avoids several drawbacks of standard EM. It is capable of selecting the number of components in an unsupervised way, which is derived from minimum message length criterion. Once the best number of components within the plaque is selected, additional neighboring information using 5-by-5 (pixels) kernel is combined with the known characteristic of contrast bubbles in-order-to correct for misclassification and finalize the classification. For 10 plaques, automated segmentation results were validated with manual segmentation of contrast in 10 frames per clip. Average dice index and area ratio was found 0.73±0.1 (mean±SD) and 98.5±29.6 (%) respectively. If a pixel was labeled as contrast over more than 70% of image sequence, it was considered as artifact and discarded. Next, 20 atherosclerotic plaques were analyzed and surface area of IPN was calculated after logical OR operation over time. Average area of IPN was found 1.84±1.52 mm2. Average area of 20 plaques was 13.1±5.4 mm2. This will allow an accurate quantification of IPN to identify vulnerable plaques.

8675-6, Session 4

Extracting cardiac myofiber orientations from high frequency ultrasound images

Xulei Qin, Zhibin Cong, Rong Jiang, Ming Shen, Mary B. Wagner, Paul Kirshbom, Baowei Fei, Emory Univ. (United States)

Cardiac myofibers play an important role in stress mechanism during heart beating periods. The orientation of myofibers determines the effects of stress distribution and whole heart deformation. It is important to image and quantitatively extract these orientations for understanding cardiac physiological and pathological mechanisms and may assist with the diagnosis of chronic diseases. Ultrasound has been wildly used in cardiac diagnosis because of its ability of performing dynamic and noninvasive imaging and because of its low cost. An extraction method is proposed to automatically detect the cardiac myofiber orientation from high frequency ultrasound images. First, heart walls containing myofibers are imaged by B-mode high frequency (>20 MHz) ultrasound imaging. Second, myofiber orientations are extracted from ultrasound images using the proposed method that combines a nonlinear anisotropic diffusion filter, Canny edge detector, and Hough transform. This method is validated by the results of ultrasound data from phantoms and pig hearts.

8675-7, Session 4

3D ultrasound registration to track ovarian follicular dynamics in polycystic ovarian syndrome, a condition leading to infertility

Christian E. Anderson, Mallory R. Busso, Case Western Reserve Univ. (United States); Noam Lazebnik, William Hurd, Univ. Hospitals Case Medical Ctr. (United States); David L. Wilson, Case Western Reserve Univ. (United States)

In polycystic ovary syndrome (PCOS), follicles develop to 5–7mm but then fail to grow into mature eggs, leading to infertility. We have created software to enable tracking of individual follicles over the menstrual cycle to elucidate follicular fate in PCOS. For example, it is unknown whether a follicle with arrested development remains or disappears. Tracking requires 3D image registration. Since follicles are anchored to the ovarian cortex which is rigidly connected to the ovarian arterial system, we can exploit these features. Briefly, we segmented Doppler images of the arterial system and ultrasound images of follicles using our interactive region growth with probabilistic classification. Gaussian blurred digital spheres were placed at the centers of mass of each follicle and copied to a blurred version of the binary artery image volume. Volume pairs were registered using normalized cross correlation with rigid body or affine transformation. To test the process, we registered multiple scans of ovaries. Registration error was determined from the average Euclidean distance between corresponding follicle centers of mass. Over >50 follicle pairs, errors were 1.05±.13mm for rigid body and not much improved with affine. Since most follicles were ≥2mm in diameter, this was deemed acceptable for determination of correspondence. 3D visualizations showed excellent registration and unambiguous correspondence. Using these methods, we can for the first time determine the pathobiology of follicular fate and role of therapeutics. Results from our clinical study of baseline patients before therapy will be presented.

8675-8, Session 4

Automated detection of adipose tissue layer in ultrasound Images

Gokul Swamy, Nitya Subramaniam, GE Global Research (India); Cynthia Davis, Ying Fan, GE Global Research (United States); Sheshadri Thiruvenkadam, GE Global Research (India)

Fat ablation, using high intensity focused ultrasound (HIFU), has been a prominent area of research targeted towards potential treatment of chronically obese patients. The fat layer is primarily composed of adipose tissue often wedged in between two fibrous connective tissue layers and can be visualized using a plethora of imaging techniques such as MRI imaging, ultrasound imaging, dual energy x-ray, etc. Cosmetic ablation of adipose tissue requires a precise determination of the location and thickness of the subcutaneous fat layer. This is necessitated both in terms of locating the fat layer to be ablated and also a post ablative examination of the residual layer. The present study details the development of an image processing algorithm for automated segmentation and sizing of the adipose tissue layer from ultrasound images of subcutaneous abdominal tissue. The algorithm comprises of two major steps where in the first step the fibrous connective tissue layers are identified using a combination of vessel enhancing filtering and active contour segmentation. Subsequently, the region between any two adjacent connective tissue layers is classified into one of two categories: fat and muscle, based on the intensity of the back-scattered reflection and the textural properties of the region. The algorithm has been tested on a set of sixteen volunteer ultrasound scans and a qualitative examination of the results indicates good segmentation accuracy.

8675-9, Session 5

2D capacitive micromachined ultrasound transducer using novel tiling based on silicon frame

Youngil Kim, Kyungil Cho, Bae-Hyung Kim, Seunghun Lee, Taeho Jeon, Jongkeun Song, Samsung Advanced Institute of Technology (Korea, Republic of)

In this study, we showed the new transducer and probe integration of 2D ultrasound probe using cMUT. cMUT ultrasound probe having 8192 elements is assembled with tiling frame. Flip chip bonded cMUT-ASIC tiles were arrayed along 2x8 directions to enlarge lateral aperture. Tiling gap between two tiles was under 100μm. RTV layer that has 1mm thick is used in 2-D probe system as a lens and protection layer. Thermal module is also analized by using the thermal network analysis, which is realized with the air fans and the fins. Designed PCB circuit for tiling module which is considered with cooling spread concept is 5cm x 5cm dimension. Uniformity and performance of tiled ultrasound transducer were tested under soybean oil at 3MHz frequency sucessfully. The measured 256 elements distribution has only 4.45% deviation. If we can remove the side edge error, the deviation will be under 3%. The performance after RTV lensing showed 35% attenuation in Tx and 35~45% attenuation in Rx.

8675-10, Session 5

CMUT-based volumetric ultrasonic imaging array design for forward looking ICE and IVUS applications

Coskun Tekes, Jaime Zahorian, Sarp Satir, Toby Xu, Georgia Institute of Technology (United States); Mustafa Karaman, Isik Univ. (Turkey); Muhammad Rashid, Gokce Gurun, Jennifer Hasler, Levent Degertekin, Georgia Institute of Technology (United States)

Designing a mechanically flexible catheter based volumetric ultrasonic imaging device for intravascular and intracardiac imaging is challenging due to small transducer area and limited number of cables. With a few parallel channels, synthetic phased array processing is necessary to acquire data from a large number of transducer elements. This increases the data collection time and hence reduces frame rate and causes artifacts due to tissue-transducer motion. Some of these drawbacks can be resolved by different array designs offered by CMUT-on-CMOS approach. We recently implemented a 2.1-mm diameter single chip 10MHz dual ring CMUT-on-CMOS array for forward looking ICE with 64-transmit and 56-receive elements along with associated electronics. These volumetric arrays have the small element size required by high operating frequencies and achieve sub mm resolution, but the system would be susceptible to motion artifacts. To enable real time imaging with high SNR, we designed novel arrays consisting of multiple defocused annular rings for transmit aperture and a single ring receive array. The annular transmit rings are utilized to act as a high power element by focusing to a virtual ring shaped line behind the aperture. In this case, image reconstruction is performed by only receive beamforming, reducing total required firing steps from 896 to 14 with a trade-off in image resolution. The SNR of system is improved more than 20 dB for the same frequency and frame rate as compared to the dual ring array, which can be utilized to achieve the same resolution by increasing the operating frequency.

8675-11, Session 5

3D ultrasound imaging performance of a row-column addressed 2D array transducer: a simulation study

Morten F. Rasmussen, Jørgen A. Jensen, Technical Univ. of Denmark (Denmark)

One of the greatest challenges of real–time 3D ultrasound imaging is the data acquisition and processing from the large amount of elements needed to achieve a reasonable image quality. In this work, a method to reduce the number of active ultrasound channels on a fully populated NxN 2D array transducer from N^2 to N+N is studied. From an NxN 2D array, an Nx1 and a 1xN array are created by connecting the rows and connecting the columns of the 2D array, respectively. The first 1D array is used for ultrasound emission and the second, which is oriented orthogonal to the first, is used to receive the echoes. In the azimuth direction, parallel to the 1D receive array, standard dynamic receive focusing is applied. Focus in the elevation direction is achieved by synthetic transmit focusing. The point spread function of a 100x100 element lambda–pitch 2D array transducer is simulated at 50mm depth. With a Hamming apodization applied, a full-width-at-half-max of 2.0mm is achieved in the azimuth direction and a ?20 dB cystic resolution of 1.7mm is achieved in the depth-azimuth-plane. This demonstrates that real-time 3D imaging with a good image quality is possible using only N channels in transmit and N channels in receive of the NxN 2D array transducer.

8675-12, Session 5

Phase-rotation based receive-beamformer for miniaturized volumetric ultrasound imaging scanners using 2-D CMUT-on-ASIC arrays

Bae-Hyung Kim, Seunghun Lee, Youngil Kim, Samsung Advanced Institute of Technology (Korea, Republic of); Taeho Jeon, Samsung Advanced Institute of Technology, SEC (Korea, Republic of); Jongkeun Song, Kyungil Cho, Samsung Advanced Institute of Technology (Korea, Republic of); Dongwook Kim, Samsung Advanced Institute of Technology, SEC (Korea, Republic of)

Up-to-date CMUT technologies provide us unique opportunities to minimize the size and cost of ultrasound scanners by integrating front-end circuits into CMUT arrays. We have developed a prototype of a portable ultrasound scan-head probe, nicknamed ‘smart probe’, using 2-D phased CMUT-on-ASIC arrays of 3-MHz 250 micron-pitch by fabricating and integrating front-end electronics with 2-D CMUT array elements. Application is cardiac imaging. In the future, a higher-frequency probe may be considered for imaging carotid and abdomen. One of the objectives of our work is to design a receive beamformer architecture for the smart probe with compact size and comparable performance. We adopted a phase-rotation based receive beamformer using quadrature sampling of 4 times the center frequency, and we used a hybrid beamforming to reduce the channel counts of the system-side. Parallel beamforming of 2 to 64 beams is considered, for the purpose of saving power consumption of battery (by firing fewer times per image). This architecture has the advantage of directly obtaining I and Q components, which makes flipping the signal spectrum easy since it only requires a complex conjugate. By using the quadrature sampling, the interleaved I/Q data from the storage is acquired and I/Q demodulation for baseband processing is directly achieved without demodulators including sin and cosine lookup tables and mixers. Currently, we are extending the presented architecture to develop a true smart probe by including lower power devices and cooling systems, and bringing wireless data transmission into consideration.

8675-13, Session 5

Volumetric ultrasound image-forming using fully controllable 2D CMUT-on-ASIC arrays

Bae-Hyung Kim, Jongkeun Song, Seunghun Lee, Youngil Kim, Kyungil Cho, Samsung Advanced Institute of Technology (Korea, Republic of); Taeho Jeon, Dongwook Kim, Samsung Advanced Institute of Technology, SEC (Korea, Republic of)

In real-time 3-D ultrasound imaging using 2-D array transducers, a large number of the 2-D array elements pose challenges in fabricating and transferring signals from/into the system. This fabrication problem has been solved by using a silicon micromachining process for capacitive micromachined ultrasonic transducer (CMUT) arrays. For real-time 3-D ultrasound imaging, manipulating massive ultrasound data acquired from a large number of system channels is a challenge as is fabricating and interconnecting hundreds or thousands of elements of 2-D array with the imaging system's front-end (FE) electronics. Minimizing the number of transmitting and receiving elements and the firing events without degrading the image quality is one of the solutions to reduce the overall system complexity and improve the frame rate. We have been developing a real-time 3-D volumetric ultrasound imaging system using 2-D CMUT arrays by integrating FE electronics with a large number of 2-D array elements. Here, we explore a configuration method to design a scalable 2-D CMUT array and a new volumetric image-formation method to provide higher information rate of a volume image. In this paper, we present the 2-D CMUT-on-ASIC arrays designed to reduce the overall system complexity, and a new volume scanning and image-forming method for real-time 3-D volumetric ultrasonic imaging using 2-D CMUT-on-ASIC arrays. To evaluate our works, we performed from theoretical studies and simulated point spread functions of the array configuration to phantom experiments with off-the-line images.

8675-14, Session 6

New developments in vector velocity imaging using the transverse oscillation approach *(Keynote Presentation)*

Jørgen A Jensen, Michael J Pihl, Jacob B. Olesen, Technical Univ. of Denmark (Denmark); Peter M Hansen, Kristoffer L Hansen, Michael B Nielsen, Department of Radiology, Rigshospitalet, Copenhagen University Hospital (Denmark)

Vector velocity imaging using the Transverse Oscillation (TO) approach has recently been FDA approved for linear array transducers on a commercial platform. It can now be used clinically for studying the complex flow at e.g. bifurcations, valves, and the heart in real time. Several clinical examples from the carotid artery to the heart will be shown. The technique is also being further developed and adapted for convex and phased array probes, for spectral velocity estimation, pressure estimation, and for three dimensional tensor velocity estimation. It is shown how the methods are optimized using Field II simulations along with several examples of their performance.

8675-15, Session 6

Non-invasive measurement of pressure gradients using ultrasound

Jacob B. Olesen, Marie S. Enevoldsen, Michael J. Pihl, Jørgen A. Jensen, Technical Univ. of Denmark (Denmark)

A method for determining pressure gradients based on vector velocity ultrasound data is presented. The pressure gradients are estimated based on the Navier-Stokes' equation and velocity gradients calculated from the vector velocity data estimated using the transverse oscillation technique. The approach is validated by comparing finite element simulations to measured data from a phantom.

A carotid artery bifurcation phantom with a stenosis is used for the validation. The phantom was MR scanned to construct a mesh model for the simulation. The steady flow was simulated using Comsol Multiphysics to derive the velocity field and pressures distribution. Data were acquired from the phantom using a BK Medical Pro Focus scanner. It is equipped with a research interface which allows transfer of scanner generated vector velocity images from which pressure gradients and relative pressures can be estimated. The simulations yield pressure gradients in the stenosis from -2.5 kPa/m to 5 kPa/m and the measurements yield gradients from -5 kPa/m to 7 kPa/m. The relative precision of the pressure gradients is 25.5%. The relative pressure within the image can also be determined through a line integral. The relative precision is here 11.2% for the measured pressure across the stenosis.

8675-16, Session 6

Preliminary examples of 3D vector flow imaging

Michael J. Pihl, Matthias B. Stuart, Borislav G. Tomov, Technical Univ. of Denmark (Denmark); Jens M. Hansen, BK Medical (Denmark) and Technical Univ. of Denmark (Denmark); Morten F. Rasmussen, Jørgen A. Jensen, Technical Univ. of Denmark (Denmark)

This paper presents 3D vector flow images obtained using the recently proposed 3D Transverse Oscillation (TO) method. The method employs a 2D matrix array and estimates the three velocity components simultaneously, which is important for estimating complex flow patterns. Data are acquired using an experimental ultrasound scanner on a flow-rig system with steady flow. The vessel of the flow-rig is centered at a depth of 30 mm, and the flow has an expected 2D circular-symmetric parabolic profile with a peak velocity of 1 m/s. Ten frames of 3D vector flow images are acquired in a cross-sectional plane of the vessel orthogonal to the length axis, which coincides with the y-axis and the flow direction. Hence, only out of plane motion is expected, which is unmeasurable by current commercial scanners. Each frame consists of 31 flow lines steered from -15 to 15 degrees in steps of 1 degree in the ZX-plane. For the center line, 3200 emissions are obtained yielding 100 M-mode lines. At the center of the vessel, the mean and standard deviation of the estimated velocity vectors are (vx,vy,vz)=(-0.03,95,1.0)±(9,6,1) cm/s compared to the expected (0,96,0) cm/s. One of the 3D vector flow image frames is illustrated by the three velocity components and the true velocity magnitude. Practically no in plane motion (vx and vz) is measured, whereas the out of plane motion (vy) and the velocity magnitude exhibits the expected 2D circular-symmetric parabolic shape. The results demonstrate the capability of the 3D TO method for 3D vector flow imaging.

