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Technical Abstract Summaries

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7622-01, Session 1

Integrated imaging for radiation therapy delivery

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Radiation therapy plays a significant role in the management of cancer and benign diseases. As a localized treatment modality, it is vulnerable to imprecision and inaccuracy in targeting of the dose within the human body. Conventional approaches rely upon poor geometric surrogates of internal anatomy, such as, skin marks, bony anatomy, or implanted fiducial markers. This approach, while successful in targeting, results in the irradiation of substantial volumes of normal surrounding tissues and limits aggressive dose escalation. The past ten years has seen an unprecedented period of change in the field with the development of a plethora of novel radiation treatment machines with integrated imaging for target localization and image-guided delivery. These include integrated megavoltage (MV) computed tomography, volumetric cone-beam CT, ultrasound imaging, and fluoroscopic tracking. These systems have altered clinical practice and are encouraging further developments to provide greater contrast-to-noise of relevant anatomy and the capacity to track mobile, deforming structures. In fact, there are currently several integrated MR-guided radiation treatment systems in development with the promise of reaching clinical application in the next 5 years. In this review, the motivation and current status of these integrated imaging systems will be examined and their impact on the development of the adaptive radiation therapy paradigm will be highlighted.

7622-02, Session 1

Low-contrast visualization in megavoltage cone-beam CT at one beam pulse per projection using thick, segmented scintillators

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Megavoltage cone-beam computed tomography (MV CBCT) using an electronic portal imager (EPID) is a highly promising technique for providing valuable volumetric information for image guidance in radiotherapy. However, active matrix flat-panel imagers (AMFPIs), which are the established gold standard in portal imaging, require a relatively large dose to create images that are clinically useful. This is a consequence of the inefficiency of the phosphor screens employed in conventional MV AMFPIs, which utilize only ~2% of the incident radiation at 6 MV. Fortunately, the incorporation of thick, segmented scintillators can significantly improve the performance of MV AMFPIs, leading to improved image quality for projection imaging at extremely low dose. It is therefore of interest to explore the performance of such thick scintillators for MV CBCT toward soft-tissue contrast visualization. In this study, prototype AMFPIs incorporating segmented scintillators based on CsI:Tl and BGO crystals with thicknesses ranging from ~11 to 40 mm have been constructed and evaluated. Each prototype incorporates a detector consisting of a matrix of 120x60 scintillator elements separated by reflective septal walls, with an element-to-element pitch of 1.016 mm. Reconstructed images of low-contrast, soft-tissue-equivalent objects, embedded in a water-equivalent phantom, were obtained down to the lowest available dose (one beam pulse per projection), corresponding to a total scan dose of ~4 cGy using 180 projections. In this presentation, results of contrast-to-noise ratio for the tissue-equivalent objects using various prototypes will be examined as a function of dose and compared to those of a conventional MV AMFPI.

7622-03, Session 1

Feasibility of proton tomosynthesis system in proton therapy

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Currently, the patient dose of proton therapy and treatment planning are based on the x-ray photon CT (computed tomography) data. However, material interactions between protons and photons are different. Proton tomograms are useful to make with accuracy the dose calculations for planning and positioning of patients. For applying CT techniques, many projection images during at least half rotation are need. It makes extremely high patient dose. We apply the proton tomosynthesis, which is the limited angle tomography using proton-beams. The proton tomosynthesis may provide more accuracy of dose calculation and verifications with less patient dose. We describe the concept of the proton tomosynthesis and demonstrate its performance with GEANT4 simulation and experiments. Comparative analysis with the x-ray photon methods will be addressed.

7622-04, Session 2

Development of a computational three-dimensional breast lesion model

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We have developed a realistic three-dimensional breast lesion model that can be computationally embedded in background images of healthy breast tissue. In order to develop new imaging techniques aimed at the detection and diagnosis of breast lesions, a large number of lesions with varying physical characteristics must be tested at a high cost, especially if physical characteristics must be correlated with observed image features. The new tool presented here, which incorporates three-dimensional tumor features, is potentially useful for testing imaging techniques such as CT, tomosynthesis, and X-ray diffraction imaging, as these require three-dimensional tissue models. The simulated lesions improve significantly upon current methods, which lack the complexity and physical attributes of real tumors, by incorporating a stochastic Gaussian random sphere model to simulate the central tumor mass and calcifications and an iterative fractal branching algorithm to model the complex spicula structures present in many tumors. Results show that user-defined lesions with realistic features can be computationally embedded in mammographic background images and that a wide range of physical properties can be modeled.

7622-05, Session 2

Development of a 3D high-resolution physical anthropomorphic breast phantom

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Analysis of complex imaging tasks requires a phantom that simulates the patient anatomy. We have developed a 3D physical anthropomorphic breast phantom for image quality assessment in digital mammography (DM), digital breast tomosynthesis (DBT), contrast-enhanced DM and contrast-enhanced DBT.

The phantom design is based on an existing computer model that can generate breast voxel phantoms of varying size, shape, glandularity, and internal composition. The physical phantom is produced in two steps. First, the computer model of the glandular tissue, skin and Coopers' ligaments is separated into sections. These sections are fabricated by high-resolution rapid prototyping using a single tissue equivalent material. The adipose tissue regions in the sections are filled using an epoxy-based resin combined with phenolic microspheres. The phantom sections are then stacked together. The phantom is provided with an extra section modified to include iodine.

We fabricated a phantom corresponding to a B-cup breast size with 25% glandularity and deformed to represent a 5 cm compressed thickness. The rapid prototype material and the epoxy based resin attenuate x rays equivalent to 50%-50% and 0%-100% glandular-adipose tissue. Both materials are radiographically uniform; signal intensity variations across samples of each material are smaller than 2%.

A method to fabricate a 3D physical anthropomorphic breast phantom has been developed with the unique feature that it has a computational "twin". This combined system of physical and computational phantoms allows for both qualitative and quantitative quality assessment.

7622-06, Session 2

Dual-modality imaging of a compressible breast phantom with realistic optical and x-ray properties

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Medical imaging equipment is routinely characterised and tested using tissue equivalent phantoms. Combined x-ray and optical mammography could provide increased screening specificity over either system alone. The ongoing evaluation of this approach depends upon the development of phantoms with simultaneously breast tissue equivalent optical and x-ray properties. Furthermore deformation models used in the registration of optical and x-ray images, which are acquired at differing levels of breast compression, require validation through phantoms which are also mechanically tissue equivalent. As well as static imaging, dynamic optical imaging of blood flow whilst breast compression is applied has been proposed as a method of enhancing screening specificity. The effect of changes in blood flow and volume in optical tomography still need to be established.

A novel phantom material created by freezing and thawing a solution of polyvinyl alcohol (PVAL) in ethanol to create a solid yet elastically compressible gel is described. These gels naturally have an x-ray attenuation equivalent to that of breast tissue whilst their optical and mechanical properties are readily modified. Titanium dioxide is added to the optically non-scattering and colourless gels to obtain the transport scattering coefficient required. Cancerous tissues are often many times stiffer than healthy. Similar differences in stiffness are achieved between gels by varying PVAL concentration. The first images of an anthropomorphically shaped breast phantom made from this gel are presented. This contains a lesion filled with blood equivalent dye whose volume changes upon compression of the phantom. Imaging results from similar phantoms will follow.

7622-07, Session 2

Triple-energy contrast enhanced digital mammography

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With the injection of iodine, Contrast Enhanced Digital Mammography (CEDM) provides functional information about breast tumour angiogenesis that can potentially help in cancer diagnosis. In order to generate iodine images in which the gray level is proportional to the iodine thickness, temporal and dual-energy approaches have already been considered. The dual-energy method offers the advantage of less patient motion artifacts and better comfort during the exam. However, this approach requires knowledge of the breast thickness at each point. Generally, as compression is applied, the breast thickness at each point is taken as the compression thickness. Nevertheless, in the breast border region, this assumption is not correct anymore and this causes inaccuracies in the iodine image. Triple-Energy CEDM could overcome these limitations by providing supplemental information in the form of a third image acquired with a different spectrum than the other two. This precludes the need of a priori knowledge of the breast thickness. Moreover, with Triple-Energy CEDM, breast thickness and glandularity maps could potentially be derived. In this study, we first focused on the method to recombine the three images in order to generate the iodine image, analyzing the performance of either quadratic, cubic or conic recombination functions. Then, we studied the optimal acquisition spectra in order to maximize the iodine SDNR in the recombined image for a given target total glandular dose. The concept of Triple-Energy CEDM was validated on simulated textured images and poly-energetic images acquired with a conventional X-ray mammography tube.

7622-08, Session 2

Development of in vivo characterization of breast tissues through absolute attenuation coefficients using dedicated cone-beam CT

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With advances in 3D in vivo imaging technology, non-invasive procedures are being used to characterize tissues to identify tumors and monitor changes over time. Using a dedicated breast CT system with a quasi-monochromatic x-ray source and flat-panel digital detector, this study was performed in an effort to directly characterize different materials in vivo based on their attenuation coefficients. CT acquisitions were acquired using a rod phantom having different materials (delrin, polyethylene, acrylic, glandular-equivalent, and fat-equivalent) and a human cadaver breast embedded with spherical acrylic lesions. Projections were collected with and without a beam stop array. For each projection, 2D scatter was estimated by cubic spline interpolating the average values behind the shadow of each beam stop inside the object. Scatter-corrected projections were then calculated by subtracting the scatter images containing only a mask of the object from corresponding projections without the beam stops. Iterative OSTR was used to reconstruct the data and estimate the non-uniform attenuation distribution. An additional post-reconstruction flattening technique was applied to further reduce image non-uniformity. Preliminary results show that scatter correction reduces cupping artifact, improves image contrast, and yields attenuation coefficients closer to narrow-beam values. Peaks in the histogram showed clear separation among different material attenuation coefficients. Although post-reconstruction flattening did not improve contrast, its combination with the scatter correction further reduced the visual cupping artifact. These findings indicate that minimizing beam hardening with a quasi-monochromatic x-ray beam and applying scatter correction make it practical to directly characterize different tissues in vivo using absolute attenuation coefficients.

7622-09, Session 2

A stepwedge-based method for measuring breast density in the UK screening population: observer variability and comparison with human reading

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Breast density has been positively linked to the risk of developing

breast cancer. We have developed a stepwedge-based method that provides an estimate of the amount of glandular tissue both by volume and by area. The method has been applied to the mammograms of 1,289 women in the UK breast screening programme.

The mammograms of 29 women (116 images) were analysed by three independent operators in order to assess inter-observer variability of the method. From this sample, a subset of 24 images were analysed on 10 separate occasions by the same operator to assess intra-observer variability.

Additionally, 168 images were analysed using the stepwedge method and assessed by two radiologists who independently scored percentage density using a visual analogue scale.

There was little intra-observer variability, with average coefficients of variation ranging from 3.49 to 5.73. However, there were significant differences in the volumes of glandular tissue obtained by the three operators. On further inspection, this was found to be caused by variation in the way in which the operators marked the breast edge, rather than by their definition of the other landmarks in the image or by variation in the measured breast thickness.

There was good correlation between percentage of dense area of the breast and radiologists' assessment of percentage density, particularly for dense and fatty breasts. A similar pattern of agreement was found between the two radiologists. Based on analysis of thresholds used in the stepwedge method, radiologists' definition of a dense pixel is one in which the percentage of glandular tissue is between 10 and 20% of the total thickness of tissue.

7622-10, Session 3

A new generation FFDM/tomosynthesis fusion system with selenium detector

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A new generation of tomosynthesis system has been designed and is commercially available outside the US. The system has both a 2D mode and a 3D mode to do either convention mammography or tomosynthesis. Uniquely, it also has a fusion mode that allows both 3D and 2D images to be acquired under the same breast compression and that results in co-registered images from the two modalities.

The aim of this paper is to give a comprehensive technical description on the design and performance of the new system. The paper covers system details such as filter options, doses, AEC operation, geometrical calibration, 2D and 3D images co-registration and display, and the selenium detector performance. We have carried out extensive physical and clinical studies to evaluate the performance of the system. In this paper the focus will be mainly on technical performance results.

7622-11, Session 3

Wide-angle breast tomosynthesis: initial comparative evaluation

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Compared to mammography, breast tomosynthesis and CT provide 3D sampling of the breast tissue and reduce overlapping anatomical structures. In that regard, CT is believed to provide superior performance. However, its required angular acquisition span can limit the imaging coverage of the chest wall area of the breast. In this paper, we propose a new breast imaging modality, Wide-angle Breast Tomosynthesis (WBT), aimed to provide a practical compromise between 3D sampling and chest-wall coverage. This study sought to provide a comparison of lesion detection between mammography, conventional tomosynthesis, WBT, and breast CT (0°, 44°, 99°, and 198° total angle range, respectively) under equal patient dose conditions. A Monte Carlo (MC) code based on the Penelope package modeled a virtual flat-panel breast tomosynthesis system which

consisted of an x-ray anode, an anthropomorphic breast phantom, and a selenium detector. The four modalities were simulated at four breast compression levels. The glandular dose to the breast was estimated and the radiation flux was subsequently adjusted to achieve a constant mean glandular dose level of 1.56 mGy, independent of the breast thickness and acquisition geometry. The projections for the volumetric modes of imaging were utilized to reconstruct the volume using statistical iterative reconstruction (SIR) methods based on maximum likelihood iterative reconstruction algorithms (SPECT-MAP). A measure of lesion detectability was estimated using 2D and 3D Hotelling model observers. The results showed improved detection with increased angular span and compression. WBT provided performance nearly equal to that of CT with breast thickness enabling additional optimization potential.

7622-12, Session 3

Effects of projection-view distributions on image quality of calcifications in digital breast tomosynthesis (DBT) reconstruction

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We are investigating factors affecting the detection of microcalcifications in DBT mammography. In this study, we analyzed the effects of projection-view (PV) distribution on spatial blurring of calcifications on the tomosynthesized slices (X-Y plane) and along the depth (Z) direction. DBT scans of a breast phantom with simulated microcalcifications were acquired with a GE prototype system at 21 angles in 3° increments over a ±30° range. Six subsets of 11 PVs were selected from the full set to simulate DBT of different angular ranges and angular increments. SART was applied to each subset to reconstruct the DBT slices. The FWHMs of the line profiles of calcifications within their in-focus DBT slices and FWHMs of the inter-plane artifact spread function (ASF) in the Z-direction for the different PV distributions were compared. The results indicate that DBT acquired with a large angular range and a reasonable number of PVs at large angles yield superior ASF with smaller FWHM in the Z-direction whereas PV distributions with narrow angular range had stronger inter-plane artifacts. On the X-Y focal planes, the normalized line profiles of the calcifications reconstructed with the different PV distributions were similar. The differences in the FWHMs between the different PV distributions were less than one pixel and within measurement errors. Further study is underway to compare different reconstruction techniques and parameters. The information will be useful for optimization of DBT for detection of microcalcifications.

7622-13, Session 3

Evaluation and optimization of the maximum likelihood and iterative FBP approaches for image reconstruction in digital breast tomosynthesis

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Digital Breast Tomosynthesis* (DBT) suffers from incomplete data and poor quantum statistics limited by the total dose absorbed in the breast. Hence, statistical reconstruction may have some advantages. This study investigates state-of-art iterative maximum likelihood (ML) statistical reconstruction algorithms for DBT and compares the results with simple backprojection (BP), filtered backprojection (FBP), and iFBP (FBP with filter derived from iterative reconstruction).

The gradient-ascent and convex optimization variants of the transmission ML algorithm assuming the photon statistics to follow a Poisson distribution were evaluated. All algorithms were evaluated with phantom and clinical data. Convergence speed is very similar for both iterative statistical algorithms and after approximately 3-5 iterations all

significant details are well displayed. The ML-convex algorithm gives smoother results than the ML-gradient algorithm. The low-contrast CNR of the ML algorithms is between CNR for simple backprojection (highest) and FBP (lowest).

Although computation time of iterative algorithms is considerably longer, it provides some benefits for breast tomosynthesis. Spatial resolution of iterative statistical and iFBP algorithms is similar to that of FBP but the quantitative density representation resembles conventional mammograms better. iFBP algorithm provided the benefits of statistical iterative reconstruction techniques but requires shorter computation time.

*Breast tomosynthesis is an investigational practice and is limited by U.S. law to investigational use. It is not commercially available in the U.S. and its future availability cannot be ensured.

7622-14, Session 3

Validation and optimization of digital breast tomosynthesis reconstruction using an anthropomorphic software breast phantom

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A digital breast tomosynthesis (DBT) reconstruction algorithm has been optimized using an anthropomorphic software breast phantom. The algorithm was optimized in terms of preserving the x-ray attenuation coefficients of the simulated tissues.

The appearance of reconstructed images is controlled in the algorithm using two input parameters related to image contrast and sharpness. We varied the input parameters to maximally preserve the attenuation information. The primary interest has been identifying adipose and fibroglandular (dense) tissues. To that end, a software voxel phantom was used which included two distinct attenuation values of simulated breast tissues. The phantom allows for great flexibility in simulating breasts of various size, glandularity, and internal composition.

Distinguishing between fatty and dense tissues was treated as a binary decision task and validated using ROC analysis. We defined the reconstruction geometry to ensure voxel-to-voxel comparison between the original and reconstructed volumes. Separate histograms of the reconstructed pixels corresponding to simulated adipose and dense tissues were computed. ROC curves were generated by varying the reconstructed intensity threshold; pixels above the threshold were classified as dense tissue. The input parameter space was searched to maximize the area under the ROC curve. The reconstructed phantom images optimized in this manner preserve qualitatively better gray scale and edge information; concordant results are seen in clinical images.

Use of the software phantom was successful and practical in this task-based optimization, providing ground truth information about the simulated tissues and flexibility in defining anatomical properties.

7622-15, Session 3

Towards an international consensus strategy for periodic quality control of digital breast tomosynthesis systems

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As an collaborative effort between scientists affiliated with the American Association of Physicists in Medicine (AAPM) and the European reference center for breast cancer screening and diagnosis (EUREF), the International Breast Phantom Working Group aims to develop phantoms and evaluation techniques for 2D & 3D breast imaging methods. In the first phase of this collaboration, this project aimed to develop a phantom and associated procedure for constancy testing of digital breast tomosynthesis (DBT) systems. The procedure involves daily and weekly components. The daily evaluation is performed on a simple, homogenous PMMA plate of 4 cm thickness. For the weekly part, a new phantom has been designed consisting of a 4 cm thick homogeneous slab of PMMA with a set of spherical and rectangular inserts at specific 3D positions, and a ruler placed at a small angle to the plane of the detector. Quality control parameters are extracted from both projection images (if available) and reconstructed planes. The homogeneous phantom for daily QC allows trend homogeneity analysis and the assessment of detector artifacts. With the proposed phantom concept for weekly QC, the stability of the following parameters can be evaluated: the propagation and correlation of the noise in plane and across the reconstructed tomographic planes, lag, signal difference to noise ratio (SDNR) and signal to noise ratio (SNR), the geometry and the motion, effective thickness of the reconstructed planes, homogeneity, distance accuracy, frequency dependent SNR, and artifacts. Analysis of the DICOM header provides information on the stability of the automatic exposure control (AEC), exposure settings, and several system parameters. In an on-going study, the proposed strategy is being applied to five tomosynthesis systems both in Europe and in the US. In this paper we report on the specifics of the phantom, the QC procedure, the practicalities of remote data analysis, and the results of the initial trial.

7622-16, Session 3

Multi-beam x-ray source breast tomosynthesis reconstruction with different algorithms

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Digital breast tomosynthesis is a new technique to improve the early detection of breast cancer by providing three-dimensional reconstruction volume of the object with limited-angle projection images. This paper investigated the image reconstruction with a standard biopsy training breast phantom using a novel multi-beam breast tomosynthesis X-ray source. Twenty-five carbon-nanotube technology based X-ray tubes were lined up along a parallel-imaging geometry to decrease the motion blur. Five representative reconstruction algorithms, including back projection (BP), filtered back projection (FBP), matrix inversion tomosynthesis (MITS), maximum likelihood expectation maximization (MLEM) and simultaneous algebraic reconstruction technique (SART), were investigated to evaluate the image reconstruction of the tomosynthesis system. Reconstructed images of the masses and micro-calcification clusters embedded in the phantom were studied. The evaluated multi-beam X-ray breast tomosynthesis source is able to generate three-dimensional information of the breast phantom with clearly-identified regions of the simulated masses and calcifications. Future study will be done soon to further improve the imaging parameters' measurement and reconstruction.

7622-17, Session 4

An analytical model of NPS and DQE comparing photon counting and energy integrating detectors

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In this work, analytical models of the optical transfer function (OTF), noise-power spectra (NPS), and detector quantum efficiency (DQE) are developed for two types of digital x-ray detectors. The two detector types are (1) energy integrating (EI), for which the point-spread function (PSF) is interpreted as a weighting function for counting x-rays, and (2)

photon counting (PC), for which the PSF is treated as a probability.

The OTF is the Fourier transform of the PSF. The two detector types, having the same PSF, possess an equivalent OTF. NPS is the discrete space Fourier transform (DSFT) of the autocovariance of signal intensity. From first principles, it is shown that while covariance is equivalent for both detectors, variance is not. Consequently, provided the two detector types have equivalent PSFs, a frequency-independent difference in NPS exists such that $NPS\_PC \geq NPS\_EI$ and hence $DQE\_PC \leq DQE\_EI$. The necessary and sufficient condition for equality is that the PSF is either zero or unity everywhere.

A PSF modeled as the convolution of a Lorentzian with a rect function is analyzed in order to illustrate the differences in NPS and DQE. The Lorentzian models the blurring of the x-ray converter, while the rect function reflects the sampling of the detector. The NPS difference increases with increasing PSF width.

In conclusion, this work develops analytical models of OTF, NPS, and DQE for energy integrating and photon counting digital x-ray detectors.

7622-18, Session 4

Digital mammography - DQE versus optimized image quality in clinical environment: an on site study

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The intrinsic quality of the detection system of 7 different digital mammography units (5 DRs; 2 CRs), expressed by DQE, has been compared with their image quality/dose performances in clinical use.

DQE measurements followed IEC 62220-1-2 using a tungsten test object for MTF determination. Evaluation was performed with the open source Java plug-in "Flat-panel" for ImageJ, extended for DQE calculation.

For image quality assessment two different methods have been applied: 1) measurement of contrast to noise ratio (CNR) corresponding to the European guidelines and 2) contrast-detail (CD) evaluation. The latter was carried out with the phantom CDMAM ver. 3.4 and the commercial software CDMAM Analyser ver. 1.1 (both Artinis) for automated image analysis. The overall image quality index IQFinv proposed by the software has been validated. Correspondence between the two methods has been shown figuring out a linear correlation between CNR and IQFinv.

Before evaluation, all systems were optimized with respect to image quality and average glandular dose (AGD). For each equipment, a good image quality level was defined by means of CD analysis and the corresponding CNR value considered as target value. The goal was to achieve for different PMMA-phantom thicknesses constant image quality, say CNR target value, at minimum dose.

All DR systems exhibited higher DQE and significantly better image quality compared to CR systems. No general difference in DQE value between direct conversion and indirect conversion flat panel detectors with comparable pixel size was found. Generally switching, where possible, to x-rays of higher energy spectrum allowed dose savings at equal image quality. The best ratios image quality/dose were achieved by 2 units with a-Se detector and W anode only recently available on the market.

7622-19, Session 4

Generalized two-dimensional (2D) linear system analysis metrics (GMTF, GDQE) for digital radiography systems including the effect of focal spot, magnification, scatter, and detector characteristics

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The MTF, NNPS, and DQE are standard linear system metrics used to characterize intrinsic detector performance. To evaluate total system performance for actual clinical conditions, generalized linear system metrics (GMTF, GNNPS and GDQE) that include the effect of the focal spot distribution, scattered radiation, and geometric unsharpness are more meaningful and appropriate.

In this study, a two-dimensional (2D) generalized linear system analysis was carried out for a standard flat panel detector (FPD) (194-micron pixel pitch and 600-micron thick CsI) and a newly-developed, high-resolution, micro-angiographic fluoroscope (MAF) (35-micron pixel pitch and 300-micron thick CsI). Realistic clinical parameters and x-ray spectra were used. The 2D detector MTF was calculated using the Noise Response method and 2D focal spot distribution measurements were done using a pin-hole assembly. The scatter MTF was simulated with a theoretical model and generated for a uniform head equivalent phantom. Different magnifications and scatter fractions were used to estimate the 2D GMTF, GNNPS and GDQE for both detectors.

Results show spatial non-isotropy for the 2D generalized metrics which provide a quantitative description of the performance of the complete imaging system for both detectors. This generalized analysis clearly demonstrated that the MAF and FPD have similar capabilities at lower spatial frequencies, but that the MAF has superior performance over the FPD at higher l frequencies even when considering focal spot blurring and scatter.

This 2D generalized performance analysis is a valuable tool to evaluate total system capabilities and to enable optimized design for specific imaging tasks.

7622-20, Session 4

Evaluation of effective detective quantum efficiency with digital radiography to optimize exposure condition for chest imaging

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In recent years, effective DQE (eDQE) has been developed and introduced. The purpose of this study was to evaluate and optimize the exposure condition for chest imaging with digital radiography (DR) using eDQE. The considered exposure factors were tube potential and anti-scatter moving grid. The entrance air kerma was adjusted for each tube potential to give and effective dose of 34 μSv. The scatter fraction (SF), transmission fraction (TF), effective modulation transfer function (eMTF), and effective normalized noise power spectrum (eNNPS) were measured with a phantom which simulate the attenuation and scatter properties of chest. The results show that eMTFs were independent on the tube potential regardless of using grid. The eNNPS was greater with anti-scatter grid than without it. The eDQE was largest at lower tube potential with no grid. The results showed that the use of low tube potential without anti-scatter grid is the most appropriate exposure conditions for DR in chest imaging. Further study will be able to optimize measurement condition for the other imaging studies.

7622-21, Session 4

Effects of image processing on the detective quantum efficiency

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Digital radiography has gained popularity in many areas of clinical practice. This transition brings interest in advancing the methodologies for image quality characterization. However, as the methodologies for such characterizations have not been standardized, the results of these studies cannot be directly compared. Therefore, the primary objective of this study was to standardize methodologies for image quality characterization. The secondary objective was to evaluate affected factors to Modulation transfer function (MTF), noise power

spectrum (NPS), and detective quantum efficiency (DQE) according to image processing algorithm. Image performance parameters such as MTF, NPS, DQE were evaluated using the international electro-technical commission (IEC 62220-1)-defined RQA5 radiographic techniques. Computed radiography (CR) images of hand posterior-anterior (PA) for measuring signal to noise ratio (SNR), slit image for measuring MTF, white image for measuring NPS were obtained and various Multi-Scale Image Contrast Amplification (MUSICA) parameters were applied to each of acquired images. In results, all of modified images had considerably influence on evaluating SNR, MTF, NPS, DQE. And Modified images on the post-processing had higher DQE than the MUSICA=0 image. This suggests that MUSICA values, as a post-processing, have an affect on the image when it is evaluating for image quality. In conclusion, the control parameters of image processing could absolutely be zero for evaluating of image quality characterization exactly. The results of this study could be used as a baseline to optimize imaging systems and their imaging characteristics by measuring MTF, NPS, and DQE for different level of radiation dose.

7622-22, Session 5

Phase-contrast and dark-field imaging: advanced contrast modalities in x-ray radiology

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In the field of x-ray imaging, the development of phase-contrast and dark-field contrast similar to the contrast modalities of microscopes using visible light has only proceeded slowly and is still a very active field of research. The development of such advanced imaging methods is particularly difficult for hard x-rays (with energies in the multi-keV range), because of the lack of efficient x-ray optics.

One way to overcome this difficulty is to use a grating based interferometer. A phase shifting grating introduces an interference pattern at a particular distance related to the Talbot distance. With this interferometer both phase-contrast and dark-field contrast can be obtained.

As opposed to most existing hard x-ray dark-field and phase-contrast imaging methods which rely on the use of crystal optics, the grating interferometer can accept a very broad energy band-width and angular divergence, and this makes the method applicable to standard, high-power x-ray tubes, e.g. as used in x-ray diagnostics applications, and thus available for widespread applications.

We will here present our recent contributions to the field of phase-contrast and dark-field x-ray imaging. In particular we will discuss the development of grating-based x-ray imaging methods for use with conventional, lab-based x-ray sources. A variety of experimental results will be shown that highlight the potential of this novel method for biomedical, clinical, and industrial applications.

7622-23, Session 5

Quantitative imaging of electron density and effective atomic number using phase contrast CT

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Compared to single energy CT, which provides only the x-ray linear attenuation coefficients, dual energy CT is able to obtain the electron density and effective atomic number for different materials in a quantitative way. In this study, as an alternative to dual energy CT, a novel quantitative imaging method based on phase contrast CT is described. Rather than two scans with different x-ray photon energies, phase contrast CT is capable of reconstructing both attenuation and phase image from a single scan. From the two images, quantitative information of both electron density and effective atomic number can be derived. Experimental results demonstrate that: (1) electron density could be determined with high accuracy; (2) effective atomic number is

able to be calibrated by a simple look-up-table method. The presented method provides more insight into the analysis of materials and will find its use in medical and non-medical applications.

7622-24, Session 5

X-ray dark-field computed tomography using a grating interferometer setup

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Dark-field x-ray projection imaging and dark-field neutron computed tomography have both recently been demonstrated. Such techniques provide insight into the small-angle scattering properties of image objects. In this work, the dark-field x-ray imaging method is extended to computed tomography in order to provide unique and complementary information to the previously reported phase contrast and absorption CT images. Dark-field reconstructions are presented and compared to these two other contrast mechanisms, all three of which can be obtained from a single acquisition using an x-ray grating interferometer setup. Objects which provide little absorption contrast, but have a significant small-angle scattering component, are better visualized in a dark-field CT reconstruction.