8675-17, Session 6

Strain estimation of carotid artery using multi-element synthetic aperture imaging with a virtual source element

Rohit Nayak, Sanghamithra Korukonda, Marvin M. Doyley, Univ. of Rochester (United States)

Cardiovascular disease (CVD) is the primary cause of morbidity and mortality. As CVD progresses, the carotid artery thickens and hardens due to atherosclerosis. Ultrasound elastography could be used to assess the changes in the elastic properties of the carotid artery. In our previous study, we demonstrated that synthetic aperture (SPA) configuration could be used to obtain higher quality strain elastograms than conventional linear-array imaging. However, the low transmit-power associated with SPA could limit its clinical application. In this paper, we report a feasibility study of using multi-element sub-aperture based SPA configuration for

elastographic imaging of carotid artery, towards improving its transmit-power. The acoustic response of an arterial cross-section of the carotid artery was simulated in Field II for different widths of the sub-aperture, at various positions of the virtual source. The normalized root mean square error (RMSE) between the true and estimated elastograms were computed to assess the imaging performance. It was observed that when the width of the sub-aperture was varied by upto 11 elements, the imaging PSF did not degrade. Specifically, the width of the main-lobe at FWHM was within 15%, and the level of the side-lobe was within 2dB of the conventional SPA. The corresponding rise in RMSE was less than 4%. The above-mentioned statistics were obtained with the virtual source located at a distance of half the width of the sub-aperture. These findings indicate the feasibility of extending the high-resolution SPA configuration for in vivo imaging of the carotid artery.

8675-18, Session 6

A new three-component signal model to objectively select power Doppler wall filter cut-off velocity for quantitative microvascular imaging

Mai Elfarnawany, Robarts Research Institute (Canada) and Biomedical Engineering Graduate Program, The Univ. of Western Ontario (Canada); James C. Lacefield, The Univ. of Western Ontario (Canada) and The Univ. of Western Ontario (Canada) and Robarts Research Institute (Canada)

The wall filter selection curve (WFSC) method was developed to automatically select cut-off velocities for high-frequency power Doppler imaging. Selection curves are constructed by plotting color pixel density (CPD) as a function of wall filter cut-off velocity. A new three-component mathematical model is developed to guide the design of an online implementation of the method for in vivo imaging. The model treats Doppler imaging as a signal detection task in which the scanner must distinguish intravascular pixels from perivascular and extravascular pixels and includes a cost function to identify the optimum cut-off velocity that provides accurate vascular quantification and minimizes the effect of color pixel artifacts on visualization of vascular structures. The goodness of fit of the three-component model to flow-phantom data is significantly improved compared to a previous two-component model (F test, $p < 0.005$). Simulations using the new model indicate that selection curves should be sampled using at least 100 cut-off velocities to ensure robust performance of the automated WFSC method and determine an upper bound on CPD variability that ensures reliable vascular quantification accuracy, defined as CPD within 5% of the reference vascular volume fraction. Results of the simulations also provide evidence that limiting the selection of the cut-off velocity to a binary choice between the middle or right end of the characteristic interval is sufficient to meet the quantification accuracy goal. The model provides an intuitive, empirical description of the relationship between system settings and blood-flow detection performance in power Doppler imaging.

8675-19, Session 7

Breast imaging with the SoftVue scanner: first results

Neb Duric, Peter Littrup, Steven Schmidt, Cuiping Li, Olivier Roy, Delphinus Medical Technologies, Inc. (United States); Lisa Bey-Knight, Karmanos Cancer Institute (United States); Roman Janer, Delphinus Medical Technologies, Inc. (United States); David Kunz, Delphinus Medical Technologies, Inc (United States); Xiaoyang Chen, Jeffrey Goll, William Greenway, Delphinus Medical Technologies, Inc. (United States); Andrea Wallen, Fouzaan Zafar, Veerendra Allada, Erik West, Ivana Jovanovic, Kuo Li, Delphinus Medical Technologies, Inc (United States)

For women with dense breast tissue, who are at the highest risk for developing breast cancer, the performance of mammography is at its worst. Consequently many cancers are missed at their earliest stages when they are the most treatable. Improved cancer detection for women with denser breasts would decrease the proportion of breast cancers diagnosed at later stages, which would significantly lower the mortality rate. MR can significantly improve on these limitations by virtue of its volumetric, radiation-free imaging capability. However, MR requires long exam times and the use of contrast agents. Furthermore, MR has long been prohibi¬tively expensive for routine use and there is a need for a low-cost equivalent alternative. Positron emission tomography is also limited by cost and radiation concerns. The lack of an alternative is a barrier to dramatically reducing mortality and morbidity because, cur¬rently, there is a trade-off between the cost effectiveness of mammography and the imaging performance of MR.

Our goal is to eliminate this trade-off by combining the low-cost advantage of mammography with the superior imaging performance of MR through the development of SoftVue, a breast scanner based on the principles of ultrasound tomography (UST). The objective of this presentation is to report on the first imaging results of SoftVue, a scanner designed for routine clinical use. The specific topics covered will be (i) clinical performance characteristics, such as patient scan time, image reconstruction time and patient throughput (ii) image reconstruction quality and (iii) level of improvement relative to our previously reported UST prototype.

8675-20, Session 7

Sound speed based patient-specific biomechanical modeling for registration of USCT volumes with X-ray mammograms

Torsten Hopp, Aurélien Stromboni, Karlsruher Institut für Technologie (Germany); Neb Duric, Barbara Ann Karmanos Cancer Institute (United States); Michael Zapf, Hartmut Gemmeke, Nicole V. Ruiter, Karlsruher Institut für Technologie (Germany)

Ultrasound Computer Tomography is an upcoming imaging modality for early breast cancer detection. For evaluation of the method, comparison with the standard method X-ray mammography is of strongest interest. To overcome the significant differences in dimensionality and compression state of the breast, in earlier work a registration method based on biomechanical modeling of the breast was proposed. However only homogeneous models could be applied, i.e. inner structures of the breast were neglected. In this work we extend the biomechanical modeling of the breast by estimating patient-specific tissue parameters automatically from the speed of sound volume. Two heterogeneous models are pro-posed modeling a quadratic and an exponential relationship between speed of sound and tissue stiffness. The models were evaluated using phantoms and clinical data. The lesion size is significantly better preserved using an exponential model and are sharper in the resulting registered images. The presented approach yields promising results and gives a physical justification to our registration method.

8675-21, Session 7

Characterization of human breast cancer by scanning acoustic microscopy

Di Chen, Barbara Ann Karmanos Cancer Institute (United States) and Wayne State Univ. (United States); Brett Senay, Univ. of Windsor (Canada); Eugene V. Malyarenko, Tessonics Corp (United States); Fedar Seviaryn, Univ. of Windsor (Canada); Mark E. Sherman, National Cancer Institute (United States); Sudeshna Bandyopadhyay, Wayne State Univ. School of Medicine (United States); Gretchen Gierach, National Cancer Institute (United

States); Elena Maeva, Univ. of Windsor (Canada); Neb Duric, Delphinus Medical Technologies, Inc. (United States); Roman G. Maev, Univ. of Windsor (Canada)

Objectives: The purpose of this study was to characterize human breast cancer tissues by the measurement of microacoustic properties.

Methods: Surgical specimens from eight breast cancer patients were investigated using a thin-slice, reflection mode acoustic microscopy technique capable of simultaneously measuring through-thickness attenuation and sound speed. For each patient, seven blocks of tumor tissue were collected from seven different positions around a tumor mass. Tumor tissues were embedded in optimal cutting temperature (OCT) compound as support medium and snap frozen by quenching in isopentane chilled in liquid nitrogen, followed by cryosections. Frozen sections (10 micrometer, µm) of human breast cancer tissues none stained and none fixed were examined in a scanning acoustic microscope with an 80 MHz focused transducer driven by short voltage pulses. Hematoxylin and Eosin (H&E) staining sections from the same frozen breast cancer tissue were imaged by optical microscope as comparisons.

Results: The results of acoustic imaging showed that increased acoustic attenuation and lower sound speed were observed in cancer cell-rich tissue regions, compared with low acoustic attenuation and higher sound speed in the tissue regions, in which most components are normal cells/tissues, such as fibroblasts, connective tissue and lymphocytes. Our observation also showed that the ultrasonic properties were influenced by cellular arrangement and intercellular junction.

Conclusions: Our data demonstrate that attenuation and sound speed imaging can provide biomechanical information of the tumor and normal tissues. The results also demonstrate the potential of acoustic microscopy as an auxiliary method for operative detection and localization of cancer affected regions.

8675-22, Session 7

Experimental evaluation of noise generated by grating lobes for a sparse 3D ultrasound computer tomography system

Nicole V. Ruiter, Michael Zapf, Torsten Hopp, Hartmut Gemmeke, Karlsruher Institut für Technologie (Germany)

3D ultrasound computer tomography requires a large number of transducers approx. two orders of magnitude larger than in a 2D system. Technical feasibility limits the number of transducer positions to a much smaller number resulting in a sparse aperture and causing artifacts due to grating lobe effects in the images. Usually, grating lobes are suppressed by using a non-sparse geometry. Thus, there is no quantitative estimation method available how much the image contrast is degraded when a sparse aperture is applied and how much the contrast is improved when adding more transducers, changing the overall aperture or the object. In this paper the effect of the grating lobes on the image quality was analyzed for a spherical, a hemispherical and the semi-ellipsoidal USCT aperture: The background noise due to grating lobes is very similar for the three apertures and mainly influenced by the sparseness and the imaged object. A model for noise reduction was fitted to the simulated and experimental data, and can be used to predict the peak-signal-to-noise-ratio for a given object and number of aperture positions.

8675-23, Session 7

GPU based acceleration of 3D USCT image reconstruction with efficient integration into MATLAB

Ernst Kretzek, Michael Zapf, Matthias Birk, Hartmut Gemmeke, Nicole V. Ruiter, Karlsruher Institut für Technologie (Germany)

3D ultrasound computer tomography (3D USCT) promises reproducible high-resolution images for early detection of breast tumors. The 3D synthetic aperture focusing technique (SAFT) used for image reconstruction is highly compute-intensive and limits currently the clinical applicability of the imaging method. As SAFT is trivially parallelizable it is very suitable for an accelerated execution on multiple GPUs. In this paper we investigate how a promising implementation of SAFT algorithm in CUDA C could be further accelerated. By exploiting special hardware capabilities like the texture fetching units and constituting multi GPUs further speed-up was achieved. As the whole USCT reconstruction algorithm including signal processing etc. is implemented in MATLAB, an efficient interface between MATLAB and the SAFT algorithm in CUDA C had to be designed. The computational flow was redesigned to minimize data transfer overhead to and from the GPUs. This implementation results for an image volume of 64 slices with 1024x1024 pixels each in a runtime reduction from 14.75 (CPU) to 1.5 hours (GPU). As the SAFT image reconstruction was speeded up with GPU by factor 23.7 the overall runtime of the reconstruction including data loading and preprocessing was decreased by 80% from 17 (CPU) to 3.5 hours (GPU).

8675-24, Session 8

Transmission mode adaptive beamforming for planar phased arrays and its application to 3D ultrasonic transcranial imaging

Kiyanoosh Shapoori, Univ. of Toronto (Canada) and Research Associate, Tessonics Inc. (Canada); Jeff Sadler, Univ. of Windsor (Canada); Adrian Wydra, Institute for Diagnostic Imaging Research, Univ. of Windsor (Canada); Eugene V. Malyarenko, Tessonics Corp. (United States); Anthony N. Sinclair, Univ. of Toronto (Canada); Roman G. Maev, Univ. of Windsor (Canada) and Institute for Diagnostic Imaging Research, Univ. of Windsor (Canada)

A new adaptive beamforming method for accurately focusing ultrasound behind highly scattering layers of human skull and its application to 3D transcranial imaging via small-aperture planar phased arrays are reported. Due to its undulating, inhomogeneous, porous, and highly attenuative structure, human skull bone severely distorts ultrasonic beams produced by conventional focusing methods in both imaging and therapeutic applications. Strong acoustical mismatch between the skull and brain tissues, in addition to the skull's undulating topology across the active area of a planar ultrasonic probe, could cause multiple reflections and unpredictable refraction during beamforming and imaging. Such effects could significantly deflect the probe's beam from the intended focal point. Presented here is a theoretical basis and simulation results of an adaptive beamforming method that compensates for the latter effects in transmission mode, accompanied by experimental verification of the simulation results.

The probe is a custom-designed 2 MHz, 256-element matrix array with 0.45 mm element size and 0.1mm kerf. Through its small footprint, it is possible to accurately measure the profile of the skull segment in contact with the probe and feed the results in our ray tracing program. The latter calculates the new time delay patterns adaptive to the geometrical and acoustical properties of the skull phantom segment in contact with the probe. The time delay patterns correct for the refraction at the skull-brain boundary and bring the distorted beam back to its intended focus. The algorithms were implemented on the ultrasound open-platform ULA-OP (developed at the University of Florence).

8675-25, Session 8

Frequency division multiple transmission method to utilize the wide bandwidth property of capacitive micromachined ultrasonic transducer arrays

Seunghun Lee, Bae-Hyung Kim, Samsung Advanced Institute of Technology (Korea, Republic of); Taeho Jeon, Samsung Advanced Institute of Technology, SEC (Korea, Republic of); Youngil Kim, Kyungil Cho, Jongkeun Song, Samsung Advanced Institute of Technology (Korea, Republic of); Dongwook Kim, Samsung Advanced Institute of Technology, SEC (Korea, Republic of)

CMUT-on-ASIC integration techniques are promising for the development of lower cost smaller volume scanners with higher performance in terms of features and image qualities because it minimizes parasitic capacitances and ultimately improves signal-to-noise ratio (SNR). Moreover, a frequency bandwidth of CMUT array is known as relatively broader than that of other ultrasonic transducer arrays. To utilize the wide bandwidth characteristic of the CMUT arrays, in this paper, we introduce a FDMA (frequency division multiple access) based ultrasound imaging technique using orthogonally band-divided coded signals to provide dynamic transmit focused imaging without sacrificing the frame rate. In the presented method, the orthogonal sub-band coded signals are simultaneously fired on multiple ranges, in which each signal is focused at a different range, in one transmission event. This paper also presents an ultrasound image-formation method and a modulation and demodulation process of orthogonal sub-band coded signals designed within the frequency bandwidth of the CMUT arrays. The presented method is verified by computer simulations using Field II and experiments. The simulation results using a computer generated tissue mimicking phantom show that the presented method can be achieved with both increased image quality and frame rate. The experimental results to verify the feasibility of the presented method using orthogonal sub-band coded signals show that the reflected signals from targets are successfully separated into two compressed signals. Currently, we are extending the presented approach to ultrasound imaging technique for volumetric ultrasound scanners using 2-D CMUT-on-ASIC arrays.

8675-26, Session 8

A delta-sigma beamformer with integrated apodization

Borislav G. Tomov, Matthias B. Stuart, Martin C. Hemmsen, Jørgen A. Jensen, Technical Univ. of Denmark (Denmark)

This paper evaluates a new design of a discrete time Sigma-Delta oversampled ultrasound beamformer which integrates apodization. A variable feedback voltage is used in the single bit sigma-delta (?Δ) analog to digital converter (A/D) to provide individual apodization for each receiving channel. The outputs of all receiving channels are delayed and summed to complete the ?Δ beamformer architecture. The simplicity of this beamformer compared to conventional methods facilitates very large channel count or low power beamformers suitable for 2-D arrays or compact portable scanners. The objective of this work is to evaluate the new design using measured data from the research scanner SARUS and a BK-8811 192 element linear array transducer (BK Medical, Herlev, Denmark). The evaluation is performed using raw radio frequency data acquired from a water phantom with four wires orthogonal to the image plane. The data are acquired using 12 bit flash A/D converters and a sampling frequency of 70 MHz. Data is upsampled off-line to 560 MHz for input to the ?Δ beamformer. B-mode images are generated using the ?Δ beamformer and compared to the output of a conventional multi-bit beamformer.

The performance is quantized by the signal-to-noise ratio and the magnitude of the lateral beam profile for four wires at a depth of 33, 56, 80, and 104 mm. The results show that the ?Δ beamformer performs equally well as a conventional multi-bit beamforming architecture with 12 bit flash A/D converters.

8675-27, Session 8

A synthetic aperture study of aperture size in the presence of noise and in vivo clutter

Nick Bottenus, Brett C. Byram, Gregg E. Trahey, Duke Univ. (United States)

Conventional wisdom in array design is that up to the limits of angular sensitivity, increasing aperture size inversely improves image resolution and, as a result, improves image quality. As modern arrays become more aggressive in achieving larger apertures, it is important to study effects that counterbalance the improvement in resolution – noise and clutter. For clinically relevant targets, contrast and contrast-to-noise ratio (CNR) serve as important indicators of diagnostic value. We propose the use of a synthetic aperture scheme to acquire data both in phantom and in vivo that can be reconstructed with varying transmit and receive aperture sizes to directly study these metrics and parse apart the limiting factors. Analysis of an anechoic lesion phantom reveals depth dependence independent of f-number (F/#, axial depth/aperture size), primarily showing the effect of channel noise on lesion detectability. Aside from this effect, both CNR and contrast asymptotically approach maximum values with decreasing F/#. In vivo analysis shows qualitatively a similar limiting effect, but the rate at which a maximum apparent quality is reached varies with levels of noise and clutter in the image. This suggests a point of diminishing returns in clinically relevant imaging arrays even before the limits of angular sensitivity are reached. We also take advantage of the technique to look at the effects of transmit and receive aperture size separately, highlighting the importance of total array size in image quality.

8675-28, Session 8

Ultrasonic reverberation and off-axis clutter suppression using aperture domain signal decomposition

Brett C. Byram, Duke Univ. (United States)

A new algorithm is presented for the purposes of reducing acoustic clutter caused by either near-field tissue reverberation or off-axis scattering. The algorithm differs from existing clutter reduction methods in that it suppresses both types of clutter and preserves the radio-frequency (RF) characteristics of the signal (in contrast to short-lag spatial coherence imaging, as an example). The RF data can then be used for typical tasks such as making B-mode images or estimating motion.

The heart of the new algorithm is the notion that in the presence of reverberation (or off-axis scattering) the signal measured by each channel includes waves arriving from multiple points of origin simultaneously. For each point of origin the arriving wave will have a unique arrival time profile, which is well described by Fresnel's approximation to the Huygens-Fresnel principle. From this principle, the arrival time profiles from sources arriving simultaneously can be modeled as a summation of linear-frequency modulated sinusoids. The collection of frequency modulated sinusoids may be decomposed into estimates of each wave's amplitude and point of origin. The estimated points of origin can then be used to reconstruct a decluttered RF signal with energy arriving only from the region of interest.

The algorithm has been applied to in vivo liver images from 4 human subjects. Improvement of imaging metrics was seen in all patients thus far. For the initial patient population the mean percent improvement in contrast is 56.9±4.87% and the mean CNR improvement is 26.2±17.5%.

8675-29, Session 8

Blind de-convolution based on coded excitation

Sungchan Park, Samsung Electronics (Korea, Republic of)

Due to the high frequency attenuation, the ultrasound imaging system has the low resolution limitation. If we modeling the spatial pulse interfering between scatter as point spread function (PSF). We can consider the image is blurred by the PSF and use deconvolution technique with estimated PSFs for high resolution image. To restore the high resolution image and estimate PSF correctly, we need to obtain the input RF image in the high SNR. But, the previous papers use the narrow band excitation pulse of the low energy. Thus, they suffer from the noise and aggregate the neighboring data in the image region to increase SNR. For accurate PSF estimation and high resolution image restoration, our new deconvolution method includes two parts. We first time introduce a blind deconvolution based on a pulse compression method. By reducing the noise power, we can obtain a smaller error rate of PSF estimation, and high quality image restoration results. Second, due to the sparse reconstruction with the pulse compression, we can suppress more noises and obtain the finer image resolution. In the Field II simulation, if the Gain of Peak SNR(GPSNR) means PSNR increments by the code compression, then our blind deconvolution is bigger by 8.5dB than ideal PSF known case on average, which represents that reducing PSF estimation errors based on the pulse compression enhances the GPSNR value more in addition to the SNR gain in original RF image.

8675-30, Session 9

Vibro-acoustography by using 1.75D ultrasound array transducer to detect and localize permanent prostate brachytherapy seeds: ex vivo study

Mohammad Mehrmohammadi, Azra Alizad, Randall R. Kinnick, Matthew W. Urban, Brian J. Davis, Mayo Clinic (United States); Mostafa Fatemi, Mayo Clinic (United States)

Effective brachytherapy procedure requires precise placement of radioactive seeds in prostate. Currently, transrectal ultrasound (TRUS) imaging is the main intraoperative imaging modalities to assist physicians in placement of brachytherapy seeds. However, seed detection rate with TRUS is poor mainly because ultrasound imaging is highly sensitive to variations in seed orientation. The purpose of this study is to investigate the abilities of a new ultrasound-based imaging modality – Vibro-acoustography (VA) – implemented in a modified clinical ultrasound scanner equipped with a customized 1.75D array transducer, to image and localize brachytherapy seeds in prostatic tissue. To perform experiments, excised cadaver prostate specimens were implanted with 16 to 31dummy brachytherapy seeds, and embedded in tissue mimicking gel to simulate the properties of the surrounding soft tissues. The samples were imaged at various depths and further processing, including filtering, contrast enhancement, and a customized image segmentation algorithm were applied to the VA images. To quantify the abilities of VA imaging, X-ray computed tomography (CT) images of the same tissue samples, serving as a gold-standard, were obtained and the results were compared to VA results. Our results indicate that VA is capable of accurately imaging brachytherapy seeds with a high contrast and can detect large ratio of the seeds implanted within the tissue samples. Feasibility of utilizing a 1.75D transrectal ultrasound probe for in vivo application is also investigated.

8675-31, Session 9

Simplified stereo-optical ultrasound plane calibration

Martin Hoßbach, Matthias Noll, Stefan Wesarg, Fraunhofer-Institut für Graphische Datenverarbeitung (Germany)

Image guided therapy is a natural concept and commonly used in medicine. In anesthesia, a common task is the injection of an anesthetic close to a nerve under freehand ultrasound guidance. Several guidance systems exist using electromagnetic tracking of the ultrasound probe as well as the needle, providing the physician with a precise projection of the needle into the ultrasound image. This, however, requires additional expensive devices. We suggest using optical tracking with miniature cameras attached to a 2D ultrasound probe to achieve a higher acceptance among physicians.

The purpose of this paper is to present an intuitive method to calibrate freehand ultrasound needle guidance systems employing a rigid stereo camera system. State of the art methods are based on a complex series of error prone coordinate system transformations which makes them susceptible to error accumulation. By reducing the amount of calibration steps to a single calibration procedure we provide a calibration method that is equivalent, yet not prone to error accumulation. It requires a linear calibration object and is validated on three datasets utilizing different calibration objects: a 6 mm metal bar and a 1.25 mm biopsy needle were used for experiments. Compared to existing calibration methods for freehand ultrasound needle guidance systems, we are able to achieve higher accuracy results while additionally reducing the overall calibration complexity.

8675-32, Session 10

Introducing nuclei scatterer patterns into histology-based intravascular ultrasound simulation framework

Silvan Kraft, Technische Univ. München (Germany) and Technische Univ. München (Germany); Athanasios Karamalis, Technische Univ. München (Germany); Debdoot Sheet, Technische Univ. München (Germany) and Indian Institute of Technology Kharagpur - School of Medical Science and Technology (India); Enken Drecoll, Ernst J. Rummeny, Nassir Navab, Peter B. Noël, Amin Katouzian, Technische Univ. München (Germany)

Medical ultrasonic grayscale images are formed from acoustic waves following their interactions with distributed scatterers within tissues media. For accurate simulation of acoustic wave propagation, a reliable model describing unknown parameters associated with tissue scatterers such as distribution, size and acoustic properties is essential. In this work, we introduce a novel approach defining ultrasonic scatterers by incorporating a distribution of cellular nuclei patterns in biological tissues to simulate ultrasonic response of atherosclerotic tissues in intravascular ultrasound (IVUS). For this reason, a virtual phantom is generated through manual labeling of different tissue types (fibrotic, lipidic and calcified) on histology sections. Acoustic properties of each tissue type are defined by assuming that the ultrasound signal is primarily backscattered by the nuclei of the organic cells within the intima and media of the vessel wall. The resulting virtual phantom is subsequently used to simulate ultrasonic wave propagation through the tissue medium computed using finite difference estimation. Then B-mode images for a specific histological section are processed from the simulated radiofrequency (RF) data and compared with the original IVUS of the same tissue section. Real IVUS RF signals for the histological sections were obtained using a single-element mechanically rotating 40MHz transducer. Evaluation is performed by trained reviewers subjectively assessing both simulated and real B-mode IVUS images. Our simulation platform provides a high image quality with a very promising correlation to the original IVUS images. This will facilitate to better understand progression of such a

chronic disease from micro-level and its integration into cardiovascular disease-specific models.

8675-33, Session 10

Model based assessment of vestibular jawbone thickness using high frequency 3D ultrasound micro-scanning

Daniel Habor, Chair of Medical Engineering, RWTH Aachen (Germany); Sarah Neuhaus, RWTH Aachen (Germany); Thorsten Vollborn, Chair of Medical Engineering, RWTH Aachen (Germany); Stefan Wolfart, RWTH Aachen (Germany); Klaus Radermacher, Stefan Heger, Chair of Medical Engineering, RWTH Aachen (Germany)

Dental implants are well-established in modern dentistry. However, without appropriate therapeutic intervention, progressive peri-implant bone loss may lead to failing implants. Conventionally, the particularly relevant vestibular jawbone thickness is monitored using radiographic 3D imaging methods. Ionizing radiation, as well as imaging artifacts caused by metallic materials of implants and superstructures are major drawbacks of these imaging modalities.

In this study, a high frequency ultrasound (HFUS) based approach to assess the vestibular jawbone thickness is being demonstrated by examining two porcine specimens with inserted implants in vitro. The Implant of the first specimen was equipped with a gingiva former while a polymer superstructure was mounted onto the implant of the second specimen.

Ultrasound data is acquired by a 4 DOF high frequency (>50MHz) laboratory ultrasound scanner. The ultrasound raw data is converted to polygon meshes including the bone, gingiva, gingiva former (first specimen) and superstructure (second specimen) surfaces. The meshes are matched with a-priori acquired 3D models of the implant, the superstructure and the gingiva former using a best-fit algorithm. Subsequently, the vestibular peri-implant bone thickness can be assessed in the resulting 3D models. The presented method does not require ultrasound penetration of the jawbone.

The accuracy of this approach is evaluated by comparing the ultrasound based thickness measurement with a reference measurement acquired with an optical extra-oral 3D scanner. As a final result, the bone thicknesses of the two specimens were measured with an error of -46±89µm (first specimen) and 70±93µm (second specimen).

8675-34, Session 10

Nonlinear response of lipid-shelled microbubbles to coded excitation: implications for carotid imaging

Himanshu Shekhar, Marvin M. Doyley, Univ. of Rochester (United States)

Atherosclerosis kills more Americans than all cancers combined. The pathophysiological state of the carotid artery can indicate the overall risk associated with atherosclerosis. The current screening test for atherosclerosis involves the assessment of the intima-media thickness (IMT) of the Carotid artery. However, IMT is limited in its ability to reliably identify high-risk plaques. Recent research has linked life-threatening plaque rupture events to the abnormal growth of the vasa vasorum. An imaging modality capable of characterizing the vasa vasorum could be employed as a sensitive screening test to predict the risk associated with plaque rupture.

Nonlinear imaging could visualize the vasa vasorum by exploiting the subharmonic/harmonic response of microbubble contrast agents. However, this technique is limited by the weak nonlinear response of the agent to the current pulsing strategy. We hypothesized that chirp-coded pulsing can enhance imaging performance by 1) improving overall nonlinear response from the agent, 2) reducing the threshold pressures required for subharmonic imaging, and 3) improving the signal-to-noise ratio, which will result in higher imaging depth. We tested our hypothesis by conducting radio-frequency measurements at 10 MHz, with 10 - 40% bandwidth sine-burst and chirp-coded pulses, to assess their ability to incite nonlinear response from Targestar-pTM. Our findings show that chirp-coded excitation can improve the subharmonic and harmonic response of the agent by 11 and 6 dB, respectively. Chirp-coded excitation also resulted in lower thresholds for the onset of subharmonic behavior. Therefore, chirp-coded excitation may be a viable approach to improve the sensitivity of nonlinear vasa vasorum imaging.

8675-35, Session 10

Reconstructing the mechanical properties of coronary arteries from displacements measured with a synthetic aperture ultrasound imaging system

Steven J. Huntzicker, Sanghamithra Korukonda, Marvin M. Doyley, Univ. of Rochester (United States)

A stroke may occur when an atherosclerotic plaque ruptures in the carotid artery. Non-invasive vascular elastography (NIVE) visualizes the strain distribution within the carotid artery, which is related to its mechanical properties. However, NIVE elastograms are difficult to interpret because strain is displayed in Cartesian rather than Polar Coordinates. Transforming axial and lateral displacements measured with a synthetic aperture (SA) ultrasound imaging system to the vessel coordinate system can resolve this problem. However, strain provides only approximate estimate of tissue mechanical properties. In this paper, we present a model-based reconstruction method for NIVE. Previously, vascular modulus-elastograms have been impossible to compute due to the large amount of noise in the ultrasound images, notably in the lateral direction. We propose to reduce the effects of noise in our reconstructions through the use of SA ultrasound images combined with a soft-priors based Tikhonov regularization method. As previously shown, synthetic aperture imaging reduces the noise in the lateral displacements. Furthermore, including the plaque location in the reconstruction algorithm addresses the ill-posed nature of the problem. Simulated NIVE results employing this method suggest that model-based elastograms could be obtained from patients this way in a clinical setting.

8675-36, Session 10

Preliminary study of synthetic aperture tissue harmonic imaging on in-vivo data

Joachim H. Rasmussen, Martin C. Hemmsen, Technical Univ. of Denmark (Denmark); Signe S. Madsen, Peter M. Hansen, Michael B. Nielsen, Copenhagen Univ. Hospital (Denmark); Jørgen A Jensen, Technical Univ. of Denmark (Denmark)

A new method for synthetic aperture tissue harmonic imaging is investigated. It combines synthetic aperture sequential beamforming (SASB) with tissue harmonic imaging (THI) to produce images with increased and more uniform spatial resolution and improved side lobe reduction compared to conventional B-mode imaging. Synthetic aperture sequential beamforming tissue harmonic imaging (SASB-THI) was used in a clinical setup and compared to dynamic receive focused tissue harmonic imaging (DRF-THI). Twenty-four simultaneously acquired video sequences of abdominal SASB-THI and DRF-THI scans on 3 volunteers of 4 different sections of liver and kidney tissues were presented to 3 radiologists in double blinded trials. Each radiologist was presented with two paired sequences and asked to score the best on a visual analog scale (VAS). Furthermore, for each sequence the radiologist was asked to determine the maximum depth where there was still clinical relevance in the images.

The accumulated median of VAS scores from one radiologist was +6

with the 25% and 75% quantiles at +5 and +9 in favor of DRF-THI. The median of the difference between DRF-THI and SASB-THI depth scores was +5 mm in favor of DRF-THI with the 25% and 75% quantiles at +2 mm and +21 mm. Preliminary results show that in the current configuration, DRF-THI produced slightly better images compared to SASB-THI, while image depth was almost the same for the two techniques. This shows that SASB-THI can produce images that reduce the computational load of the scanner with only a small loss in image quality compared to DRF-THI.

8675-37, Session 10

A stochastic filtering approach to recover strain images from ultrasound elastography

Minhua Lu, Shenzhen Univ. (China); Weifang Li, Wuhan Univ. of Science and Technology (China); Ruichao Sun, shenzhen university (China); Heye Zhang, Shenzhen Institute of Advanced Technology (China); Tianfu Wang, Siping Chen, National-Regional Engineering Laboratory for Key Technology of Medical Ultrasound, (China)

A Kalman filtering approach is developed to reconstruct the strain images with a realistic bio-mechanical constraint in this paper. However, how to define a realistic model constraint in the environment of elastography, especially in quasi-static ultrasound elastography, is a challenge because of the discrepancies between the model and image data. Model-based reconstruction algorithms have shown potentials over conventional strain-based methods in quasi-static elastographic image by using “accurate” finite element(FE) or bio-mechanical models. Strictly speaking, however, the measurement noises are always exists and thus do not meet basic assumptions of these algorithms. In addition, the difficulty in determining the proper system model also greatly affects the quality of the reconstructed images. In this paper, we explore the usage of state space principles for the estimation of elastographic imaging. The proposed strategy formulates the displacement distribution through bio-mechanical models, and the ultrasound-derived measurements through observation equations, thus makes it possible to compute the optimal estimation of

full displacement field using a Kalman filter. Further, the model-data discrepancy is modeled as uncertainties,

i.e. Gaussian white noise, and the measurement noise is treated as another independent Gaussian white noise in the stochastic state space space. In our implementation of this stochastic state approach, the linear isotropic bio-mechanical model is transformed into a system equation, and the ultrasound-derived measurements is assimilated

through an observation equation. The optimal estimation of kinematic functions, i.e. the full displacement and velocity field, are computed through this Kalman filter. Then the strain images can be easily calculated from the estimated displacement field. The accuracy and robustness of our proposed framework is first evaluated in synthetic data in controlled conditions, and the performance of this framework is then evaluated in the real data collected from elastography phantom and patients using the ultrasound machine with favorable results.

8675-38, Session PSWed

Intense acoustic burst ultrasound modulated optical tomography for elasticity mapping of soft biological tissue mimicking phantom: a laser speckle contrast study

Suheshkumar Singh, Rajan Kanhirodan, Ram Mohan Vasu, Indian Institute of Science (India)

This report addresses the assessment of variation in elastic property of soft biological tissues non-invasively using laser speckle contrast measurement. In this an intense acoustic burst of ultrasound (an acoustic pulse with high power within standard safety limits), instead of continuous wave, is employed to induce large modulation of the tissue materials in the ultrasound insonified region of interest (ROI); it results in enhanced ultrasound modulated optical signal strength in ultrasound modulated optical tomography (UMOT) system. The intensity fluctuation of speckle patterns formed by interference of light scattered (while traversing through tissue medium) is characterized by the motion of scattering sites. The displacement of scattering particles is inversely related to the elastic property of the tissue medium. We study the feasibility of laser speckle contrast analysis (LSCA) technique to reconstruct a map of the elastic property of a soft tissue-mimicking phantom. We employ source synchronized parallel speckle detection scheme to (experimentally) measure the speckle contrast from the light traversing through ultrasound (US) insonified tissue-mimicking phantom. The measured relative image contrast (the ratio of the difference of the maximum and the minimum values to the maximum value) for intense acoustic burst is 86.44% in comparison to 67.28% for continuous wave excitation of ultrasound. The sensitivity of measured speckle contrast to the variation of exposure time of the optical detector is studied and presented. We also present 1-D and 2-D image of speckle contrast which is the representative of elastic property distribution. The experimental as well as the numerical (Monte Carlo simulation) studies are carried out to validate the results.