7622-25, Session 5

Spectroscopic x-ray phase-contrast computed tomography with a Talbot-interferometer

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We present a simulation framework for X-ray phase-contrast computed tomography imaging (PCTI) inheriting the wave-like as well as the particle behavior of photons. The developed tool includes the modeling of a partially coherent X-ray source, the propagation of the X-ray photon through samples, and the interfering properties of photons.

Hence, the simulation is capable of physically modeling a grating-based interferometric imaging system reported in e.g. Pfeiffer et al. 2006. The information gained comprises the three potentially measurable images, which are the absorption image, the phase image, and the darkfield image.

Results on such a setup concerning spatial and temporal coherence will be shown. Samples consisting of elements and structures similar to biological tissue were implemented to demonstrate the applicability on medical imaging. For the purpose of CT-imaging a head-like phantom was simulated and the results suggest the use of PCTI for thick biological objects.

The simulation was developed with a modular concept so that the influences of each imaging component can be considered seperately. Thus the grating based interferometry for X-ray phase-contrast imaging can be optimized towards dedicated medical applications using this simulation-tool.

7622-26, Session 5

Numerical evaluation of a polycapillary optical element for in-line phase-contrast imaging

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X-ray phase-contrast imaging promises to have a major impact on diagnostic radiology and has reached the point of feasibility for routine clinical use. A fundamental issue in X-ray phase-contrast imaging is the tradeoff between the coherence properties of the beam, which determine the degree of phase-contrast enhancement, and the beam

intensity, which determines image acquisition time. In order to observe significant phase-contrast enhancement with tube sources, the source-to-object distance must be sufficiently large for the beam to enhance its coherence properties via the act of free-space propagation. However, due to the divergent nature of the beam emitted from the anode, this results in a large loss of flux due to the inverse square effect. Collimating the beam with a polycapillary optical device can potentially solve these problems. In this work, we investigate the use of a polycapillary X-ray optic as a means to improve beam coherence and intensity that can enhance the clinical effectiveness of phase-contrast imaging. To accomplish this, we have built and numerically implemented models of a polycapillary optic device, which will reveal the relationship between the output beam coherence properties and the parameters of the source and optic. We use this model to investigate the extent to which a polycapillary optic can improve the spatial coherence of a beam produced by a conventional X-ray source and assess the usefulness of the output for phase-contrast imaging.

7622-27, Session 5

Contributions to ideal observer SNRs in x-ray phase-contrast imaging

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At diagnostic X-ray energies, variations in the real component of the refractive index of tissues are several orders of magnitude larger than variations in the imaginary component, or equivalently, the X-ray attenuation coefficient. Consequently, X-ray phase-contrast imaging permits the visualization of tissues that have very similar X-ray absorption properties, which may benefit a number of clinical applications including cancer detection. Unlike conventional radiographic contrast that is related to the projected absorption properties of tissue, image contrast in phase-contrast-enhanced radiographs contains contributions from absorption-contrast and phase-contrast. In this work, we develop a general theoretical framework for assessing the contributions of these contrast mechanisms to signal detectability measures in X-ray phase-contrast imaging. Specifically, concepts from signal detection theory are utilized to analyze the contributions of phase- and absorption-contrast to the ideal observer figure of merit for a signal-known-exactly/background-known-exactly detection task. We demonstrate that signal-to-noise ratio (SNR) of the ideal observer test statistic can be decomposed into three terms that can be interpreted in terms of higher-order detection tasks. Our analysis is relevant to any linear shift-invariant X-ray phase-contrast imaging system, including propagation-based systems and systems employing diffracting elements such as crystals or gratings. Numerical studies of signal detectability are conducted to identify situations in which phase-contrast enhancement can significantly improve detectability.

7622-28, Session 6

The myth of mean dose as a surrogate for radiation risk?

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The current estimation of risk associated with medical imaging procedures rely on assessing the organ dose via direct measurements or simulation. Each organ dose is assumed to be homogeneous, a representative sample or mean of which is weighted by a corresponding tissue weighting factor provided by ICRP publication 103. The weighted values are summed to provide Effective Dose, the most-widely accepted surrogate for population radiation risk. For individual risk estimation, one may employ Effective Risk, which further incorporates gender- and age-specific risk factors. However, both the tissue-weighting factors (as used by ED) and the risk factors (as used by ER) were derived (mostly from the atomic bomb survivor data) under the assumption of a homogeneous dose distribution within each organ. That assumption is significantly violated in most medical imaging procedures. In chest CT, for example, superficial organs (eg, breasts) demonstrate a heterogeneous distribution while organs on the peripheries of the irradiation field (eg, liver) possess a nearly discontinuous dose profile. Projection radiography and mammography involve an even wider range of organ dose heterogeneity spanning up to two orders of magnitude. As such, mean dose or point measured dose values do not reflect the maximum energy deposited per unit volume of the organ, and therefore, effective dose or risk dose, as commonly computed, can grossly underestimate irradiation risk. In this paper, we report the magnitude of the underestimation in both CT and projection x-ray imaging, and provide alternative assessment techniques for effective risk for imaging techniques involving heterogeneous organ dose distributions.

7622-29, Session 6

Multi-pinhole dynamic SPECT imaging: simulation and system optimization

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Dynamic imaging of the first-pass tracer uptake requires high temporal resolution (~ 1 sec) and high efficiency due to short scan times. This work optimized a multi-pinhole collimator in a stationary three-camera SPECT system used for dynamic imaging through simulations.

The pinhole size was first determined by comparing the spatial resolution, SNR and efficiency, while adjusting the pinhole diameter, acceptance angle and channel height of the simulated single-pinhole collimator. A stationary three-camera multi-pinhole SPECT system was then investigated by adjusting the number of pinholes and pinhole arrangement to increase the efficiency and SNR while maintaining minimal projection overlap. Collimators with 6, 8, or 9 pinholes were simulated. The projection images from different pinhole configurations were reconstructed using the MLEM algorithm. The efficiency and SNR metrics were used to compare the different multi-pinhole configurations. The simulated object was a cylinder (20-mm radius, 40-mm height, 0.05-mCi/ml activity).

The spatial resolution-efficiency tradeoff curve resulting from the single-pinhole SPECT system simulation showed that a pinhole diameter and channel height of about 1.5mm was optimal. The nine-pinhole oval-arrangement collimator system exhibited the highest SNR and efficiency.

Therefore the optimal pinhole size and multi-pinhole configuration compromise the tradeoffs of spatial resolution, efficiency and SNR. The oval arrangement enables adding pinholes without changing the magnification, which increases the efficiency and maintains spatial resolution. The results support the use of the nine-pinhole oval-arrangement collimator for a stationary three-camera SPECT system used for rapid dynamic imaging.

7622-30, Session 6

SPECT data acquisition and image reconstruction in a stationary small animal SPECT/MRI system

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The purpose of the study is to investigate data acquisition strategies and image reconstruction methods for a stationary small animal (SA) SPECT insert that can operate inside an MRI scanner with a bore diameter of 12 cm. The SPECT insert consists of 3 rings of 8 MR-compatible CZT detectors surrounding a multi-pinhole (MPH) collimator sleeve with one pinhole matched to one detector. All pinholes are focused on a cylindrical FOV of ~25 mm in diameter and ~34 mm in length. We developed an analytic simulator that uses a stored system matrix incorporating the geometric response function (GRF) of the MPH

collimator. The simulator was used to generate projection data of a digital phantom with pinhole aperture sizes of 1 mm and 2 mm and with different azimuthal sampling patterns. Iterative ML-EM reconstruction with and without GRF compensation were used to reconstruct projection data from the central ring of 8 detectors only, and from all 24 detectors.

Our results indicate that accurate GRF compensation with the ML-EM method significantly improves the reconstructed image resolution and reduces image artifacts. By rotating the MPH collimator, the increased azimuthal sampling further reduces image artifacts and improves image quality. The improvements are more prominent with the 2 mm pinhole than with the 1 mm pinhole.

In conclusion, our simulations demonstrate the image quality that can be achieved using the current SPECT insert with different data acquisition strategies and image reconstruction methods. They provide valuable guide to the further development of the SA SPECT/MRI system.

7622-31, Session 6

Evaluation of a 3D point spread function (PSF) model derived from Monte Carlo simulation for a small animal PET scanner

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We previously designed a component based 3-D PSF model to obtain a compact yet accurate system matrix for a dedicated human brain scanner. In this work, we adapted the model to a small animal scanner. Based on the model, we derived the system matrix for back-to-back gamma source in air, fluorine-18 and iodine-124 source in water by Monte Carlo simulation. The characteristics of the PSF model were evaluated and the performance of the newly derived system matrix was assessed by comparing its reconstructed images with the established reconstruction program provided on the animal PET scanner.

The new system matrix showed strong PSF dependency on the line-of-response (LOR) incident angle and LOR depth. This confirmed the validity of the two components selected for the model. The effect of positron range on the system matrix was observed by comparing the PSFs of different isotopes. A simulated and an experimental hot-rod phantom study showed that the reconstruction with the proposed system matrix achieved better resolution recovery as compared to the algorithm provided by the manufacturer. Quantitative evaluation also showed better convergence to the expected contrast value at lower noise level. In conclusion, it has been shown that the system matrix derivation method is applicable to the animal PET system studied, suggesting that the method may be used for other PET systems and different isotope applications.

7622-32, Session 6

A hypothesis testing approach for microwave breast imaging in conjunction with CT

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The recent findings of high heterogeneity of human breasts and much lower than predicted dielectric contrast between tumors and their host tissues have raised questions about the potential of the existing stand-along microwave breast imaging techniques. The relatively unexplored multi-modal approaches, in which two or more modalities work together, seem more promising and require increasing research attention. This study investigates a CT-microwave combination in which microwave inspection utilizes prior information obtained from volumetric CT scans and knowledge of tissue dielectric properties. In particular, a detailed patient-specific tissue distributions is first obtained from a 3D-CT scan (using a system developed at the

University of Massachusetts Medical School). It is assumed that from this scan a limited suspicious region is identified. Then from recent research results on the dielectric properties of breast tissues, dielectric maps of the breast can be constructed under the hypotheses of normal and cancerous tissue in the suspect region. Microwave inspection is then performed. Instead of trying to recover a complete dielectric image from the microwave scan, the question of interest in this approach is simply which hypothesis is more consistent with the electromagnetic responses of the microwave system. A hypothesis testing method based on computer simulations and with receiver operating characteristic (ROC) optimization is proposed. The results for a simple ideal case show good potential and certainly invite further studies.

7622-33, Session 7

The generalized NEQ and detectability index for tomosynthesis and cone-beam CT: from cascaded systems analysis to human observers

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Purpose: Anatomical background noise is recognized as a major impediment to detectability in both 2D and 3D (tomosynthesis and CBCT) imaging. This paper incorporates semi-empirical characterization of anatomical background noise with 3D cascaded systems analysis (CSA) to yield "generalized" performance metrics, which are validated with human observers for various imaging tasks and acquisition conditions.

Methods: A physical phantom was designed based on principles of self-similarity to exhibit power-law spectral density (k/f^b) comparable to various anatomical sites (e.g., breast and lung). Background power spectra were computed as a function of orbital extent under 1) constant angular increment between projections (variable dose); and 2) constant total number of projections (constant dose). Anatomical power spectra were incorporated in "generalized" NEQ and detectability index computed from 3D CSA of tomosynthesis and CBCT. Theoretical detectability was compared to human observer performance in 9AFC tests as a function of tomosynthesis angle, dose, and imaging task.

Results: The phantom yielded power-law spectra and quantified the rejection of clutter with increasing tomosynthesis angle. Generalized NEQ provided a useful framework for analyzing tradeoffs between anatomical, quantum, and electronics noise. Distinct indications arise for tomosynthesis system design regarding anatomical background and the imaging task, and, therefore, the optimal selection of orbit, number of projections, and dose. Initial results demonstrate correspondence of theoretical detectability index with human observer performance in simple detection and discrimination tasks under varying degrees of anatomical background noise.

Conclusions: Optimal 3D image acquisition depends on the imaging task and complex tradeoffs among quantum and background noise sources. Validation in observer studies shows "generalized" detectability to be a meaningful descriptor of task-based imaging performance.

7622-34, Session 7

Extending the detectability index to quantitative imaging performance: applications in tomosynthesis and CT

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This study aimed to establish a relationship between Fourier-based theoretical descriptions of imaging task and maximum likelihood estimator performance. Tomosynthesis and CT were used as a platform for investigating this relationship, presenting a host of acquisition and processing parameters (e.g., kVp, acquisition angle and pitch) that

can significantly affect noise-equivalent quanta (NEQ) and quantitative imaging performance. The detectability index was computed using the modulation transfer function and noise-power spectrum for tomosynthesis and CT combined with a Fourier description of imaging task. Three imaging tasks were considered: detection, estimation (size and intensity), and localization of a small spherical target. Based upon images of a chest phantoms acquired on a clinical CT and simulations of breast phantoms, estimation and localization performance was assessed in terms of the bias (accuracy) and mean square error (precision). Task functions for the estimation and localization tasks were empirically derived using training data and iterative methods. The detectability index computed for estimation tasks correlated well with accuracy and precision over a broad range of imaging conditions and tasks. Results showed that optimal tomosynthesis and CT acquisition parameters depend significantly on imaging task. For example, mass area estimation in breast tomosynthesis was optimal at with an acquisition angle of 85o while volume estimation and localization of the same mass were optimal at 125o and 160o, respectively. This study provided important initial validation that the Fourier-based detectability index, when extended to estimation and localization tasks, can represents a meaningful metric and predictor of quantitative imaging performance.

7622-35, Session 7

Observer model optimization of a multislit spectral breast imaging system

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We present the optimization of a photon counting scanning mammography system using model observers. The detector and multislit geometry are well suited for projection mammography and breast tomosynthesis; the photon-counting detector with two thresholds enables spectral imaging and the multislit geometry has intrinsic scatter rejection. The properties of the pre-breast multislit collimator can be optimized to increase observer performance by improving the conventional detective quantum efficiency (DQE). We show that a dose efficiency figure of merit can be increased by 20% for small objects using an additional operating position of the collimator. The properties of the energy sensitive detector can be optimized to increase observer performance for subtraction techniques, which thereby improves a generalized DQE. We show an increase in a similar figure of merit of at least 50% for larger objects.

7622-36, Session 7

Task-based performance analysis of SART for digital breast tomosynthesis using signal CNR and channelized hotelling observers

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In this study, we examine the performance of the simultaneous algebraic reconstruction technique (SART) for digital breast tomosynthesis under variations in key imaging parameters, such as the number of iterations, number of projections, angular range, initial guess, radiation dose, etc. We use a real breast CT volume as a ground truth digital phantom from which to simulate x-ray projections under the various selected conditions. The reconstructed image quality is measured using task-based metrics, namely signal CNR and the AUC of a Channelized Hotelling Observer with Laguerre-Gauss basis functions. The task at hand is a signal-known-exactly (SKE) task, where the objective is to detect a simulated mass inserted into the breast CT volume.

7622-37, Session 7

Task specific evaluation of clinical full field digital mammography system using the Fourier definition of the Hotelling observer SNR

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Pixel SNR is the most common metric in clinical practice for evaluating projection mammography. However, as we show in this paper, the pixel SNR can produce misleading results under certain system settings. More specifically, for the breast tissue-equivalent series (BRTES) phantom, no significant change in pixel SNR was observed as we increased the exposure. The purpose of this paper is to develop a simple, reliable and clinically applicable methodology to evaluate mammographic imaging systems using a task specific SNR which accounts for the imaging system performance in the presence of the patient. We used the definition of the Hotelling observer in the Fourier frequency domain to calculate the task specific SNR considering the BRTES phantom for the GE Senographe Full Field Digital Mammography (FFDM) system. The results were compared to the pixel SNR. To calculate the Hotelling observer SNR, the generalized modulation transfer function (GMTF), noise power spectrum (NPS) as well as the noise equivalent quanta (NEQ) were determined in the presence of the breast phantom. The task specific SNR we calculated increased with exposure as expected. Furthermore, we found no significant difference between the "Fine View" and the standard modes of the imaging system. The task specific SNR is a more reliable method for evaluating the performance of imaging systems especially under realistic clinical conditions where patient equivalent phantoms or image processing is used.

7622-38, Session 7

FFDM image quality assessment using computerized image texture analysis

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Quantitative measures of image quality (IQ) are routinely obtained during imaging system evaluation. These measures, however, do not necessarily correlate with the IQ of actual clinical images, which can also be affected by factors such as patient positioning. No quantitative method currently exists to evaluate clinical IQ. Therefore, we investigated the potential of using image texture analysis to quantitatively assess IQ. Our hypothesis is that image texture features can be used to assess IQ as a measure of the image signal-to-noise ratio (SNR). To test feasibility, the "Rachel" anthropomorphic breast phantom (Model 169, Gammex RMI) was imaged with a Senographe 2000D FFDM system (GE Healthcare) using 220 unique exposure settings (target/filter, kVs, and mAs combinations). The mAs were varied from 10%-300% of that required for an average glandular dose (AGD) of 1.8 mGy. A 2.5cm2 retroareolar region of interest (ROI) was segmented from each image. SNR was computed from the linear image ROIs. Image texture features of skewness, coarseness, contrast, energy, homogeneity, and fractal dimension were computed from the Premium ViewTM processed image ROIs. Multiple linear regression demonstrated strong association between image texture features and SNR (R2=0.92, p≤0.001). When including target/filter and kV as additional predictor variables, a stronger association with SNR was observed (R2=0.95, p≤0.001). The strong associations observed suggest that computerized image texture analysis could be used to measure SNR and potentially aid in automating IQ assessment as a component of the clinical workflow. Further work is underway to validate our findings in larger clinical datasets.

7622-39, Session 8

Monte Carlo simulation of amorphous selenium imaging detectors

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We present a Monte Carlo simulation framework for modeling the signal formation process in amorphous Selenium (a-Se) imaging detectors for design validation and optimization of direct imaging systems. The assumptions and limitations of the proposed and previous models are examined. The PENELOPE subroutines for Monte Carlo simulation of radiation transport are used to model incident x-ray photon and secondary electron interactions in the photoconductor. Our simulation model takes into account applied electric field, atomic properties of the photoconductor material, carrier trapping by impurities, and bimolecular recombination between drifting carriers. The particle interaction cross-sections for photons and electrons are generated for Se over the energy range of medical imaging applications. Since inelastic collisions of secondary electrons lead to the creation of electron-hole pairs in the photoconductor, the electron inelastic collision stopping power are compared for the PENELOPE's Generalized Oscillator Strength model with the established EEDL and NIST ESTAR database libraries. Sample simulated particle tracks for photons and electrons in Se are presented, along with the 2D dose distribution. The PENEASY general-purpose main program is extended with custom transport subroutines to take into account generation and transport of electron-hole pairs in electromagnetic field. The charge transport routines consider trapping and recombination, and the energy required to create a detectable electron-hole pair can be estimated from simulations. This modular simulation infrastructure is designed for future modeling of the complete image formation.

7622-40, Session 8

50 µm pixel size a-Se mammography imager with high DQE and increased temperature resistance

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It is known that a-Se as a photoconductor imaging material provides excellent resolution (MTF) and acceptable absorption in the mammography energy range. It has only two major drawbacks, namely its relative low x-ray - electrical charge conversion efficiency and its narrow temperature working range. Several authors have tried to improve the low electrical charge conversion efficiency by using special combined structures, like additional avalanche multipliers [1] or indirect-direct imager combinations [2] to just mention a few. However, none of these have become practical yet. Hamamatsu's new a-Se material shows significant improvement in both areas without using any additional layers or avalanche multiplier structures.

The imager presented in this paper has a special blocking structure that ensures very low dark current of less than 1 pA/mm2 even with a 20 V/um electric field. Hence the electric field can be increased from the generally applied 10 V/um to 20V/um, this reduces the energy required to produce an electron-hole (e-h) pair from 50 eV/e-h pair to about 30 eV/e-h pair. Furthermore, with special doping and manufacturing processes this a-Se layer is very stable in the 0-70 C temperature range as demonstrated by Ogusu et al. [3]

A new 5 cm x 5 cm size TFT array was developed with 50 um pixel size, specifically for testing the resolution of photoconductor based imagers. The first new imager of this type had a 200 um thick a-Se layer evaporated onto the array. Its MTF, NPS and DQE values were evaluated using 28kVp Mo anode x-ray source with a 0.03mm thick Mo and an additional 2 mm thick Al filters. The MTF value is about 40% and 50% in x-and y directions at the Nyquist frequency of 10 lp/mm.

The DQE (0) is over 70% at 183 mGy dose and drops only 10% when going down to 23 mGy.

This new array also has excellent lag properties. The measured first frame image lag is less than 0.5%. Such low lag provides opportunities to use this material not only for mammography but also for breast tomosynthesis applications. Breast phantom images demonsrate that even the smallest 0.13 mm calcifications are clearly visible with this high resolution imager.

7622-41, Session 8

Investigation of x-ray induced ghosting and its recovery mechanisms in multilayer selenium structures under low bias for mammography

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The ghosting and its recovery mechanisms in multilayer Selenium structures for mammography are experimentally and theoretically investigated. The experiments have been carried out under low positive bias (~1V/ m) since no ghost can be seen under normal operating bias (10V/ m). A ghost removal technique is investigated by shining back light and reversing the bias polarity during the natural recovery process. The theoretical model considers accumulated trapped charges and their effects (trap filling, recombination, electric field profile, electric field dependent electron-hole pair creation), the carrier transport in the blocking layers, and the effects of charge injection. We consider carrier trapping in both valence alternation pair (VAP) and intimate valence alternation pair (IVAP) types defect states. It has been assumed that the X-ray induced deep trap centers are IVAP type defects. The time dependent carrier detrapping and structural relaxation (recovery of meta-stable trap centers) are also considered. The sensitivity in a rested sample is recovered mainly by the carrier detrapping and the recombination of the injected carriers with the carriers captured by the IVAP type defects. The electric fields at the metal contacts increases with time at the beginning of the ghosting recovery process which leads to the initial increase of the dark current. Later the electric fields at the metal contacts decrease and hence the dark current decays over time. The sensitivity is expected to recover almost fully by resting the sample longer than the recovery time constant of the meta-stable trap centers. The theoretical model shows a very good agreement with the experimental results.

7622-42, Session 8

Amorphous selenium metal-semiconductor-metal photodetector integrated with an amorphous silicon passive pixel sensor array for large area, high speed, indirect detection, medical imaging applications

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Thick amorphous selenium (a-Se) photoconductor layers are commonly used in direct conversion X-ray imaging modalities, primarily mammography and to a lesser extent, chest radiography. However, due to substantial charge trapping inherent in thick a-Se, such detectors experience a long X-ray response time and suffer from slow speed of operation. Therefore, their implementation in real-time or faster imaging applications is limited.

Previously, we reported preliminary results from a detector based on a lateral metal-semiconductor-metal (MSM) photoconductor using a thin a-Se layer [1]. The steady-state dark current of this detector was below 200 fA for a 50 µm×25 µm pixel pitch at electric field strengths ranging from 6 to 12 V/µm and the photogain was 1.2 in the blue wavelength

region. Furthermore, the photocurrent of the fabricated device exhibited a fast response to blue light illumination, with a rise time, fall time and time constant of 50 μs, 60 μs and 30 μs, respectively.

Given the low dark current and greater than unity photogain achievable with this detector and coupled with its fast photoresponse, we believe that a-Se MSM photodetector can achieve high sensitivity and fast operation in emerging medical imaging applications such as mammography tomosynthesis, low dose fluoroscopy and cone-beam computed tomography (CT). In this work, we investigate the integration challenging and process of such an a-Se MSM photodetector with an amorphous silicon (a-Si) passive pixel sensor (PPS) array for indirect conversion mammography tomosynthesis, and fluoroscopy applications.

7622-43, Session 8

Removal of trapped charge in selenium detectors

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In selenium x-ray detectors, the high voltage bias electrode must be coupled to the selenium layer by either an insulating dielectric layer, a charge blocking structure such as a non-insulating polymer, or a thin layer of selenium doped to be n-type or p-type. Among all these designs, only the insulating dielectric can maintain a low leakage current after repeated exposure to high doses of radiation; however, this design results in trapping of electrons or holes in the bulk selenium and at the selenium-insulator interface. Image erase procedures are needed to remove residual charges and to restore the radiation sensitivity.

A systematic investigation of the mechanism of AC and DC charge removal and de-trapping has been conducted. Small selenium samples were configured to simulate a single selenium pixel. Trapped charges were introduced by x-ray exposures. Comparing the conventional methods of de-trapping using reversed bias and light, we have found that the effectiveness can be substantial increased when AC voltage of proper frequency and amplitude is applied. We have also investigated the use of infrared radiation for removing deeply trapped charge. A novel method of using lateral conductivity to remove interfacial trapped charge will also be introduced.

In conclusion, novel methods with high efficiency of charge removal will be reported. AC driven photo-current is an effective way of removing shallow trapped charge. However, infrared radiation is needed for removing charges trapped in deep potential wells. Residual charges can be removed and x-ray sensitivity restored with selection of these methods.

7622-44, Session 9

Noise in energy-discriminating photon-counting x-ray imaging detectors

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A generalized approach to describing transfer of signal and noise (MTF and NPS) through medical imaging systems has been developed over the past several years in which image-forming processes are represented in terms of serial and parallel cascades of amplified point processes. Here we use the techniques of both cascaded systems analysis and stochastic point process theory to develop fundamental limitations of system performance for single photon counting (SPC) x-ray imaging detectors to assist in the optimal design of new systems. Using this approach the mean signal and signal variance for a simple model of a hypothetical flat-panel x-ray imaging detector are calculated. We show that the uncertainty in detector values can be limited by either the scatter point-spread function of secondary image quanta, or by the escape and reabsorption of characteristic emissions from the detector material (Swank absorption noise). Swank noise in particular can limit element squared SNR to substantially less than 0.5

which will impose a severe limitation on the ability of these detectors to be used for energy discriminating tasks where the x-ray photon energy is assumed proportional to single-photon detector signal. Methods and strategies such as element binning will have to be incorporated into new detector designs to overcome these limitations.

7622-45, Session 9

Photon counting pixel and array in amorphous silicon technology for large area digital medical imaging applications

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A single photon counting Voltage Controlled Oscillator (VCO) based pixel architecture in amorphous silicon (a-Si) technology is reported for large area digital medical imaging. The VCO converts X-ray generated input charge into an output oscillating frequency signal. Experimental results for an in-house fabricated VCO circuit in a-Si technology are presented and external readout circuits to extract the image information from the VCO's frequency output are discussed. These readout circuits can be optimized to reduce the fixed pattern noise and fringing effects in an imaging array containing many such VCO pixels. Noise estimations, stability simulations and measurements for the fabricated VCO are presented. The reported architecture is particularly promising for large area photon counting applications (e.g. low dose fluoroscopy, dental computed tomography (CT)) due to its very low input referred electronic noise, high sensitivity and ease of fabrication in low cost a-Si technology.

7622-46, Session 9

Microcomputed tomography with a second generation photon-counting x-ray detector: contrast enhancement and material separation

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This work aimed at building and investigating a prototype of a microCT system using a second generation photon-counting X-ray detector which counts photons simultaneously above 6 energy thresholds. Previously, we have investigated a first generation of the detector. Compared with the previous version, the new one has more energy thresholds, better pixel uniformity, and can handle higher count rates. With proper tuning of the threshold settings, it demonstrated improved uniformity and reduced ring artifacts. We evaluated the detector in terms of contrast-to-noise-ratio in different energy windows for different target materials. We also explored the use of this detector for decomposing images containing more than two basis materials. We found that the energy discrimination capability provides improved contrast-to-noise ratios, the ability to decompose objects into 2 or more basis materials, and thus the ability to separate more than 2 basis materials.

7622-47, Session 9

An analytical model of the effects of pulse pileup on the energy spectrum recorded by energy resolved photon counting x-ray detectors

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States); J. S. Iwanczyk, W. C. Barber, DxRay, Inc. (United States)

Recently, a novel CdTe photon counting x-ray detector (PCXD) with energy discrimination capabilities has been developed [1, 2]. When such detectors are operated under a high count rate, however, coincident pulses and tails of pulses distort the recorded energy spectrum. These distortions are called pulse pileup effects. It is essential to compensate for these effects on the recorded energy spectrum in order to take a full advantage of spectral information PCXDs provide. In this study, we have developed a new analytical pulse pileup model which uses a model of the measured pulse shape measured for a PCXD [1, 2]. We validated the model using Monte Carlo simulations of monochromatic and polychromatic spectra compared to predictions from our model. Excellent agreement was found between the recorded spectra obtained by the MC simulations and those calculated by our analytical model.

7622-48, Session 9

Practical energy response estimation of photon counting detectors for spectral x-ray imaging

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Spectral x-ray imaging is an emerging technique to improve x-ray diagnostic accuracy, since energy discrimination enables material decomposition and/or material identification. Unlike conventional charge-integration based x-ray detectors, photon counting x-ray detectors (PCXDs) can discriminate the energies of incident x-rays and capture multiple energy images in a single exposure. The energy spectra of incident x-rays are, however, usually distorted while x-rays pass through a detector, according to the energy response function (ERF) characterized by detector properties. Thus the ERF should be estimated in advance for spectral imaging. Previous attempt to estimate the ERF is based on a monochromatic x-ray source and an x-ray simulator. But it is hard to realize tunable monochromatic sources. We present a simple ERF estimation method based on a conventional polychromatic x-ray source, which is used in most medical imaging systems. Our method consists of three steps: measurement of source spectra, spectra reconstruction from a PCXD, and inverse estimation of an ERF. First, a set of predefined polychromatic source spectra at all kVs are measured by a conventional x-ray spectrometer with an ideal ERF. Second, for the same set of source spectra, the distorted spectra are reconstructed by using a PCXD with variable energy thresholds. Based on the two set of spectra, we obtain the ERF by least squares inverse estimation. It is also shown that, based on the estimated ERF, the continuous spectra of incident x-rays can be reconstructed from a PCXD output with limited energy resolution. Experimental results show that the proposed method is very effective for ERF estimation, and may potentially improve the accuracy of a variety of dual-energy or multi-energy x-ray imaging applications.