8675-39, Session PSWed

Random forest learning of ultrasonic statistical physics and object spaces for lesion detection in 2D sonomammography

Debdoot Sheet, Technische Univ. München (Germany) and Indian Institute of Technology Kharagpur (India); Athanasios Karamalis, Silvan Kraft, Peter B. Noël, Tibor Vag, Technische Univ. München (Germany); Anup Sadhu, EKO CT&MRI Ctr., Medical College and Hospitals Campus (India); Amin Katouzian, Nassir Navab, Technische Univ. München (Germany); Jyotirmoy Chatterjee, Ajoy K. Ray, Indian Institute of Technology Kharagpur (India)

Breast cancer is the most common form of cancer in women. Early diagnosis can significantly improve life-expectancy and allow different treatment options. Clinicians favor 2D ultrasonography for breast tissue abnormality screening due to high sensitivity and specificity compared to competing technologies. However, inter- and intra-observer variability in visual assessment and reporting of lesions often handicaps its performance. Existing Computer Assisted Diagnosis (CAD) systems though being able to detect solid lesions are often restricted in performance. These restrictions are inability to (1) detect lesion of multiple sizes and shapes, and (2) differentiate between hypo-echoic lesions from their posterior acoustic shadowing. In this work we present a completely automatic system for detection and segmentation of breast lesions in 2D ultrasound images. We employ random forests for learning of tissue specific primal to discriminate breast lesions from surrounding normal tissues. This enables it to detect lesions of multiple shapes and sizes, as well as discriminate between hypo-echoic lesion from associated posterior acoustic shadowing. The primal comprises of (i) multiscale estimated ultrasonic statistical physics and (ii) scale-space characteristics. The random forest learns lesion vs. background primal from a database of 2D ultrasound images with labeled lesions. For segmentation, the posterior probabilities of lesion pixels estimated by the learnt random forest are hard thresholded to provide a random walks segmentation stage with starting seeds. Our method achieves detection and segmentation with mean contour-to-contour error < 3 pixels on a set of 40 images with 49 lesions.

8675-40, Session PSWed

Quality evaluation of ultrasound imaging using a MATLAB test-bench

Xin Zhao, Stony Brook Univ. (United States); Jun Zhou, Texas A&M Univ. (United States); Wing-Fai Loke, Purdue Univ. (United States); Mohan Chirala, Charlie Zhang, Samsung Dallas Technology Lab. (United States)

The goal of this paper is to investigate and evaluate image quality, based on quality metrics and visual perception in ultrasound imaging under different imaging conditions. We first generate and simulate B-mode ultrasound images of various objects, using Field-II simulation toolbox [1]. Then we implement and embed front-end functional modules, mid-end functions including beamforming, receive beamforming, envelop detection and log compression, and back-end image processing methods (filtering and image enhancement). Ultrasound images are evaluated as pairs using various image quality evaluation metrics and visual perception evaluation. The experimental results of this study show that: (1) better image quality is significantly obtained using over sampling and signal emphasizing (high signal level); (2) the normalized images with speckle filters are rated better in terms of index-quality; and (3) enhanced images show better visual perception on all simulation datasets. This paper shows the utility of our MATLAB test-bench favoring simulated image quality and further demonstrates that the evaluation design is an important pre-processing step especially for hardware design of ultrasound system.

8675-41, Session PSWed

Accelerating ultrasound image analysis research through publically available database

Vikas Revanna Shivaprabhu, Andinet Enquobahrie, Zach Mullen, Stephen Aylward, Kitware, Inc. (United States)

Ultrasound is widely used intra-operatively to provide real-time feedback in image guided intervention procedures. Registration of pre- and intra-operative images is a crucial step in the procedure. Unfortunately, real-time US images often have poor signal-to-noise ratio and suffer from imaging artefacts. Hence, registration using US images can be challenging and significant preprocessing is often required to make the registrations robust. The amount of preprocessing required can be reduced by incorporating US physical imaging process. However, progress in this research is hampered due to lack of publicly available database for training and testing image analysis algorithms that take in to consideration ultrasound phsical process. We present here a new database that we are building to archive and distribute ultrasound images of an abdominal phantom acquired at different image acquisition parameters. The database contains tracking information of the transducer in addition to the 2D ultrasound image slices. We believe a publicly available database like this one will provide a valuable resource for the research community and it will be instrumental in developing a collaborative scientific community needed to advance the field.

8675-42, Session PSWed

Hardware system of X-wave generator with simple driving pulses

Xu Li, Yaqin LI, Feng Xiao, Mingyue Ding, Ming Yuchi, Huazhong Univ. of Science and Technology (China)

The limited diffraction beams such as X-wave have the properties of larger depth of field.Thus, it has the potential to generate ultra-high frame rate ultrasound images.However, in practice, the real-time generation of X-wave ultrasonic field requirescomplex and high-costsystem,especially the precise andspecific voltage time distribution part for the excitation of eachdistinct array element.In order to simplify the hardware realization of X-wave, based on the previous works, X-wave excitation signals were decomposed and expressed as the superposition of a group of simple driving pulses, such as rectangular and triangular waves.The hardware system for the X-wave generator was also designed. The generator consists of a computer for communication with the circuit, universal serial bus (USB) based micro controller unit (MCU) for data transmission, field programmable gate array (FPGA) basedDirect Digital Synthesizer(DDS), 12-bit digital-to-analog (D/A) converter and a two stage amplifier.The transmit circuit adopts theDDSwhich is a kind of accurate frequency synthesization technique. DDS cangenerate arbitrary waveforms from a single,fixed-frequency reference clock, which can meet the need of complex transmit signals requirement of X-wave. The hardware simulation results show that the designed system can generate the waveforms at different radius approximating the theoretical X-wave excitations with a maximum error of 0.48% triggered by the quantification of amplitude data.

8675-43, Session PSWed

Reduction of rotational asymmetry in PSF synthesis for a broadband forward-looking ring array

Jing Jin, Ralph T. Hoctor, GE Global Research (United States)

Aperture synthesis using a forward-looking ring array is an area of current interest in intracardiac imaging [1]. In general, such schemes require that multiple transmissions be made and combined coherently in order to make the boundary array produce a low-sidelobe point spread function (PSF) such as could be obtained with a filled array of the same planar size. Methods for designing the transmit and receive beam patterns of the component transmissions of such a combination are a topic of long-standing interest. One design approach that is often cited is the truncated Wild series [2], which is based on the narrowband Bessel series approach proposed by J.P. Wild [3]. Recently, a new method was proposed specifically for pulse-echo imaging, called “delay dithering” [4]. Both of these design approaches, when applied to broadband imaging systems, often produce imaging PSFs that the lack rotational symmetry obtained from ordinary use of the ring array. This is a potential disadvantage since the orientation of the array with respect to strong sidelobe reflectors may not be controllable. In the present work, we look for aperture synthesis approaches that produce rotationally symmetric PSFs with low peak sidelobe level while transmitting a short pulse. In some cases it is possible to produce a symmetric PSF using an existing scheme with extra transmits, and an example of this is presented. Such an approach reduces the frame rate, and so two alternatives are considered: the use of two-ring arrays, and the use of element-by-element signal inversion on transmit and receive. The latter approach allows the design of the desired rotationally symmetric PSFs. Examples of both truncated series designs and numerical designs are given.

[See suppliment for reference list.]

8675-44, Session PSWed

Embedded S/W beamforming platform with reconfigurable multicore processors

Minsoo Kim, SAMSUNG Electronics Co., Ltd. (Korea, Republic of); Changyong Son, Kangeun Lee, Do-Hyung Kim, SAMSUNG Electronics Semiconductor (Korea, Republic of); Shihwa Lee, Samsung Digital City (Korea, Republic of)

In modern medical ultrasound signal processing, beamforming is usually implemented on H/W solution by ASIC(Application Specific Integrated Circuit) because of its huge computation. ASIC solution has a problem with flexibility to support various beamforming algorithms. Nowadays, computing ability of GPU(Graphic processing unit) becomes very high, therefore many approaches have been proposed for S/W beamforming

on GPU. Although the high performance of GPU, commercial GPU is not proper for portable ultrasound, because of its large power consumption. The motivation of this paper is evaluating the feasibility of embedded multi-core system as S/W beamforming solution for portable ultrasound. To develop embedded S/W beamforming platform, we propose the platform with multiple embedded processors called RP(Reconfigurable Processor) and special co-processors. Whole system is composed of 6 computing clusters and single cluster is composed of 8 RP processors and 1 co-processor. The number of clusters in the system can be changed depending on computational requirement. To evaluate the performance of the proposed platform, we implemented MV(Minimum Variance) beamforming, which is one of the most complex beamforming, on that platform. 4 approaches were mainly used to accelerate MV beamforming. The first one is co-processor for accelerating MAC(Multiply and Accumulate) operations, the second one is special instructions for beamforming, the third one is SIMD(Single Instruction Multiple Data), and the last one is CGA(Corse Grained Architecture) acceleration which is special function of RP. As a final result, 128channel 30fps(frame per second) real-time MV beamformer was achieved on the proposed platform.

8675-45, Session PSWed

A GPU-based real-time short-lag spatial coherence ultrasound imaging system

Dongwoon Hyun, Jeremy J. Dahl, Gregg E. Trahey, Duke Univ. (United States)

Short-lag spatial coherence (SLSC) imaging is a recently developed ultrasound beamforming technique that is based on the spatial coherence of the backscattered wavefront. SLSC images are formed based on the local measurements of spatial coherence between closely spaced signals using normalized cross-correlation. Experimental and simulation studies indicate that SLSC images are superior to conventional B-mode images when using lesion contrast-to-noise ratio and speckle signal-to-noise ratio as performance metrics. However, SLSC is a computationally intensive algorithm; a single SLSC image requires several seconds of computation on the CPU. As a result, previous SLSC experiments have been guided entirely by B-mode imaging, with acquisitions of brief channel data segments at target locations being processed offline.

Through the use of graphics processing unit (GPU) computing, we have implemented a real-time SLSC imaging system capable of displaying several frames per second (FPS). When imaging in vivo livers with 50 A-lines per frame at a sampling frequency of 10 MHz (2.5 MHz transmit frequency), the GPU-accelerated system has achieved approximately 4 FPS at a depth of 10 cm, and 10 FPS when imaging depths of 7 cm. These rates are sufficient for visual tracking of speckle with motion, and it is likely that these rates can be exceeded with further optimizations to the code and improvements to the hardware.

The real-time capabilities of this prototype indicate a significant step toward clinical applications of SLSC imaging and demonstrate the feasibility of implementing custom beamforming techniques in real-time through the use of GPU computing.

8675-46, Session PSWed

Ultrasonic ray tomography of long bones: a simulation study

Peng Shao, Mauricio D. Sacchi, Edmond Lou, Lawrence H. T. Le, Univ. of Alberta (Canada)

While the use of ultrasound to image soft-tissue and to evaluate bones status has been studied thoroughly, little attention has been directed to tomographical imaging of hard tissue. The main reason is the inability of the well-established tomography to apply to the intricacy in hard tissue imaging. In this study, we investigate the feasibility of ultrasound in tomographic imaging of long bones.

This project utilizes ray tomography with time-of-flight data in transmission mode rather than diffraction tomography to estimate cross-sectional ultrasonic velocity distribution. The simulation object phantom imaged was extracted from an X-ray CT image of a piece of bovine tibia. A transducer ring with 120 ultrasound transducers is positioned circumferentially around the bone with soft-tissue removed. Each transducer works in pulse-echo mode once to collect data for estimating the two surfaces of the cortical portion of the long bone which can later be used as an initial guess of the bone structure. Then one transducer on the ring serves as a transmitter and 9 transducers in the opposite position serve as receivers to collect time-of-flight data in transmission mode. The bone sample is then rotated 180 times to cover a full 360o range. The reconstruction of the map is accomplished in an iterative manner. Ray tracing is conducted with an updated version of the velocity map from the previous iteration for inversion until satisfactory results are obtained. The simulation results demonstrate success of our proposed scheme.

8675-47, Session PSWed

Beyond the first Fresnel zone resolution limitation of travel time tomography

Cuiping Li, Delphinus Medical Technologies, Inc. (United States); Neb Duric, Delphinus Medical Technologies, Inc. (United States) and Karmanos Cancer Institute (United States)

Ray theory based travel-time tomography plays a central role in ultrasound medical imaging because of its robustness. Ray theory is an asymptotic high-frequency approximation of the propagating signal and it ignores the influence of structures near the ray path due to the finite bandwidth of the propagating signal. The first Fresnel zone associated with the dominant frequency is commonly cited in the literature as the resolution limit of travel-time tomography. In this paper, we study the factors affecting the resolving power of travel-time tomography. Our simulations demonstrate that, with accurate travel-time picking, good signal-to-noise ratio and enough ray coverage, travel-time tomography can resolve objects much smaller than the first Fresnel zone.

8675-48, Session PSWed

Breast density measurements using ultrasound tomography for patients undergoing tamoxifen treatment

Mark A. Sak, Karmanos Cancer Institute (United States); Neb Duric, Delphinus Medical Technologies, Inc. (United States); Peter Littrup, Karmanos Cancer Institute (United States); Cuiping Li, Delphinus Medical Technologies, Inc. (United States); Lisa Bey-Knight, Karmanos Cancer Institute (United States); Mark E. Sherman, National Cancer Institute (United States); Norman Boyd, Princess Margaret Hospital (Canada); Gretchen Gierach, National Cancer Institute (United States)

It is known that women with high breast densities have an increased risk of developing breast cancer. Tamoxifen is a selective estrogen receptor modulator that has been shown to reduce breast density as assessed by mammography and the incidence of breast cancer in some women by up to 50%. Ultrasound tomography (UST) is an imaging modality that can create tomographic sound speed images of the patient's breast. These sound speed images are useful because breast density is proportional to sound speed. The aim of this work is to examine the relationship between UST-measured breast density and the use of tamoxifen. So far, preliminary results for a small number of patients have been observed. Initial results on the tamoxifen tracking show that approximately 50% of the patients have shown a decrease in density. The UST breast density measurements have also been repeated by a total of three separate users and have shown a high intraclass correlation coefficient (ICC) of greater than 0.95. These results suggest that UST can be used to reliably assess quantitative changes in breast density.

8675-49, Session PSWed

Ultrasound waveform tomography with a modified total-variation regularization scheme

Youzuo Lin, Lianjie Huang, Los Alamos National Lab. (United States)

Reliably characterizing small breast tumors is crucial for early cancer detection. We develop a new ultrasound waveform tomography method with a modified total-variation regularization scheme for accurate sound-speed reconstructions of small breast tumors. We have recently developed an ultrasound waveform tomography method with the total-variation regularization. To further improve sound-speed reconstructions and reduce image artifacts, we make use of a modified total-variation regularization in our ultrasound waveform tomography. Our numerical examples demonstrate that our new method can accurately reconstruct sound-speed values of small breast tumors and greatly reduce image noise.

8675-50, Session PSWed

Ultrasound waveform tomography using an wave-energy-weighted gradient

Zhigang Zhang, Lianjie Huang, Los Alamos National Lab. (United States)

Ultrasound waveform tomography has great potential to produce accurate image of small breast tumors for early breast-cancer detection. However, ultrasound waveform tomography is usually based on the conjugate gradient method, which produces an image with different qualities in different regions of the model. That is partly because the wave energy is dominant around transducer elements, and this uneven distribution of the wave energy slows down the convergence of the inversion. We develop an new ultrasound waveform tomography method that weights the gradient using the wave energies of the forward and backward propagation wavefields. Our method balances the wave energy distribution throughout regions of interests. We numerically demonstrate that our new ultrasound waveform tomography method improves sound-speed reconstructions of the breast and accelerates the convergence of ultrasound waveform tomography.

8675-51, Session PSWed

A new high definition zoom method based on compounded direct pixel beamforming for medical ultrasound imaging: preliminary results

Sungsoo Yoon, Sogang Univ. (Korea, Republic of); Jin Ho Chang, Interdisciplinary Program of Integrated Biotechnology, Sogang Univ. (Korea, Republic of) and Sogang Institute of Advanced Technology, Sogang Univ. (Korea, Republic of); Tai-Kyong Song, Sogang Univ. (Korea, Republic of) and Sogang Institute of Advanced Technology, Sogang Univ. (Korea, Republic of); Yangmo Yoo, Sogang Univ. (Korea, Republic of) and Interdisciplinary Program of Integrated Biotechnology, Sogang Univ. (Korea, Republic of)

Conventional ultrasound imaging based on scan conversion suffers from blurring artifacts caused by interpolation. Especially, when zooming an image for enlarging lesions during scan conversion (i.e., read-zoom), this blurring artifact becomes severe. To reduce blurring artifacts, a write-zoom method was previously proposed. However, it still presents blurring artifacts and lowers the frame rate due to increased line density. In this paper, a new high definition zoom method based on compounded direct pixel beamforming (CDPB) capable enhancing the detail and boundary of lesions is presented. The performance of the proposed method was evaluated with phantom and in vivo experiments by measuring the information entropy contrast (IEC). The radio-frequency channel data were acquired by using a 3.5-MHz convex array transducer with the SonixTouch research platform (Ultrasonix Medical Corp., Vancouver, BC, Canada). The enlarged images using a new high-definition zoom method based on CDPB (i.e., HDZ-CDPB) with 128 transmit scanlines were reconstructed along with read- and write zoom (RZ and WZ) images based on scan conversion by using 128 and 256 transmit scanlines, respectively. From the phantom experiments, the IEC value with the proposed HDZ-CDPB method was enhanced by maximally 42% and 29% compared to the RZ and WZ methods, respectively. This preliminary results indicate that the proposed HDZ-CDPB method would be useful for generating a high definition ultrasound zoom image with improved image quality compared to the conventional scan conversion based methods (i.e., RZ and WZ) while achieving the high frame rate.