7622-49, Session 9

Fast photon counting CdTe detectors for diagnostic clinical CT: dynamic range, stability, and temporal response

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We report results from the development of a second-generation CdTe direct-conversion compound-semiconductor x-ray detector for photon-counting clinical CT. The first-generation detector has 512 pixels with a 1 mm pitch and is vertically integrated with the readout. A 32-row multi-slice CT system using first-generation detectors has been used for clinical low-dose CT applications at up to 40 mA of tube current. To provide adequate performance for whole-body diagnostic CT, which typically uses up to 160 mA, we have designed and fabricated new

0.25 mm2 pixels to increase the maximum output to greater than 20 Mcps per mm-squared while preserving sufficient energy resolution for photon-counting CT. In addition to the need for dynamic range, CT places stringent uniformity and temporal response requirements on the detector. We have measured detector parameters including the dynamic range, energy resolution, noise floor, stability, and temporal response. Temporal response is determined by rapid cycling of the input flux with shutter driven attenuators. Cycling between high and low flux generates reproducible counts, within counting statistics, with a response time less than 1 ms. Stability is determined by measuring uniformity corrected flood images repeatedly over a time interval exceeding whole-body diagnostic CT scan times. Long exposure to uniform flux generates a number of counts which drift in some pixels slightly in excess of statistics. These results demonstrate the potential for these detectors to achieve whole-body CT. Our future work involves investigating the mechanism for the observed drift in excess of statistics to make improvements to the long term stability.

7622-50, Session 10

Performance assessment of a new dynamic scan mode for perfusion computed tomography using a biological phantom

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Perfusion computed tomography is increasingly being used for stroke and tumor assessment. Using continuous periodic table movement the spatial coverage can be increased beyond the detector width with a new adaptive spiral scanning technique (A4DS). The purpose of this study was to compare perfusion values acquired with the A4DS technique with results from standard dynamic scans at different temporal sampling rates.

A biological perfusion phantom (preserved porcine kidney) was scanned with both techniques. In standard mode three scans were performed at adjacent overlapping positions (detector width 38.4mm) covering the whole phantom. Data were reconstructed with temporal resolutions of 0.5, 1 and 1.5 s. The A4DS scan was performed with a cycle time of 1.5 s and scan ranges of 100 and 148mm respectively. The phantom was not repositioned between scans in order to assure that identical image slices showed identical phantom slices.

Tissue flow was calculated with a deconvolution type algorithm. Regions of interest were drawn in strongly and moderately enhancing areas and around the whole cortex in three slices in the upper, central and lower portion of the phantom. In the flow range of 40 to 100 ml/100ml/min values did not differ by more than 5 ml/100ml/min between any of the scan protocols used. The correlation between the continuous table movement modes and the 0.5 s standard mode was excellent (r2>0.98) indicating that the new mode is well suited for perfusion measurements and allows increasing the coverage by almost a factor of four.

7622-51, Session 10

Design, optimization and testing of a multi-beam micro-CT scanner based on nanotechnology enabled x-ray source

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Constantly facing the challenge of providing better imaging technologies for various pre-clinical research and studies, micro-CT, as a widely adopted imaging modality is in need of better temporal as well as spatial resolution. Meanwhile, faster CT scanning speed is also preferred to achieve higher imaging throughput. We have recently

proposed a gantry-free, fully stationary multi-beam micro-CT (MBµCT) design which holds great potentials to overcome some of the intrinsic limitations of current CT architecture and meet those challenges. In order to demonstrate the feasibility of this novel CT configuration, we have constructed a prototype micro-CT scanner with a multi-beam field emission x-ray source (MBFEX), comprising 20 individually controllable x-ray emitting pixels in a linear array. Recently the prototype MBµCT system has been further optimized based on the analysis of extensive computer simulations on electron optics and experimental results of our previous imaging experience. The newly designed imaging system has been fully characterized and commissioned following our standard imaging protocol. It has clearly shown improved system stability and enhanced imaging capability. As a result of reduced mechanical rotation during imaging acquisition, higher CT scanning speed has been achieved without significantly sacrificing imaging quality. This prototype MBµCT system, although still in its early development phase, has been proved to be an ideal testing platform for the proposed stationary gantry-free micro-CT scanner and also other novel imaging methods such as multiplexing x-ray imaging.

7622-52, Session 10

High power distributed x-ray source

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This paper summarizes the development of a high power distributed x-ray source. Component integration and test results are shown for the dispenser cathode electron gun, fast switching controls, high voltage insulation, brazed anode, and vacuum system. Example focal spot measurements and x-ray radiographs are included. Lastly, future development opportunities are highlighted.

7622-53, Session 10

Improved CT image quality using a new fully physical imaging chain

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This paper describes the image quality improvements achieved by developing a new fully physical imaging chain. The key enablers for this imaging chain are a new scatter correction technique and an analytic computation of the beam hardening correction for each detector. The new scatter correction technique uses off-line Monte Carlo simulations to compute a large database of scatter kernels representative of a large variety of patient shapes and an on-line combination of those based on the attenuation profile of the patient in the measured projections. In addition, profiles of scatter originating from the wedge are estimated and subtracted. The beam hardening coefficients are computed using analytic simulations of the full beam path of each individual ray through the scanner. Due to the new approach, scatter and beam hardening are computed from first principles with no further tuning factors, and are thus straight forward to adapt to any patient and scan geometry.

Using the new fully physical imaging chain unprecedented image quality was achieved. This is demonstrated with a special scatter phantom. With current image correction techniques this phantom typically shows position dependent inhomogeneity and streak artifacts resulting from the impact of scattered radiation. With the new imaging chain these artifacts are almost completely eliminated, independent of position and scanning mode (kV). Further preliminary patient studies show that in addition to fully guaranteeing an absolute Hounsfield scale in arbitrary imaging conditions, the new technique also strongly sharpens object boundaries such as the edges of the kidney.

7622-54, Session 10

Patient-specific dose and risk estimation in pediatric chest CT: a study in 28 patients

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Radiation-dose awareness and optimization in CT can greatly benefit from a dose-reporting system that provides dose and risk estimates specific to each patient and each CT examination. The current dose-reporting method, however, is patient-generic; a patient's dosimetry report only contains reference dose quantities such as CT dose index measured in cylindrical phantoms of a single standard size (e.g., 16-cm phantom for pediatric body). The size and hence dose variations from patient to patient are not reflected. Furthermore, protocol designs based on dose as a surrogate for risk of cancer incidence neglect the strong dependence of risk on age and gender. In this study, we aimed to develop a paradigm for patient-specific dose and risk estimation. Our study included twenty-eight pediatric CT patients (15 boys and 13 girls; 0-16 years old). From each patient's clinical CT data, a full-body computer model was created to serve as an input into a validated Monte Carlo program. Organ dose from four chest scan protocols was simulated and used to determine patient-specific effective dose. Patient-specific risk was calculated using the recently proposed concept of "effective risk", which employs gender-, age-, and tissue-specific cancer risk coefficients. Effective dose was found to correlate with chest diameter (r = -0.91 to -0.96) and showed slight gender dependence. Effective risk correlated strongly with chest diameter (r = -0.97 to -0.98) and was highly gender-dependent. Such strong correlations can be used to estimate patient-specific risk prior to an imaging study and provide a basis for individualized protocol design and optimization.

7622-55, Session 11

Fluoroscopic x-ray demonstrator using a CdTe polycrystalline layer coupled to a CMOS readout chip

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Dynamic X-ray imagers require large surface, fast and highly sensitive X ray absorbers and dedicated readout electronics.

Monocrystalline photoconductors offer the sensitivity, speed, and MTF performances. Polycrystalline photoconductors offer the large surface at a moderate cost. The challenge for them is to maintain the first performances at a compatible level with the medical applications requirements.

This work has been focused on polycrystalline CdTe grown by Close Space Sublimation (CSS) technique. This technique offers the possibility to grow large layers with a high material evaporation yield.

This paper presents the results obtained on an image demonstrator using 350µm thick CdTe_css layers coupled to a CMOS readout circuit with Indium bumping.

The present demonstrator has 200 x 200 pixels, with a pixel pitch of 75µm x 75µm. A total image surface of 15mm x 15mm has then been obtained.

The ASIC works in an integration mode, i.e. each pixel accumulates the charges coming from the CdTe layer on a capacitor, converting them to a voltage.

Single images as well as video sequences have been obtained.

Performance in terms of sensitivity, noise, spatial resolution (MTF), lag and DQE(f) will be presented.

Although present demonstrator surface is moderate, it demonstrates that high performance can be expected from this assembly concept and its interest for medical applications.

7622-56, Session 11

Pixel electronic noise as a function of position in an active matrix flat panel imaging array

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We present an analysis of output referred pixel electronic noise as a function of position in the active matrix array for both active and passive pixel architectures. Three different noise sources for Active Pixel Sensor (APS) arrays are considered: readout period noise, reset period noise and leakage current noise of the reset TFT during readout. For the state-of-the-art Passive Pixel Sensor (PPS) array, the readout noise of the TFT switch is considered. Measured noise results are obtained by modeling the array connections with RC ladders on a small in-house fabricated prototype. The results indicate that the pixels in the rows located in the middle part of the array have less random electronic noise at the output of the off-panel charge amplifier compared to the ones in rows at the two edges of the array. These results can help optimize for clearer images as well as help define the region-of-interest with the best signal-to-noise ratio in an active matrix digital flat panel imaging array.

7622-57, Session 11

Multilayer x-ray detector for contrast-enhanced digital subtraction mammography

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Contrast-enhanced mammography relies on the growth of new blood vessels (i.e. tumor angiogenesis) during the development of cancer. The growth accompanies an increase in tumor cell population to provide sufficient materials for cell proliferation. Since cancers will accumulate an injected contrast agent more than other tissues, it is possible to use one of several methods to enhance the area of lesions and remove the contrast of normal tissue. Magnetic resonance imaging (MRI) and computed tomography (CT) have been examined for use in contrast-enhanced mammography however their use can be limited by drawbacks such as cost, limited spatial resolution, and high radiation dose in the case of CT. Large area flat panel detectors may also be used for contrast-enhanced mammography wherein the subtraction of two acquired images is used to create the resulting enhanced image. Existing methods include temporal subtraction and dual energy subtraction, however these methods suffer from artifacts due to patient motion between the registration of images to be subtracted. In this paper we propose using a multilayer flat panel detector for contrast-enhanced mammography. The detector is designed to acquire both images simultaneously, thus avoiding motion artifacts in the resulting subtracted image. We examine the design of the multilayer detector assuming a direct detector with amorphous selenium (a-Se) as the conversion material. Specifically, we examine the optimal weight factor and the signal difference to noise ratio. We find that the multilayer detector has the potential for energy discrimination, and thus the ability to be used for contrast-enhanced mammography.

7622-58, Session 11

Gain uniformity in a novel two TFT, current programmed amorphous silicon active pixel sensor for fluoroscopy, chest radiography and mammography tomosynthesis applications

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Passive pixel sensor (PPS) is the most widely used architecture in large area amorphous silicon (a-Si) flat panel imagers. It consists of a detector and a thin film transistor acting as a readout switch. While the PPS is advantageous in terms of providing a simple and small architecture suitable for high-resolution imaging, it directly exposes the signal to the noise of data line and external readout electronics.

An alternative to PPS is active pixel sensor (APS) circuit. Due to its better signal-to-noise ratio at low dose and higher readout speeds, this technology enables high performance, high resolution digital x-ray imaging applications such as real-time fluoroscopy, chest radiography and mammography tomosynthesis. In this paper, a two-TFT current-programmed, current-output APS circuit is fully investigated. Its performance in terms of gain uniformity across the imager array, modulation transfer function (MTF), noise power spectrum (NPS) and Detective Quantum Efficiency (DQE) for two cases of fabrication in a-Si and polycrystalline (poly-Si) technologies are examined and the results are compared to state-of-the-art PPS panels for real-time fluoroscopy and mammography tomosynthesis applications. Programming the APS with a fixed, well defined off-panel current course enables the proposed scheme to compensate for inherent instabilities of the TFTs under electrical and thermal stress.

7622-59, Session 11

Effect of scintillator crystal geometry and surface finishing on depth of interaction resolution in PET detectors: Monte Carlo simulation and experimental results using silicon photomultipliers

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Silicon photomultipliers (SiPMs) are promising devices to replace photomultiplier tubes (PMTs) in positron emission tomography (PET) detectors for applications requiring higher image resolution and/or more compact scanners as well as immunity to magnetic fields. We used Monte Carlo simulation and experiments using silicon photomultipliers coupled to two ends of LYSO crystals to study the effect of scintillator geometry and surface finishing on detector performances such as depth of interaction (DOI) resolution, energy discrimination, and coincidence timing resolution. Measurements indicate almost linear DOI with sensitivity of 7.1% mm-1 and resolution of 2.3+/-0.6 mm for saw-cut, and 2.6% mm-1 and 9.0+/-1.5 mm, respectively, for polished scintillator crystals. Energy discrimination improves from 19% when DOI is in the center, to 15% with DOI at either ends of the saw-cut crystal, while it remains constant around 14% for polished scintillators. With detectors at both ends of the scintillator, the trade-off is between DOI resolution on one side, and energy and timing resolution on the other side, which is controlled by scintillator crystal surface finishing and geometry. However, accurate extraction of DOI information helps improving energy resolution by alleviating DOI dependency of energy discrimination. We will model the detector performance based on simulation and experimental results and use the model to optimize the detector performance for finely pixilated crystals necessary for high resolution PET.

7622-60, Session 11

The solid state x-ray image intensifier (SSXII) in single photon counting (SPC) mode

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The new Solid State X-Ray Image Intensifier (SSXII) has the unique ability to operate in single photon counting (SPC) mode, with improved resolution, as well as in traditional energy integrating (EI) mode. The SSXII utilizes an electron-multiplying CCD (EMCCD), with an effective pixel size of 32μm, which enables variable signal amplification (up

to a factor of 2000) prior to digital readout, providing very high-sensitivity capabilities. The presampled MTF was measured in both imaging modes using the standard angulated-slit method. A measured detector entrance exposure of 36µR per frame was used to provide approximately 0.8 interaction events per pixel in the 10µm-wide slit area. For demonstration purposes, a simple thresholding technique was used to localize events in SPC mode and a number of such frames were summed to provide an image with the same total exposure used for acquiring the EI image. The MTF for SPC mode, using a threshold level of 15% of the maximum 12-bit signal and 95% of the detected events, and for EI mode (in parentheses) was 0.67 (0.20), 0.37 (0.07), 0.20 (0.03), and 0.11 (0.01) at 2.5, 5, 7.5, and 10 cycles/mm, respectively. Increasing the threshold level resulted in a corresponding increase in the measured SPC MTF and a lower number of detected events, indicating a tradeoff between resolution and count efficiency is required. The SSXII in SPC mode was shown to provide substantial improvements in resolution relative to traditional EI mode, which should benefit applications that have demanding spatial resolution requirements, such as mammography.

7622-83, Poster Session

Non-convex prior image constrained compressed sensing (NC-PICCS)

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The purpose of this paper is to present a new image reconstruction algorithm for dynamic data, termed non-convex prior image constrained compressed sensing (NC-PICCS). This algorithm generalizes the prior image constrained compressed sensing (PICCS) algorithm with the use of non-convex priors. We present some examples using a simulated phantom, as well as in vivo data. We show that NC-PICCS can provide additional undersampling compared to both conventional convex compressed sensing methods and PICCS.

7622-84, Poster Session

Potential benefit of the CT adaptive statistical iterative reconstruction method for pediatric cardiac diagnosis

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Objective: Adaptive Statistical Iterative Reconstruction (ASIR) is a new imaging reconstruction technique recently introduced by General Electric (GE). This technique, when combined with a conventional filtered backprojection (FBP) approach, is able to take into account the statistical fluctuation of noise. To quantify the benefits provided on the image quality and the dose reduction by the ASIR method with respect to the pure FBP one, the standard deviation (SD), modulation transfer function (MTF), noise power spectrum (NPS), signal-to-noise ratio (SNR) and low contrast detectability were examined.

Materials and methods: A multidetector-row CT was employed. Measurements were performed on different phantoms when varying the CT dose index (CTDIvol) and the kernel reconstruction. Images were reconstructed on a CT console for different percentages of ASIR. Three radiologists and one cardiologist also assessed cardiac pediatric images reconstructed with ASIR using the visual grading analysis (VGA) method.

Results: For all reconstruction kernels, SD is linearly reduced when the ASIR percentage increases up to 100% with a higher benefit for low CTDIvol. MTF medium frequencies were slightly improved and modifications of the NPS shape curve were observed. However for clinical images, radiologists are not satisfied with the image texture and do not use more than 60% of ASIR.

Conclusion: Although combinations of FBP and ASIR methods improve phantom images, for a clinical application, 50% of ASIR is usually the best trade-off between the noise reduction and the clinical realism of the organ image. With ASIR, image quality assessments require the use of other types of phantoms.

7622-85, Poster Session

3D numerical test objects for the evaluation of a software used for an automatic analysis of a linear accelerator mechanical distortion

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Mechanical stability of a medical LINear ACcelerator (LINAC), particularly the quality of the gantry, collimator and table rotation and the accuracy of the isocenter position, are crucial for the radiation therapy process, especially in stereotactic radio surgery and in Image Guided Radiation Therapy (IGRT). This mechanical stability (flex) is perturbed due to the weight of the LINAC head and the kV x-ray tube and detector.

In this paper, we present a new method to evaluate a software which is used to perform an automatic measurement of the "size" (flex map) and the location of the isocenter of the linear accelerator beam arms during gantry, table and collimator rotation. The method consists of developing a complete numerical 3D simulation of a LINAC and physical phantoms in order to produce Electronic Portal Imaging Device (EPID) images including calibrated distortions of the mechanical movement of the gantry and isocenter misalignments.

7622-86, Poster Session

Properties of a parameterization of Radon projections by the reconstruction on circular disc

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The parameterization of projection profiles within the filtered back projection reconstruction algorithm relates to equally distant parallel rays and therefore is insufficient in cases where it is necessary to rebin from fan beam data to parallel beam data because of different topology of parallel beam vs. fan beam geometry. The problem of rebinning becomes even more cumbersome if the fan angle is big. Another kind of parameterization of projection profiles, a parameterization on a disc, has been proven to be more natural within the problem of rebinning from fan beam geometry to parallel beam geometry of this special kind. This was done by analysing reconstructions made from fan beam projection data simulated for different phantoms by different radiation levels. Both, parallel FBP and fan beam FBP as well as OPED were used for the reconstruction. For the OPED reconstruction, data were rearranged in order to fit best parallel projection and then put into the main formula of OPED.

7622-87, Poster Session

Investigation on PI-line selecting method base on GPU accelerated back-projection filtered VOI reconstruction

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Abstract: Cone-beam computed tomography (CBCT) represents a state-of-the-art CT technique. Reconstruction algorithms based on PI-line or Chord are active subject in CBCT. Among them back-projection filtered (BPF) reconstruction algorithm has obvious influence

for it exact reconstruction results and less computations especially in selected VOI regions. Since BPF algorithm using PI-line segment as the minimum reconstructed unit, the selecting and sampling method of PI-line segment can directly affect the quality of reconstructed images. In this paper, we propose a general PI-line selecting/sampling scheme to reconstruct VOI regions by using BPF algorithm, which mainly based on the relationship between reconstructed coordinate and PI-line coordinate. The scheme provides a general method to define parameters of PI-line segments with small projection angle, less PI-line segments quantity and high reconstruction quality both in VOI or full reconstruction. Since the PI-line selected rule is invariable, the proposed scheme is applicable for GPU accelerated back-projection filtered reconstruction. And the scheme provides a novel way to pre-establish the scan protocol for VOI reconstruction, which contains the helical of scan, the start and end points of X-ray irradiation and reconstructed field. It is a valuable attempt in low dose VOI scan and reconstruction by using dental or other CBCT.

7622-88, Poster Session

A new approach to limited angle tomography using the compressed sensing framework

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The limited angle problem is a well-known problem in computed tomography. It is caused by missing data over a certain angle interval, which make an inverse Radon transform impossible.

In the last years there has been a big development in the field of compressed sensing based algorithms in computed tomography, which deal very good with incomplete data. The most popular way is to integrate a total variation norm in form of a cost function into the iteration process. To find an exact solution of such a constrained minimization problem, computationally very demanding higher order algorithms should be used. Due to the non perfect sparsity of the total variation representation, reconstructions often show the so called staircase effect.

The method proposed here uses the solutions of the iteration process as an estimation for the missing angle data. Compared to a pure compressed sensing based algorithm we reached much better results within the same number of iterations and could eliminate the staircase effect.

The algorithm is evaluated using measured clinical datasets.

7622-89, Poster Session

Embossed radiography utilizing a subtraction program

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Currently, it is difficult to carry out refraction-contrast radiography by using a conventional x-ray generator. Thus, we developed an embossed radiography system utilizing dual-energy subtraction for decreasing the absorption contrast of unnecessary regions, and contrast resolution of a target region was increased by use of image-shifting subtraction and a linear-contrast system in a flat panel detector (FPD). To carry out embossed radiography, we developed a computer program for two-dimensional subtraction. The x-ray generator had a 100-micrometer-focus tube. Energy subtraction was performed at tube voltages of 40 and 70 kV, a tube current of 0.50 mA, and an x-ray exposure time of 5.0 s. A 1.0-mm-thick aluminum filter was used for absorbing low-photon-energy bremsstrahlung x-rays. Embossed radiography was achieved with cohesion imaging by use of the FPD with pixel sizes of 48×48 micrometers, and the shifting dimension of an object in the horizontal and vertical directions ranged from 100 to 200 micrometers. We obtained high-contrast embossed images of fine bones and coronary arteries approximately 100 micrometer in diameter.

7622-90, Poster Session

Enhanced image quality from segmentation based SPECT reconstruction

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Quality of Single Photon Emission Computed Tomography (SPECT) projection images captured from the camera is degraded due to several factors. As a result, the reconstructed volume is degraded providing limited information to the user. Focus of this work is to enhance the resolution and the signal to noise ratio (SNR) of the reconstructed SPECT volumes without altering the information in the input projection. The region of interest (ROI) is segmented from the input projection and only the segmented ROI is reconstructed. On an average, increase of 37% in SNR is observed from three reconstruction algorithms on two cardiac patient projections. The enhanced resolution obtained by segmenting and then reconstructing the input projection is promising or it is just a truncation artifact?

7622-91, Poster Session

Efficacy of iterative reconstruction in CT imaging

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CT images have traditionally been reconstructed using filtered back projection techniques. However, this image reconstruction approach has limitations regarding three-dimensional cone-beam geometry, data completeness, and low radiation dose acquisitions. Recently, iterative image reconstruction approaches have been proposed to provide more flexibility for accurate physical noise modelling and geometric system description. Initial experience suggests that these reconstruction methods allow for improvements in image quality and lower image noise and thus appear to be particularly promising for cardiovascular CT.

The purpose of this study is to compare the effect of reducing radiation dose (i.e., mAs) on lesion detection in CT examinations, with images reconstructed using standard filtered back projection with those reconstructed with iterative reconstruction. CT images reconstructed using standard filtered back projection were be modified using a simulation package (Syngo Explorer) allowing us to simulate the image acquisition at 70%, 50%, and 25% of the original tube current. Three observers were used to perform Alternate Forced Choice (2-AFC) experiments that measure the lesion contrast (I92%) corresponding to a detection accuracy of 92%. The lesion sizes were be varied from 5 mm to 12 mm and the results plotted as log(I92%) versus log(mAs), for each lesion size. The raw image data will also be reconstructed with the iterative technique and a similar lesion detection experiment will be conducted to yield I92% values corresponding to the iteratively reconstructed images. A comparison of the I92% values will allow us to compare the relative efficacy of the iterative reconstruction technique.

7622-92, Poster Session

TV-regularized iterative image reconstruction on a mobile C-ARM CT

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Computed tomography on the C-arm CT has been extensively studied and widely used in modern society. Although most manufacturers choose the filtered backprojection algorithm (FBP) for its accuracy and

efficiency, iterative reconstruction methods have a significant potential to provide superior performance for incomplete, noisy projection data. However, iterative methods have a high computational cost, which hinders their practical use. Furthermore, regularization is usually required to reduce the effects of noise. In this paper, we analyze the use of the Simultaneous Algebraic Reconstruction Technique (SART) with total variation (TV) regularization. Additionally, graphics hardware is utilized to increase the speed of SART implementation. NVIDIA's GPU and Compute Unified Device Architecture (CUDA) comprise the core of our computational platform. The results from the FDK algorithm on the 3D Shepp-Logan phantom and real data are provided in this summary. Experimental results of SART from CPU using cone-beam are also provided on 3-D synthetic images. Preliminary results on 3D synthetic images using TV regularization and GPU computation are discussed. Results on 3-D GPU reconstructed images from data acquired with the anthropomorphic phantoms are in progress. This work is performed jointly by the Scientific Computing and Imaging (SCI) institute in the University of Utah and GE Healthcare Surgery.

7622-93, Poster Session

Anatomy guided automated SPECT renal seed point estimation

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Quantification of SPECT images can be enhanced if accurate segmentation of region of interest (ROI) is achieved. Segmenting ROI from SPECT images is challenging due to poor image resolution. SPECT is utilized to study the kidney function, though the challenge involved is to accurately locate the kidneys and bladder for analysis. This paper presents an automated method for generating seed point location of both kidneys using anatomical location of kidneys and bladder. A model is generated based on manual segmentation of the bladder and both the kidneys on 10 patient datasets (including sum and max images). Centroid is estimated for manually segmented bladder and kidneys. Relatively easier bladder segmentation is followed by feeding bladder centroid coordinates into the model to generate seed point for kidneys. Percentage error observed in centroid coordinates of organs from ground truth to estimated values from our approach are acceptable. Percentage error of approximately 1%, 6% and 2% is observed in X coordinates and approximately 2%, 5% and 8% is observed in Y coordinates of bladder, left kidney and right kidney respectively.

The motivation for this work is based on the premise that the anatomical location of the bladder relative to the kidneys will not differ much. Using a regression model and the location of the bladder, the ROI generation for kidneys is facilitated. The model based seed point estimation will increase the robustness of kidney ROI estimation for noisy cases.

7622-94, Poster Session

Evaluation of dual-front active contour segmentation and metal shadow filling methods on metal artifact reduction in multi-slice helical CT

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A novel metal artifact reduction strategy including projection reformation, metal region segmentation, and metal shadow filling was proposed. Both metal region segmentation and shadow filling are critical steps to assure good artifact suppression results. This preliminary study evaluated the performance of two segmentation methods and three region filling methods on metal artifact reduction of clinical cases. Gradient-based threshold method (GBT) and dual-front active contour model-based method (DFAC) were utilized to segment metal implants from reformatted projections, Delaunay triangulation-based (DTB), anisotropic diffusion-based, and exemplar-based, interpolation methods were utilized to fill the metal shadows,

respectively. The image quality was evaluated by a radiologist in terms of visual conspicuity of the bladder base, prostate, and rectum. Overall, the image quality and the conspicuity in some critical organs were significantly improved for all corrections. Compared to the GBT method, the DFAC method had more accurate segmentation, which resulted in better artifact suppression. The interpolation process does not guarantee the data consistency among projection views, which can introduce additional artifacts, especially for large metal objects. Although the DTB method produced the smoothest metal shadow interpolation results, which is considered the worst scenario according to the criterion of image restoration, it induced the least additional artifacts to the reconstructed images compared to the other two structure-saving methods. As such, region interpolation methods should follow the criterion to generate metal shadow data consistent with the CT acquisition geometry, which might be quite different from the general standard of image restoration in computer vision and image processing.

7622-95, Poster Session

Adaptive modulation of bilateral filtering based on a practical noise model for noise reduction in multislice CT

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Noise control in CT is important for improving image quality and reducing radiation dose. We have recently developed a locally-adaptive method for noise control in CT based upon bilateral filtering. Different from the previous adaptive filters, which were locally adaptive by adjusting the filter strength according to local photon statistics, our use of bilateral filtering in projection data incorporates a practical CT noise model and takes into account the local structural characteristics, and thus can preserve edge information in the projection data and maintain the spatial resolution. Despite the incorporation of the CT noise model and local structural characteristics in the bilateral filtering, the noise-resolution properties of the filtered image are still highly dependent on predefined parameters that control the weighting factors in the bilateral filtering. An inappropriate selection of these parameters may result in a loss of spatial resolution or an insufficient reduction of noise. In this work, we employed an adaptive strategy to modulate the bilateral filtering strength according to the noise-equivalent photon numbers determined from each projection measurement. With the use of this strategy, bilateral filtering not only takes into account the CT noise model, but also is adaptive to both local photon statistics and structural characteristics. We evaluated the proposed technique using a head/neck angiographic CT exam, which had highly non-uniform attenuation levels during the scan. The results demonstrated that the technique can effectively reduce the noise and streaking artifacts caused by high attenuation, while maintaining the reconstruction accuracy in less attenuating regions.