8675-52, Session PSWed

3D ultrasound coherence imaging based on 2D array design

Yanping Jia, Mengling Xu, Mingyue Ding, Ming Yuchi, Huazhong Univ. of Science and Technology (China)

During the last decade, various design methods of 2D array have been developed for real-time 3D ultrasonic imaging. Most of the methods concentrate on how to reduce the number of elements and channels to overcome the difficulties in array fabrication and mass data processing. Few works focus on the beamforming technique for a certain array, which narrow the main lobe width and suppress the side and grating lobe levels, thus improve the 3D image quality.

Coherence imaging (CI) has been verified to suppress the side and grating lobes of the 2D ultrasound images in an effective way. It was based on a statistical analysis of the received signals dispersion at the fixed time. In this paper, two kinds of CI, coherence factor (CF) and sign coherence factor (SCF) are modified for 2D arrays and combined with array design to improve the 3D ultrasound image qualities and reduce front-end complexity. The simulation results of point spread functions show that the main lobe width is narrowed from 1.26mm to 1.01mm and the side lobe level is suppressed from -48.79dB to -79.31dB for dense arrays with CF. Similar simulation results can be obtained for other array designs. The combination of CI and 2D array design provides a potential approach to increase the 3D imaging resolution and contrast without increasing the system complexity.

8675-53, Session PSWed

Non-blind de-convolution based on PSF selection of minimum variance method for ultrasound imaging

Jooyoung Kang, Sung-Chan Park, Kyuhong Kim, Jung-Ho Kim, SAMSUNG Electronics Co., Ltd. (Korea, Republic of)

In the ultrasound imaging system, blurring which occurs after passing through ultrasound scanner system, represents point spread function (PSF) that describes the response of the ultrasound imaging system to a point source distribution. So, de-blurring can be achieved by de-convolving the images with an estimated of PSF. However, it is hard to attain an accurate estimation of PSF due to the unknown properties of the tissues of the human body through the ultrasound signal propagates. In this paper, we proposed new method for selection of the 2D PSF (estimated PSF of the average speed sound and depth) simultaneously with performing fast non-blind 2D de-convolution in the ultrasound imaging system. Our algorithm works on the beam-formed uncompressed radio-frequency data, with pre-measured and estimated 2D PSFs database from actual probe used. In the 2d PSF database,

there are pre-measured and estimated 2D PSFs that classified the each different depth (about 5 different depths) and speed of sound (about 1450 ~ 1540m/s). Using a minimum variance method with input ultrasound image, we select the appropriated PSF that considered depth and speed of sound from candidate 2D PSFs database. Then, in order to prevent discontinuities between the differently restored each depth image regions, we use the piecewise linear interpolation on overlapping regions. We have tested our algorithm with vera-sonic system and commercial ultrasound scanner (Philips C4-2), in known speed of sound phantoms and unknown speeds in vivo scans. Unlike the most conventional estimation of 2D PSF using phase unwrapping with iteration, the presented technique can be implemented using currently available hardware in real-time imaging using prior knowledge of PSF.

8675-54, Session PSWed

Optimal basis for real-time compression of ultrasound RF signals

Sharmin Kibria, Patrick A. Kelly, Tamara Sobers, Univ. of Massachusetts Amherst (United States); Jai Gupta, Linda Gupta, Compressive Technologies, Inc. (United States)

Modern medical ultrasound machines produce enormous amounts of data, as much as several gigabytes/sec in some systems. The difficulties of generating, propagating and processing such large amounts of data have motivated recent research into means for compression of the radio frequency (rf) signals received at an ultrasound system's analog front end. Most of this work has concentrated on the digitized data available after sampling and A/D conversion. We are interested in the possibility of compression implemented directly on the received analog signals, so we focus on efficient real-time representations for the rf signals comprising a single receive aperture. We first derive an expression for the (time and space) autocorrelation function of the set of signals received in a linear aperture. This is then used to find the autocorrelation's eigenfunctions, which form an optimal basis for compression of the aperture signal set. We show that computation of the coefficients of the signal set with respect to the basis amounts to calculation of Fourier Series coefficients for the received signal at each aperture element, with frequencies slightly scaled by aperture position, followed by linear combinations of corresponding frequency components across the aperture. The combination weights at each frequency are determined by the eigenvectors of a matrix whose entries are averaged cross-spectral coefficients of the received signal set at that frequency. The principal eigenvector generates a combination that amounts to a beamformed aperture center line, while the combinations from other eigenvectors represent aperture information that is not contained in the beamformed line.

8675-55, Session PSWed

Adaptive sound speed correction for abdominal ultrasonography: preliminary results

Sungmin Jin, Jeeun Kang, Tai Kyong Song, Sogang Univ. (Korea, Republic of); Yangmo Yoo, Sogang Univ. (Korea, Republic of) and Interdisciplinary Program of Integrated Biotechnology, Sogang Univ. (Korea, Republic of)

Ultrasonography has conducted a critical role in assessing abdominal disorders due to its noninvasive, real-time, and low cost capabilities. However, for imaging obese patients with a thick fat layer, it is challenging to achieve appropriate image quality with a conventional beamforming (CON) method due to phase aberration caused by different sound speeds in liver and fat, e.g., 1580 and 1450m/s, respectively. For compensating this difference, various sound speed correction methods (SSC) that estimate the accumulated sound speed for a region-of-interest (ROI) have been proposed. However, the improvement in image quality was limited only for a specific depth, i.e., ROI. In this paper, we present a new adaptive sound speed correction (ASSC) method which can enhance the image quality over whole imaging depths by estimating two accumulated sound speeds at different depths in the lower layer. Since the accumulated sound speeds contain the respective contributions of upper and lower layers, an optimal sound speed for each depth can be estimated by solving contribution equations. To evaluate the proposed ASSC method, the phantom study was conducted with pre-beamformed RF data acquired with a SonixTouch research package (Ultrasonix Corp., Canada) with a linear probe from the gel pad-stacked tissue mimicking phantoms (Parker Lab. Inc., USA and 040GSE, CIRS, USA) whose sound speeds are 1610 and 1540 m/s, respectively. From the phantom study, the ASSC method showed improved mean spatial resolution with low standard deviation, compared to the SSC method, i.e., 0.47±0.05 mm vs. 0.56±0.13 mm, respectively. This result indicates that the proposed ASSC method can provide better spatial resolution than the conventional SSC method and can be applied for enhancing image quality when imaging obese patients in abdominal ultrasonography.

8675-56, Session PSWed

Real-time sound speed correction using golden section search to enhance ultrasound imaging quality

Chong Ook Yoon, Changhan Yoon, Sogang Univ. (Korea, Republic of); Yangmo Yoo, Sogang Univ. (Korea, Republic of) and Interdisciplinary Program of Integrated Biotechnology, Sogang Univ. (Korea, Republic of); Tai-Kyong Song, Sogang Univ. (Korea, Republic of); Jin Ho Chang, Interdisciplinary Program of Integrated Biotechnology, Sogang Univ. (Korea, Republic of) and Sogang Institute of Advanced Technology, Sogang Univ. (Korea, Republic of)

In medical ultrasound imaging, high-performance beamforming is important to enhance spatial and contrast resolutions. A modern receive dynamic beamfomer uses a constant sound speed that is typically assumed to 1540 m/s in generating receive focusing delays. However, this assumption leads to degradation of spatial and contrast resolutions particularly when imaging obese patients or breast since the sound speed is significantly lower than the assumed sound speed; the true sound speed in the fatty tissue is around 1450 m/s. In our previous study, it was demonstrated that the modified nonlinear anisotropic diffusion is capable of determining an optimal sound speed and the proposed method is a useful tool to improve ultrasound image quality. In the previous study, however, we utilized at least 21 iterations to find an optimal sound speed, which may not be viable for real-time applications. In this paper, we demonstrates that the number of iterations can be dramatically reduced using the golden section search method with a minimal error. To evaluate performances of the proposed method, in vitro experiments were conducted with a tissue mimicking phantom. To emulate a heterogeneous medium, the phantom was immersed in the water. From the experiments, the number of iterations was reduced from 21 to 7 with the golden section search method and the maximum error of the lateral resolution between direct and golden section search was less than 1%. These results indicate that the proposed method can be implemented in real time to improve the image quality in the medical ultrasound imaging.

8675-58, Session PSWed

Development of a 3D ultrasound system to investigate post-hemorrhagic hydrocephalus in pre-term neonates

Jessica Kishimoto, Robarts Research Institute (Canada) and Lawson Health Research Institute (Canada); Sandrine de Ribaupierre, The Univ. of Western Ontario (Canada); Aaron Fenster, Robarts Research Institute (Canada); Keith St. Lawrence,

Lawson Health Research Institute (Canada); David Lee, The Univ. of Western Ontario (Canada)

Intraventricular hemorrhage (IVH) is a common disease among preterm infants with an occurrence of 12-20% in babies born at less than 35 weeks. While mild IVH is generally associated with favourable outcome, severe IVH can result in hydrocephalus and cerebral palsy. The mechanisms involved in intraventricular hemorrhage and ventricular dilatation are not well understood, nor is their connection to the observed pattern of brain damage.

Neonates at risk of IVH are monitored by conventional 2D ultrasound (US) for hemorrhage and potential ventricular dilation. However, the sensitivity of 2D US to dilation is poor because it cannot provide accurate measurements of irregular volumes such as the ventricles; measurements on a single slide are done and a value called “Evan’s ratio” is calculated, but doesn’t reflect the true volumetric change.

A modified 3D US system that has been used previously in breast imaging has been designed. This technology will enable us to more accurately measure subtle increases in ventricular size by acquiring volumetric images of the entire ventricles.

Our system has been found to be with 1% of actual distance measurements in all three directions in a 95% CI and volume measurements of manually segmented volumes from phantoms are statistically the same as actual values ($p>0.3$). We have proceeded to clinical scans, and they are ongoing. We are also in the process of creating a novel volumetric phantom with transfontanel ventricle-like properties with geometries from manually segmented MRI images to further validate our system.

8675-59, Session PSWed

Accuracy assessment of high frequency 3D ultrasound for digital impression-taking of prepared teeth

Stefan Heger, Thorsten Vollborn, RWTH Aachen (Germany); Klaus Radermacher, RWTH Aachen (Germany); Joachim Tinschert, Stefan Wolfart, Univ. Clinic Aachen (Germany)

Silicone based impression-taking of prepared teeth followed by plaster casting is well-established but potentially less reliable, error-prone and inefficient for newly emerging techniques such as computer aided design and manufacturing (CAD/CAM) of dental prosthetics. Intra-oral optical scanners have been introduced to overcome these drawbacks but optical waves can hardly penetrate liquids or soft-tissues. Sub-gingival preparations still need to be uncovered invasively prior to scanning and a reflecting powder coating is required in some cases. High frequency ultrasound (HFUS) based micro-scanning has been recently introduced as an alternative to optical scanning. Ultrasound is less sensitive against oral fluids and in principal able to penetrate gingiva in a patient-friendly and cost-effective way. Nevertheless, spatial resolution as well as digitization accuracy of an ultrasound based micro-scanning system remains a critical parameter since the wavelength of ultrasound is usually much smaller than that of optical waves. In this contribution, the accuracy of ultrasound based micro-scanning in the context of teeth geometry reconstruction is being investigated and compared to its extra-oral optical counterpart. In order to increase spatial resolution of the system, second harmonic frequencies were separated by band pass filtering and corresponding 3D surface models were calculated. Comparison of optical and ultrasound data suggest that our results are in good agreement with clinical requirements for CAD/CAM based tooth restoration.

8675-60, Session PSWed

High-resolution synthetic-aperture ultrasound imaging using wave-equation migration: a clinical study

Lianjie Huang, Los Alamos National Lab. (United States); Michael Williamson, The Univ. of New Mexico (United States)

High-resolution ultrasound imaging could be important for many clinical applications, such as breast microcalcification detection and breast cancer diagnosis. We use clinical breast ultrasound data to study the capability of wave-equation migration imaging for high-resolution synthetic-aperture ultrasound imaging. Wave-equation migration imaging can more properly account for ultrasound propagation effects in the heterogeneous breast than conventional ultrasound imaging that is based on the ray theory. We have demonstrated using numerical breast phantom data that wave-equation migration imaging can produce clear images of breast-tumor margins. In this study, we acquire breast ultrasound data for more than 30 patients using our custom-built real-time synthetic-aperture ultrasound, and apply our wave-equation migration imaging to the patient data. We also study the effects on the breast sound speed on wave-equation migration imaging. We demonstrate that wave-equation migration imaging produces better images than conventional ultrasound imaging.

8676-1, Session 1

Dawn of the digital diagnosis assistance system, can it open a new age for pathology? *(Keynote Presentation)*

Akira Saito, Eric COsatto, NEC Corp. (United States); Tomoharu Kiyuna, NEC Corporation (Japan); Michiie Sakamoto, KEIO University (Japan)

For the past decade, digital image acquisition devices and especially whole slide imaging scanners have greatly improved in resolution, image quality as well as speed of acquisition. Today, a handful of manufacturers compete for the sale of such devices to hospitals, institutes and pathology laboratories in the United States, Europe and Asia. Although many pathology departments have purchased and installed such equipment, its usage remains mostly confined to archival and educational purposes. To gain wider acceptance for use in diagnosis assistance and tele-pathology, today's systems still need to overcome technical challenges and undergo standardization. At first, we will give an overview of such environment of digital pathology, and then "e-Pathologist", NEC's digital pathology diagnosis assistance system and discuss the problems we faced during its development and installation at a large Japanese commercial pathology lab. We started the development of "e-Pathologist" in 2002 and focused on cancer detection on H&E-stained gastric and colorectal biopsy samples. Now the system is deployed as a component of quality control/assurance to reduce false negatives. We are currently expanding it to breast and prostate core samples and are introducing interactive assistance for high throughput grading, IHC slide evaluation and fluorescence image analysis. In a second part, we will describe current efforts in quantitative pathology for liver cancer, a Japanese government-funded project in collaboration with Japanese Universities. Through both these experiences, we have furthered our understanding on how to reconcile the pathologist's thinking with a computer system while trying to provide effective diagnosis assistance. Advanced countries are becoming aged societies and the number of cancer patients is increasing steadily, creating an acute shortage of pathologists. At the same time, anatomical pathology examination has essentially remained the same as 100 years ago and is still providing the final word for diagnosis. We expect the introduction of digital pathology and computer assisted diagnosis to lead to a revolution in anatomical pathology.

8676-2, Session 1

Tensor-based computation and modeling in multi-resolution digital pathology imaging: application to follicular lymphoma grading

Evrim Acar, Univ. of Copenhagen (Denmark); Gerard Lozanski, Metin N. Gurcan, The Ohio State Univ. (United States)

In this work, we introduce a tensor-based computation and modeling framework for the analysis of digital pathology images at different resolutions. We represent digital pathology images as a third-order tensor (a three-way array) with modes: images, features and scales, by extracting features at different scales. The constructed tensor is then analyzed using the most popular tensor factorization methods, i.e., CANDECOMP/PARAFAC and Tucker. These tensor models enable us to extract the underlying patterns in each mode (i.e. images, features and scales) and examine how these patterns are related to each other. As a motivating example, we analyzed 500 follicular lymphoma images corresponding to high power fields, evaluated by three expert hematopathologists. Numerical experiments demonstrate that (i) tensor models capture easily-interpretable patterns showing the significant features and scales, and (ii) patterns extracted by the right tensor model, which in this case is the Tucker model commonly used for exploratory analysis of higher-order tensors, perform equally well or better than the reduced dimensions captured by matrix factorization methods on unfolded data, in terms of follicular lymphoma grading.

8676-3, Session 1

Identifying in vivo DCE MRI parameters correlated with ex vivo quantitative microvessel architecture: A radiohistomorphometric approach

Asha Singanamalli, Case Western Reserve Univ. (United States); Rachel E. Sparks, Rutgers, The State Univ. of New Jersey (United States); Mirabela Rusu, Case Western Reserve Univ. (United States); Natalie Shih, Amy Ziober, Univ. of Pennsylvania (United States); John E. Tomaszewski, Univ. at Buffalo (United States); Mark Rosen, Michael Feldman, Univ. of Pennsylvania (United States); Anant Madabhushi, Case Western Reserve Univ. (United States)

Implementation of active surveillance for prostate cancer (CaP) is currently hampered by the lack of definitive in vivo imaging markers for tumor aggressiveness. Microvascular density (MVD), measured from vascular stained radical prostatectomy (RP) specimens, is known to be highly correlated with CaP outcome and is thus a reliable indicator of CaP aggressiveness. In this work, we aim to identify in vivo imaging markers for aggressive CaP by correlating MVD with Dynamic contrast enhanced (DCE) Magnetic resonance imaging (MRI) kinetic parameters. This retrospective study consisted of six patients who underwent 3 Tesla multiparametric MRI prior to RP. CaP annotations provided by expert pathologist on CD31 stained RP sections were mapped onto DCE MRI on a per voxel basis via co-registration using thin plate splines. Association of kinetic features with MVD within CaP regions was estimated by Spearman's rank correlation test. Preliminary results show that rate of washout, enhancement and enhancement ratio are significantly correlated with MVD ($p < 0.05$), suggesting that they may be candidate imaging markers for aggressive CaP.