7622-96, Poster Session

Sparse object reconstruction from a small number of projections in cone-beam micro-CT by constrained, total-variation minimization

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In cone-beam micro-CT, high-quality volume images in general require acquisition of projection data from hundreds of view angles, which sets a limitation to system throughput. It is desired to have a reconstruction technique which is capable of yielding 3D images with satisfactory quality from a smaller amount of projection data. In certain

applications such as angiography, the objects to be reconstructed are sparse, and norm-minimization-based methods have been investigated to incorporate such image sparsity as prior knowledge for image reconstruction from a small number of projections. In this study, we investigated the applicability of a new constrained, total-variation-minimization algorithm for image reconstruction of sparse objects from a small number of projections. The algorithm employed the steepest-descent method for minimization of image total-variation, and the projection-onto-convex-sets method for enforcement of data fidelity and other constraints. The algorithm was applied to real measurement data of a vascular cast sample collected by a custom-made cone-beam micro-CT system. Results show that the proposed algorithm outperformed the FDK algorithm when reconstructing the image from a small number of projections. Using the proposed algorithm, 3D images can be accurately reconstructed from as few as five projections. Therefore, the technique is potentially useful for yielding useful 3D image visualization and quantitative information from a significantly reduced projection data.

7622-97, Poster Session

Effect of dose reduction on lesion delectability in abdominal CT

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The purpose of this study was to evaluate the effect of reducing radiation dose (i.e., mAs) on lesion detection in abdominal CT examinations. A simulation package (Syngo Explorer) was used to reconstruct 4-mm thick CT images of a patient undergoing a standard abdominal exam. The package allowed us to simulate the image acquisition at 70%, 50%, and 25% of the original tube current. Three observers were used to perform a series of two Alternate Forced Choice (2-AFC) experiments that measure the lesion contrast (I92%) corresponding to a detection accuracy of 92%. The lesion sizes were varied from 5 mm to 12 mm and the results were plotted as log(I92%) versus log(mAs). Data of the pooled I92% as a function of lesion size were also plotted for all tube currents. In general, lower mAs resulted in reduced lesion detection performance for all lesions. The slopes of the I92% versus mAs curves were ~ -0.20 for 5 mm lesions, ~ -0.10 for 7, 10 and 12 mm lesions. Doubling the x-ray intensity improved lesion detection performance by ~ 20%, for the smallest lesions investigated (5 mm), ~ 12 % for the largest sized lesions (12 mm), and ~ 6 % for the intermediate sized lesions (7 and 10 mm). The change in tube current affects the smallest lesion size the most, a reflection of the fact that noise adversely affects the detection of small lesions much more than the medium or large sized ones. For all tube currents, plots of the I92% as a function of lesion size exhibit a minima near ~ 10 mm, implying a size range where the effects of anatomic structure are minimized.

7622-98, Poster Session

Imaging properties for gold nanoparticles: CT number dependence study

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In recent years, there has been a rapid research progress of molecular imaging technology. Many investigations in molecular imaging such as the nanoparticle applications in targeted drug delivery have been widely studied in several key small animal models. Various nanoparticles used as either the drug delivery carriers, imaging contrast mediums or target-specific therapeutic agents have established a novel research platform for biomedical related scientists. Among these nanoparticles, gold nanoparticles have the unique non-toxic and stability properties. In this work, a commercially-available micro CT imaging system was used to specifically study the imaging properties for 15 nm spherical-shaped gold particles. Imaging properties were quantified by the CT numbers obtained from a series of photon energy levels in the micro CT scanner. We also compared the imaging results

between gold nanoparticles and iodinated contrast medium to study the potential impact of gold nanoparticles served as the contrast agent.

7622-99, Poster Session

Computed tomography patient's examination in Kenya

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Abstract. Computed tomography (CT) is a very important tool in medical practice. CT contributes over 34% of collective dose from diagnostic X- Ray examinations in the world. Radiation doses received from CT exams are higher than those received in conventional radiology.The objective of the study was to establish the performance level of the Computed Topography (CT) scanners in Kenya in accordance with the International Commission on Radiation Protection (ICRP) and International Atomic Energy Agency (IAEA) standards, to estimate the patient dose and to develop effective performance tests criteria for quality assurance compliance of CT scanner. The dose measurements were measured using Axial slicing for two methods Dose in the air and in the phantoms. Head and Body phantoms were used with 10 cm dose length probe. Computed Tomography Dose Index (CTDIw), Dose Length Product (DLP), Multiple Scan Average Dose (MSAD) and Effective Dose (E) for 10 CT units from different companies have been investigated in different hospitals distributed all over Kenya. Mean CTDIw was found to be 83, 98, 94 and 94 mGy for brain, chest, abdomen and pelvis respectively. Mean DLP was found to be 67, 50, 35, and 31 for brain, chest, abdomen and pelvis respectively. Mean MSAD was found to be 67, 0, 47 and 0 for brain, chest, abdomen and pelvis respectively. Mean E was found to be 67, 44, 29 and 50 for brain, chest, abdomen and pelvis respectively. There was no clear documentation kept under a standard data form.

7622-100, Poster Session

An exact modeling of signal statistics in energy-integrating x-ray computed tomography

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Energy-integrating detection of X-ray sources is widely used by modern computed tomography (CT) scanners and has been an interesting research topic for the purpose of more accurately processing the data toward low-dose applications. While the energy-integrating detection can be described by a compound Poisson distribution, this work provides an alternative means to explicitly consider the Poisson statistics of the quanta and the energy spectrum of the X-ray generation. An exact solution for the first two orders of the compound Poisson statistics is presented. Given the energy spectrum of an X-ray source, the mean and variance of the measurement at any count-density level can be computed strictly. This solution can provide a quantitative measure on the condition under which an assumption of employing the most commonly-used independent identical distribution (i.i.d.), such as Gamma, Gaussian, etc, would be valid. A comparison study was performed to estimate the introduced errors of variance by using these substitute statistical functions to approximate the actual photon spectrum. The presented approach would further be incorporated in an adaptive noise treatment method for low-dose CT applications.

7622-101, Poster Session

Evaluation of the adaptive statistical iterative reconstruction technique for cardiac computed tomography imaging

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Recently Cardiac applications have been one of the very active research and development areas for Computed Tomography imaging. Because of its unique challenges, Cardiac CT imaging requires high spatial and temporal resolution and is often associated with high radiation dose and image noise.

The newly introduced Adaptive Statistical Iterative Reconstruction (ASIR) technique has shown the capability to offer large reduction of patient radiation dose while maintaining the image quality. This paper evaluates the optimization of ASIR technique for Cardiac CT applications. To achieve high resolution imaging, the dynamical focal spot control technique and fast sampling technique are often employed in CT systems, which provides higher system frequency bandwidth and resolution. However, high resolution is usually associated with high image noise. Since noise is more dominant in Cardiac CT imaging, the optimization of the signal to noise ratio is very critical to Cardiac CT.

The purpose of this work is to study the effectiveness of ASIR technique for Cardiac CT applications. Phantoms as well as clinical data have been evaluated. Spatial resolution in terms of Modulation Transfer Function is studied on the images generated with and without applying ASIR. Noise power spectrum is compared between the ASIR and non-ASIR images reconstructed from the same scan data. In terms of clinical data, low contrast objects (such as soft plaque) and high resolution objects (such as stent) have been evaluated. Initial results have demonstrated the effectiveness of ASIR technique for Cardiac CT imaging applications.

7622-102, Poster Session

Towards iterative reconstruction in clinical CT: significant dose reduction and increased sharpness to noise owing to a new class of regularization priors

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We present a FBP-based iterative reconstruction scheme with very fast convergence due to the pre-filtration of projection data using a classical (sharp) CT convolution kernel. Image artifacts, e.g. cone-beam artifacts, are efficiently suppressed after only 2 iterations. Furthermore, a new class of regularization priors has been devel-oped. The priors control the image impression so that it resembles that of a conventional CT convolution kernels. The regularization term consists of a linear combination of two l2-Norm priors. The first part operates on homo-geneous tissue: specifying a target convolution kernel for the convergence image allows for the computation of a (non-local) regularization filter, that produces the desired image impression (texture). The second term of the regularizer, operating on contrast edges, preserves or even enhances spatial resolution.

Due to the sharp convolution kernel used in the projector/backprojector loop and specific enhancement functions in the regularization procedure, contrast-dependent sharpness is achieved. It will be shown, that for at constant radiation exposure, the sharpness to noise ratio is significantly improved compared to classical FBP methods. This can be utilized either to increase sharpness at constant noise and radiation dose, or, alternatively, to reduce radiation dose and image noise at preserved sharpness. Clinical data of abdominal scans have been evaluated, demonstrating reduction of radiation dose of up to 60% while preserving image sharpness. In case of cardiac CT data, an even higher dose saving was obtained. Alternatively, blooming artifacts near calcifications in coronary vessels can be significantly reduced.

Our GPU-based implementation facilitates an image rate of 5 frames per second. Due to most recent results showing artifact and noise reduction, increased image sharpness and dose savings, iterative image reconstruction technique is now ready to enter clinical practice.

7622-103, Poster Session

Quantitative CT: technique dependency of volume assessment for pulmonary nodules

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Current lung nodule size assessment methods typically determine the maximum diameter of nodules from radiographs, and suffer from this 2D nature. New 3D volume assessment using helical CT scan data has brought possible solutions to this challenge, but is still open to evaluation since its accuracy and precision is expected to depend on a variety of factors. To identify some of these important factors, we scanned an anthropomorphic thoracic phantom with different protocols under isodose level, by varying kVps, pitches, nodule material and sizes, and scanners. Plastic spheres of various sizes were inserted in the phantom's lung cavity to simulate nodules. The nodule's volume was estimated by a lung analysis software package LungVCAR. Accuracy (bias) and precision (standard deviation) of volume assessment were then calculated across the nodules and compared between protocols. Results showed that under isodose conditions, kVp had small impacts on the estimation's accuracy and precision, while smaller pitch showed better performances. The largest effect on volume estimation performance was found as a function of nodule location, where nodules adjacent to multiple vessels or the pleura had a large variability in estimated volume. To our knowledge, this study is one of the first attempts to study volume measurement performance under isodose conditions, identifying the importance of scanning protocols on volume estimation in chest CT.

7622-104, Poster Session

Spatial comparison of synchrotron radiation microcomputed tomography and polychromatic microcomputed tomography bone images

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The study of trabecular bone tissue mineral density (TMD) may contribute to increased understanding of biomechanics and mineralization of bone. Conventional micro-computed tomography (micro-CT) is widely used for 3D imaging of bone, but TMD analysis from this modality is complicated by the polychromatic source and cone-shaped beam geometry.

In this work we evaluate micro-CT-based TMD measurements by a comparison to synchrotron radiation microcomputed tomography (SR micro-CT) TMD values from 14 specimens. Inter-modal rigid registration using a normalized mutual information metric allowed for a direct spatial comparison of TMD distributions. Gaussian smoothing on increasing scales were applied to the micro-CT images and resulting TMD values was compared to SR micro-CT data.

The correlation between SR micro-CT and micro-CT mean TMD values was highly improved with smoothing of the micro-CT images (r=0.85, p < 0.0002) compared to without smoothing (r=0.45, p < 0.2). This implies that noise removal can contribute to increased reliability of TMD estimates from micro-CT data.

7622-105, Poster Session

Imaging of basic function unit of small/medium animal via diagnostic x-ray CT scanner with an adaptor-and-holder assembly: feasibility study

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The imaging of the basic functional unit (BFU) of small/medium animal - an organ's smallest assembly of diverse cells that functions like the organ itself - is of significance in pre-clinical research. A BFU is usually a spheroid with its horizontal, transverse and vertical radii equal to ~50 μm and its dimension is virtually the same in small/medium animal and human. Apparently, state-of-the-art diagnostic CT scanners can't image the small/medium animal BFU directly because of its insufficient spatial resolution. Micro-CT is of sufficient spatial resolution, but its contrast, temporal and spectral resolutions are inferior to its counterparts in diagnostic CT. We propose to image the small/medium animal BFU using diagnostic CT with an adaptor-and-holder assembly (AHA) that can be mounted on the patient table and away from CT's iso-center (and thus closer to x-ray source). In data acquisition, the AHA device spins along its own axis while it is rotating along the CT gantry axis, leading to a temporal resolution that is primarily determined by the AHA device spin speed. Due to the geometric magnification, the spatial resolution of CT imaging with the AHA device is expected to be improved substantially for imaging the small/medium animal BFU. However, in practice, the AHA device may not be aligned perfectly and rotate/spin in phase with the CT gantry, resulting in motion blurring in reconstructed images. A robust motion-compensated reconstruction solution to appropriately deal with the AHA motion is proposed and evaluated in this feasibility study. In addition, the performance of CT imaging with such an AHA device, including the spatial, temporal and spectral resolutions and radiation dose efficiency are quantitatively analyzed and optimized in detail. It is believed that, the potential of CT imaging with the AHA device will enable the imaging of small/medium animal BFU, which may facilitate the translation of pre-clinical research findings in animal model into clinical applications.

7622-106, Poster Session

Third-generation x-ray computed tomography system utilizing a cadmium telluride detector

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An energy-discriminating Computed Tomography (CT) system is useful for increasing contrast resolution of a target region utilizing contrast media and for reducing the absorbed dose for patients. The CT system is of the third generation type with a cadmium telluride (CdTe) detector, and a projection curve is obtained by the linear scanning using the CdTe detector in conjunction with an x-stage. An object is rotated by the rotation pitch using a turn table between the linear scans. Thus, CT is carried out by repeating the linear scanning and the rotating of an object. Penetrating x-ray photons from the object are detected by the CdTe detector, and event signals of x-ray photons are produced using charge-sensitive and shaping amplifiers. Both the photon energy and the energy width are selected out by use of a multi-channel analyzer, and the number of photons is counted by a counter card. In energy-discriminating CT, the tube voltage and the current were 100 kV and 20 microampere, respectively. Demonstration of enhanced gadolinium K-edge x-ray CT was carried out by selecting photons with energies just beyond gadolinium K-edge energy of 50.3 keV.

7622-107, Poster Session

Applying an innovative approach for the quality characterization of CT systems to evaluate novel CT concepts

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Novel geometrical designs of CT scanners in combination with novel image reconstruction algorithms promise to halve the exposure dose in CT scans while the image quality could even be increased concerning contrast and noise. In this study, we experimentally test these theoretical predictions for the Micro-CT and the CT D'OR recently developed in our working group. In these novel CT systems the images are reconstructed using the OPED algorithm.

We use an innovative method for the quantitative and independent evaluation of such CT systems. The effects of the detection and the image reconstruction process on image quality parameters are separately evaluated. A technical enhancement of this approach was necessary in order to evaluate novel CT scanners such as the CT systems we developed. This technical enhancement is also checked for its proper operation.

The modulation transfer functions MTFR and MTFI from the detection (raw data - R) and image reconstruction (image - I) process are determined using the same metal edge device. Void scans allow the analysis of the noise power spectra NPSR and NPSI considering the raw data and the reconstructed image, respectively. The quantum performance of the CT scanners investigated, i.e., the detective quantum efficiency DQER;I of detector and entire system, can simultaneously be determined. Because of an absolute scaling of the raw data and the CT image, the quality parameters derived from the novel CT systems can theoretically be used for a subsequent quantitative comparison with the quality parameters derived from any other, conventional CT scanner.

7622-108, Poster Session

Fast cardiac CT simulation using a graphics processing unit-accelerated Monte Carlo code

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The simulation of imaging systems using Monte Carlo x-ray transport codes is a computationally intensive task. Typically, many hours of computation are required to simulate a radiographic projection image and, as a consequence, the simulation of the hundreds of projections required for a tomographic reconstruction may require an unaffordable amount of computing time. To speed up x-ray transport simulations, a MC code that can be executed in a Graphics Processing Unit (GPU) was developed using the CUDA programming model, an extension to the C language for the execution of general-purpose computations on NVIDIA's GPUs. The code implements the accurate photon interaction models from PENELOPE and takes full advantage of the GPU massively parallel architecture by simulating hundreds of particle tracks simultaneously. A new version of this code adapted to the simulation of CT scans, and allowing the execution in parallel in multiple GPUs, is introduced. An example simulation of a cardiac CT using a detailed voxelized anthropomorphic phantom is presented. The effect of scattered radiation on the CT is studied comparing planes reconstructed with and without scatter against the original voxelized geometry. A detailed analysis of the simulation performance in one or multiple GPUs, and CPUs, and a benchmark with PENELOPE, are provided. This study shows that low-cost GPU clusters are a good alternative to CPU clusters for Monte Carlo simulation of x-ray transport.

7622-109, Poster Session

Designing a phantom for dose and image quality evaluation of MSCT

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The advent of MSCT allows for faster imaging studies using x-ray beams wider than those of previous generations of scanners. Accurately characterizing radiation dose delivered to patients becomes a concern as the maximum beam width of some of these machines tends to become larger than the 100-mm charge-collection length of the pencil ionization chamber conventionally used in CT dosimetry. We investigate the size specications for the design of a cylindrical phantom for both dose and image-quality evaluation of CT scanners. Our requirements are that the phantom capture approximately the same dose as would an innitely long cylinder, but yet be of a size and weight that a physicist could easily carry and position. We simulate dose proles in cylindrical phantoms using the PENELOPE Monte Carlo package. X-ray energy depositions were estimated in PMMA (polymethylmethacrylate) phantoms of 15, 20, 25 and 32-cm diameter and 3 m length.

Beamwidths were varied from 3.2 to 32 cm. Lengths necessary to integrate doses associated with the tails were then calculated using relative energies deposited at various lengths along the phantom. The resulting lengths suggest that for larger beamwidths, phantoms longer than those currently used are necessary.

CTDI100 uses an active length of 100 mm, whereas the minimum length calculated in any of our simulations was 220 mm. However, when cylinders with smaller diameters are considered, shorter lengths are possible.

The results demonstrate that increasing beamwidth or increasing phantom diameter necessitates an increased phantom length.

7622-110, Poster Session

Use of beam shapers for cone-beam CT with off-centered flat detector

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While cone-beam CT using flat x-ray detectors has gained increased popularity in the past years, the 3D imaging quality is still limited by scatter and low dynamic range of the detector. Especially for large objects, the high dynamic range of the projections is a common source for detector specific artifacts. In conventional CT, the application of beam shapers (or bowtie filters) to decrease the signal dynamic in the projections is quite common. In this paper we investigate the use of a beam shaper for cone-beam CT with an off-centered flat detector.

The shift of the detector out of the central axis increases the field of view and allows the imaging of larger patients, but in turn leads to a very high dynamic range signal and poor scatter-to-primary ratios (SPR). The impact of a half bowtie filter on the imaging chain is investigated by means of Monte-Carlo simulations and the potential of reducing the patient dose is evaluated. It is shown that a beam shaper significantly improves the SPR especially for large patients.

The use of beam shapers for CBCT requires a modified pre-processing chain that accounts for image artifacts introduced by the beam modulation filter. In particular, the spectral hardening of the x-ray beam due to the beam shaper has to be corrected. In the paper, the pre-processing chain including scatter correction is adapted accordingly and validated using test bench experiments. A comparison of phantom scans with/without beam shaper evaluates the potential of beam shapers to improve the image quality in flat detector cone-beam CT.

7622-111, Poster Session

Image registration and superimposition for dual resolution cone beam CT: a preliminary study

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Purpose: To develop and investigate the processing of the image registration and superimposition algorithms for dual resolution cone beam CT.

Methods: Dual-resolution cone beam CT requires integration of two data sets with different image size and resolution. One set is low resolution open field images acquired with a flat panel detector; the other set is high resolution volume-of-interest (VOI) only images acquired with collimated x-rays and a high resolution detector. The correct registration and superimposition of the high resolution VOI images to the low resolution open field images is essential to correct image reconstruction. To locate the VOI position on the low resolution detector, another data set with VOI mask in but no object was acquired by low resolution detector. The high contrast VOI boundaries were used to determine the positions of the VOI. Thus the high resolution images can be interpolated first according to the ratio of the VOI projection sizes on different plane and then used to superimpose to the low resolution open field images. The combined images were tested by subtracting them from open field images to evaluate the registration accuracy and then used to reconstruct 3D images for the VOI with Feldkamp algorithm.

Results: In the combined images, the phantom structure passes through the edge of the VOI smoothly. The histograms of the subtraction images follow a Gaussian distribution. In the reconstructed images, Al wires with a diameter of 152 μm can be seen in the VOI.

7622-112, Poster Session

Implementation of ART and SIRT methods in image reconstruction of CBCT with limited data

W. Qiu, C. N. Mitchell, Univ. of Bath (United Kingdom); T. E. Marchant, C. J. Moore, Christie Hospital (United Kingdom); M. Soleimani, Univ. of Bath (United Kingdom)

Cone beam computed tomography (CBCT) provides a volumetric image reconstruction from tomographic projec-tion data. However, challenges still exist for image reconstruction due to sampling problems or insufficient data collection in some practical applications, which leads to the studies in limited data CBCT reconstruction. Iterative algorithms, firstly proposed as an approach for full-scan tomographic image reconstruction, have been studied and results showed that they are also applicable and even performed better in the situation when projection data are limited. In our work, comparison of the CBCT iterative algorithms (ART and SIRT) implemented in the Multi-Instrument Data Analysis System (MIDAS) tomography software are presented, where limited projection data are applied. Convergence rate, edge recovery, computational time and quality of the image are the main crite-ria for considerations, where the selection of the relaxation parameter and number of iterations are studied. Results are presented, with the image reconstructed from limited but evenly sampled CBCT projection data using iterative algorithms (ART and SIRT). They are compared in terms of the criteria mentioned while a FDK FBP image using a full data set from the same system is used as a reference. In our continued effort we are working towards further optimisation of iterative methods as well as their clinical relevance. The MIDAS platform will enable us to develop further innovative approaches.

7622-113, Poster Session

Pseudo super-resolution for improved calcification characterization for cone beam breast CT (CBBCT)

D. Yang, R. Ning, R. Betancourt-Benitez, J. Liu, X. Zhang, W. Cai, Univ. of Rochester Medical Ctr. (United States)

Cone Beam Breast CT imaging (CBBCT) is a promising tool for breast tumor detection, diagnosis and other specific application. Current CBBCT possess a flat panel detector (40 by 30 cm) with the virtual pixel pitch for normal scanning mode as 273 μm. The matrix size of the detector is 1024 × 768. When the x-ray tube is fixed with the size of 300 μm, the highest cutoff frequency is 3.2 lp/mm based on the MTF evaluation using the ramp linear operation on the projection data. This is actually a paradox since the Nyquist frequency which is determined by the detector virtual pixel pitch is 1.83 lp/mm. That means any information content beyond Nyquist frequency can not be shown on the detector. That's true in one dimension operation, when circular scanning and reconstruction are considered however, the image content beyond the detector Nyquist frequency can be shown. That's why voxel size of 155 μm is used for high resolution reconstruction for calcification characterization based on normal projection matrix size (1024 × 768) in the current CBBCT, and indeed the improvement on the visualization of calcification in the reconstructed breast was observed. This phenomenon actually indicates that the projection data the 2D flat panel detector acquires has information content beyond the detector Nyquist frequency. In order to further tap into the frequency limitation of the CBBCT system, a pseudo super resolution (PSR) method was proposed to get a better MTF without compromising the noise.

7622-114, Poster Session

Development and characterization of a beam hardening filter for a cone beam CT imaging system

R. Betancourt-Benitez, R. Ning, D. Yang, Univ. of Rochester Medical Ctr. (United States)

Generally, Cone Beam CT imaging systems utilize polychromatic x-ray beams since they are easier to generate and their output power is larger than those from monochromatic beams. However, polychromatic beams have main drawbacks in medical imaging. For example, the relative high content of low energy photons introduce two main phenomena that degrade the image quality. First, most of the low energy photons are absorbed within the soft tissue hardening the beam. This beam hardening deteriorates the image quality by decreasing the uniformity. Second, due to the polychromatic nature of the beam and beam hardening, the image is degraded by high contrast objects. In order to solve these problems, a filter was developed and implemented in a Flat Panel Detector-based Cone Beam CT. First, the initial energy spectrum of the system was acquired and computer simulations were done to evaluate and develop the best suitable filter to harden the x-ray beam to an optimized spectrum. Second, experiments were performed to evaluate the improvements on image quality based on uniformity, scattering and artifact due to high contrast objects. The results demonstrate that the newly developed filter improves the image quality in these two areas. The uniformity increases as observed in the images acquired using a water phantom. For instance, the cupping artifact was significantly reduced in these images. The high contrast artifacts were also reduced as illustrated in the images from the arm phantom with the metal implant. Based on these results, the use of this filter to harden the beam has increased the image quality.

7622-115, Poster Session

GPU-based iterative reconstruction with total variation minimization for micro-CT

S. M. Johnston, G. A. Johnson, C. T. Badea, Duke Univ. (United States)

Imaging with micro-CT entails the reconstruction of 3-dimensional data from a series of 2-dimensional projections. This reconstruction is traditionally performed with a filtered backprojection (FBP)-based algorithm, which is fast but suffers from reconstruction artifacts, especially if the number of projections is limited or the projections are not sampled at constant angular increments, which is often the case in dynamic imaging. To remedy this problem, iterative algorithms have been developed to refine reconstructions by minimizing various measures of error. One popular metric is the total variation (TV), which measures the discontinuities in an image, and can be used to reduce noise in an image while preserving sharp boundaries. However, these iterative algorithms can take much longer to run than simple FBP, which has hindered their use and development. To overcome this limitation, the graphics processing unit (GPU) has emerged as a powerful computational tool for accelerating reconstruction. In this work, we describe the implementation of a variety of TV-based iterative reconstruction algorithms using a GPU server program. These algorithms include the simultaneous algebraic reconstruction technique (SART), the method of steepest descent (SD), and the nonlinear conjugate gradient method (CG). We demonstrate that the GPU server program allows the rapid development and operation of these algorithms, and we test and compare their performance.

7622-116, Poster Session

GPU implementation of prior image constrained compressed sensing (PICCS)

B. E. Nett, J. Tang, G. Chen, Univ. of Wisconsin-Madison (United States)

The Prior Image Constrained Compressed Sensing (PICCS) algorithm (Med. Phys. 35, pg. 660, 2008) has been applied to several computed tomography applications with both standard CT systems and flat-panel based systems designed for guiding interventional procedures and radiation therapy treatment delivery.

The PICCS algorithm has demonstrated utility in several applications including: improved temporal resolution reconstruction, 4D respiratory phase specific reconstructions for radiation therapy, and cardiac reconstruction from data acquired on an interventional C-arm.

One disadvantage of the PICCS algorithm, just as other iterative algorithms, is the long computation times typically associated with reconstruction. In order for an algorithm to gain clinical acceptance reconstruction must be achievable in minutes rather than hours.

In this work the PICCS algorithm has been implemented on the GPU in order to significantly reduce the reconstruction time of the PICCS algorithm.

The Compute Unified Device Architecture (CUDA) was used in this implementation.

7622-117, Poster Session

Accelerating ring artifact correction for flat-detector CT using the CUDA framework

W. Chen, D. Prell, Y. Kyriakou, W. A. Kalender, Friedrich-Alexander-Univ. Erlangen-Nürnberg (Germany)

Ring artifacts often appear in flat-detector CT because of imperfect or defect detector elements or calibration. In high-spatial resolution CT images reducing such artifacts becomes a necessity. In this paper, we use the post-processing ring correction in polar coordinates (RCP) to eliminate the ring artifacts. The median filter is applied to the uncorrected image in polar coordinates and ring artifacts are extracted

from the original images. The algorithm has a very high computational cost due to the time-expensive median filtering and coordinate transformation on CPUs. Graphics processing units (GPUs) can be seen as parallel coprocessors of high computational power. All steps of the RCP algorithm are implemented with CUDA(Compute Unified Device Architecture, NVIDIA), which is a parallel computing architecture for solving complex computational problems on GPUs. We evaluated the performance of the RCP method using 512 slices, each slice consisted of 512×512 pixels. Our CUDA-based RCP is up to 8 times faster than the optimized CPU-based (single core) routine. To achieve this performance, we exploit the highspeed on-chip shared memory provided by NVIDIA GPUs, particularly for median filtering. A multi-GPU solution showed that the performance scaled nearly linearly.

7622-118, Poster Session

Demonstration of dual resolution come beam CT technique with an a-Si/a-Se flat pnale detector

Y. Shen, Y. Zhong, L. Chen, T. Han, Z. You, Y. Yi, S. Ge, C. Lai, X. Liu, T. Wang, C. C. Shaw, The Univ. of Texas M.D. Anderson Cancer Ctr. (United States)

Purpose:

To demonstrate volume of interest (VOI) scanning technique in dual resolution cone beam CT (CBCT) breast imaging.

Methods:

A paraffin cylinder with a diameter of 135mm was used to simulate breast. A wire phantom with a diameter of 15mm was constructed as VOI. The phantom contains 8 vertically aluminum wires of various diameters surrounded by paraffin. The wire phantom was inserted into the breast phantom 45mm away from the center. The phantoms were first scanned with a bench top experimental CBCT system at a low exposure level with the detector operated in a binning mode. Then a VOI mask was placed between the x-ray source and the phantoms. The phantoms were scanned again with high exposure level and the detector operated in the non-binning mode. The VOI mask was moved to follow the wire phantom during the whole CT scan to limit the exposures to cover the VOI only. The low resolution and high resolution images were then combined together for reconstruction with FDK algorithm.

Results:

Visual review of the regular and dual resolution CBCT images shows that thinnest resolvable wire in the dual resolution CBCT images has a diameter of 152μm. The thinnest resolvable wire in regular CBCT images has a diameter of 254μm. The estimated dose to the phantom for dual resolution CBCT is 117% of the dose level for regular CBCT.

Conclusions:

The dual resolution CBCT technique greatly enhances the CT image quality while still remains a low exposure level to the phantom.

7622-120, Poster Session

Initial investigation into lower-cost CT for resource limited regions of the world

J. T. Dobbins III, W. P. Segars, C. Li, J. R. Wells, C. J. N. Kigongo, Duke Univ. (United States)

This paper describes an initial investigation into means for producing lower-cost CT scanners for resource limited regions of the world. In regions such as sub-Saharan Africa, intermediate level medical facilities serving millions have no CT machines, and lack the imaging resources necessary to determine whether certain patients would benefit from being transferred to a hospital in a larger city for further diagnostic workup or treatment. Low-cost CT scanners would potentially be of immense help to the healthcare system in such regions. Such scanners would not produce state-of-the-art image quality, but rather would be intended primarily for triaging purposes to determine the patients who

would benefit from transfer to larger hospitals.