8676-4, Session 2

Automated gastric cancer diagnosis on H&E-stained sections; large scale training with multiple instance machine learning

Eric Cosatto, Christopher Malon, Pierre-Francois Laquerre, Hans-Peter Graf, NEC Labs. America, Inc. (United States); Akira Saito, Tomoharu Kiyuna, Atsushi Marugame, Ken'ichi Kamijo, NEC Corp. (Japan)

We present a system that detects cancer on H&E-stained gastric tissues. At its heart is a classifier trained using the semi-supervised multi-instance learning (MIL) framework, where a whole tissue is represented by a set of regions-of-interest (ROI) and a single label. Such labels are obtained from pathologists' diagnoses performed during regular clinical exams. From a large dataset of over 26K gastric tissue sections from over 12K patients, we train a MIL classifier on a patient-level partition and obtain a very high performance of 96% (AUC), tested on patients not used for training. We show this level of performance to match the more costly traditional supervised learning approach where individual ROIs must be labeled manually. The large amount of data used to train this system gives us confidence in its robustness and that it can be safely used in a clinical setting. We demonstrate how it can improve the clinical workflow when used for prescreening or quality control. For prescreening, the system can diagnose 47% of the tissues with a very low likelihood (<1%) of missing cancers, thus halving the clinicians' caseload. For quality control, compared to random rechecking, the system achieves a three-fold increase in the likelihood of catching missed cancers while maintaining

a 33% recheck rate. The system is currently being field-tested at a large Japanese clinical lab where it is used to double-check clinicians' diagnoses.

8676-5, Session 2

An automated method for counting cytotoxic T-cells from CD8 stained images of renal biopsies

M. Khalid Khan Niazi, Anjali A. Satoskar M.D., Tibor Nadasdy M.D., Metin N. Gurcan, The Ohio State Univ. (United States)

Studying inflammatory cell subsets in transplant biopsies can be important for diagnosis and to understand pathogenesis. Counting the different subsets of lymphocytes and macrophages in the immunostained renal biopsy is often considered as the only way to characterize the inflammatory infiltrate. Counting each subset of cells in each biopsy under a light microscope can be extremely tedious, time consuming and subject to inter- and intra-personal variability. This paper presents a new method to automatically count the number of CD8 positive cytotoxic t-cells on scanned images of immunostained slides of renal allograft biopsies. The method uses normalized multi-scale difference of Gaussian to detect the potential cytotoxic t-cell candidates regions, both in the color channel and the intensity channel. Then, it fuses the information from both channels' candidate regions to detect the individual cells within cell clumps. The evaluation of the proposed method shows that there is a strong consensus between the proposed method's markings with the pathologist's markings (97.49%).

8676-6, Session 2

Detecting mitotic figures in breast cancer histopathology images

Mitko Veta, Univ. Medical Ctr. Utrecht (Netherlands); Paul J. van Diest, Univ. Medical Ctr. Utrecht (Netherlands); Josien P. W. Pluim, Univ. Medical Ctr. Utrecht (Netherlands)

The scoring of mitotic figures is an integrated part of the Bloom and Richardson system for grading of invasive breast carcinoma. It is routinely done by pathologists by visual examination of hematoxylin and eosin (H&E) stained histology slides on a standard light microscope. As such, it is a tedious process prone to inter- and intra-observer variability. In the last decade, whole-slide imaging (WSI) has emerged as the "digital age" alternative to the classical microscope. The increasing acceptance of WSI in pathology labs has brought an interest in the application of automatic image analysis methods, with the goal of reducing or completely eliminating manual input to the analysis.

In this paper, we present a method for automatic detection of mitotic figures in breast cancer histopathology images. The proposed method consists of two main components: candidate extraction and candidate classification. Candidate objects are extracted by performing image segmentation with the Chan-Vese level set method. The candidate classification component aims at classifying all extracted candidates as being a mitotic figure or a false object. A statistical classifier is trained with a number of features that describe the size, shape, color and texture of the candidate objects. The proposed detection procedure was developed using a set of 18 whole-slide images, with over 800 manually annotated mitotic figures, split into independent training and testing sets. The overall true positive rate on the testing set was 59.5% while achieving 4.2 false positives per one high power field (HPF).

8676-7, Session 2

Novel chromatin texture features for the classification of pap smears

Babak Ehteshami Bejnordi, Ramin Moshavegh, Chalmers Univ. of Technology (Sweden) and MedTech West, Sahlgrenska Univ. Hospital, Gothenburg (Sweden); K Sujathan, Regional Cancer Ctr. (India); Patrik Malm, Ewert Bengtsson, Ctr. for Image Analysis, Uppsala Univ. (Sweden); Andrew Mehnert, Chalmers Univ. of Technology (Sweden) and MedTech West, Sahlgrenska Univ. Hospital, Gothenburg (Sweden)

This paper presents a set of novel structural texture features for quantifying nuclear chromatin patterns in cells on a conventional Pap smear. The features are derived from an initial segmentation of the chromatin into blob-like texture primitives. The results of a comprehensive feature selection experiment, including the set of proposed structural features and competing features, show that two of the four top ranking features are structural features. They also show that a combination of structural and conventional features yields a classification performance of 0.954 ± 0.019 (AUC±Std. Dev.) for the discrimination of normal (NILM) and abnormal (LSIL and HSIL) slides. The results of a second classification experiment, using only normal-appearing cells from both normal and abnormal slides, demonstrates that a single structural feature measuring chromatin margination yields a classification performance of 0.815 ± 0.019. Overall the results demonstrate the efficacy of the proposed structural approach and that it is possible to detect malignancy associated changes (MACs) in Papanicoloau stain.

8676-8, Session 2

Improved quantification of disease progression and treatment monitoring using steady-state tumor-model parameters

Joyoni Dey, Robert Licho M.D., Univ. of Massachusetts Medical School (United States)

Clinical Oncological imaging is performed with various modalities, CT, MRI and F-18-FDG-PET. Tumor volume, shape irregularity (and where PET scans available) SUV are important markers for monitoring of disease progression and treatment response. Recently, investigators have used diffusion-advective-reaction tumor-growth models for registration to brain-atlas for MRI brain-tumor datasets. We wish to extract model parameters from clinical time series scans of lung and brain tumors (CT or MRI) to see if the parameters -- tumor growth rate and/or diffusion-coefficient -- could potentially serve as predictive markers for monitoring disease and treatment response. We can then correlate with disease history and/or PET SUV to assess the viability of the model parameters as markers. One hurdle to performing this is that for majority of patients only 1 or 2 scans would be available for a specific tumor. In a novel approach, we hypothesize that over a short time scale the tumor density/volume change is small (or undetectable). Thus the cell birth and death and diffusion terms are in near-equilibrium. This steady-state model diffusion-coefficient and growth parameters may then be extracted from even a single CT or MRI scan available for each patient. Our steady state forward simulation and inversion could recover steady-state diffusion and growth-rate parameters with (0% & 0%) error for no-noise case and (0% & 7%) error for a high-noise case. The steady-state model fitted excellently to a lung-tumor (1-d) profile of an (anonymized) patient with only 1.74% fitting error in a sum-squared sense.

8676-9, Session 3

3D prostate histology reconstruction: an evaluation of image-based and fiducial-based algorithms

Eli D. Gibson, Robarts Research Institute (Canada) and Biomedical Engineering Graduate Program, The Univ. of Western Ontario (Canada); Mena Gaed, Robarts Research Institute (Canada) and Lawson Health Research Institute (Canada); José A. Gómez-Lemus, Madeleine Moussa, Cesare Romagnoli, Joseph L. Chin, The Univ. of Western Ontario (Canada); Cathie Crukley, Robarts Research Institute (Canada) and Lawson Health Research Institute (Canada); Glenn S. Bauman, Lawson Health Research Institute (Canada) and The Univ. of Western Ontario (Canada); Aaron Fenster, The Univ. of Western Ontario (Canada) and Robarts Research Institute, The Univ. of Western Ontario (Canada) and Dept. of Medical Biophysics, The Univ. of Western Ontario (Canada); Aaron D. Ward, Lawson Health Research Institute (Canada) and The Univ. of Western Ontario (Canada) and Baines Imaging Research Lab, London Health Sciences Ctr. (Canada)

Imaging may enable the determination of the spatial distribution and aggressiveness of prostate cancer in vivo before treatment, possibly supporting diagnosis, therapy selection, and focal therapy guidance. 3D reconstruction of prostate histology facilitates the validation of such imaging applications. We evaluated four histology–ex vivo magnetic resonance (MR) image 3D reconstruction algorithms comprising two similarity metrics (mutual information M_MI or fiducial registration error M_FRE) and two search domains (affine transformations T^A or fiducial-constrained affine transformations T^F). Seven radical prostatectomy specimens were imaged with MR imaging, processed for whole-mount histology, and digitized as histology images. The algorithms were evaluated on the reconstruction error and the sensitivity of same to translational and rotational errors in initialization. Reconstruction error was quantified as the target registration error (TRE): the post-reconstruction distance between homologous point landmarks (7–15 per histology section; 132 total) identified on histology and MR images. Sensitivity to initialization was quantified using a linear model relating TRE to varied levels of translational/rotational initialization errors. The algorithm using M_MI and T^A yielded a mean TRE of 1.2±0.7mm when initialized using an approach that assumes histology corresponds to the front faces of tissue blocks, but was sensitive to initialization error. The algorithm using M_FRE and T^A yielded a mean TRE of 0.8±0.4mm with minimal sensitivities to initialization errors. Compared to the method used to initialize the algorithms (mean TRE 1.4±0.7mm), a study using an algorithm with a mean TRE of 0.8mm would require 27% fewer subjects for certain imaging validation study designs.

8676-10, Session 3

Dynamically constrained pipeline for tracking neural progenitor cells

Jacob S. Vestergaard, Anders L. Dahl, Technical Univ. of Denmark (Denmark); Peter Holm, Faculty of Life Sciences, Copenhagen Univ. (Denmark); Rasmus Larsen, Technical Univ. of Denmark (Denmark)

Large scale in vitro cell growth experiments require automated segmentation and tracking methods to construct cell lineages in order to aid cell biologists in further analysis. Flexible segmentation algorithms that easily adapt to the specific type of problem at hand and directly applicable tracking methods are fundamental building blocks of setting up multi purpose pipelines. Segmentation by discriminative dictionary learning and a graph formulated tracking method constraining the allowed topology changes are combined here to accommodate for highly irregular cell shapes and movement patterns. A mitosis detector constructed from empirical observations of cells in a pre-mitotic state interacts with the graph formulation to dynamically allow for cell mitosis when appropriate. We validate the proposed pipeline by tracking pig neural progenitor cells through a time lapse experiment consisting of 825 images collected over 69 hours. The number of tracked cells increase from approximately 350 to 650 during the time period.

8676-11, Session 3

A statistical deformation model (SDM) based regularizer for non-rigid image registration: application to registration of multimodal prostate MRI and histology

Srivathsan Babu Prabu, Rutgers, The State Univ. of New Jersey (United States); Robert J. Toth, Rutgers, The State Univ. of New Jersey (United States); Anant Madabhushi, Case Western Reserve Univ. (United States)

Free form deformation (FFD) is a popular algorithm for non-linear image registration because of its ability to accurately recover deformations. However, due to the unconstrained elastic registration, FFD may introduce unrealistic deformations, especially when differences between template and target image are large, thereby necessitating a regularizer to constrain the registration to a physically meaning transformation. Prior knowledge in the form of a Statistical Deformation Model (SDM) in a registration scheme has been shown to function as an effective regularizer. With a similar underlying premise, in this paper, we present a novel regularizer for FFD that leverages knowledge of known, valid deformations to train a statistical deformation model (SDM). At each iteration of the FFD registration, the SDM is utilized to calculate the likelihood of a given deformation occurring and appropriately influence the similarity metric to limit the registration to only realistic deformations. We quantitatively evaluate robustness of the SDM regularizer in the framework of FFD through a set of synthetic experiments using brain images with a range of induced deformations and 3 types of noise—speckle(multiplicative), gaussian and salt & pepper. Here, it is demonstrated that FFD with inclusion of the SDM regularizer performed as much as 13% better than un-regularized FFD measured by normalized cross correlation (NCC). Qualitative evaluation of registration performance in spatially aligning ex vivo pseudo-whole mount histology (WMH) and in vivo prostate MRI to quantify multiprotocol MRI signatures of prostate cancer (CaP) revealed more accurate overlays compared to un-regularized FFD.

8676-12, Session 3

Reconstruction of vessel structures from serial whole slide sections of murine liver samples

Michael Schwier, Horst K. Hahn, Fraunhofer MEVIS (Germany); Uta Dahmen, Olaf Dirsch, Jena Univ. Hospital (Germany)

Image-based analysis of vascular structures of murine liver samples is an important tool for scientists to understand liver physiology and morphology. Typical assessment methods are MicroCT, which allows for acquiring images of the whole organ, while lacking resolution for fine details, and confocal laser scanning microscopy, which allows detailed insights into fine structures, while lacking the broader context.

Imaging of histological serial whole slide sections is a recent technology able to fill this gap, since it provides a fine resolution up to the cellular level, but on a whole organ scale. However, whole slide imaging is a modality providing only 2D images. Therefore the challenge is to use stacks of serial sections from which to reconstruct the 3D vessel structures.

In this paper we present a semi-automatic procedure to achieve this goal.

We employ an automatic method that detects vessel structures based on continuity and shape characteristics. Furthermore it supports the user to perform manual corrections where required.

With our methods we were able to successfully extract and reconstruct vessel structures from two stacks of 100 serial sections of a mouse liver lobe, thus proving the potential of our approach.

8676-13, Session 3

Registration of whole-mount histology and tomography of the prostate using particle filtering

Guy Nir, Septimiu E. Salcudean, The Univ. of British Columbia (Canada)

Registration of histological slices to tomography of the prostate is an important task that can be used to optimize imaging for cancer detection. Such registration is challenging due to change in volume of the specimen during fixation, and misalignment of the histological slices during preparation and digital scanning.

In this work we propose a multiple-slice to volume registration method in which a stack of equispaced, uniaxial but unaligned 2D contours, extracted from digitally scanned whole-mount histological slices, is registered to a 3D surface, extracted from a volumetric imaging of the prostate.

Initially, the stack of unaligned contours is coarsely aligned to the surface as a whole. Then, sequentially, each contour is finely registered to the surface while being confined to its plane along the sectioning axis.

We incorporate the method in a particle filtering framework to compensate for the high dimensionality of the search space and multi-modal nature of the problem. Moreover, such framework allows modelling the uncertainty in the segmentation of the contours and surface, in order to derive optimal registration parameters in a Bayesian approach.

The proposed algorithm is demonstrated and evaluated on both synthetic and clinical data. The mean area overlap of the registered gland and the segmented histology was found to be 90.2%, with a mean registration error of 1.8mm between visible landmarks.

8676-14, Session 3

Toward quantitative digital histopathology for prostate cancer: comparison of inter-slide interpolation methods for tumour measurement

Mehrnoush Salarian, Maysam Shahedi, Western Univ. (Canada); Eli D. Gibson, Robarts Research Institute (Canada); Mena Gaed, Jose A. Gómez-Lemus, Madeleine Moussa, Glenn S. Bauman, London Health Sciences Ctr. (Canada); Aaron D. Ward, Western Univ. (Canada)

Accurate pathology assessment of post-prostatectomy specimens is important to determine the need for and to guide potentially life-saving adjuvant therapy. Digital pathology imaging is enabling a transition to a more objective quantification of some surgical pathology assessments, such as tumour volume, that are currently visually estimated by pathologists and subject to inter-observer variability. One challenge for tumour volume quantification is the traditional 3–5 mm spacing of images acquired from sections of radical prostatectomy specimens. Tumour volume estimates may benefit from a well-motivated approach to inter-slide tumour boundary interpolation. We implemented and tested a level set-based interpolation method and found that it produced 3D tumour surfaces that may be more biologically plausible than those produced via a simpler nearest-slide interpolation. We found that the simpler method produced larger tumour volumes, compared to the level set method, by a median factor of 2.3. For contexts where only tumour volume is of interest, we determined that the volumes produced via the simpler method can be linearly adjusted to the level set-produced volumes. The smoother surfaces from level set interpolation yielded measurable differences in tumour boundary location; this may be important in several clinical/research contexts (e.g. pathology-based imaging validation for focal therapy planning).