The lower-cost scanner investigated here consists of a fixed digital radiography system and a rotating patient stage. This paper describes initial experiments to determine if such a configuration is feasible. Experiments were conducted using (1) x-ray image acquisition, a physical anthropomorphic chest phantom, and a flat-panel detector system, and (2) a computer-simulated XCAT chest phantom. Both the physical phantom and simulated phantom produced excellent image quality reconstructions when the phantom was perfectly aligned during acquisition but artifacts were noted when the phantom was displaced to simulate patient motion. Lateral motion of the phantom by 5-mm during 360-degree acquisition of images produced reconstructions with artifacts likely to be acceptable for triaging purposes, but more complicated motion produced more severe artifacts. These experiments demonstrated feasibility for this approach, but additional work is required to determine the exact limitations produced by patient motion.

7622-121, Poster Session

GPU-accelerated metal artifact reduction (MAR) in FD-CT

M. Beister, D. Prell, Y. Kyriakou, W. A. Kalender, Friedrich-Alexander-Univ. Erlangen-Nürnberg (Germany)

Metallic implants are responsible for various artifacts in flat-detector computed tomography visible as streaks and dark areas in the reconstructed volumetric images. In this paper a novel method for a fast reduction of these metal artifacts is presented using a three-step correction procedure to approximate the missing parts of the raw data. Besides image quality, this paper also deals with the problem of high correction latencies by proposing a reconstruction and correction framework, that utilizes the massive computational power of graphics processing units (GPUs). An initial volume is reconstructed, followed by a 3-dimensional metal voxel segmentation algorithm. These metal voxels allow us to identify metal-influenced detector elements by using a simplified geometric forward projection. Consequently, these areas are corrected using a 3D interpolation scheme in the raw data domain, followed by a second reconstruction. This volume is then segmented into three materials with respect to bone structures using a threshold-based algorithm. A forward projection of the obtained tissue-class model substitutes missing or corrupted attenuation values for each detector element affected by metal and is followed by a final reconstruction. The entire process including the initial reconstruction, takes less than a minute (512^3 volume with 496 projections of size 1024^2) and offers significant improvements of image quality. The method was validated with data from a FD-CT C-arm system (Artis Zeego, Siemens Healthcare, Forchheim, Germany).

7622-122, Poster Session

Scatter in an uncollimated x-ray CT machine based on a Geant4 Monte Carlo simulation

N. Wadeson, W. Lionheart, The Univ. of Manchester (United Kingdom); E. Morton, Rapiscan Systems Ltd. (United Kingdom)

A high-speed motionless-gantry x-ray CT machine may be designed to allow for 3D images to be collected in real time. By using multiple, switched x-ray sources and fixed detector rings, the time consuming mechanical rotation of conventional CT machines can be removed. However, the nature of this design limits the possibility of detector collimation since each detector must now be able to record the energy of x-ray beams from a number of different directions. The lack of collimation has implications in the reconstructed image due to an increase in the number of scattered photons recorded. A computer simulation of the x-ray machine has been developed, using the Geant4 software toolkit, to analyse the behaviour of both Rayleigh and Compton scattered photons when considering airport baggage and medical applications. Four different scattering objects were analysed based on 50kVp, 100kVp and 150kVp spectra for a tungsten target. Two suitcase objects, a body and a brain phantom

were chosen as objects typical of airport baggage and medical CT. The results indicate that the level of scatter is negligible for a typical airport baggage application, since the majority of space in a suitcase consists of clothing, which has a low density. Scatter contributes to less than 1% of the image in all instances. However, due to the large amounts of water found in the human body, the level of scatter in the medical instances are significantly higher, reaching 37% when the body phantom is analysed at 50kVp.

7622-123, Poster Session

Off-center object of interest (OOI) imaging for filtered region of interest rotational angiography (FROI-RA)

S. Schafer, P. B. Noël, A. M. Walczak, Toshiba Stroke Research Ctr. (United States); A. T. Kuhls-Gilcrist, Univ. at Buffalo (United States); K. R. Hoffmann, Toshiba Stroke Research Ctr. (United States)

Rotational angiography (RA) is widely used clinically to obtain 3D data of the vasculature of interest. In many procedures, e.g., neurovascular interventions, the imaged field of view (FOV) is much larger than the region of interest (ROI), thereby subjecting the patient to unnecessary x-ray dose. To reduce the dose in these procedures, we propose placing an x-ray attenuating filter with an open aperture (ROI) in the x-ray beam (called filtered region of interest (FROI) RA). We have shown that this approach yields high quality data for centered objects of interest (OoIs). In this study, we investigate the noise behavior of the FROI approach for off-center OoIs.

Using filter-specific attenuation and noise characteristics, simulated FROI projection images were generated. The intensities in the peripheral region were equalized, and the 3D data were reconstructed. For each reconstructed voxel, the intersections with the full intensity beam (ROI) were determined for each projection, and noise properties were evaluated. Off-center OoIs intersect the high intensity beam in more than 40% of the projections (ROI having 30% FOV area), with intersection frequency increasing with increasing ROI area and OoI proximity to the central region. The noise increases with distance from the central region up to a factor of two. Integral dose reductions range between 50% and 75%.

Substantial dose reductions (75%) are achieved with less than a factor of two increase in noise for OoIs peripheral to the central region, indicating the FROI approach might be an alternative for reducing dose during standard procedures.

7622-124, Poster Session

Phase-selective image reconstruction of the lungs in small animals using micro-CT

S. M. Johnston, B. A. Perez, D. G. Kirsch, C. T. Badea, Duke Univ. (United States)

Gating in small animal imaging using micro-CT can compensate for artifacts due to physiological motion. This paper presents strategies for sampling and image reconstruction in rodent lung using micro-CT. The approach involves fast sampling of free-breathing mice without additional hardware to detect respiratory motion. The projection images are analyzed post-acquisition to derive a respiratory signal, which is used to provide weighting factors for each projection that favor a selected phase of the respiration (e.g. end-inspiration or end-expiration) for the reconstruction. Since the sampling cycle and the respiratory cycle are uncorrelated, and the number of projections is limited by time and radiation dose, the sets of weighted projections corresponding to any of the selected respiratory phases are not regularly angularly distributed. This drastically affects the image quality of reconstructions based on simple filtered backprojection. To address this problem, we use an iterative reconstruction algorithm that combines the Simultaneous Algebraic Reconstruction Technique with Total Variation minimization (SART-TV). At each SART-TV iteration, backprojection is performed with a set of weighting factors that favor

the desired respiratory phase. For increased efficiency, the algorithm is implemented on a graphics processor unit. The performance of the proposed approach was investigated in mice with primary lung cancers imaged with our in-house developed dual tube/detector micro-CT. We note that if the ECG signal is acquired during sampling, the same considerations could be applied for phase-selective cardiac imaging. Further results will be presented at the meeting.

7622-125, Poster Session

Contrast-enhancement, image noise and dual-energy simulations for quantum-counting clinical CT

S. G. Kappler, D. Niederloehner, K. Stierstorfer, T. G. Flohr, Siemens Healthcare (Germany)

The spectral sensitivity of quantum-counting detectors promises increased contrast-to-noise ratios and dual-energy capabilities for Computed Tomography (CT). In this article we quantify the benefits as well as the conceptual limitations of this technology under realistic clinical conditions. We present detailed simulations of a CT system with CdTe-based quantum-counting detector and compare to a conventional energy-integrating detector with Gd2O2S scintillator. Detector geometries and pixel layouts are adapted to specific requirements of clinical CT and its high-flux environment. The counting detector is realized as a two-threshold counter. An image-based method is used to adapt thresholds and data weights optimizing contrasts and image noise with respect to the typical spectra provided by modern high-power tungsten anode X-ray tubes. We consider the case of moderate X-ray fluxes and compare contrasts and image noise at same patient dose and image sharpness. We find that spectral sensitivity offers dose reduction potentials of 31.5% (9.2%) maintaining Iodine-water contrast-to-noise ratios at 120kVp (80kVp). The improved contrast-to-noise ratios result mainly from improved contrasts and not from reduced image noise. The presence of fluorescence effects in the sensor material is the reason why image noise levels are not significantly reduced in comparison to energy-integrating systems. Dual-energy performance of quantum-counting single-source CT in terms of bone-Iodine separation is found to be somewhat below the level of today's dual-source CT devices with optimized pre-filtration of the X-ray beams.

7622-126, Poster Session

The impact of dual energy CT on pseudo enhancement of kidney lesions

J. Müller, Univ. zu Lübeck (Germany); T. J. Vrtiska, Mayo Clinic College of Medicine (United States); B. T. Schmidt, Siemens Medical Solutions GmbH (Germany); B. M. Howe, C. H. McCollough, Mayo Clinic (United States); T. M. Buzug, Univ. zu Lübeck (Germany); C. D. Eusemann, Siemens Medical Solutions USA, Inc. (United States)

Lesion detection using Computed tomography is an import application in genitourinary radiology. Unfortunately, the well known problem of pseudoenhancement complicates the detection. Here, the HU values inside a cyst incorrectly increase with increasing iodine enhanced in surrounding soft tissue. Frequently, pseudoenhancement creates severe difficulties to distinguish lesion from the kidney tissue.

In the study, the standard procedure based on a single energy 120 kV mode is compared to three dual energy modes available on the Siemens Somatom Definition Flash scanner.

In order to simulate the kidney and the lesions, several plastic rods were placed inside a small container filled with different iodine concentrations. This phantom is then positioned inside water tanks of different sizes. The rods simulating the lesions are made out of a special plastic with constant HU value throughout the relevant X-ray energy range.

During the project, three important aspects have been discovered: 1)

for normal situations, the new 100/140 Sn kV mode on the Siemens Flash is very similar to the clinically used 120 kV mode. 2) For small patient sizes, all Dual Energy modes show a reduction of pseudo enhancement. 3) For larger patients, only the 100/140 Sn kV mode retains the reduction of pseudo enhancement. Both the 80/140 kV and the 80/140 Sn kV mode show a worse performance than the 120 kV single energy mode in a very large phantom size.

7622-127, Poster Session

Comparison of contrast and noise in subtraction-based and dual-energy kV-switching-based CT images of Xe gas for lung ventilation imaging

J. Tanguay, I. A. Cunningham, Robarts Research Institute (Canada)

Abstract Dual-source and kV-switching CT scanners have enabled the acquisition of material-specific images of Xe gas contrast for lung ventilation imaging in a single breathold. In this study, a comparison is made of CT image contrast and noise resulting from Xe gas using pre- and post-injection subtraction, conventional dual-energy (two acquisition) imaging, and kV-switching dual-energy imaging. For each case, the comparison is made for the same total "dose" to the test phantom. Preliminary result based on images acquired using conventional three-material decomposition show excellent separation of Xe, glass and perspex, the three materials in the test phantom. This comparison will show how sucessfully the kV-switching approach can isolate Xe in a single acquisition relative to conventional two-acquisition dual-energy methods.

7622-128, Poster Session

Fast kV switching dual energy CT effective atomic number accuracy for kidney stone characterization

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The fast switching clinical application of dual energy CT for effective atomic number characterization of compounds is explored in the context of noninvasive kidney stone characterization. Analytical and experimental measurements are reported and contrasted. Stone specimens representing compositions of Uric Acid, Struvite, Cystine, Calcium Phosphate, and Brushite spanning an effective atomic number range of approximately 7 to 14 are considered. While Uric Acid and Calcium based stones are generally distinguishable in conventional CT, other stone compositions such as Cystine and Struvite are difficult to distinguish resulting in treatment uncertainty. Experimental phantom measurements are made under increasing complex imaging conditions to illustrate the impact of various factors on measurement error. Preliminary clinical studies are reported.

See attached for more detailed description

7622-129, Poster Session

Impact of photon counting detector spectral response on dual energy approaches

A. S. Wang, N. J. Pelc, Stanford Univ. (United States)

Photon counting detectors with energy discriminating capabilities offer the exciting prospect of dose efficient dual energy x-ray imaging. Several techniques have been proposed to form the energy-dependent detector measurements needed for dual energy. However, their performance depends on the limitations of the detectors. An important one is the detector spectral response. Therefore, in this paper, we study the effect of a detector's spectral response on several dual energy techniques with photon counting detectors.

Realistic spectral response functions exhibit a Gaussian photopeak trailed by a lower energy tail. We use a two-parameter model to characterize the width of the photopeak and the photopeak fraction. The dual energy techniques compared all reduce the spectral data into two measurements using the following methods: (1) binning with an optimally chosen energy threshold; (2) a hybrid photon counting/energy integrating detector; (3) μ-weights, which have been shown to be optimal for ideal detectors. Their performances for different spectral responses are compared by evaluating the Cramer-Rao Lower Bound (CRLB) for estimating the unknown material thicknesses. We show that as the spectral response worsens, μ-weights rapidly deteriorate in performance while a hybrid detector's relative performance improves. Therefore, energy weighting is highly sensitive to a detector's spectral response.

Furthermore, we prove that for arbitrary non-ideal spectral response functions, no set of two energy weighting functions exist that provide a sufficient statistic over all material thicknesses. Nonetheless, numerical optimization techniques can be used to find two sets of weights whose performance is close to that of measuring the full detected spectrum for all material thicknesses.

7622-130, Poster Session

Evaluation of an image-based algorithm for quantitative spectral CT applications

B. J. Heismann, Siemens Medical Solutions GmbH (Germany); M. Balda, Friedrich-Alexander-Univ. Erlangen-Nürnberg (Germany)

In this paper we describe and evaluate an image-based spectral CT method. Its central formula expresses measured CT data as a spectral integration of the spectral attenuation coefficient multiplied by a Local Weighting Function (LWF). The LWF represents the local energy weighting in the image domain, taking into account the system and reconstruction properties and the object self attenuation. A generalized image-based formulation of spectral CT algorithms is obtained, with no need for additional corrections of e.g. beam hardening. The iterative procedure called Local Spectral Reconstruction (LSR) yields both the mass attenuation coefficients of the object and a representation of the LWF.

The quantitative accuracy and precision of the method is investigated in several applications, including beam hardening correction, attenuation correction for SPECT/CT and PET/CT, a quantitative iodine density evaluation and a direct identification of spectral attenuation functions using the LWF result is demonstrated. In all applications the ground truth of the objects is reproduced with a quantitative accuracy in the sub-percent to two percent range. An exponential convergence behavior of the iterative procedure is observed, with one to two iteration steps as a good compromise between quantitative accuracy and precision. We conclude that the method can be used to perform image-based spectral CT reconstructions with quantitative accuracy. Existing algorithms benefit from the intrinsic treatment of beam hardening and system properties. Novel algorithms are enabled to directly compare material model functions to spectral measurement data.

7622-131, Poster Session

In vivo measurement of iron concentration using dual-source, dual-energy CT

P. T. Weavers, M. Jacobsen, X. Liu, R. Morin, C. H. McCollough, Mayo Clinic (United States)

Dual energy computed tomography has been previously shown to be capable of quantifying iron concentration in a phantom model. In

this work, a commercial three material decomposition algorithm is investigated with the aim of quantifying iron concentration in vivo with dual energy. Five iron (III) nitrate solutions of differing concentrations were scanned at various tube potentials, phantom sizes, and x-ray beam filtration levels. A commercial three material decomposition software package was used to measure iron concentration values in specified regions of interest. These values were used to investigate the effects tube potential, phantom size, and beam filtration on the ability of dual energy computed tomography to accurately quantitate iron concentration. In most cases, the greater spectral separation afforded by the addition of a tin filtration to the high-energy beam improved the accuracy of the iron quantification. Dual energy CT measurements of the three highest iron concentrations had a maximum percent difference from the known value of 21%. The method's accuracy was not significantly influenced by kV combinations (80/140 kV, 80/ 40 kV with additional tin filtration, and 100 /140 kV with additional tin filtration) or phantom size.

7622-132, Poster Session

Differentiation of uric acid versus non-uric acid kidney stones in the presence of iodine using dual-energy CT

J. Wang, M. Qu, S. Leng, C. H. McCollough, Mayo Clinic (United States)

In this study, the feasibility of differentiating uric acid from non-uric acid kidney stones in the presence of iodinated contrast material was evaluated using dual-energy CT (DECT). Iodine subtraction was accomplished with a commercial three material decomposition algorithm to create a virtual non-contrast (VNC) image set. VNC images were then used to segment stone regions from tissue background. The DE ratio of each stone was calculated using the CT images acquired at two different energies with DECT using the stone map generated from the VNC images. The performance of DE ratio-based stone differentiation was evaluated at five different iodine concentrations (21, 42, 63, 84 and 105 mg/ml). DE ratio of stones in iodine solution was found larger than those obtained in non-iodine cases. This is likely caused by the partial volume effect and infiltration of iodine into the stone. However, the comparison of DE ratio of stones shows that there is still significant difference in DE ratio between uric acid and non-uric acid stones even under the influence of iodine solution. Furthermore, by using tin filtration in 140kV tube, the separation of UA stones from non-UA stones was enhanced, which shows promising solution to differentiate stone types in the iodine filled system clinically.

7622-133, Poster Session

Simulation study of an energy sensitive photon counting silicon strip detector for computed tomography: identifying strengths and weaknesses and developing work-arounds

H. Bornefalk, C. Xu, Royal Institute of Technology (Sweden); C. Svensson, Linköping Univ. (Sweden); M. E. Danielsson, Royal Institute of Technology (Sweden)

Advances in detector technology has brought renewed attention to the use of energy discriminating photon counting detectors for use in clinical computed tomography (CT) and several groups are developing photon counting CT prototypes. Two main types of semi-conductor materials have been proposed: CadmiumZinkTelluride (CZT) and silicon (Si). Compared to CZT, Si suffers from its relatively low atomic number making it a worse photo-electric absorber than CZT. CZT on the other hand suffers from relatively low drift velocities of the charge carriers, resulting in high intrinsic pile-up of the signals. Whether photon counting CT will eventually replace energy integrating approaches is still very much an open question, and if so, it is not clear what the detector material of choice will be.

We model an silicon strip detector for CT in terms of the physical processes resulting in limited energy resolution and count rate: charge sharing, time constant of the detector electronics and resulting pile-up, electronic noise and signals induced in neighboring pixels (cross talk). The result is a detector response function allowing inversion, i.e. it allows determination of the distribution of actual impinging photon energies given a certain detected energy (pulse height). This recoups some of the energy information lost due to high fraction of Compton interactions in the detector. The model is applied to simulated images yielding energy dependent reconstructions.

7622-134, Poster Session

Electronic noise comparison of amorphous silicon current mode and voltage mode active pixel sensors for large area digital x-ray imaging

D. Wu, N. Safavian, M. Y. Yazdandoost, M. H. Izadi, K. S. Karim, Univ. of Waterloo (Canada)

A detailed experimental and theoretical investigation of noise in both current mode and voltage mode amorphous silicon (a-Si) active pixel sensors (APS) has been performed. Both flicker (1/f) and thermal are considered in this study. The experimental result in this paper emphasizes the computation of the output noise variance, and not the output noise spectrum. This study determines which mode of operation is superior in term of output noise. The current noise power spectral density of a single a-Si TFT is also measured in order to find the suitable model for calculating the flicker noise. This experimental result matches Hooge's model. The theoretical analysis shows that the voltage mode APS has an advantage over the current mode APS in terms of the flicker noise due to the operation of the readout process. The experimental data are compared to the theoretical analysis and are in good agreement. The results obtained in this study apply equally well to APS circuits made using polycrystalline silicon (poly-Si) and single crystal silicon.

7622-135, Poster Session

Amorphous selenium lateral Frisch photodetector and photomultiplier for high performance medical x-ray and gamma-ray imaging applications

A. H. Goldan, K. S. Karim, K. Wang, F. Chen, Univ. of Waterloo (Canada)

In this research, we propose a new indirect x-ray and gamma-ray detector which is comprised of a scintillating crystal coupled with an amorphous selenium (a-Se) metal-semiconductor-metal (MSM) photodetector. A lateral Frisch grid is embedded between the anode and the cathode to provide (1) unipolar charge sensing and (2) avalanche multiplication gain during hole transport inside the detection region. Unipolar charge sensing operation reduces the persistent photocurrent lag and increases the speed of the photodetector. Approximately 95% of the pixel charge is induced during carrier transport inside the detection region. Also, with proper biasing of the electrodes, we can create a high-field region between the lateral Frisch grid and the cathode for avalanche multiplication gain. Thus, we can convert the photodetector into a photomultiplier for higher signal-to-noise ratio and single photon-counting gamma-ray imaging. We present for the first time, a lateral Frisch photodetector structure that provides unipolar charge sensing operation, its theory of operation, proposed implementation, and simulation results for x-ray and gamma-ray imaging applications that need faster image frame rate and avalanche multiplication gain for higher signal-to-noise ratio.

7622-136, Poster Session

Phosphor-filled micro-well arrays for digital x-ray imaging: effects of surface treatments

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In the previous study [S. M. Yun et al., Proc. SPIE 7258, 72583N (2009)], we successfully demonstrated the concept of pixel-structured scintillators for digital x-ray imaging by coupling with a photodiode array. The pixel-structured scintillators were prepared by filling Gd2O2S:Tb phosphor powder into the silicon micro-well arrays by using a simple sedimentation method. The micro-well arrays were fabricated by deep reactive ion etching of silicon wafers. Compared with the conventional Gd2O2S:Tb phosphor screen, the pixel-structured scintillators with pixel pitches of 50 um and 100 um showed greater image sharpness while the detective quantum efficiencies (DQEs) were significantly lower. The reason of the lower DQE is due to the loss of signal or optical photons in the surrounded silicon wall surfaces because silicon is a strong absorber of optical photons. Furthermore, the signal loss seriously degrades the Swank noise factor in the optical signal distributions at the photodiode array. In the current study, we fabricated silicon micro-well arrays with reflectance at the inside wall surfaces. Two different inside-surface treatments were applied; 2000-Å-thick titanium which has 60% reflectance at 545 nm wavelength and silicon dioxide which was naturally grown. The filling method of scintillation materials into the micro-well arrays is the same as the previous study while the depth of the micro-well arrays is deeper than that of the previous samples by a factor of ~2 (180 um). The imaging performance will be evaluated in terms of modulation-transfer function, noise-power spectrum, and DQE. We expect that an increased thickness of scintillator layer and the surface treatment can provide a much improved imaging performance. Theoretical Monte Carlo simulations and the cascade modeling will support the analysis of the measured results.

7622-137, Poster Session

Development of a large-area CMOS-based detector for real-time x-ray imaging

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Complementary metal-oxide-semiconductor (CMOS) active pixel sensors (APSs) with high electrical and optical performance are now being attractive for digital radiography (DR) and dental cone-beam computed tomography (CBCT). In this study, we report our development of CMOS-based detectors capable of real-time imaging. The field-of-view of the detector is 12 x 14.4 cm. The detector employs a CsI:Tl scintillator as an x-ray-to-light converter. The electrical performance of the developed CMOS APS, such as readout noise and full-well capacity, was evaluated. The x-ray imaging characteristics of the detector were evaluated in terms of characteristic curve, pre-sampling modulation transfer function, noise power spectrum, detective quantum efficiency, and image lag. The overall performance of the detector will be demonstrated with phantom images obtained for DR and CBCT applications. The detailed development description and measurement results will be addressed. With the results, we might suggest that the developed CMOS-based detector has the potential for CBCT and real-time x-ray imaging applications.

7622-138, Poster Session

Modeling of pulse signals in photon-counting detectors

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We are developing a theoretical model describing signal pulses from a detector-amplifier system operated in photon-counting mode. The detector is assumed to have a simple planar geometry. The amplifiers consist of charge-sensitive preamplifier and shaping amplifier. In the model, we include incomplete signal generation due to the charge trapping within a detector as well as to the ballistic deficit caused by insufficient charge integration time. This model can be utilized for the characterization of detector material properties such as the mobility and the life time, as well as the optimization of operation conditions such as the applied bias voltages and the charge integration time. The model will be experimentally verified with the measurement of charge collection efficiency of a planar cadmium zinc telluride detector with respect to the applied bias voltage and the charge integration time. We expect that the developed model will be useful for the design of photon-counting detectors.

7622-139, Poster Session

Performance of a prototype amorphous silicon active pixel sensor array using a-Se for direct x-ray conversion

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Active pixel sensor (APS) circuits are an alternate to passive pixel sensor (PPS) technology which, when integrated with a direct detection amorphous selenium (a-Se) photoconductor, can enable high performance, digital x-ray imaging applications such as real-time fluoroscopy due to their better signal-to-noise ratios at low dose. This paper presents experimental imaging results from a prototype 64x64 APS pixel array fabricated in a-Si technology. The prototype APS array is coated with a one millimeter thick layer of a-Se and the experimental results are evaluated using a standard radiography x-ray beam quality RQA5. The APS experimental results are compared with a standard real-time detector (FPD14) imaging array under the same x-ray beam conditions. In addition, we will theoretically examine the best achievable performance for our APS array fabricated in state-of-the-art a-Si technology and compare the results to state-of-the-art PPS panels for real-time fluoroscopy and mammography tomosynthesis applications.

7622-140, Poster Session

Scanning translucent glass-ceramic x-ray storage phosphors

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A simple benchtop apparatus has been built, to measure the x-ray imaging properties of fluorozirconate-based glass-ceramic x-ray storage phosphor materials. The MTF degradation due to stimulating light spreading in the plate is lower compared to the case of optically turbid screens resulting in higher image MTF, and additionally the degree of transparency, or the amount of light scattering at the wavelength of the stimulating (laser) light is adjustable by means of

the glass preparation process. The amount of stimulating exposure required for plate readout is generally higher than in previous systems, but well within the range of commercially available laser systems, for practical readout times. The effects of flare, or unwanted readout due to back-reflection from the imaging plate, are generally less than in previous systems.

A novel telecentric scanning system has been developed that is able to rapidly read out the latent image stored in the translucent imaging plates. This system features a reflective primary scan mirror to achieve telecentricity, optical correction for scan line bow, and the design should enable the construction of a relatively inexpensive scanner system for the translucent x-ray storage plates.

Keywords: DET, MG, GH

7622-141, Poster Session

Amorphous silicon p-i-n photodetector with Frisch grid for high-speed medical imaging

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In indirect digital x-ray detectors, photodetectors such as hydrogenated amorphous silicon (a-Si:H) p-i-n photodetectors are used to convert the optical photons generated by the scintillating material to collectible electron-hole pairs. A problem that arises during the collection of the charges is that the mobility and lifetime of both types of carriers (electrons and holes) differ. In a-Si:H, the mobility of holes is much lower than that of electrons which leads to depth-dependent signal variations and causes the charge collection time to be extensive.

It has been shown that the use of a Frisch grid can reduce the effect of the slower carriers in direct x-ray detectors. The Frisch grid is essentially a conducting grid that shields carriers from the collecting electrode until they are in close proximity. When the pixel electrodes are properly biased, the grid prevents the slow moving carriers (traveling away from the collecting electrode) from being collected and puts more weight on the fast moving carriers, thus allowing the total charge to be collected in less time.

In this paper we investigate the use of a Frisch grid in a-Si:H p-i-n photodetectors for indirect x-ray detectors. Through simulations and theoretical analysis we determine the grid line sizes and positioning that will be most effective for practical p-i-n photodetector designs. In addition we compare the results of photodetectors with and without the grid to characterize the improvement achievable. We are currently working on methods to fabricate the devices.

7622-142, Poster Session

An aging study of the signal and noise characteristics in large-area CMOS detectors

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A flat-panel detector has been developed for real-time digital x-ray imaging applications. It employs a large field-of-view (144 × 120 mm2) photodiode array sensor based on the CMOS (complementary metal-oxide-semiconductor) technology and the detector is completed with the CsI:Tl scintillator as an x-ray converter. We experimentally observe the long-term stability of the signal and noise characteristics in the developed detector as a function of accumulated dose at the entrance surface of the detector. We investigate the aging effects in terms of dark pixel signal and noise, signal-to-noise ratio, dynamic range, and spatial resolution. The experimental observation is supported by the Monte Carlo simulation. The detailed measurement and simulation results will be discussed. This study will give an initial motivation that the periodic monitoring of the image-quality degradation is of great importance for the long-term and healthy use of digital x-ray imaging detectors.

7622-143, Poster Session

Cadmium zinc telluride detector for low photon energy applications

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Cadmium Zinc Telluride (CdZnTe or CZT) is a polycrystalline radiation detector that has been investigated over the years for a variety of applications including Constellation X-ray space mission [1] and direct-conversion medical imaging such as digital mammography [2]. Due to its high conversion gain and low electron-hole pair creation energy (~ 4.43 eV) [3], it has found use in high end, photon counting medical imaging applications including positron emission tomography (PET), computed tomography (CT) and single photon emission computed tomography (SPECT). However, its potential in low photon energy applications has not been fully explored. In this work, we explore the capacity of the CZT material to count low photon energies (6 keV - 20 keV). These energies are of direct relevance to applications in gamma ray breast brachytheraphy and mammography, X-ray protein crystallography, X-ray mammography and mammography tomosynthesis. We also present a design that integrates the CZT direct conversion detector with an in-house fabricated amorphous silicon (a-Si:H) thin film transistor (TFT) passive pixel sensor (PPS) array. A CZT photoconductor (2cm×2cm size, 5mm thick) prepared by the traveling heat method (THM) from RedlenTM is characterized. The current-voltage characteristics reveal a resistivity of 3.3×10^{11} Ohm*cm and a steady state dark current in the range of nA. Photocurrent transients under different biases and illumination pulses are studied to investigate photogeneration and the charge trapping process. It is found that charge trapping plays a more significant role in transient behavior at low biases and low frequency.