8676-15, Session 4

EM-based segmentation-driven color standardization of digitized histopathology

Ajay N. Basavanhally, Rutgers, The State Univ. of New Jersey (United States); Anant Madabhushi, Case Western Reserve Univ. (United States)

The development of computerized image analysis tools (e.g. object segmentation) for digitized histology images is often complicated by color nonstandardness – the notion that different image regions corresponding to the same tissue will occupy different ranges in the color histogram – due to variations in slide thickness, staining, and lighting. Nonstandardness (i.e. intensity drift) can be addressed via standardization, which aims to improve color constancy by realigning color distributions of images to match that of a pre-defined template image. Unlike color normalization methods, which aim to scale (usually linearly or assuming that the transfer function of the system is known) the intensity of individual images, standardization is used to match color levels in imagery across an entire pathology irrespective of institution, protocol, or scanner. Intensity standardization has previously been used for radiological images; however, histopathological imagery is complicated by (a) the added complexity of color images and (b) variations in tissue structure. In this paper, we present a novel color standardization scheme (EMS) to decompose histological images into independent tissue classes (e.g. nuclei, epithelium, stroma, lumen) via the Expectation Maximization algorithm and align the color distributions for each class independently. By contrast, global standardization (GS) methods attempt to align histograms of the entire image and cannot account for the heterogeneity created by varying proportions of different tissue classes in each image. Evaluation was performed on prostate and oropharyngeal histopathology tissues from 19 and 26 patients, respectively. In a comparison of normalized median intensities, EMS produces lower standard deviations (i.e. greater consistency) of 0.0054 and 0.0030 for prostate and oropharyngeal cohorts, respectively, than non-standardized (0.034 and 0.038) and GS (0.0305 and 0.0175) approaches.

8676-16, Session 4

Cell cluster graph for prediction of biochemical recurrence in prostate cancer patients from tissue microarrays

Sahirzeeshan N. Ali, Case Western Reserve Univ. (United States); Robert Veltri, Jonathan A. Epstein, Christhunesa Christudass, The Johns Hopkins Hospital (United States); Anant Madabhushi, Case Western Reserve Univ. (United States)

Prostate cancer (CaP) is evidenced by profound changes in the spatial distribution of cells. Spatial arrangement and architectural organization of nuclei, especially clustering of the cells, within CaP histopathology is known to be predictive of disease aggressiveness and potentially patient outcome. Traditionally, graph theory has been used to characterize the spatial arrangement of these cells by constructing a graph with cell/nuclei as the node. One disadvantage of this approach is the inability to extract local attributes from complex networks that emerges from large histopathology samples. In this paper, we define a cluster of cells as a node and construct a novel graph called Cell Cluster Graph (CCG). CCG is constructed by first identifying the cell clusters to use as nodes for graph construction. Pairwise spatial relation between nodes is translated to the edges (links) of CCG with a certain probability. We then

extract global and local features from the CCG that best capture the tumor morphology. We evaluated the ability of the CCG to capture the characteristics of CaP morphology in order to predict 5 year biochemical failures in men with CaP and treated with radical prostatectomy. Extracted features from CCG constructed using nuclei as nodal centers on tissue microarray (TMA) images obtained from the surgical specimens allowed us to predict biochemical recurrence. A randomized 3-fold cross-validation via support Vector Machine classifier achieved an accuracy of 83.1 +/- 1.2 % in dataset of 67 patients comprising 30 Gleason grade of 3 and 37 Gleason grade 4.

8676-17, Session 4

Entropy based quantification of Ki-67 positive cell images and its evaluation by a reader study

M. Khalid Khan Niazi, Michael Pennell, Camille Elkins M.D., Jessica Hemminger M.D., Ming Jin M.D., Sean Kirby M.D., Habibe Kurt M.D., Barrie Miller M.D., Elizabeth Plocharczyk M.D., Rachel Roth M.D., Rebecca Ziegler M.D., Arwa Shana'ah M.D., Fred Racke M.D., Gerard Lozanski, Metin N. Gurcan, The Ohio State Univ. (United States)

Presence of Ki-67, a nuclear protein, is typically used to measure cell proliferation. The quantification of the Ki-67 proliferation index is performed manually by the pathologist, however, this is subject to inter- and intra-reader variability. Automated techniques utilizing digital image analysis by computers have emerged. The large variations in specimen preparation, staining, and imaging as well as true biological heterogeneity of tumor tissue often results in variable intensities in Ki-67 stained images. These variations affect the performance of currently developed methods. To optimize the segmentation of Ki-67 stained cells, one should define a data dependent transformation that will account for these color variations instead of defining a fixed linear transformation to separate different hues. To address these issues in images of tissue stained with Ki-67, we propose a methodology that exploits the intrinsic properties of CIE L* a* b* color space to translate this complex problem into an automatic entropy based thresholding problem. The developed method was evaluated through two reader studies with pathology residents and expert hematopathologists. Agreement between the proposed method and the expert pathologists was good (CCC = 0.80).

8676-18, Session 4

Psycho-visual evaluation of image quality attributes in digital pathology slides viewed on a medical color LCD display

Ljiljana Plati?a, Univ. Gent (Belgium); Leen Van Brantegem, Univ. Gent (Belgium); Yves Vander Haeghen, Ghent Univ. Hospital (Belgium); Cédric Marchessoux, Barco N.V. (Belgium); Ewout Vansteenkiste, Wilfried Philips, Univ. Gent (Belgium)

We investigate the effects of common types of image degradation on the perceived quality of digital pathology slides. The non-degraded (reference) images in our study were pathological slides of the gastric fundic glands of a dog and of the liver of a foal. All images were details of tissues, stained with haematoxylin and eosin. To vary image attributes, reference images were artificially degraded by the following manipulations, always one at a time: blur filtering, gamma, noise, color saturation and JPG compression. Three groups of human observers: expert veterinary pathologists, students of veterinary medicine and researchers in digital image processing assessed image quality and its attributes in two types of experiments: double- and single-stimulus trials. The following observer scores were collected: 1) image dissimilarity, 2) image quality preference (double-stimulus), judgment of the level of 3) blur, 4) contrast, 5) noise, 6) color saturation, and 7) overall quality scores (single-stimulus). Preliminary analysis is based on the mean opinion scores (MOS) computed for all three observer groups and all seven scores. The results suggest the major causes of perceptual dissimilarity to involve decrease in color saturation (all groups) and increase in blurriness (imaging experts only). Furthermore, the dominant source of quality degradation according to expert and student pathologists was blurring, while for imaging experts it was JPG compression. The ongoing further analysis employs multidimensional scaling techniques to construct a perceptual space (dimensions corresponding to image attributes) which would facilitate understanding of the interaction between quality and its attributes.

8676-19, Session 4

Comparison study of five different display modalities for whole slide images in histo and cytopathology in Europe

Nicky D'Haene, Calliope Maris, Erasme Univ. Hospital, Univ. Libre de Bruxelles (Belgium); Rorive Sandrine, Erasme Univ. Hospital, Univ. Libre de Bruxelles (Belgium) and DIAPATH - Ctr. for Microscopy and Molecular Imaging (CMMI) (Belgium); Xavier Moles Lopez, DIAPATH - Ctr. for Microscopy and Molecular Imaging (Belgium) and LIST-LISA, Ecole Polytechnique de Bruxelles, Univ. Libre de Bruxelles (Belgium); Johan Rostang, Cédric Marchessoux, Barco N.V. (Belgium); Liron Pantanowitz, Anil V. Parwani, Univ. of Pittsburgh Medical Ctr. (United States)

User experience with viewing images in pathology is crucial for accurate interpretation and diagnosis. With digital pathology images are being read on a display system, and this poses new types of questions: such as what is the difference in terms of pixelation, refresh lag or obscured features compared to an optical microscope. Is there a resultant change in user performance in terms of speed of slide review, perception of adequacy and quality or in diagnostic confidence? A prior psychophysical study was carried out comparing various display modalities on whole slide imaging (WSI) in pathology at the University of Pittsburgh Medical Center (UPMC) in the USA. This prior study compared professional and non-professional grade display modalities and highlighted the importance of using a medical grade display to view pathological digital images. This study was duplicated in Europe at the Department of Pathology in Erasme Hospital (Université Libre de Bruxelles (ULB)) in an attempt to corroborate these findings. Digital WSI with corresponding glass slides of 58 cases including surgical pathology and cytopathology slides of varying difficulty were employed. Similar non-professional and professional grade display modalities were compared to an optical microscope (Olympus BX51). Displays ranged from a laptop (DELL Latitude D620), to a consumer grade display (DELL E248WFPb), to two professional grade monitors (Eizo CG245W and Barco MDCC-6130). Three pathologists were selected from the Department of Pathology in Erasme Hospital (ULB) in Belgium to view and interpret the pathological images on these different displays. The results show that non-professional grade displays (laptop and consumer) have inferior user experience compared to professional grade monitors and the optical microscope.

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8676-20, Session 4

Content-based white blood cell retrieval on bright-field pathology images

Xin Qi, Rebekah H. Gensure, David J. Foran, Univ. of Medicine and Dentistry of New Jersey (United States); Lin Yang, Univ. of Kentucky (United States)

The purpose of this work was to evaluate a newly developed content-based retrieval approach for characterizing a range of different white blood cells from a database of imaged peripheral blood smears. Specimens were imaged using a 20x magnification to provide adequate resolution and sufficiently large field of view. The resulting database included a test ensemble of 96 images (1000x1000 pixels each). In this work, we propose a four-step content-based retrieval method and evaluate its performance. The content-based image retrieval (CBIR) method starts from white blood cell identification, followed by three sequential steps including coarse-searching, refined searching, and finally mean-shift clustering using a hierarchical annular histogram (HAH). The prototype system was shown to reliably retrieve those candidate images exhibiting the highest-ranked (most similar) characteristics to the query. The results presented here show that the algorithm was able to parse out subtle staining differences and spatial patterns and distributions for the entire range of white blood cells under study. Central to the design of the system is that it capitalizes on lessons learned by our team while observing human experts when they are asked to carry out these same tasks.

8676-21, Session PSMon

An algorithm to evaluate the number of trabecular cell layers using nucleus arrangement applied to hepatocellular carcinoma

Hideki Komagata, Naoki Kobayashi, Ayako Katoh, Yasuka Ohnuki, Saitama Medical Univ. (Japan); Masahiro Ishikawa, Tokyo Institute of Technology (Japan); Kazuma Shinoda, Saitama Medical Univ. (Japan); Masahiro Yamaguchi, Tokyo Institute of Technology (Japan); Tokiya Abe, Akinori Hashiguchi, Michiie Sakamoto, Keio Univ. (Japan)

Recent advances in information technology have improved pathology virtual-slide technology and studies of diagnostic support systems for pathological images. The diagnostic support systems have been expected to using quantitative indices evaluated by image processing. In previous studies on the diagnostic support system, carcinoma areas of breast or lung carcinoma has been recognized using feature quantities of the nuclei sizes, nuclei complexities, and internuclear distances based on graph theory, among other features. Improving the recognition accuracy is important to add new feature quantities. We have focused on hepatocellular carcinoma, and investigated new feature quantities of histological image of hepatocellular carcinoma. One of the most important histological features of hepatocellular carcinoma is trabecular pattern, and to make a cancer diagnosis, it is important to recognize the tumor cell trabeculae. In this paper, we propose a new algorithm to calculate the number of layers in histological images of hepatocellular carcinoma stained by hematoxylin and eosin. To calculate them, we used a Delaunay diagram based on median points of the nucleus, deleted the sinusoid and fat droplet regions from the Delaunay diagram, and counted the Delaunay lines along with an application of a thinning algorithm. Moreover, we experimented to calculate the number of layers using our method at each tumor differentiation of the hepatocellular carcinoma. Our results discriminated differences across the tumor differentiation; therefore, our algorithm is possible to be one of the indices of hepatocellular carcinoma for the diagnostic support system.

8676-22, Session PSMon

Quantitative analysis of TDLUs using adaptive morphological shape techniques

Adrian Rosebrock, Univ. of Maryland, Baltimore County (United States); Jesus J. Caban, Walter Reed National Military Medical Ctr. (United States); Jonine Figueroa, Gretchen Gierach, Laura Linville, National Cancer Institute (United States); Stephen M. Hewitt, Mark E. Sherman, National Institutes of Health (United States)

Within the complex branching system of the breast, terminal duct lobular units (TDLUs) are the anatomical location where most cancer originates. TDLUs and their associated morphological changes have been associated with breast cancer risk. However, quantitative measures using image analysis methods that characterize the morphologic changes in TDLUs that could be informative in risk prediction are lacking. This paper introduces a technique to automatically estimate a set of quantitative measurements and use those variables to more objectively describe and classify TDLUs. In particular, image features such as area, elongation, perimeter, and roundness of each acini that forms a TDLU are used to objectively describe the morphological properties of terminal units. To validate the accuracy of our system, the computer-based morphological properties of 51 TDLUs were compared with the annotations of an expert pathologist and we found that our system was able to obtain 70.59% agreement. Lastly, we demonstrate the ability to uncover novel measures when researching the structural properties of the acini by applying machine learning and clustering techniques. Through our study we found that while the number of acini in a TDLU grow exponentially with the size of diameter, the average elongation and roundness do not change as the diameter of the TDLU increases. This finding allows us to conclude that even though a TDLU with more acini is structurally larger, the acini that comprise the TDLU do not exhibit deviant morphological changes.

8676-23, Session PSMon

Assessing color reproducibility of a whole slide-imaging scanner

Wei-Chung Cheng, U.S. Food and Drug Administration (United States); Tyler Keay, Neil O'Flaherty, Joel Wang, Adam Ivansky, U.S. Food and Drug Administration (United States); Marios A. Gavrielides, Brandon D. Gallas, Aldo Badano, U.S. Food and Drug Administration (United States)

Evaluating the color performance of a whole slide-imaging (WSI) scanner is challenging because of the difficulties in establishing the ground truth of color samples: (1) cellular structures in tissue slides are too small for any colorimeter to measure, (2) tissue staining color is difficult to control and reproduce, and (3) WSI systems render images after white balancing assuming an ideal white illuminant which can never be observed in an optical microscope. In this study, we describe a new method of establishing the color truth with a color phantom for assessing color reproducibility of WSI systems. Photographic film with 140 color patches was mounted on a glass slide. The spectral power distributions (SPDs) of the color patches and light source were measured with a spectroradiometer attached to an optical microscope. The spectral transmittance of each color patch was determined by dividing the color patch SPD by the light source SPD. Then, the standard daylight illuminant, CIE D65, substituted the light source SPD to calculate an ideal color reproduction. CIE 1976-based color differences between the truth and the WSI scans were calculated for both color-managed and -unmanaged image viewers. The results show pronounced color differences for certain hues when color management is activated and even worse performance without color management. The findings suggest that color reproducibility of WSI scanners is stain-dependent and demands careful adjustments within a color management framework.

8676-24, Session PSMon

Calibration and test of a hyperspectral imaging prototype for intra-operative surgical assistance

Dorra Nouri, Univ. d'Orléans (France); Yves Lucas, Univ. d'Orléans (France); Sylvie Treuillet, Univ. d'Orléans (France)

Multispectral imaging has been used for decades in the field of earth remote sensing. The recent advances on sensor technology now open the door of the operating room to this new medical imaging modality, as there is an increasing need to bring imaging devices closer to the surgeon. This is attested by new hybrid rooms embedding C-arms for intra-operative X-ray scanning, to enable registration of the operation field with anatomic structures for tool guidance or diagnostic. Such as ultrasound or fluorescence technique, multispectral imaging falls in the category of non invasive and low cost techniques. Before becoming of practical interest for the clinician, such system should meet important requirements. Firstly, it should enable real reflectance measurements and high quality images to dispose of valuable physical data after calibration. Secondly, quick band pass scanning and a smart interface are needed for intra-operative mode. Finally, experimentation is needed to develop expert knowledge for multispectral image interpretation and result display on standard three channel screens, to assist the surgeon with tissue detection and diagnostic capabilities during an intervention. We perform these different steps here through the development of a new prototype. Among the targeted advances we can cite with underlying anatomic structure location, tumour margin evaluation and tissue ischemia detection. To resume, the intention is to offer sharper vision to the surgeon, not only due to multispectral imaging and processing but also to near infrared waveband sensing.

8676-25, Session PSMon

An adaptive image representation learned from data for cervix cancer tumor detection

Angel Cruz Roa, Eduardo Romero Castro, Fabio González Osorio, Univ. Nacional de Colombia (Colombia)

This paper proposes an adaptive image representation learning method for cervix cancer tumor detection. The method learn an adaptive image representation in two stages, local feature description using sparse dictionary learning and global image representation using a bag-of-features (BOF) approach. The proposed method was evaluated in a dataset of 394 cervical histology images with tumoral and non-tumoral pathologies acquired at a 10X magnification and a resolution of 3800 x 3000 pixels in RGB color. The sparse dictionary was selected choosing the dictionary with a good parameter combination (patch size, number of basis and lambda) using as criteria a lower value for both coherence measure, between sparse dictionary and canonical basis, and average of sparsity of patch representations. A conventional approach for image representation based on BOF was selected as baseline, which uses raw-block linearized as local descriptor. The preliminary results show that our proposed method improves the baseline for all different BOF dictionary sizes (125, 250, 500, 1000 and 2000). The best performance achieved was 0.77 +/- 0.04 in average accuracy of 10 cross-validation, for a BOF dictionary of 2000, improving in 2.5% the baseline. These results suggest that the learning could be performed at every stage, and not only during the final link between image representation and high-level concepts for classifying.