7622-144, Poster Session

New development of large-area direct conversion detector for digital radiography using amorphous selenium with a C60-doped polymer layer

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We have developed a new direct conversion detector for digital radiography using a fullerene (C60)-doped polymer layer added on a thick amorphous selenium (a-Se) layer coupled to an amorphous silicon thin film transistor (a-Si TFT) array, which shows highly improvement on lag characteristics and durability in high ambient temperatures. C60-doped polymer, which is uniformly fabricated from solution directly on an a-Se layer followed by inorganic electron-transporting layer, changes the electronic junction between a-Se and the inorganic layer smoothly. It smoothens the emission of photocurrents from the a-Se photo-conversion layer and leads to the improved lag characteristics. The other merit of using C60-doped polymer is its stability in high temperature ambient and not causing degradation by humidity or a large amount of X-ray exposure. This polymer layer prevents crystallization of a-Se caused by high temperature not only during the deposition of the inorganic layer or metal electrode layer in the fabricating process but also in actual use.

A prototype detector, the size of 17in x 17in with 150 um pixel-pitch, showed a good resolution, whose DQE is approximately 45% at 1 cy/mm in 258 uC/kg (RQA5). This new development can simplify cooling apparatus and detector modules, and also make the wide range of operational environment available. In addition, the improved lag characteristics make it possible to reduce the exposure intervals for static imaging, tomosynthesis, and other various exposure techniques.

7622-145, Poster Session

Daily quality control for breast tomosynthesis

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Breast tomosynthesis is a new imaging modality that has recently became available for breast examination. For conventional projection mammography quality control procedures are well described. For breast tomosynthesis, on the other hand, such procedures have not yet been established. In this paper we propose a simple method and phantom for daily quality control (DQC). The goal of DQC is to identify image quality problems after acceptance of the system. Thus, the DQC procedure need to test the performance of the most critical components of the system. For breast tomosynthesis we assume that the most critical items are the image receptor, X-ray tube and the rotating elements. In the proposed procedure the image receptor homogeneity and system stability are evaluated using an image of a homogeneous block. The rotating elements and the reconstruction algorithm are evaluated together using an image of a phantom with two small spheres. The proposed DQC procedure has been evaluated on two different tomosynthesis systems: A multi slit scanning system in which both detector and X-ray tube move and a system which make use of a stationary a-Se detector. The preliminary results indicate that the proposed method is useful for DQC, but that more experience over longer periods of time, with different systems is required.

7622-146, Poster Session

Determination of mass attenuation coefficients for threshold contrast evaluation in digital mammography

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According to the 'European protocol for the quality control of the physical and technical aspects of mammography screening' (EPQC) image quality has to be evaluated at different breast thicknesses. At the standard thickness of 50 mm PMMA image quality is determined by the analysis of CDMAM images where threshold contrasts are calculated for different gold disc diameters. To extend these results to other breast thicknesses contrast-to-noise ratios (CNR) and threshold contrast (TC) visibilities have to be calculated for all required thicknesses. To calculate the latter one has to know the mass attenuation coefficient (MAC) of gold for all possible beam qualities in the tube voltage range between 26 and 32 kV.

First, the CNRs of three different PMMA thicknesses were determined by applying one specific beam quality. Additionally we acquired the threshold contrast visibility using the CDMAM phantom with the same beam setup. Based on the Rose theory the corresponding mass attenuation coefficients were calculated. This method was repeated for four different beam qualities.

Next, we calculated the aluminum half value layer (HVL) of the used x-ray spectra. Assuming a linear correlation between HVL and MAC the results from the image quality measurements were used to calculate a linear fitting function. Finally, the MACs for all desired beam qualities can be interpolated respectively extrapolated when the HVL of the spectrum is known.

The MAC as a function of the HVL was derived as MAC_{hvl}=-286.97 * hvl + 186.03 with R^2 = 0.997, where MAC_{hvl} indicates the MAC for the specific x-ray spectrum defined by its aluminum half value layer. Based on this function all necessary MACs needed for QA were calculated. The results were in good agreement with the data found in the protocol.

7622-147, Poster Session

Singular system analysis of breast tomosynthesis systems for choosing projection angles

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Optimization of digital breast tomosynthesis (DBT) has been investigated in the medical imaging field for the last several years as DBT has the potential for improved detection of breast cancer. However, a systematic method for choosing the angular range and number of projections of DBT has yet to be developed. Singular system analysis of a linear imaging system1 gives knowledge of how much information in the object to be imaged can be actually transferred through the given system, or equivalently how much information in the object can be lost through the system, yielding the zero output at the detector. These components of the object to be imaged, which are fully transferrable and non-transferrable through the imaging system in the absence of noise, are respectively called measurable and null components of the object. In this work, given a projection angle, a ray tracing algorithm is used to linearly approximate the nonlinear x-ray imaging process in the 3D object and hence to produce a matrix for representing the imaging process. For a DBT system using a combination of different projection angles, the imaging matrices corresponding to the projection angles are combined to form a DBT system matrix, to which the singular system analysis is applied in order to produce singular vectors of the given DBT system. The singular vectors of the DBT system are then used to estimate the null and measurable components of the object for choosing angular projections of the DBT system that transfer maximum information regarding the object to be imaged. We will show how this method provides the ability to choose more effective projection angles for transferring the maximum information through the system.

7622-148, Poster Session

Optimization of the exposure parameters with signal-to-noise ratios considered human visual characteristics in digital mammography

M. Yamada, Y. Kato, N. Fujita, Y. Kodera, Nagoya Univ. School of Medicine (Japan)

The uses of digital mammography systems have become widespread recently. However, the optimal exposure parameters are uncertain in clinical. We need to optimize the exposure parameter in digital mammography with maximization of the image quality and minimization of patient dose. We investigated the most advantageous tube voltage for different compressed breast thicknesses by measuring the noise power spectrum (NPS) and signal-to-noise ratios derived from the perceived statistical decision theory model with the internal noise of eye-brain system (SNRi),which has been contrived and studied by Loo LN, Ishida M and et al. Both were calculated under a fixed average glandular dose (AGD). The NPS values obtained with a fixed image contrast. From our research about the NPS, we knew that high voltages gave superior noise property of images especially for thick breast but the improvement of the NPS by tube voltage was not so remarkable.

7622-149, Poster Session

Quantifying breast density with a cone-beam breast CT

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Volumetric breast density was evaluated using a simulated cone beam breast CT with 80 kVp. The breast was modeled as a cylinder with background tissue composition of 20% glandular and 80% adipose. Various objects with different sizes and tissue compositions were

embedded. Ray-tracing algorithm was utilized to obtain projection images in a full rotation without considering scatter, beam hardening and imaging noise. Filtered backprojection was adopted for image reconstruction with high quality. Reconstructed images had flat profiles except at large cone angle of 8.6° to 10°. They were calibrated using known linear attenuation coefficients of two image contrast objects. A 3D mapping of tissue densities could be directly computed within 5% error. Tissue volumes were obtained by counting voxels in appropriate attenuation coefficient ranges. Results of contrast objects were consistent with true volumes within 10% error. However, cone angle artifact decreased pixel values, and a reduction algorithm was required for accurate tissue assessment at large cone angles. This study indicates the possibility of excellent quantitative breast density measurements and volume assessments with cone-beam breast CT.

7622-150, Poster Session

Reliability study of reconstruction methods in tomosynthesis imaging of various geometrical objects

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The primary objective of this paper is to illustrate the applicability of reconstruction methods to objects of various geometrical shapes. Signal difference noise ratio, artifact spread function, object extension and artifact extension are taken into consideration to determine the efficiency of the reconstruction methods. The reliability of reconstruction methods is compared qualitatively and quantitatively by graphically plotting the cumulative average of individual parameters against corresponding reconstruction methods. All the four parameters are found to be in good agreement with one another. Seven different filters namely Shift add filter, filtered back projection, enhanced shift add filter, enhanced filtered back projection, enhanced 2 shift add filter, enhanced 2 filtered back projection filter and enhanced 3 filtered back projection filter are compared in this paper for the quality of reconstruction and their reliability. Of all the methods, enhanced 3 filtered back projection proved to be the best one. Filtered back projection filter is found to be superior to the shift add filter in viewing cylindrical as well as spherical objects. Besides, shift and add filter fails to trace minute spherical objects as well as low contrast objects. Also, the histograms of average image contrast and object extension of both cylinder and the sphere follow the same pattern. A novel technique to compare reconstruction methods from a geometric perspective is developed.

7622-151, Poster Session

A consideration of the signal-to-noise ratio in phase contrast mammography

Y. Kato, N. Fujita, Y. Kodera, Nagoya Univ. School of Medicine (Japan)

Recently, the mammography shifts from the screen-film system (analog system) to the digital system such as computed radiography (CR) system or flat panel detector (FPD) system. The phase contrast mammography (PCM) that is one of the digital systems and applies the 1.75-x-maginified imaging becomes available in the market. To study the effect of the air gap in the PCM, we measure the scatter fraction ratio (SFR) and calculate the signal-to-noise ratio (SNR) in the PCM to the CM with digital system. Then, we calculated the noise equivalent quanta (NEQ) used by the modulation transfer function (MTF) and the noise power spectrum (NPS). Results indicated that the SFR of the CM with a grid was the least. When exposure dose was constant, the SNR of the PCM was the highest in all images. Moreover, the NEQ for the PCM was higher than that for the CM (G-). These results showed the scattered x-rays were cut down sufficiently by the air gap in the PCM.

7622-152, Poster Session

Noise characteristics of the reduction image displayed on the liquid crystal display in digital mammography

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Recently, the soft-copy diagnosis of the medical image is widespread. Because the pixel size of digital mammogram is very small, the matrix size is extremely large. When such an image is displayed on the liquid crystal display, it is displayed as a reduction image. Therefore, the displayed image with an appropriate reduction rate and the interpolation method are demanded so that the reduction processing should not influence the diagnosis. We obtained the image exposured uniformly, and measured the noise power spectrum (NPS) of the image reduced by using a nearest neighbor, bilinear, bicubic methods with several reduction rates. The results show the best interpolation method was a bilinear method. Moreover, the NPS value increased by a factor of the square of the reduction rate.

7622-153, Poster Session

Simulation of low dose positron emission mammography scanner for global breast health applications

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Positron emission mammography ("PEM") is a highly-accurate breast imaging modality which typically involves the administration of relatively high doses of radiotracer. In order to reduce tracer costs and consider PEM for global screening applications, it would be helpful to reduce the required amount of administered radiotracer so that patient dose would be comparable to conventional x-ray mammograms. We performed GATE Monte Carlo investigations of several possible camera configurations, in order to arrive at design choices that would be attractive for global breast health applications. Increasing the detector length from 1 to 3 cm, increasing the camera area from 5x20 cm2 to 20x20 cm2, and applying depth-of-interaction information to increase the acceptance angle, increased the overall efficiency to radiation emitted from a breast cancer by a factor of 24 as compared to existing commercial systems.

7622-154, Poster Session

Performance characterization of a computed radiographic mammography system

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Computed Radiography (CR) is a potentially cost-effective technology for digital mammography. In order to optimize the quality of images obtained using CR Mammography, we characterized the electro-optical components of the CR imaging chain. Various metrics were used for assessing the image quality. The Contrast Detail Response, Contrast to Noise Ratio (CNR), Modulation Transfer Function (MTF) and Noise Power Spectrum (NPS) were calculated. These metrics are practical tools to characterize the electro-optical components of the system. An

18x24 cm high-resolution granular phosphor imaging plate was used to acquire the images. Contrast detail curves were obtained using a contrast-detail phantom that was scored by independent observers. The range of theoretically acceptable values for the CR laser was (5-40) mW and voltage range for PMT's was (4-8) V. The light detection amplifier was investigated, and the optimal Laser Power & PMT gain used for scanning was measured. Hence, the tools that we used (CNR, MTF, NPS & Contrast-detail curves) are effective means of selecting optimal values for the electro-optical components of the system. The procedure enabled us to obtain good quality CR mammograms which have less noise & improved contrast.

7622-155, Poster Session

Design of, and some clinical experience with, a novel optical surface measurement system in radiotherapy

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Optical imaging is becoming more prevalent in image guided radiotherapy as a complementary technology to traditional ionizing radiation based modalities. We present a novel structured light based device that can capture a patient's body surface topology with a large field of view and high spatial and temporal resolution. The system is composed of three cross-calibrated sensor heads that enable 'wrap around' imaging previously unavailable with similar line of sight optical techniques. The system has been installed in a treatment bunker at the Christie Hospital alongside an Elekta linear accelerator equipped with cone beam CT (CBCT) on-board imaging. In this paper we describe the system, including measurements made to ascertain its repeatability and precision, and present some initial experiences in using the device for pre-treatment patient set-up. We compare its use to established CBCT based patient alignment methods.

The repeatability and accuracy of the system, i.e. the surface variation over sequential frames and the absolute location of the surface respectively, is determined to be sub-millimetre using a variety of geometrical and anthropomorphic rigid test phantoms. We similarly show the captured surfaces agree with isosurfaces extracted from simultaneously obtained CBCT volumes to 2mm. Additionally, we discuss some initial clinical experiences with the system that suggest it could perform equivalently to CBCT based methods in measuring pre-treatment patient set-up.

7622-156, Poster Session

Measurement of contrast-to-noise ratio for differential phase contrast computed tomography

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Differential phase contrast imaging has recently been demonstrated using both synchrotron and conventional x-ray sources with a grating interferometer. This approach offers the possibility of simultaneous CT reconstructions of both absorption and index of refraction from a single acquisition. This enables direct comparison of both types of reconstructed images under identical conditions. One of the most important performance metrics in CT imaging is that of contrast-to-noise ratio. These results measure the contrast-to-noise ratio for a grating interferometer-based differential phase contrast imaging system at a range of exposure levels and for several materials. In all cases measured, the contrast-to-noise ratio of differential phase contrast CT images was superior to that of absorption CT images. The most dramatic improvement was noted in the contrast between PMMA and water, where the contrast-to-noise ratio increased from less than 1 in absorption CT images, to approximately 8 in the differential phase contrast CT images.

7622-157, Poster Session

Adaptive platform for fluorescence microscopy-based high content screening

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Fluorescence microscopy has become a widely used tool for the study of medically relevant intra- and intercellular processes. Extracting meaningful information out of a bulk of acquired images is usually performed during a separate post-processing task. Thus capturing raw data results in an unnecessary huge number of images, whereas usually only a few images really show the particular information that is searched for.

Here we propose a novel automated high-content microscope system, which enables experiments to be carried out with only a minimum of human interaction. It facilitates a huge speed-increase for cell biology research and its applications compared to the widely performed workflows. Our fluorescence microscopy system can automatically execute application-dependent data processing algorithms during the actual experiment. They are used for image contrast enhancement, cell segmentation and/or cell property evaluation. On-the-fly retrieved information is used to reduce data and concomitly control the experiment process in real-time. Resulting in a closed loop of perception and action the system can greatly decrease the amount of stored data on one hand and increases the relative valuable data content on the other hand.

We demonstrate our approach by addressing the problem of automatically finding cells with a particular combination of labeled receptors and then selectively stimulate them with antagonists or agonists. The results are then compared against the results of traditional, static systems.

7622-159, Poster Session

Image formation of volume holographic microscopy using intensity point spread functions

Y. Luo, S. B. Oh, Massachusetts Institute of Technology (United States); S. S. Kou, C. Sheppard, National Univ. of Singapore (Singapore); G. Barbastathis, Massachusetts Institute of Technology (United States)

We present a theoretical formulation to quantify the imaging properties of volume holographic microscopy (VHM). Volume holograms are formed by exposure of a photosensitive recording material to the interference of two mutually coherent optical fields. Recently, it has been shown that a volume holographic pupil has spatial and spectral sectioning capability for fluorescent samples. Here, we analyze the intensity point spread function (IPSF) to assess the imaging behavior of the VHM with a point source and detector. The incoherent IPSF of the VHM is derived, and the results are compared with those from conventional microscopy, and confocal microscopy with point and slit apertures. According to our analysis, the IPSF of the VHM can be controlled in the lateral direction by adjusting the parameters of the VH. Compared with confocal microscopes, the performance of the VHM is comparable or even potentially better, and the VHM is also able to achieve real-time and three-dimensional (3D) imaging due to its multiplexing ability.

7622-160, Poster Session

Nonintrusive, noncontacting frequency-domain photothermal tomography of human teeth

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Among diffusion methods, photothermal radiometry (PTR) has the ability to penetrate and yield information about an opaque medium well beyond the range of conventional optical imaging. Owing to this ability, pulsed-laser PTR has been extensively used in turbid media such as biological tissues1-3 to study the sub-surface deposition of laser radiation, a task that may be difficult or impossible for many optical methods due to excessive scattering and absorption. In this paper considers the achievements of Pulsed Photothermal Radiometry using IR camera in the investigation of physical properties of biological materials and the diagnostics of the interaction of laser radiation with biological materials. A three-dimensional heat conduction formulation with the use of three-dimensional optical diffusion is developed to derive a turbid frequency-domain PTR model. The present photo-thermal model for frequency-domain PTR may prove useful for non-contact; non-invasive, in situ evaluate the depth profilometric imaging capabilities of FDPTR in monitoring carious and artificial subsurface lesions in human teeth.

7622-161, Poster Session

A balanced, filterless, K-edge energy window multilayer detector for dual energy computed tomography

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Ross (or balanced) filter-based systems have been studied extensively in the past, however they have only recently been studied for medical applications such as computed tomography and contrast-enhanced mammography. Balanced filters are filters composed of different materials which have thicknesses designed to match the attenuation for all radiation energies except those within a certain energy window (between the K-edges of the filter materials). Images obtained using different filters to attenuate the incident x-rays can be subtracted to obtain an image which contains information solely within the energy window. The disadvantage of this image acquisition method is the requirement of a separate exposure for each filter. This can lead to motion artifacts in the resulting image for example due to cardiac, respiratory, or patient movement.

In this paper we investigate a filterless, multilayer detector design using the general concept of balanced filters. In the proposed detector, energy discrimination is achieved using stacked layers of different conversion materials. Similar to how the thicknesses of balanced filters are chosen, the thicknesses of the conversion layers are designed to match the attenuation of x-rays except between the K-edges of the conversion materials. Motion artifacts are suppressed in the final image due to the simultaneous acquisition of images on all layers during a single exposure. The proposed multilayer design can be used for a number of applications depending on the energy range of interest. To study the proposed design, we consider dual energy computed tomography (CT) using a gadolinium-based contrast agent.

7622-162, Poster Session

Quantitative dark-field tomography

P. Modregger, S. McDonald, T. Thuering, M. Stampanoni, Paul Scherrer Institut (Switzerland)

The grating interferometer is a recently established phase-sensitive X-ray imaging technique [1,2]. It utilizes a phase grating and an absorption grating for the analysis of local propagation directions of the wave. This setup provides a moderate resolution in the order of few micrometers, but a very high sensitivity towards density variations in the sample [3].

In addition to the absorption and phase contrast the grating interferometer also delivers the complementary information of local scattering strength at the sample (i.e. the dark-field image) [4]. Since scattering may be regarded as unresolved local phase variations, the scattering signal provides information on a length scale smaller than the pixel size of the utilized detector.

However, up to now the details about the dark-field imaging process are not yet understood. Thus, the image analysis in general and the tomographic reconstruction in particular is only qualitative and not quantitative. To overcome this limitation a theory of the image formation process has to be developed and the tentative result of the ongoing research will be reported in the presentation. The final goal is to arrive at an image analysis procedure, which exploits scattering information in a quantitative way.

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7622-163, Poster Session

Coherent-scatter tomography using a sliding detector system

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The distribution of coherent-scatter is useful for determining the structure of a material, hence computed tomography applying coherent-scatter has been developed by several authors. To obtain the exact distribution of coherent-scatter requires a monochromatic, high flux, and a highly parallel X-ray beam; hence this technique is suited for a synchrotron radiation source. When using synchrotron radiation source, it is difficult to rotate the source around the patient or even the patient itself. We propose a method for the estimation of coherent-scatter distributions from any point, by moving only the position of the detector along the beam path. We acquired projection data at different positions along the beam path, and applied the maximum likelihood expectation maximization algorithm. Simulations and experiments were performed to confirm the effectiveness of this method. The estimated scatter distributions were in approximate agreement with that of the measured values. Although improvement in the accuracy of estimation is necessary, the new method we proposed is useful for cases when the X-ray source cannot be rotated around the patient.

7622-164, Poster Session

Adapted erase method using ultraviolet light and the influence of ghosting image on a clinical CR image

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In Storage Phospher (SP) used for Computed Radiography (CR), the quite stable latent image remains due to impurities and the lattice imperfections by the existence of trapped electron and hole. The quite stable latent image appears again by the passage of time etc., is recognized as Ghosting image, and becomes an artifact in a clinical CR image. This study verified the influence of Ghosting image on a clinical image by a physical characteristic and the subjective

evaluation, and examined the method to delete this artifact by the exposure of ultraviolet light as a method of improving image. As a result, Ghosting image can be confirmed by the dose used by the diagnosis domain, and it is taken as deterioration of the granularity on a physical characteristic. The decrease of the granularity of about 15% (winner spectrum) was admitted by the frequency band of 2cycle/mm in SP that had been used for a long term. As the method of improving these, Ghosting image was erased with the ultraviolet light lamp with the peak wavelength at 310nm, and has band from 290 nm to 320 nm, and is useful for the improvement of the image quality. In this study, we examine the influence of Ghosting image on a clinical image, and report on the method to delete them by the exposure to ultraviolet light radiation for the image quality improvement plan that uses the X-ray used for usual diagnosis domain.

7622-165, Poster Session

Imaging quality assessment of multiplexing x-ray radiography based on distributed x-ray source array technology

J. Zhang, R. Peng, S. Wang, X. Calderon-Colon, S. Sultana, S. Chang, J. Lu, O. Zhou, The Univ. of North Carolina at Chapel Hill (United States)

Boosted by the technology advancements of high power x-ray tube, multi-slice x-ray detector, and high speed rotating gantry, CT scanning speed has been greatly improved during the past decade. However its intrinsic imaging throughput is still bottlenecked by its sequential data acquisition scheme. In a typical CT scan, up to a thousand projection images need to be acquired one at a time, in a sequential fashion, which in turn limits the overall imaging speed. Multiplexing technique has been widely used in various communication areas to increase signal transmission throughput. However it has only been adopted for x-ray imaging applications recently because of the emergence of distributed x-ray source array technology. Here we report the imaging quality assessment study of multiplexing x-ray radiography using a distributed x-ray source array based on carbon nanotube (CNT) field emission x-ray technology. A MATLAB based computer program was written to simulate the imaging performance of the multi-beam imaging system under different noise environments. A mouse carcass was then imaged with the x-ray system to demonstrate the feasibility of multiplexing x-ray radiography. Our preliminary results indicated that the performance of multiplexing x-ray radiography is closely related to the noise composition and tube current stability of the imaging system. Under appropriate imaging conditions, multiplexing radiography has the potential to achieve higher imaging speed without significantly sacrificing the imaging quality. It could be used in applications such as image-guided radiation therapy (IGRT) for which sometimes imaging speed instead of imaging quality is the main concern of the task.

7622-167, Poster Session

MEG source detection revisited

T. Lei, T. P. L. Roberts, The Children's Hospital of Philadelphia (United States)

Magnetoencephalography (MEG) is a multi-channel imaging technique. It uses an array composed of a large number of Superconducting Quantum Interference Device (SQUID) to measure the magnetic fields produced by the primary electric currents inside the brain. The measured spatio-temporal magnetic fields are then used to estimate the locations and strengths of these electric currents, often known as MEG sources. The estimated quantities are finally superimposed with the images generated by magnetic resonance imaging (MRI). The combination of information from MEG and MRI forms the magnetic source image (MSI).

A great variety of signal processing and modeling techniques such as Inverse problem, Subspace approach, Independent component analysis (ICA) method, and Beamforming (BF) are used to estimate these sources. The first three approaches require the number of sources be detected a priori. Several shortcomings exist in the

currently used methods for detecting the source number. First, the source detection is completed only after - not before - MSI is generated. Secondly, the detection methods are somewhat subjective.

In order to provide a solution to the problem of detecting MEG source number for all these approaches, a novel method is developed. The covariance matrix of MEG measurements over all channels is decomposed into the signal and the noise subspaces. The number of sources is shown to be equal to the dimension of the signal subspace. The selection of this dimension is translated into a problem of determining the order of the underlying statistics. This statistical identification is resolved by using Information theoretic criteria which are derived based on Kullback-Leibler divergence. Because the method utilizes originally acquired MEG measurements and implemented before magnetic source images are generated, it is an entirely data-driven approach, more efficient, and less likely to be subjective.

7622-168, Poster Session

Silicon nanowire metal-semiconductor-metal photodetectors

M. M. Adachi, K. Wang, F. Chen, K. S. Karim, Univ. of Waterloo (Canada)

Silicon nanowire photodetectors are investigated for high speed digital imaging applications. Nanowires have unique properties such as low optical reflectance and ability to engineer optical absorption properties making them promising in nano-electronics. In this work an array of silicon nanowires were incorporated into a metal-semiconductor-metal (MSM) photodetector. Nanowires are fabricated by plasma enhanced chemical vapor deposition (PECVD), compatible with current infrastructure used for manufacturing large area amorphous silicon based imagers.

Indirect detection of x-rays using flat panel imagers using hydrogenated amorphous silicon (a-Si:H) photodiodes in combination with a phosphor demonstrate high image quality and offer large area imaging and relatively high resistance to radiation damage. However image lag, or remnant information carried over between successive image frames, is known to occur in a-Si:H based imagers caused mostly by trapped charges within the a-Si:H photodiode. Crystalline silicon nanowires are investigated as an alternative to a-Si:H for photodetection. Key advantages of the nanowires include crystallinity, making them less susceptible to charge trapping, and very low optical reflectance which could be used to improve quantum efficiency. In view of these unique properties, these photodetectors represent a promising technology for digital imaging requiring low image lag.

7622-169, Poster Session

Advanced differential phase contrast tomographic imaging using a grating interferometer

S. McDonald, P. Modregger, T. Thuering, Paul Scherrer Institut (Switzerland); M. Stampanoni, Paul Scherrer Institut (Switzerland) and ETH Zürich (Switzerland)

Phase sensitive X-ray imaging methods can provide substantially increased contrast sensitivity over conventional absorption based imaging, enabling the structure of soft tissue samples, for example, to be investigated without the need for tissue alteration/modification for contrast enhancement. An added advantage is that phase signals can be produced with much lower dose deposition than absorption. Differential Phase Contrast (DPC) imaging, which is based on grating interferometry, has been integrated into TOMCAT, a beamline dedicated to tomographic microscopy and coherent radiology experiments at the Swiss Light Source. A range of DPC tomographic imaging techniques can be applied and will be illustrated. Local DPC tomography allows one to focus with higher magnification on a particular region of interest of a sample, with a pixel size down to 3-4 µm, without the presence of local tomography reconstruction artifacts. 'Widefield' tomography is shown for DPC scans, enabling the field of view of the imaging system

to be doubled for samples that are larger than the magnification allows. A case study will be shown focussing on the advantages of these new features for the visualization of soft tissue features within fixed mice brains. With a sensitivity of the order of 1 mg/cm3, the method allows to visualize regions of the brain such as hippocampus, cortex and cerebellum (with white and grey matter) with a contrast impossible to reach using conventional absorption-based imaging. Current on-going development aiming at the transfer of this technology (including region-of-interest and widefield tomography) onto conventional, X-ray tube-based, systems will also be presented.

7622-170, Poster Session

Bone cartilage imaging with X-ray interferometry using a practical X-ray tube

K. Kido, C. Makifuchi, J. Kiyohara, T. Itou, C. Honda, Konica Minolta Medical & Graphic, Inc. (Japan); A. Momose, The Univ. of Tokyo (Japan)

The purpose of this study is to design an X-ray Talbot-Lau interferometer for imaging of bone cartilage using a practical X-ray tube and to develop its imaging system for clinical use. Simulation with the wave-optic was performed to design the interferometer with prerequisite of specifications in a practical X-ray tube, a multi-slit, two X-ray gratings and an X-ray detector as follows. The focal spot size was 0.3 mm in an X-ray tube of a tungsten anode(Toshiba, Tokyo, Japan). The tube voltage was set at 40 kVp with an additive aluminum filter, and the mean energy was 28 keV. The pixel size of an X-ray detector, Condor486 (Fairchild Imaging, California, USA), was 15 μm. The second grating was a Ronchi-type grating whose pitch was 5.3 μm. Based on the simulation results, the specifications and alignment of the multi-slit and two gratings were determined, and the imaging system was created. Imaging performance of the system was examined with X-ray dose at 0.5, 3 and 9 mGy so that bone cartilage of a chicken wing was clearly depicted with X-ray dose at 3 and 9 mGy that was consistent with the prediction of the simulation. These results suggest that the X-ray Talbot-Lau interferometry would be a promising tool to detect soft tissues in human body such as bone cartilage for X-ray image diagnosis of rheumatoid arthritis. Further optimization of the system would follow to reduce the X-ray dose for clinical use.

7622-171, Poster Session

Mobile measurement setup according to IEC 62220-1-2 for DQE determination on digital mammography systems

M. B. Greiter, C. Hoeschen, Helmholtz Zentrum München GmbH (Germany)

The international standard IEC 62220-1-2 defines the measurement procedure of the detective quantum efficiency (DQE) for digital x-ray imaging devices used in mammography. A mobile setup complying to this standard and adaptable to most current systems was constructed in the Helmholtz Zentrum München to allow for an objective technical comparison of current full field digital mammography units employed in mammography screening in Germany.

The setup was first used in a DQE measurement for two radiation qualities, RQA-M 2 (Mo/Mo, 28 kV) and W/Rh, 28 kV, in a dose range of 87 - 550 μGy air kerma at detector surface. Irradiation geometry can be characterized independent of a system's positioning utilities, enabling to optimize dosimetry and edge phantom positioning in the radiation beam for measurement of the modulation transfer function (MTF).

Relative measurement uncertainties calculated according to IEC recommendations were 1.6 % for air kerma, 0.14 - 1.4 % for MTF, increasing with spatial frequency from 0.5 - 9.5 mm-1, and 1.4 - 3.5 % for the noise power spectrum above 1.5 mm-1 (coverage factor 1). The relative expanded uncertainty (coverage factor 2 as required in IEC 62220-1-2) of the DQE was 4 - 8 % for spatial frequencies of 2 - 9.5 mm-1; the corresponding absolute expanded uncertainties were between 0.007 and 0.06.

7622-172, Poster Session

Practical evaluation of image quality in computed radiographic (CR) imaging systems

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A number of complementary metrics are available to assess the performance of digital x-ray imaging systems. However, the sensitivity of these metrics to changes in the electro-optical imaging chain is poorly understood. Some of the commonly used metrics include Contrast to Noise ratio (CNR), limiting spatial resolution, Modulation Transfer Function (MTF), Noise Power Spectrum (NPS) and the Detective Quantum Efficiency (DQE). We evaluated the utility of these metrics in characterizing the imaging plate, imaging system optics and electronics of computed radiography (CR) systems. We developed practical and easy to use test objects (phantoms) and implemented software to aid in calculating each metric. The results of this research enable us to characterize differences in CR systems using the appropriate metrics.

7622-173, Poster Session

A software tool to measure the geometric distortion in X-ray image systems

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A software tool is presented to measure the geometric distortion in images obtained with X-ray systems that provides a more objective method than the usual measurements over the image of a phantom with usual rulers. In a first step, this software has been applied to mammography images and makes use of the grid included into the CDMAM phantom (University Hospital Nijmegen).

For digital images, this software tool automatically locates the grid crossing points and obtains a set of corners (up to 237) that are used by the program to determine 6 different squares, at top, bottom, left, right and central positions. The sixth square is the largest that can be fitted in the grid (widest possible square). The distortion is calculated as ((length of left diagonal - length of right diagonal)/ length of left diagonal) (%) for the six positions. The algorithm error is of the order of 0.3%. The method might be applied to other radiological systems without any major changes to adjust the program code to other phantoms.

In this work a set of measurements for 54 CDMAM images, acquired in 11 different mammography systems from 6 manufacturers are presented. We can conclude that the distortion of all equipments is smaller than the recommendations for maximum distortions in primary displays (2%).

7622-174, Poster Session

Effect of image lag on real-time target tracking in radiotherapy

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There is a strong concern that image lag may reduce accuracy of real-time target tracking in radiotherapy. This study was performed to investigate influence of image lag on the accuracy of target tracking in radiotherapy. Fluoroscopic images were obtained using a direct type of dynamic flat-panel detector (FPD) system in conditions of target tracking during radiotherapy. The images were continued to be read out after X-ray irradiations and cutoff, and image lag properties in the

system were then determined. Subsequently, a tungsten materials plate with a precision edge was mounted on to a motor control device, which provided a constant velocity. The plate was moved into the center of detector at movement rate of 10 and 20 mm/s, covering lung tumor movement of normal breathing, and MTF and profile curves were measured on the edges covering and uncovering the detector. A lung tumor with blurred edge due to image lag was simulated using the results and then superimposed on breathing chest radiographs of a patient. The moving target with and without image lag was traced using a template-matching technique respectively. In the results, the target could be traced within a margin for error in external radiotherapy. The results indicated that there was no effect of image lag on target tracking in usual breathing speed in a radiotherapy situation. Further studies are required to investigate influence by the other factors, such as exposure dose, target size and shape, imaging rate, and thickness of a patient.

7622-175, Poster Session

Temporal-spatial characteristic evaluation in a dynamic flat-panel detector system

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The purpose of this study was to present fundamental temporal-spatial characteristic for digital radiographic system based on dynamic a flat-panel detector (FPD). We investigated the relationship between pixel value and X-ray output and addressed its reproducibility, pulse width, tube voltage and capture rate dependency.

Temporal images were obtained using a direct conversion type of dynamic FPD, (Sonialvision Safire , Shimadzu). The exposure conditions were as follows; 110kV, 80mA, 6.3msec, 7.5 frames per second, source to image distance (SID) 1.5m. The output of X-ray pulse was measured using a dosimetry system (NERO mAx, VICTOREEN) with sampling interval of 70μsec, to obtain temporal changes of each X-ray pulse output. Temporal changes in pixel value were measured in the images obtained and the relationship between the pixel value and X-ray output was examined. The reproducibility was assessed in the three sequential images obtained in the same exposure conditions. Moreover, various dependent properties were evaluated by changing the pulse width (12msec and 25msec), tube voltage (80kV, 90kV and 100kV) and capture rate (3.75fps and 15fps).

The results showed that the present system had a high-precision of X-ray pulse output. The X-ray pulse output showed a good correlation with pixel values, although some measuring error was included. Therefore, the fluctuation of the pixel value measured in sequential images is thought to be caused by the changes in X-ray pulse output. The present study indicated that dynamic imaging with a FPD system has potential for a functional evaluation method based on changes in pixel value.

7622-176, Poster Session

Effect of choice of region-of-interest in an abdominal 2-AFC experiment

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The purpose of this study was to evaluate the effect of changing the choice of regions-of-interest (ROIs) on lesion detectability in abdominal CT exams during a two Alternate Forced Choice (2-AFC) experiment. For the first 2-AFC experiment (case 1), the two ROIs were drawn either encompassing the whole liver or an area in the abdomen other than the liver. For the second 2-AFC experiment (case 2), both the ROIS were drawn within one of the two halves of the liver. Thus in the first case the lesion is randomly placed either somewhere within the liver or external to it, whereas in the second case the lesion is always placed within the liver. Three observers were used for the experiments and the lesion size

was varied from 5 to 15 mm. I92% values, corresponding to a 92% detection rate, were computed for each of the observers. The pooled average was plotted as a log(I92%) vs log(lesion size) graph. The slopes of graphs for both the cases were ~ -0.15. In both cases, the I92% value for the smallest lesion (5 mm) was ~ 30% higher than that of the largest lesion (15 mm). However, the I92% values in the first case were consistently higher than the second one for all lesion sizes. The data are consistent with the fact that the detection task is easier within the liver, which is a relatively uniform object, as compared to outside the liver where anatomic structures make it more difficult

7622-177, Poster Session

Characterization of focal spots of x-ray tubes in CT systems: method development and examples

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Characterizations of x-ray based imaging systems often focus on a detailed examination of the detector properties while the x-ray tube and its properties usually are investigated to a limited extend. Here we present a method to measure the size of x-ray focal spots, using the measurement system provided by the CT system.

The method is based on the measurement of the intensity profile of a highly absorbing plate placed within the x-ray geometry of the imaging system. A beam blocking plate yields an intensity step function. For the case of an ideal point-like focal spot, the response function would be a theta (step) function. For real focal spot sizes with finite spatial extension, the step function will be smeared out. The derivative of the intensity step function yields the intensity profile of the focal spot. Knowledge of the system geometry - i.e. the focus-detector distance and the position of the absorbing edge - allows calculating the intensity profile with an absolute spatial scale at the tube anode.

In our experimental realization the edge is made of tungsten. The edge of the 2 mm plate is machined precisely to limit the effects of the transition zone between air and high absorption. Since we are using the detector of the imaging system, we can evaluate the focal spot performance in all modes available at the scanner. This allows e.g. measuring the dependence of the x-ray intensity profile on kVp and mA settings or even the dynamic behaviour in time.

7622-178, Poster Session

A method for the determination of the two-dimensional MTF of digital radiography systems using only the noise response

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We present a new method that enables the determination of the two-dimensional MTF of digital radiography systems using the noise response measured from flat-field images. Unlike commonly-used methods that measure the one-dimensional MTF, this new method does not require precision-made test-objects (slits/edges) or precise tool alignment. Although standard methods are dependent upon data processing that can result in inaccuracies and inconsistencies, this method based on the intrinsic noise response of the imager is highly accurate and less susceptible to such problems. A cascaded-linear-systems analysis was used to derive an exact relationship between the noise power spectrum (NPS) and the presampled MTF of a generalized detector system. The NPS was then used to determine the two-dimensional MTF for three systems: a simulated detector in which the "true" MTF was known exactly, a commercial indirect flat-panel detector (FPD), and a new solid-state x-ray image intensifier (SSXII). For the simulated detector, excellent agreement was observed between the "true" MTF and that determined using the noise response method, with an averaged deviation of 0.3%. The FPD MTF was shown to increase on the diagonals and was measured at 2.5 cycles/mm to be 0.086±0.007, 0.12±0.01, and 0.087±0.007 at 0, 45, and

90°, respectively. No statistically significant variation was observed for the SSXII as a function of angle. Measuring the two-dimensional MTF should lead to more accurate characterization of the detector resolution response, incorporating any potential non-isotropy which may result from the physical characteristics of the sensor, including the active-area shape of the pixel array.

7622-179, Poster Session

The impact of processing delay on the exposure index value in computed radiography

M. Butler, Univ. College Dublin (Ireland); P. C. Brennan, The Univ. of Sydney (Australia); J. Last, L. A. Rainford, Univ. College Dublin (Ireland)

Digital radiography poses the risk of unnoticed exposure creep increases in patient radiation dose. Manufacturers responded to this by offering an exposure index (EI) value to clinicians. Use of the EI value in clinical practice is encouraged by the American College of Radiology and American Association of Physicists in Medicine. This study assesses the impact of processing delay on the EI value. An anthropomorphic phantom was used to simulate three radiographic examinations; skull, pelvis and chest. For each examination, the phantom was placed in the optimal position and exposures were chosen in accordance with international guidelines. A Carestream computed radiography system was used. The imaging plate was exposed, and processing was delayed for a range of timed delays representing clinical practice along with exaggerated delays. The EI value was recorded for each exposure. The EI value decreased by 100 within 25 minutes delay for the chest, and 20 minutes for the skull and pelvis. Within 1 hour, the EI value had fallen by 180, 160 and 100 for the chest, skull and pelvis respectively. After 24 hours, the value had decreased by 370, 350 and 340 for the chest, skull and pelvis respectively, representing to the clinician more then a halving of exposure to the detector in Carestream systems. The assessment of images using EI values should be approached with caution in clinical practice when delays in processing occur. The use of EI values as an accurate feedback mechanism is questioned.

7622-180, Poster Session

Detection of simulated microcalcifications in digital mammography- effects of quantum and anatomic noises: preliminary study

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To study the effects of overlapping anatomy on microcalcification detection at various incident exposure levels. Images of an anthropomorphic breast phantom (RMI 169) overlapping with simulated MCs ranging from 150 to 212 micron in size placed at two regions, fatty and dense areas, were acquired with a flat panel based digital mammography system (Selenia) operated with Mo-Mo target/filter combination at 28 kVp. The mammograms were exposed with 10, 20, 30, 40, 60, 80, 120, 160, 240 and 325 mAs. 4-AFC was performed for evaluation of the detection performance. 4-400x400 images, one of which contained microcalcifications, were displayed randomly on a LCD flat panel based review workstation. The observers were asked to select the image with microcalcifications and to report the number of visible microcalcifications. The fraction of correct responses was computed and plotted as a function of exposure level for each region. The statistical significance of the differences in fractions between two anatomic noises was computed by the Student t-test. The fraction of correct responses improved quickly with exposure level in the fatty area, indicating that the detection appeared to be mainly limited by quantum noise. The fraction of correct responses improved slowly with exposure level in the dense area, indicating that the detection appeared to be mainly limited by anatomic noise. The detection performance

was significantly degraded when breast density became denser. (this work was supported in part by grants CA104759 and CA124585 from the NIH-NCI, a research grant EB00117 from the NIH-NIBIB, and a subcontract from NIST-ATP).

7622-181, Poster Session

Noise characterization of computed tomography using the covariance matrix

C. Brunner, Helmholtz Zentrum München GmbH (Germany); S. Hurowitz, U.S. Food and Drug Administration (United States); C. Hoeschen, Helmholtz Zentrum München GmbH (Germany); I. S. Kyprianou, U.S. Food and Drug Administration (United States)

In order to compare different imaging systems, it is necessary to obtain detailed information about the system noise, its deterministic properties and task specific Signal to Noise Ratio (SNR). The current standard method for characterizing noise in CT scanners is based on the pixel standard deviation of the image of a water-equivalent uniform phantom. The Fourier-based Noise Power Spectrum improves on the limitations of the pixel SNR by accounting for noise correlations. However, it has been shown that the Fourier methods used to describe the system performance result in systematic errors as they make some limiting assumptions such as shift invariance and wide sense stationarity, which are not satisfied by real CT systems. For a more general characterization of the imaging system noise, a covariance matrix eigenanalysis can be performed. In this paper we present the experimental methodology for the evaluation of the quantum and electronic noise of computed tomography systems. We used the FDA bench-top flat-panel-based cone-beam CT scanner and a cylindrical water-filled PMMA phantom. For the 3-dimensional reconstructed volume, we calculated the covariance matrix, its eigenvectors and eigenvalues for the x-y-direction as well as for the y-z-direction, and compared with the NPS. As expected, the covariance matrix was not cyclostationary.

7622-182, Poster Session

Quality control of eclipse treatment planning system using the Penelope Monte Carlo code and anatomical digital test objects

Y. Y. Ben Hdech, S. S. Beaumont, QualiFormeD SARL (France); J. Guédon, Univ. de Nantes (France); T. J. Torfeh, QualiFormeD SARL (France)

Quality control (QC) for the treatment planning system (TPS) is now based on the comparison of calculated and measured dose distribution. These methods are often considered complex and cumbersome and made the TPS-QC hardly possible when implemented in clinical conditions.

To simplify and automate the TPS-QC we have developed a new method that is presented in this paper. First, we use in one hand anatomical Digital Test Objects (DTO) instead of tissue-equivalent phantoms. This allows for a more precise dose computation. Second, Monte Carlo simulations are computed instead of dosimetric measurements for the same reason. To carry out this method we have modeled three anatomical-DTO: head and neck, prostate and chest regions and we have parallelized the PENELOPE Monte Carlo particle transport simulation package; our parallelization is based on the standard message passing interface (MPI).

In the final paper, we will present a QC of Eclipse TPS using anatomical DTO and PENELOPE Monte Carlo simulation.

7622-183, Poster Session

Epp: a C++ Monte Carlo simulation EGSnrc user code for dose calculation and imaging

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Epp (Easy particle propagation) is a Monte Carlo simulation EGSnrc user code that we have developed for dose calculation in a voxelized volume, and to generate images for an arbitrary geometry irradiated by a particle source. The dose calculation aspect is a reimplementation of the function of DOSXYZnrc with the performance being significantly improved. The functionality can be readily extended to trace other kinds of particles.

Epp is based on the EGSnrc C++ class library (egspp) that offers great simplicity for setting up particle sources and simulation geometries, compared to DOSXYZnrc. Using an XML format for the input file makes the file parsing at least 1,000 times faster than the original input file format of egspp.

Compared to DOSXYZnrc, Epp is at least two times faster. Photon propagation to the image plane is integrated into Epp (other particles possible with minor extension to the current program). When only the resultant images are needed, there is no need to save the particle data. This results in significant savings of data storage space, network load, and time for file I/O.

Epp was validated against DOSXYZnrc by comparing their simulation results with the exact same input. Epp can thus be used for faster Monte Carlo simulation for radiation dose applications and imaging applications.

7622-184, Poster Session

Comparing experimental measurements of indirect x-ray detector responses with Monte Carlo predictions: figures of merit and model development

N. Rao, M. Freed, A. Badano, U.S. Food and Drug Administration (United States)

Thalium-activated Cesium Iodide (CsI:Tl) scintillator screens coupled with optical readout arrays are currently the most commonly implemented detection method for digital x-ray imaging. The development of Monte Carlo code to provide detailed simulations of particular screen designs has created the need to quantitively compare Monte Carlo simulated versus experimentally measured point-response functions (PRFs) in order to validate the simulated data. In this work, we have rigorously analyzed figure-of-merits (FOMs) to compare simulated and experimental PRFs and used these FOMs to fine tune Monte Carlo models to best represent a particular screen

design.

7622-185, Poster Session

A local and iterative neural reconstruction algorithm for cone-beam data

I. Gallo, Univ. degli Studi dell'Insubria (Italy)

This work presents a new neural algorithm designed for the reconstruction of tomographic images from Cone Beam data. The main objective of this work is the search of a new reconstruction method, able to work locally, more robust in presence of noisy data and in situations with a small number of projections data. This study should be intended as the first step to evaluate the potentialities of the proposed algorithm. The algorithm is iterative and based on a set of neural networks that are working locally and sequentially. All the x-rays passing through a cell of the volume to be reconstructed, give origin to a neural network which is a single-layer perceptron network. The network does not need a training set but uses the line integral of a single x-ray as ground-truth of each output neuron. The neural network uses a gradient descent algorithm in order to minimize a local cost function by varying the value of the cells to be reconstructed.

The proposed strategy was first evaluated in conditions where the quality and quantity of input data varies widely, using a the Shepp-Logan Phantom. Then with a second series of experiments the algorithm was compared with the iterative ART algorithm and the well known filtered backprojection method. The results show how the proposed algorithm is much more accurate even in the presence of noise and under conditions of lack of data. In situations with little noise the reconstruction, after a few iterations, is almost identical to the original.

7622-186, Poster Session

Hyperparameter selection for OSEM SPECT reconstruction in mesh domain with total variation regularization

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We implemented Bayesian one-step late OSEM reconstruction algorithm with the Total Variation (TV) prior in mesh domain in order to limit image noise accumulation with increasing iteration number while preserving the edges in the reconstructed images. The purpose of this study was to investigation the L-curve method performance for selection of optimized hyperparameter.

We synthesized SPECT data with three noise levels for a simple numerical phantom with six different mesh structures and obtained the L-curves for each case. The L-curve is a log-log plot of the TV regularization norm vs. the loglikelihood. We investigated relationship between the shape of the L-curve, the mesh structure, and noise level in the projection data. A global minimum of L-curve was used to determine optimum value of the hyperparameter.

We found that the shape of L-curves is mesh- and noise-dependent. The L-curves obtained for reconstructions with geometric meshes have single minima while the L-curves of reconstructions using singularity-based meshes have multiple local minima in addition to well-defined global minima. The width of L-curves decreases with mesh resolution and increases with noise. The value of optimal hyperparameter strongly depends on the noise level and mesh geometry but only weakly on the spatial resolution of the mesh.

We investigated the reconstructed image quality and confirmed that the hyperparameter's value obtained by the L-curve method resulted in optimized reconstruction.

We conclude that the L-curve method is well suited for the optimal hyperparameter value selection for Bayesian one-step late OSEM reconstruction algorithm with the TV prior in mesh domain.

7622-187, Poster Session

Two-sheet surface rebinning for real time cone beam x-ray CT

M. Betcke, W. Lionheart, The Univ. of Manchester (United Kingdom)

There is no doubt of the desirability of fast cone beam CT image acquisition. In particular the cardiac and lung imaging at present require gating techniques, which diminish the quality of the reconstructed images. The main speed limiting factor in the state of the art CB scanners is the mechanical motion of the gantry. One solution is that the mechanical rotation of the gantry be replaced by a stationary ring of sources, which can be quickly switched electronically, and multiple stationary rings of detectors. However, as a consequence of this design it is not possible to place detectors opposite the source ring. The Rapiscan RTT 80 scanner is such a system designed for airport

baggage rather than medical use. In this the detectors are installed only on one side of the ring of sources and their axial offset from the plane of sources is substantial (of the order of the detector axial length), see Fig. 1. This new geometry requires new reconstruction algorithms different from those devised for the standard cone beam CT.

In this contribution we present a two-sheet surface rebinning algorithm for this offset cone beam CT. The more general approach, a multi-sheet surface rebinning will be described in [1], where we also present a rigorous mathematical derivation and discuss the properties of the multi-sheet surface rebinning methods in more detail.

7622-188, Poster Session

Combined algorithmic and GPU acceleration for ultra-fast backprojection

J. Brokish, P. Sack, Y. Bresler, InstaRecon, Inc. (United States)

In this paper we describe the first implementation and performance of a fast O(N3logN) hierarchical backprojection for circular cone beam CT, developed for a modern Graphics Processing Unit (GPU). The resulting tomographic backprojection system for 3D cone beam geometry combines speedup through algorithmic improvements provided by the hierarchical backprojection algorithm, with speedup from a massively parallel hardware accelerator. For data parameters typical in diagnostic CT, and using a mid-range GPU card, we report reconstruction speeds of 190 frames per second, and relative speedup of almost 10x compared to conventional backprojection on the same hardware. The significance of these results is twofold. First, they demonstrate that the reduction in operation counts demonstrated previously for the hierarchical backprojection algorithm can be translated to a comparable actual run time improvement in a massively parallel hardware implementation, while preserving stringent diagnostic image quality. Second, the dramatic speedup and throughput numbers achieved indicate the feasibility of systems based on this technology, which achieve real-time 3D reconstruction for state-of-the art diagnostic CT scanners with a small footprint, high-reliability, and affordable cost.

7622-189, Poster Session

Microwave detecting and locating breast tumors through the reconstruction of breast surface impedance

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One of the main threats for the woman's health is the breast cancer

and a huge number of woman lost their life every year. Today, early detection is the key approach in reducing the fatal effects of this disease and several approaches are in research progress in order to detect malignant tissues more accurately.

One of the emerging breast cancer imaging methodologies is based on the use of electromagnetic waves in the microwave region. The experimental studies on the human tissues demonstrated that there is a significant contrast in dielectric properties between the malignant tumors and normal fatty tissue at microwave frequenciescite{eps1}. The main motivation in using microwave imaging is that it is nonionizing, comfortable, sensitive to tumors, and specific to malignancies. Microwaves can also penetrate in lossy fatty tissue and their interaction with malignant tumors create measurable scattered fields which can be used to extract information about the tissue dielectric-properties distribution or other tissue characteristics.

In this paper we propose a new approach for detecting and locating malignant tumors in breast. The method is based on the determination of the surface impedance of the breast through the non-invasive scattered field measurements over the breast surface. The surface impedance is defined in terms of standard impedance boundary condition and is calculated by analytically continuing the measured field values to the breast surface through the single layer potential

approach. It has been shown that, in the microwave region, the malignant tumors make observable contributions to the surface impedance and the locations and values of these contributions on the breast surface are related to the locations as well as sizes of the tumors. Reconstruction of the surface impedance in several frequencies allows us to obtain a general mapping function for the tumor locations which can be used as a reference mapping for clinical applications. Contrary to the existing microwave breast cancer imaging approaches the method is computationally effective and leads very accurate determination of tumors.

7622-190, Poster Session

Optimizing kernel size in generalized auto-calibrating partially parallel acquisition in magnetic resonance imaging

Y. M. Kadah, H. Mohamed, A. Youssef, R. Gabr, Cairo Univ. (Egypt)

Parallel magnetic resonance imaging achieves reduction in scan time by collecting a partial set of signals using an array of receiving coils each with a local sensitivity pattern. An image is then reconstructed from the partial dataset using the additional information of coil sensitivity. GRAPPA (generalized auto calibrating partially parallel acquisitions) is one of the most successful reconstruction techniques in which the missing k-space lines are interpolated from the acquired data in the whole coil array using a convolution kernel estimated from a fully sampled data patch in the center of k-space. The interpolation kernel is usually small and fixed in size for all coils. Here, we show that a variable kernel with a size dependent on the coil sensitivity can lead to better image quality. The kernel size is estimated from the ratio of the coil sensitivities obtained from a reference scan or from the same dataset. Conventional GRAPPA kernel estimation and image reconstruction is modified to employ the variable size kernel for improved reconstruction. The new technique shows improved image quality compared to GRAPPA. It can also provide a criterion for selecting the optimal scan parameters like the number of auto-calibration signals (ACS).

7622-191, Poster Session

Analytical solution to cone-beam SPECT reconstruction with non-uniform attenuation and distance-dependent resolution variation

J. Wen, H. Zhang, J. Yang, P. Hu, Beijing Institute of Technology (China); Z. Liang, Stony Brook Univ. (United States)

Single photon emission computed tomography (SPECT) is a nuclear medicine imaging technique and widely used in the clinical applications. SPECT image reflects not only organizational structure but also functional activities of human body, such as blood-flow and metabolism condition, therefore diseases can be found much earlier. For many clinical applications, cone-beam geometry is preferred, which can improve count density and spatial resolution, and quantitative reconstruction of radiotracer distribution inside the body is desired. In this paper, we developed an efficient, analytical solution to cone-beam SPECT reconstruction with simultaneous compensation for attenuation and distance-dependent resolution variation (DDRV), as well as accurate treatment of Poisson noise. We applied wavelet based Revised BivaShrink de-noising method to remove Possion noise in the sinograms. Then the de-noised cone-beam projections were rebinned to the parallel-beam projections by using the Fourier rebinning algorithm (FORE). After DDRV correction, SPECT images were reconstructed by using the Novikov's reconstruction formula. The simulation results show our reconstruction framework is feasible.

7622-192, Poster Session

Accurate determination of the shape and location of metal objects in x-ray computed tomography

J. Wang, L. Xing, Stanford Univ. (United States)

The presence of metals in patient causes streaking artifacts in X-ray CT and has long been recognized as a problem that limits various applications of CT imaging. Accurate localization of metals in CT images is a critical step for metal artifacts reduction in CT imaging and many practical applications of CT images. In this work, we propose a method capable of auto-identifying the shape and location of metallic object(s) in the image space. The proposed method is based on the fact that when a metal object is present in a patient, a CT image can be divided into two prominent components: high density metal and low density normal tissues. This prior knowledge is incorporated into an objective function as the regularization term whose role is to encourage the solution to take a form of two intensity levels. Computer simulation and experimental studies are performed to evaluate the proposed approach. Both simulation and experimental studies show that the presented algorithm works well even in the presence of complicated shaped metal objects. For a hexagonally shaped metal embedded in a water phantom, for example, it is found that the accuracy of metal reconstruction is within sub-millimeter. These results suggest that it is feasible to accurately determine the shape and location of metal object(s) by introducing an intensity gradient-based regularization in image reconstruction and searching for high gradient interface between the metal and tissue. The algorithm is of practical importance for imaging patients with implanted metals.

7622-193, Poster Session

System matrix for OSEM SPECT reconstruction with attenuation compensation in mesh domain

L. O. Vogelsang, Syracuse Univ. (United States); A. Krol, SUNY Upstate Medical Univ. (United States); Y. Lu, Univ. of Michigan Health System (United States); Y. Xu, Syracuse Univ. (United States); D. H. Feiglin, SUNY Upstate Medical Univ. (United States)

We present an efficient and robust method for determination of the system matrix for SPECT OSEM reconstruction in mesh domain including attenuation. The radiopharmaceutical emission distribution in 2D mesh domain is approximated by 2D triangular, irregular, piece-wise, bilinear mesh expansion functions with a minimum element size not exceeding the width of a detector unit. System matrix elements are defined by integrals over the response and expansion function. The purpose of this study was to develop and implement an accurate and computationally efficient method for determination of the mesh-domain system matrix including attenuation compensation. Here, mesh-domain system matrix elements were estimated by first dividing the object space into strips parallel to detector face and with width not exceeding the size of a detector unit. This was followed by approximating the integration over the strip/mesh-element union. This approximation is product of: (i) strip width, (ii) intersection length of a ray central to strip with a mesh element, and (iii) the response and expansion function evaluated at midpoint of the intersection length. Reconstruction was preformed using OSEM without regularization and with exact attenuation map. The method was evaluated using synthetic and physical SPECT data. Comparative quantitative and qualitative analysis included: bias, variance, accuracy and artifacts in reconstructed images. We found that the strip width should match the mesh resolution. For a mesh with smallest element size comparable to detector unit width, the smallest strip width should be of the same size. In this case, using smaller strip widths does not significantly improve reconstructed image quality.

7622-194, Poster Session

Rapid 3D regularized EM reconstruction for Compton cameras using GPU

S. Lee, V. Nguyen, M. N. Lee, Pai Chai Univ. (Korea, Republic of)

This paper describes the development of rapid 3-D regularized EM (expectation maximization) reconstruction for Compton cameras using commodity graphics hardware. Since the system matrix of a typical Compton camera is extremely large compared to the conventional emission tomography, it is almost intractable to use a caching scheme to accelerate the repeated calculations of conical projection and backprojection, which are the key operations but most time consuming in iterative Compton camera reconstruction. In this paper we propose GPU (graphics processing unit) accelerated methods that can rapidly perform the conical projection and backprojection operations on the fly. Since the conventional ray-based backprojection method is inefficient for GPU, we develop fully voxel-based conical backprojection methods using two different approaches. In the first approach, we approximate the intersecting chord length of the ray passing through a voxel with the normal distance from the center of the voxel to the ray. In the second approach, each voxel is regarded as a dimensionless point, and the backprojection is performed without the need for calculating intersecting chord lengths. Our experimental studies with the M-BSREM (modified block sequential regularized EM) algorithm show that the GPU-based method significantly outperforms the conventional CPU-based method in computation time without loss of visible accuracy. To obtain an acceptable image using M-BSREM with 64 subsets and 8 iterations, the CPU-based method takes 2.3 hours, whereas the GPU-based method takes only 2.7 minutes. Our net conclusion is that, for iterative Compton camera reconstruction, the GPU-based method is clearly more practical than the CPU-based method.

7622-195, Poster Session

Low dose CT image reconstruction based on high-order total variation technique in clinical scanner

S. Do, Massachusetts General Hospital (United States); W. C. Karl, Boston Univ. (United States); M. K. Kalra, T. J. Brady, H. Pien, Massachusetts General Hospital (United States)

Total variation (TV) based iterative image reconstruction has been shown to possess desirable noise suppression and edge preservation characteristics. However, such approaches also produce ``staircase effects" where intensity ramps are discret ized into steps, resulting in images which appear blocky or patchy. In this paper, we present an improved regularization technique by incorporating higher-order derivatives to reduce staircase artifacts without sacrificing edge sharpness. In this preliminary investigation we demonstrate our approach using both phantom and clinical images acquired at 25% of conventional radiation dosage (i.e., 75% dose reduction).