8676-26, Session PSMon

A level-set method for pathology segmentation in fluorescein angiograms and en face retinal images of patients with age-related macular degeneration

Fatimah Mohammad, Rashid Ansari, Mahnaz Shahidi, Univ. of Illinois at Chicago (United States)

The nature of lesions caused by retinal diseases such as age-related macular degeneration (AMD) and diabetic retinopathy provides clues that aid in detection and early diagnosis of the disease. The visibility and continuity of the inner segment outer segment (ISOS) junction layer of the photoreceptors on spectral domain optical coherence tomography images is known to be related to visual acuity in patients with AMD. Automated detection and segmentation of lesions and pathologies in retinal images is crucial for the screening, diagnosis, and follow-up of patients with retinal diseases. Building on the level-set method based on the classical Chan-Vese model, we propose an improved method for pathology segmentation in fluorescein angiograms and en face retinal images of the ISOS layer which automatically isolates the pathology without the need to specify the location of an initial contour. This was accomplished by exploiting a priori knowledge of the shape and intensity distribution allowing the use of projection profiles to detect the presence of pathologies that are characterized by intensity differences with surrounding areas in retinal images. The method showed improved reliability in the segmentation which may fail in classical algorithms with an incorrect choice of the initial contour. We first tested our method by applying it to fluorescein angiograms. We then applied our method to the en face retinal images of patients with AMD. These images show more textured changes due to disease. Results showed that an improved outcome was attained with a reduced number of iterations thereby increasing the speed of convergence as the initial contour encloses the region of interest on the first iteration. The experimental results included demonstrate that the proposed method with automatic detection of lesions provided better results than the classical Chan-Vese method in which the initial contour is specified thus indicating the potential to provide a more accurate and detailed view of changes in pathologies due to disease progression and treatment.

8676-27, Session PSMon

Meningioma subtype classification using morphology features and Random Forests

Harry Strange, Reyer Zwiggelaar, Aberystwyth Univ. (United Kingdom)

The majority of meningiomas belong to one of four subtypes: fibroblastic, meningothelial, transitional and psammomatous. Classification of histopathology images of these meningioma is a time consuming and error prone task, and as such automatic methods aim to help reduce time spent and errors made. This work is concerned with classifying histopathology images into the above subtypes by extracting simple morphology features to represent each image subtype. Morphology features are identified based on the pathology of the meningioma subtypes and are used to classify each image into one of the four WHO Grade I subtypes. The morphology features correspond to visual changes in the appearance of cells, and the presence of psammoma bodies. Using morphological image processing these features can be extracted and the presence of each detected feature is used to build a vector for each meningioma image. These feature vectors are then classified using a Random Forest based classifier. A set of 80 images was used for experimentation with each subtype being represented by 20 images, and a ten-fold cross validation approach was used to obtain an overall classification accuracy. Using the above methodology a maximum classification accuracy of 91.25% is achieved across the four subtypes with coherent misclassification (e.g. no misclassification between fibroblastic and meningothelial). This work demonstrates that morphology features can be used to perform meningioma subtype classification and

provide an understandable link between the features identified in the images and the classification results obtained.

8676-28, Session PSMon

Quantification of relative chromatin content in Flow Cytometry standards using 3D OPTM Imaging technique

Nitin Agarwal, Univ. of Washington (United States); Alberto Biancardi, Cornell Univ. (United States); Florence Patten, VisionGate, Inc. (United States); Anthony P. Reeves, Cornell Univ. (United States); Eric J. Seibel, Univ. of Washington (United States)

A potential biomarker for early diagnosis of cancer is assessment of high cellular DNA content. Conventional hematoxylin staining is neither stoichiometric nor reproducible. Feulgen stain though stoichiometric is time consuming and destroys nuclear morphology. We used acidic thionin stain, which can be stoichiometric and also preserve the nuclear morphology used in conventional cytology. Fifty chicken erythrocyte nuclei (CEN) singlets, diploid trout erythrocyte nuclei (TENs) and Triploid TENs were stained for 15 and 30 minutes each. After imaging with optical projection tomography microscope (OPTM), 3D reconstructions of the nuclei were processed to calculate chromatin content. Absolute error with reference to the standard values was computed for individual ratios of the flow cytometry standards. Mean error, standard deviation and 97% confidence interval was computed for the ratios of these standards. At 15 and 30 minutes, the ratio of Triploid TEN to TEN was 1.72 and 1.76, TEN to CEN was 1.27 and 2.01 and Triploid TEN to CEN was 2.11 and 3.39 respectively. Estimates of DNA indices for all 3 types of nuclei had less mean error at 30 minutes of staining; Triploid TEN to TEN 0.349±0.04, TEN to CEN 0.36±0.04 and Triploid TEN to CEN 0.64 ± 0.07. In conclusion, imaging of cells with thionin staining and 3D reconstruction provides reasonably accurate quantitative assessment of cell chromatin content. The addition of this quantitative feature of aneuploidy is expected to add greater accuracy to a classifier for early diagnosis of cancer based on 3D cytological imaging.

8676-29, Session PSMon

Learning semantic histopathological representation for basal cell carcinoma classification

Ricardo Gutiérrez, Univ. Nacional de Colombia (Colombia); Andrea Rueda, Univ. Nacional de Colombia (Colombia); Eduardo Romero Castro, Univ. Nacional de Colombia (Colombia)

Accurate diagnosis of Alzheimer's disease (AD) from structural Magnetic Resonance (MR) images is difficult due to the complex alteration patterns in brain anatomy that could indicate the presence or absence of the pathology. Currently, an effective approach that allows to interpret the disease in terms of global and local changes is not available in the clinical practice. In this paper, we propose an approach for classification of brain MR images, based on finding pathology-related patterns through the identification of regional structural changes. The approach combines a probabilistic Latent Semantic Analysis (pLSA) technique, which allows to identify image regions through latent topics inferred from the brain MR slices, with a bottom-up Graph-Based Visual Saliency (GBVS) model, which calculates maps of relevant information per region. Regional saliency maps are finally combined into a single map on each slice, obtaining a master saliency map of each brain volume. The proposed approach includes a one-to-one comparison of the saliency maps which fed a Support Vector Machine (SVM) classifier, to group test subjects into normal or probable AD subjects. A set of 56 brain MR images from healthy (28) and pathological (28) subjects, splitted into a training set (20 non-demented and 20 demented subjects) and one testing set (16 subjects), was used to evaluate the performance of the proposed approach. Preliminary results show that the proposed method reaches a classification accuracy of 68.75%.

8676-30, Session PSMon

Analysis of the spatial distribution of prostate cancer obtained from histopathological images

Kristians E. Diaz Rojas, Benjamin Castañeda, Maria L. Montero, Pontificia Univ. Católica del Perú (Peru); Jorge L. Yao M.D., Deborah J. Rubens M.D., Jean V. Joseph M.D., Univ. of Rochester Medical Ctr. (United States); Kevin J. Parker, Univ. of Rochester (United States)

Understanding the spatial distribution of prostate cancer and how it changes according to PSA values, capsule penetration, tumor size, Gleason score and age of the patients may help comprehend the disease and increase the overall success rate of biopsies. This work aims to build 3D spatial distributions of prostate cancer according to the abovementioned parameters. The border of the gland and cancerous regions from whole mount histopathological images are used to reconstruct 3D models showing the localization of tumor. This process utilizes color segmentation and interpolation based on mathematical morphological distance. 58 glands are warped against one prostate subjectively selected as an atlas using a combination of rigid, affine and b-spline deformable registration techniques. Spatial distribution is developed by counting the number of occurrences in a given position in 3D space from each registered prostate cancer. Finally a difference between proportions is used to compare different spatial distributions. Results show that prostate cancer has a significant difference (SD) in the right zone of the prostate between populations with PSA greater and less than 5ng/ml. Age does not have any impact in the spatial distribution of the disease. Positive and negative capsule penetrated cases show a SD in the right posterior zone. There is SD in almost all the gland between cases with tumors larger and smaller than 10% of the whole prostate. A larger database is needed to improve statistical power of the test. Finally, information from whole mount-histopathological images could provide a better insight into prostate cancer.

8676-31, Session PSMon

Computer assisted detection of regions of interest in histopathology using a hybrid supervised and unsupervised approach

Alessandro Gherardi, ARCES - Univ. degli Studi di Bologna (Italy); Alessandro Bevilacqua, ARCES - Univ. degli Studi di Bologna (Italy) and DEIS - Dept. of Electronics, Computer Science and Systems (Italy)

The detection of suspicious cancerous regions is still a problematic task in histopathology, where complex qualitative, and highly subjective, analyses are required by experts. Digital pathology is the option for building semi-automated tools that could assist pathologists in carrying out their analysis in a quantitative way. Methods for assisted detection of cancerous areas are mostly based on low level textural features of the tissue, whose semantic level is far from the visual appearance that histopathologists consider during their analysis.

In order to bridge the "semantic gap" between histopathology and machine representation, we propose an algorithm for the detection of cancerous regions in lung and bladder adenocarcinoma samples, based on a supervised multi-level representation directly linked to histopathological characteristics. Instead, our unsupervised clustering method performs a segmentation of the histopathology structures according to their visual appearance through a similarity metric based on histograms of samples in the Lab perceptive color space. This permits to increase the sensitivity of the supervised approach by extending

the regions (i.e., hits) it detects. We validated the accuracy of the proposed segmentation approach, using a group of ten users using 40 histopathology cases, showing a good response.

The experiments, performed using the ground truth provided by a board of certified experts on different samples of adenocarcinoma (graded G1), prove the effectiveness of our overall approach both in terms of sensitivity and precision in detecting suspicious regions. Our algorithm is currently under testing on more samples and different cancerous histotypes.

8676-32, Session PSMon

Fast GPU-based segmentation of H&E stained squamous epithelium from multi-gigapixel tiled virtual slides

Benjamin Bryant, Hamed Sari-Sarraf, Mitchell Wachtel, Texas Tech Univ., Applied Vision Lab. (United States); Sameer Antani, National Library of Medicine (United States); Rodney Long, National Library of Medicine (United States)

The processing of multi-gigapixel virtual histology slides presents a computationally intensive and time consuming task. Common tiled TIFF slide formats, such as those used by Aperio [1], contain inherent header information that can be used to rapidly locate tissue regions for cervical intraepithelial neoplasia (CIN) diagnosis. Tiles used in these formats are individually compressed subsections of the virtual slide, whose compression ratio varies based on their individual content. This paper discusses a method that exploits this information to rapidly identify regions of interest in an iterative process to locate epithelial tissue. These regions are decompressed using a multi-core CPU, from which a Compute Unified Device Architecture (CUDA) enabled GPU rapidly generates features and Support Vector Machine (SVM) decisions. A posteriori SVM data is used in a post-processing scheme to remove apparently spurious misclassifications. The mean overall execution time when using a high-end desktop PC, together with a GTX 560 GPU, is roughly 3 seconds per gigapixel, while maintaining the area under an ROC curve above 0.9 when classifying squamous epithelium versus other tissues.

8676-33, Session PSMon

Automatic classification of hepatocellular carcinoma images based on nuclear and structural features

Tomoharu Kiyuna, Akira Saito, Atsushi Marugame, Yoshiko Yamashita, Maki Ogura, NEC Corp. (Japan); Eric Cosatto, NEC Labs. America, Inc. (United States); Tokiya Abe, Akinori Hashiguchi, Michiie Sakamoto, Keio Univ. (Japan)

Diagnosis of hepatocellular carcinoma (HCC) on the basis of digital images is a challenging problem because, unlike gastrointestinal carcinoma, strong structural and morphological features are limited and sometimes absent from HCC images. In this study, we describe the classification of HCC images using statistical distributions of features obtained from image analysis of cell nuclei and hepatic trabeculae. Images of 130 hematoxylin-eosin (HE) stained histologic slides were captured at 20X by a slide scanner (Nanozoomer, Hamamatsu Photonics, Japan) and 1112 regions of interest (ROI) images were extracted for classification (551 negatives and 561 positives,including 134 well-differentiated positives). For a single nucleus, the following features were computed: area, perimeter, circularity,ellipticity, long and short axes of elliptic fit, contour complexity and co-occurrence gray level matrix (CGLM) texture features (angular second moment, contrast, homogeneity and entropy). In addition,distributions of nuclear density and hepatic trabecula thickness within an ROI were also extracted. To represent an ROI, statistical distributions(mean, standard deviation and percentiles) of these features we reused. In total, 78 features were extracted for each ROI and a support vector machine (SVM) was trained to classify negative and positive ROIs. Experimental results using 5-fold cross validation show 90% sensitivity for an 87.8% specificity. The use of statistical distributions over a relatively large area makes the HCC classifier robust to occasional failures in the extraction of nuclear or hepatic trabecula features, thus providing stability to the system.

8676-34, Session PSMon

Marked point processes with simple and complex shape objects for cell nuclei extraction from breast cancer H&E images

Christophe Avenel, Univ. Pierre et Marie Curie (France); Maria S. Kulikova, CNRS IPAL UMI (Singapore)

According to the Nottingham Grading System for breast cancer grading, nuclear pleomorphism is one of the three criteria along with tubule formation and mitotic count taken into account in grading procedure. Nuclear pleomorphism is largely based on the infomation about variation of nuclei appearance, size, and shape. Nuclei extraction from breast cancer images is thus necessary for cancer grading, and has become one of the major problem in the domain of automatic image analysis. Recently, several papers have showed that stochastic Marked Point Processes are a promising tool for dealing with this kind of problems.

In this paper, we will present visual and quantitative comparison of results obtained with two Marked Point Process based models with two types of objects used, and analyse the advantages of each of them. We will first show a way to detect nuclei position and size using ellipse-shaped objects. Ellipses give a good approximation of nuclei shape size in a fast way. We will then use arbitrarily-shaped object to delineate more precisely nuclei contour. As this method is a data driven method, we will discuss the best data energy to use for each kind of objects, based on common criteria of the nucleus in any cancer grade.

Results will be shown on Haematoxylin and Eosin (H&E) stained breast cancer slide images. As appearance, size and shape may vary a lot depending on the cancer grade, we will show results on different grades and compare our methods for each of them.

8676-35, Session PSMon

Medical image fusion based on Spiking Cortical Model

Rui Wang, Yi Wu, Mingyue Ding, Xuming Zhang, Huazhong Univ. of Science and Technology (China)

Medical image fusion plays an important role in clinical applications such as image-guided surgery, image-guided radiotherapy, non-invasive diagnosis, and treatment planning. Although numerous researches have been done in developing various medical image fusion algorithms, the disadvantage of these approaches is that they lack universality in dealing with different kinds of medical images. To address this problem, we have proposed a novel method of medical image fusion using the spiking cortical model (SCM) for the first time. In the paper, firstly the mathematical model of SCM is described, and then image fusion algorithm with spiking cortical model is introduced in detail. To show that the SCM based fusion method can deal with multimodal medical images, we have used three pairs of medical images with different modalities in the simulation experiments and made comparisons among the proposed method and the state-of-art fusion methods such as Laplacian pyramid, Contrast pyramid, Morphological pyramid and Gradient pyramid, etc. The performance of various methods is investigated using such image assessment metrics as Mutual Information (MI), the edge preservation values (QAB/F), the Local Structural Similarity (LSSIM) and the Universal Image Quality Index (UIQI). The experimental results show that our proposed method outperforms other methods in both visual effect and objective evaluation. It demonstrates that the SCM based method is a highly effective method for multi-modal medical image fusion due to its versatility and stability.

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Automatic segmentation of hepatocellular structure from HE-stained liver tissue

Masahiro Ishikawa, Sercan Taha Ahi, Yuri Murakami, Fumikazu Kimura, Masahiro Yamaguchi, Tokyo Institute of Technology (Japan); Tokiya Abe, Akinori Hashiguchi M.D., Michiie Sakamoto M.D., Keio Univ. (Japan)

The analysis of hepatic tissue structure is required for quantitative assessment of liver histology. The structure comprises various components, such as nuclei, cell cytoplasm, fibers, and sinusoids, and the tissue segmentation from HE-stained histology images is a difficult task. In this study, we propose an approach for the segmentation of hepatocytes. Our approach starts with the identification of sinusoids and fibers. Although sinusoids basically have white regions, in reality HE-stained sinusoids include cytoplasm, red blood cells, lymphocytes, and endothelial cells; and the boundaries between sinusoids and hepatocytes sometimes loose the contrast. To be able to segment sinusoids correctly, we proposed an orientation selective filter to improve the contrast of boundaries.1

Then expectation-maximization algorithm is applied for clustering bright pixels. To segment fiber regions, we formed feature vectors using texture and color information in small rectangular regions in the image. We trained a linear support vector machine (SVM) using 4000 training images of 64x64 pixels that are acquired at 20x magnification level. When a new unlabeled image arrived, we first extract pixel-wise SVM probabilities. Then in order to obtain more precise boundaries, we use super pixels that group similar and nearby pixels. Super pixels that exceed an empirically determined probability are assumed to be fibers. Segmentation is finalized by setting the center line of the non-sinusoid and non-fiber regions as hepatocytes. We present segmentation outputs for a qualitative assessment of hepatic trabecula including hepatocellular carcinoma.