7622-196, Poster Session

DR with a DSLR

X. Fan, H. L. Durko, B. Miller, College of Optical Sciences, The Univ. of Arizona (United States); S. K. Moore, The Univ. of Arizona (United States); J. Moore, L. R. Furenlid, H. H. Barrett, College of Optical Sciences, The Univ. of Arizona (United States); S. Pradhan, Tribhuvan Univ. (Nepal)

An inexpensive, portable digital radiography (DR) detector system for use in remote regions such as Nepal has been built and evaluated. The system utilizes a large-format digital single-lens reflex (DSLR) camera to capture the x-ray image from a standard fluorescent screen. This approach has been considered in the past, but it has not been used for general radiography for two reasons: the large light loss in the optical system needed to demagnify the image onto the CCD or CMOS

sensor used in digital cameras, and the large readout noise typically associated with these sensors. The latest DSLRs, such as the Nikon D700 and Canon 5D, ameliorate both of these problems. They have large sensors so that demagnifications in the range 10:1 to 12:1 suffice even for chest radiography, and their readout noise is significantly less than that of more expensive scientific cameras.

We have built a portable DR system using the Nikon D700 and an F/1.4 Nikon camera lens. The camera and a Lanex screen are mounted on an aluminum frame that folds up into a small suitcase, which also contains a light-tight shroud, a laptop computer and a solar panel for charging the batteries in the camera and computer. The system has been used for initial phantom tests in urban hospitals and Himalayan clinics in Nepal, and it has been evaluated in the laboratory by measurement of noise power spectrum, detective quantum efficiency and other detectability metrics.

7622-197, Poster Session

Design and construction of a micro-focus in-line phase-contrast cone-beam CT (PC-CBCT) system for soft tissue imaging

W. Cai, R. Ning, Univ. of Rochester Medical Ctr. (United States)

In recent years, the in-line phase-contrast (in-line PC) technique has been implemented using synchrotrons and micro-focus x-ray tubes for soft tissue imaging because of in-line PC's image quality enhancement. In this study, a new in-line phase-contrast cone-beam CT (PC-CBCT) system has been designed and tested in our lab to produce higher image quality enhancement. The PC-CBCT system consists of a micro-focus x-ray tube, a high-resolution detector and a rotating phantom holder. The nominal focal spot size is 9 microns, which is expected to produce partially coherent x-rays. The detector system has a phosphor screen, an optical fiber coupling unit and a CMOS chip with an effective pixel pitch of 22.5 microns. Some key system parameters, including tube voltage (or x-ray spectrum), source-to-object distance and object-to-detector distance were balanced and optimized to achieve enough spatial coherence and degree of interference to acquire edge-enhanced phase-contrast images as projection images. The phantom holder was rotated for 360 degrees with a step of 1.2 degrees, and during the rotation in-line PC images were acquired at all angular positions. The FDK algorithm was applied to compute the reconstruction using the edge-enhanced PC images. Small soft tissue samples (breast tissues and animal organs) were scanned and reconstructed. The tomographic images showed enhanced structure edges and details.

7622-198, Poster Session

Design and characterization of a carbon nanotube based micro-focus x-ray tube for small animal imaging

S. Sultana, X. Calderon-Colon, O. Zhou, J. Lu, The Univ. of North Carolina at Chapel Hill (United States)

We report the development of carbon nanotube (CNT) field emission micro-focus x-ray tubes for dynamic small animal imaging with high spatial and temporal resolution. Extensive electron optics simulations were performed to study the focusing structure and optimize the tube design. A commercial 3D finite element simulation package was used for modeling and simulations which include the field emission model and particle trajectory analysis. Simple and intuitive model of CNT emission distribution were studied. The emission model gives the flexibility to specify the starting conditions of the electron trajectories. The dependence of focus spot size and the anode current on the gate extracting voltage, the focusing voltages, the gate mesh geometry, cathode-anode distance, and other geometric parameters were studied. Several tubes were build according to the design parameters. The experimentally measured focus spot size and its dependence on the focusing voltage were found to be in quantitative agreement with simulations

7622-199, Poster Session

Design and construction of a differential phase-contrast cone-beam CT (DPC-CBCT) system for soft tissue imaging

W. Cai, R. Ning, D. Yang, Univ. of Rochester Medical Ctr. (United States)

In recent years, the differential phase-contrast (DPC) technique has been developing very quickly. A hospital-grade x-ray tube can be used for a DPC system, where the self-imaging effect and the phase-stepping method are implemented through three gratings to manifest phase contrast and differentiated phase images can be obtained. A new DPC technique-based cone-beam computed tomography (DPC-CBCT) system has been designed and constructed in our lab for soft tissue imaging. The DPC-CBCT system consists of a hospital-grade x-ray tube, a high-resolution detector, a rotating phantom holder and three gratings. DPC images can be acquired from different view angles and tomographic images can be reconstructed. The x-ray focal spot size is 0.3mm x 0.3mm, and the output x-ray beam is divided into several coherent line sources using the source grating. The detector system has a phosphor screen, an optical fiber coupling unit and a CCD chip with an effective pixel pitch of 22.5 microns. The optical elements were aligned to minimize unexpected moiré patterns, and key system parameters, including tube voltage (or equivalently x-ray spectrum), distances between gratings, source-to-object distance and object-to-detector distance were balanced and optimized. Small soft tissue samples (breast tissues and small animals) were scanned and 3-D volumetric phase-coefficients are reconstructed. The reconstructed linear phase-coefficients were about 1000 times larger than the linear attenuation coefficient. The total exposure level was equivalent to a conventional CBCT scan of small animals, and the spatial resolution of the reconstruction was about 20 microns.

7622-200, Poster Session

Progress in the development of a new angiography suite including the high resolution micro-angiographic fluoroscope (MAF), a control, acquisition, processing, and image display system (CAPIDS), and a new detector changer integrated into a commercial C-arm angiography unit to enable clinical use

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Due to the high-resolution needs of angiographic and interventional vascular imaging, a Micro-Angiographic Fluoroscope (MAF) detector with a Control, Acquisition, Processing, and Image Display System (CAPIDS) was installed on a detector changer which was attached to the C-arm of a clinical angiographic unit. The MAF detector provides high-resolution and real-time imaging and consists of a 300 µm CsI phosphor, a dual stage micro-channel plate light image intensifier (LII) coupled to a fiber optic taper (FOT), and a fast-frame-rate, progressive-scan, frame-transfer CCD camera providing 1024x1024 pixels with 12 bit depth. The changer allows the MAF or a Solid-State X-ray Image Intensifier (SSXII) region-of-interest (ROI) detector to be inserted in front of the standard flat-panel detector (FPD) when higher resolution is needed during angiographic or interventional vascular imaging procedures. The CAPIDS developed and implemented using LabVIEW software provides a user-friendly interface that allows control of several clinical radiographic imaging modes using the MAF or SSXII including: fluoroscopy, roadmapping, radiographic mode, and digital-subtraction-angiography (DSA). Additional features of CAPIDS, including recursive filtering, contrast enhancement, patient registry and image archival have been implemented and should facilitate the clinical use of the MAF- or SSXII-based dual-detector system. The total

system has been used for image guidance during endovascular image-guided interventions (EIGI) using prototype self-expanding asymmetric vascular stents (SAVS) in over 10 rabbit aneurysm creation and treatment experiments which have demonstrated the system's potential capability for future clinical use.

7622-201, Poster Session

Deblurring in digital tomosynthesis by iterative self-layer subtraction

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Recent developments in large-area flat-panel detectors have made tomosynthesis technology revisited in multiplanar x-ray imaging. However, the typical shift-and-add or backprojection reconstruction method is notably claimed by a lack of sharpness in the reconstructed images because of blur artifact which is the superposition of objects which are out of planes. In this study, we have devised an intuitive simple method to reduce the blur artifact based on an iterative approach. This method repeats a forward and backward projection procedure to determine the blur artifact affecting on the plane-of-interest (POI), and then subtracts it from the POI. The proposed method does not include any Fourier-domain operations hence excluding the Fourier-domain-originated artifacts. We describe the concept of the self-layer subtractive tomosynthesis and demonstrate its performance with numerical simulation and experiments. Comparative analysis with the conventional methods, such as the shift-and-add and filtered backprojection methods, will be addressed.

7622-202, Poster Session

Impulse response characterization of breast tomosynthesis reconstruction with parallel imaging configurations

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Early detection, diagnosis, and suitable treatment are known to significantly improve the chance of survival for breast cancer (BC) patients. To date, the most cost effective method for screening and early detection is screen-film mammography, which is also the tool that has demonstrated its ability to reduce BC mortality. Tomosynthesis is an emerging technology that offers an alternative to conventional two-dimensional mammography. Tomosynthesis produces three-dimensional (volumetric) images of the breast that may be superior to planar imaging due to improved visualization. In this paper we examined the effect of varying the number of projections (N) and total view angle (VA) on the shift-and-add (SAA), back projection (BP) and filtered back projection (FBP) image reconstruction response characterized by impulse response (IR) simulations. IR data were generated by simulating the projection images of a very thin wire, using various combinations of VA and N. Results suggested that BP and FBP performed better for in-plane performance than that of SAA. With bigger number of projection images, the investigated reconstruction algorithms performed the best by obtaining sharper in-focus IR with simulated parallel imaging configurations.

7622-203, Poster Session

Angular dependence of mammographic dosimeters in digital breast tomosynthesis

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Commercial dosimeters currently available for mammography have been designed for perpendicularly incident radiation. However, due to the rotation of the x-ray tube in digital breast tomosynthesis (DBT), the angular dependence of such devices is of clinical importance to DBT dosimetry.

To simulate an isocentric DBT system, two ionization chambers (Model 96035B, Fluke Biomedical, Cleveland, OH, and Model 1515-6M, Radcal Corporation, Monrovia, California) and a semiconductor detector (Barracuda MPD, RTI, Sweden), were rotated relative to a mammographic x-ray beam. The resulting angular dependence was recorded over energies of 26 to 34 kV for a Mo-target, Mo-filter combination.

For all dosimeters, the maximum air kerma measurement occurred with normal incidence and decreased with increasing angle of rotation. Angular dependence decreased with increasing kV and varied between detectors. The solid-state detector showed greater angular dependence as compared to the ionization chambers. For use with DBT systems, correction factors were computed for a 28 kV beam over a varying range and number of tomosynthesis views. For example, in simulating a 28kV, 15-view DBT image with a +/- 30o range from the perpendicular, the reading from the 1515-6M ion chamber requires a correction factor of 1.031, while the Barracuda MPD requires a correction factor of 1.179.

Overall, the results do indicate angular dependence of mammographic dosimeters, thus necessitating either correction factors or the development of a low-energy, angle independent dosimeter for use with DBT.

7622-204, Poster Session

Distributed source x-ray tube technology for tomosynthesis imaging

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Tomosynthesis requires projection images from different viewing angles. Using a distributed x-ray source this can be achieved without mechanical motion of the source. This has the potential for faster image acquisition speed. An overview of the underlying field-emission source technology will be given. X-ray tubes for two different tomosynthesis applications are presented: (i) a linear source array for stationary digital breast tomosynthesis (DBT) and (ii) a square array with a total of 52 sources for fast imaging in image guided radiation (IGRT) therapy.

DBT systems with a moving source have been studied in the last years and are becoming now commercially available. However these systems have to make a trade-off between the source movement speed (scanning time desired as short as possible for patient comfort and avoidance of motion artifacts) and the induced motion blur of the focal spot (achievable resolution, slow source movement desired). Stationary DBT sources do not suffer from these limitations. The distributed source is designed to work in a next generation DBT system.

In the case of IGRT the square source can be mounted directly to the moving gantry of a MV linear accelerator. This allows generating tomosynthesis images in the beam's eye view of the treatment beam. Due to the fast image acquisition intrafractional quasi 3D imaging becomes possible. The presented x-ray tube has been designed for a Siemens ARTISTE radiation treatment system. Results from phantom studies are presented.

Required for the operation of the distributed sources is a dedicated driving electronics. We have developed a driving electronics that can be easily integrated in new or existing imaging systems.

7622-61, Session 12

A super resolution technique for clinical multislice CT

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Increasing the spatial resolution of current multislice clinical CT system is always desirable. However, further resolution improvement by reducing the pixel pitch or the aperture of the detector elements is difficult because of the tradeoff between the pixel size and dose level. In this paper, we demonstrate a methodology for improving spatial resolution of a clinical multislice CT without reducing the detector element size. The flying focal spot (i.e. electron beam wobbling) technique is used to increase the data sampling rate for in-plane (x-y) and z-axis scan acquisitions. In order to reduce the number of focal spot positions to achieve a certain spatial resolution, a super resolution technique using projections onto convex sets (POCS) is applied here to improve projection raw data sampling with reduced number of focal spot positions. The results indicate that it is possible to significantly increase spatial resolution on current multislice clinical CT systems without reducing the detector element size. In absence of noise, super resolution algorithms employing iterative regularization, such as POCS, can reduce the required number of focal spot positions. Thus, technical requirements on the multislice CT systems, such as rotation time and number of projections per rotation, can be much relaxed. However, noise reduction methods and methods of reducing projections per rotation, such as compressed sensing, are needed to work with super resolution technique to keep the radiation exposure from exceeding the current limit of clinical multislice CT.

7622-62, Session 12

Iterative circular conebeam CT reconstruction using fast hierarchical backprojection/reprojection operators

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This is the first report on a new fast statistical iterative CT reconstruction algorithm for circular cone beam CT, accelerated by InstaRecon's fast O(N3logN) hierarchical cone beam backprojection and reprojection (BP/RP) algorithms. We report on the results of both quantitative and subjective image quality evaluations for dose reduction and on run-time comparisons with iterative algorithms based on conventional backprojection and reprojection algorithms. We demonstrate that the iterative algorithm introduced here can provide image quality indistinguishable from an iterative algorithm using conventional BP/RP operators, while providing over 10x speedup in reconstruction rates. Combining the 10x algorithmic acceleration with additional hardware acceleration by FPGA, Cell, or GPU implementation, this work indicates the feasibility of iterative reconstruction algorithms for dose reduction and image quality improvement in routine CT practice, at competitive speeds and affordable cost.

7622-63, Session 12

Histogram-driven cupping correction (HDCC) in CT

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Typical cupping correction methods are pre-processing methods which require either pre-calibration measurements or simulations of standard objects to approximate and correct for beam hardening and scatter. Some of them require the knowledge of spectra, detector characteristics, etc. The aim of this work was to develop a practical histogram-driven cupping correction (HDCC) method to post-process the reconstructed images. We use a polynomial representation of the raw-data generated by forward projection of the reconstructed images; forward and backprojection are performed on graphics processing units (GPU). The coefficients of the polynomial are optimized using a simplex minimization of the joint entropy of the CT image and its gradient. The algorithm was evaluated using simulations and

measurements of homogeneous and inhomogeneous phantoms. For the measurements a C-arm flat-detector CT (FD-CT) system with a 30x40cm² detector and a micro-CT system were used. The algorithm reduced cupping artifacts both in simulations and measurements using a fourth-order polynomial and was in good agreement to the reference. The minimization algorithm required less than 70 iterations to adjust the coefficients only performing a linear combination of basis images, thus executing without time consuming operations. HDCC reduced cupping artifacts without the necessity of pre-calibration or other scan information enabling a retrospective improvement of CT image homogeneity. However, the method can work with other cupping correction algorithms or in a calibration manner, as well.

7622-64, Session 12

Constrained optimization for CT metal artifact reduction

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Computed tomography (CT) streak artifacts caused by metal implants have long been recognized as a problem that limits various applications of CT imaging. An effective and robust algorithm is highly desirable to minimize metal artifacts and achieve clinically acceptable CT images. In this work, the raw projection data is viewed as "incomplete" with the existence of metal shadows. Automatic image segmentation based on intensity histogram is first used to extract out the metal shadows. An iterative algorithm based on constrained optimization is then used for the image reconstruction. This algorithm minimizes a quadratic penalized smoothness measure function of the image, subject to the constraint that the estimated projection data is within a specified tolerance of the available metal-shadow-excluded projection data, with image non-negativity enforced. The constrained minimization problem is optimized through the combination of projection onto convex sets (POCS) and steepest descent of smoothness measure objective. Digital phantom study shows that the proposed constrained optimization algorithm has superior performance in reducing metal artifacts, suppressing noise and improving soft-tissue visibility. Some comparisons are performed with the filtered-back-projection (FBP), POCS and constrained optimization with total-variation (TV) objective. Although the algorithm is presented in the context of metal artifacts, it can be generated to image reconstruction from incomplete projections caused by limited angular range or low angular sampling rate in both 2D and 3D cases.

7622-65, Session 12

Accurate image reconstruction of a small ROI using fully truncated data in differential phase contrast computed tomography

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Differential phase contrast computed tomography (DPC-CT) is a novel X-ray imaging method that uses the wave properties of imaging photons as the contrast mechanism. It has been demonstrated that differential phase contrast images can be obtained using either synchrotron radiation or a conventional X-ray tube and a Talbot-Lau-type interferometer. These data acquisition systems offer only a limited field of view and thus, are prone to data truncation. In this work, we demonstrated that an small region of interest (ROI) of a large object can be accurately and stably reconstructed using fully truncated projection datasets provided that a priori information on electron density is known inside the ROI. The method reconstructs an image iteratively to satisfy a group of physical conditions, i.e., projection onto convex set (POCS). In this work, this POCS algorithm is validated using both numerical simulations and physical phantom experimental data.

7622-66, Session 13

Initial use of fast switched dual energy CT for coronary artery disease

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Fast switched Dual energy CT (DECT) imaging of coronary disease (CAD) has the potential for expanding the use of conventional CT in the evaluation of CAD. In addition to routine calcium and stenosis evaluation, it is possible to more accurately identify and characterize the presence of soft plaque, including risk factors such as plaque location, extent of circumferential involvement and density. Dual phase fast switched DECT, in which a second fast switched DECT is performed after a ten minute delay can identify residual iodine in the myocardium - thereby possibly differentiating infarcted myocardium from ischemic regions of myocardium.

Fast switched DECT is requisite in order to perform both the 80 kVp and 140 kVp exposures at the same projection and optimum time of the R-R interval. Dual phase DECT is necessary to evaluate perfusion. Radiation dose for this protocol is reduced by obtaining the calcium score from the perfused DECT thereby eliminating a separate series. Further dose reductions occur by limiting the extent of Z axis coverage to the left ventricle for the delayed acquisition.

Phantom measurements validated the agreement of calcified plaque using conventional 120 kVp versus fast switch DECT. Density measurements of fabricated soft plaque were placed in the phantom and demonstrated agreement.

These patient examinations show the feasibility of using fast switched DECT in the evaluation of four major indices of CAD; stenosis, calcified plaque score, soft plaque measurements, and left ventricular myocardium perfusion.

7622-67, Session 13

Multi-material decomposition of dual-energy CT data

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Fast kV switching dual-energy computed tomography (DECT) is an imaging modality which extends the capabilities of conventional computed tomography (CT). DECT enables the estimation of the full linear attenuation curve of the imaged subject at each voxel in the CT volume, instead of a scalar image in Hounsfield units. Because the space of linear attenuation curves in the energy ranges of medical applications can be described as a two-dimensional manifold plus a negligible residual difference which is too small to be measured under current CT technology, this decomposition procedure would be, in principle, limited to two materials. This report describes an algorithm that overcomes this limitation, allowing for the estimation of N-tuples of material-decomposed images. The algorithm works by assuming that the mixing of substances and tissue types in the human body has the physicochemical properties of an ideal solution, which yields a model for the density of the imaged material mix. Under this model the mass attenuation curve of each voxel in the image can be estimated, immediately resulting in a material-decomposed image triplet. Decomposition into an arbitrary number of pre-selected materials can be achieved by automatically selecting adequate triplets from an application-specific material library. One important application of this technique is in the digital removal of observed contrast agent from a dual-energy exam, producing a virtual nonenhanced image.

7622-68, Session 13

Material decomposition with inconsistent rays (MDIR) for cone-beam dual energy CT

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Dual energy CT (DECT) provides material-selective CT images by acquiring the object of interest with two different x-ray spectra, a low and a high energy spectrum. Today, two techniques to process the rawdata are in use: Image-based DECT reconstructs the low and the high energy data separately and then performs a linear combination of the images to yield the desired material-selective images. This method can only provide a first order approximation to the true material decomposition and it will not be able to remove beam hardening artifacts from the images. By contrast, rawdata-based DECT naturally allows to deal with higher order approximations and is therefore the better way to go. However, rawdata-based DECT requires the same line integrals to be available for both scans (consistent scans). This requirement may not be met for CT scanner that are available today. To handle the material decomposition of DECT from inconsistent scans (i.e. non-overlapping rays for each measured spectrum) we have developed and evaluated a material decomposition algorithm (MDIR) that allows for different scan trajectories and scan geometries for the low and the high energy scan. The results of our iterative algorithm are close to those obtained by a rawdata-based approach that may not be applicable in frequently occurring cases of inconsistent rays. It should be noted that MDIR can be extended to scans with more than two different spectra and to decompositions into more than two basis functions in a straightforward way.

7622-69, Session 13

Head and body CTDIw of dual energy x-ray CT with fast-kVp switching

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Dual-energy (DE) CT has attracted much attention in recent years. Most recently, we have presented a fast-kVp switching (FKS) method and demonstrated the efficacy of our approach with clinical and phantom results. In this study, we will quantitatively compare the CTDIw of FKS with conventional single energy under the body and head conditions. In FKS protocols, x-ray generator is switching rapidly between 140kVp and 80kVp in adjacent views, and the effective tube current is around 600mA. In addition to the tube voltage and current, we optimize the flux ratio between high and low kVp by asymmetric sampling of 30%-70%. The head and body protocols further differ by the gantry speed (0.9sec/1.0sec), scan field of view (25cm/50cm), and type of bowtie filter (head/body). For baseline single energy, we follow the IEC standard head and body protocols (120kV, 310mA, 1sec, 8x5mm). We measure CTDIw using either a 16 cm (for head scanning) or a 32 cm (for body scanning) PMMA phantom of at least 14 cm in length. The low contrast detectability (LCD) is measured using Catphan 600 (the water section). To make the study repeatable, we use the automated statistical LCD measurement tool available on GE Discovery CT750 scanner. The mean CTDIw for the head and body single energy acquisitions are 53.1mGy and 25.7mGy, respectively. The LCD (statistical) is measured at 0.31% and 0.32% (slice thickness=5mm, object size=3mm, central 4 images), respectively. The mean CTDIw for the FKS (65keV monochramatic energy) head and body scans is 58.9mGy and 28.5mGy, respectively. The corresponding LCD (statistical) is measured at 0.29% and 0.30%, respectively. This demonstrates that, under matching LCD, the CTDIw of FKS is comparable to those of the single energy under head and body conditions.

7622-70, Session 13

A research prototype system for quantum-counting clinical CT

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Recent publications emphasize the benefits of quantum-counting applied to the field of Computed Tomography (CT) [1]. We present a research prototype scanner with a CdTe-based quantum-counting detector and 20 cm field-of-view (FOV). As of today there is no direct converter material on the market able to operate reliably in the harsh high-flux regime of clinical CT scanners [2]. Nevertheless, we investigate the CT imaging performance that could be expected with high-flux capable material. Therefore we chose pixel sizes of 0.05 mm², a good compromise between high-flux counting ability and energy resolution. Every pixel is equipped with two energy threshold counters, enabling contrast-optimization and dual-energy scans. We present a quantitative analysis of contrast measurements, in which we limit ourselves to a low-flux scenario. Using an Iodine-based contrast agent, we find 17% contrast enhancement at 120 kVp compared to energy-integrating CT. Dual-energy measurements with Iodine-dilutions and liquid bone samples demonstrate the general dual-energy capability. However, as predicted by earlier simulation studies, we observe reduced material separation power compared to state-of-the-art dual-source devices. We conclude our work by demonstrating good agreement of measurement results and detailed CT-system simulations [3].

7622-71, Session 13

ChromAIX: high-rate energy-resolving photon-counting ASIC for computed tomography

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In Computed Tomography applications a major opportunity has been identified in the exploitation of the spectral information inherently available due to the polychromatic emission of the X-ray tube and the energy dependence of the attenuation coefficient. CT technology based on indirect-conversion and integrating-mode detection can be used to some extent to distinguish the two predominant physical causes of energy-dependent attenuation (Photo-electric and Compton) by using dual-energy techniques, e.g. kVp switching, dual-source or detector stacking. Further improvements can be achieved by transitioning to direct-conversion technologies and counting-mode detection, which exhibits a better signal-to-noise ratio. Further including energy discrimination enables new applications while avoiding such dual-energy techniques. Such new applications relate to the possibility to discriminate K-edge features (contrast agents, e.g. Gadolinium) from other contributions to x-ray attenuation. The capability of providing energy-resolved information with more than two distinct measurements is referred here as Spectral CT.

To support the development of Spectral CT, an energy-resolving photon counting ASIC (ChromAIX) has been developed to provide high count-rate capabilities while offering energy discrimination. The ChromAIX consists of an arrangement of 4 x 16 pixels with an isotropic pitch of 300 µm. Each pixel contains four energy discriminators with their corresponding counters with continuous read-out capability. Poissonian count-rates exceeding 10 Mcps (> 40 Mcps input rates) have been experimentally validated through electrical characterization. A measured noise of 2 mVRMS (3.3 keV FWHM) has been shown to be consistent with simulations. The ChromAIX ASIC has been specifically designed to support direct-converting materials CdZnTe and CdTe.

7622-72, Session 14

The dependence of image quality on the number of high and low kVp projections in dual energy CT using the Prior Image Constrained Compressed Sensing (PICCS) algorithm

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The Prior Image Constrained Compressed Sensing (PICCS) algorithm is applied to dual energy CT in this paper. In dual energy CT, a low and a high energy projection data set are acquired. These data sets are then used to reconstruct images which can be used for image based decomposition, or the projection data can be used in a projection based decomposition. Most dual energy systems developed by vendors today also present a mixed image, formed using both the high and low kVp data sets. In the PICCS framework, this mixed image can be taken as a prior image and used to constrain the reconstruction of the high and low kVp images. This paper explores the ability to undersample one or both of the kVp data sets and use the combined data to reconstruct a mixed image to be used as a prior image. The effect of varying the ratio of high to low kVp projections for different mA levels on image quality is explored in this paper.

7622-73, Session 14

Performance study of the temporal resolution improvement using prior image constrained compressed sensing (TRI-PICCS)

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A technique for temporal resolution improvement using prior image constrained compressed sensing (TRI-PICCS) in multi-detector computed tomography (MDCT) cardiac imaging is proposed. In this work, the performance of TRI-PICCS was studied using a hybrid phantom which consists of realistic cardiac anatomy and objects moving with designed trajectories. Several simulated moving vessels were added to different locations in the heart. Different motion orientations and simulated heart rates were investigated using half projection data of the short-scan angular range in TRI-PICCS. Different angular ranges of projection data were also investigated in TRI-PICCS to evaluate the highest achievable temporal resolution. The results showed that the temporal improvement of TRI-PICCS is independent of the locations of the moving objects and motion orientations. The motion artifacts at 100bmp simulated heart rate can still be significantly improved using TRI-PICCS. The minimum angular range requirement of TRI-PICCS is about 90°, corresponding to a temporal resolution improve factor of 2.6 compared with the standard short-scan FBP reconstruction.

7622-74, Session 14

Compressive sensing of images with a priori known spatial support

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In medical imaging, image background is often defined by zero signal. Moreover, in medical images the background area - or conversely, the spatial support (the extent of the non-zero part of the image) - is often known a priori or can be easily estimated. For example, support information can be estimated from the low-resolution "scout" images

typically acquired during pre-scan localization in both MRI and CT. In dynamic scans, object support in a single time-frame is often obtainable from a prior time frame, or from a composite image formed from data from multiple time frames. In this work, incorporation of either complete or partial a priori knowledge of object spatial support into the compressive sensing (CS) framework is investigated. Following development of the augmented reconstruction model, examples of support-constrained CS reconstruction of MR images under both exact and inexact support definitions are given. For each experiment, the straightforward incorporation of the proposed spatial support constraint into the standard CS model was shown to both significantly accelerate reconstruction convergence and yield a lower terminal RMSE compared to a conventional CS reconstruction. The proposed augmented reconstruction model was also shown to be robust to inaccuracies in the estimated object support.

7622-75, Session 14

Direct pharmacokinetic parameter estimation using spectral weighted least squares

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Conventional dynamic PET studies estimate pharmacokinetic parameters using a two-step procedure of first reconstructing the spatio-temporal activity volume before applying a pharmacokinetic model. This indirect procedure leads to low SNR due to using only a subset of the temporal data when reconstructing each image. Our work concentrates on the estimation of parameters directly from the dPET temporal projections. We present here a one-step direct pharmacokinetic algorithm based on the Ordered Subset (OS) Weighted Least Squares (WLS) iterative estimation algorithm. We explicitly incorporate a priori temporal information by modelling the Time Activity Curves (TACs) as a sum of exponentials convolved with an Input Function. Our OS-WLS-PK algorithm is appropriate for both 3D projection data which has been Fourier Rebinned into 2D slices, and when pre-corrected for attenuation, randoms and scatter. The main benefit of spectral analysis applied to dynamic PET reconstruction is that no particular pharmacokinetic model needs to be specified a priori, with only the input function needing to be sampled at scan time. We test our algorithm on highly realistic SORTEO generated data.

7622-76, Session 14

Noise properties as a function of energy of monoenergetic images from DECT used for attenuation correction with PET/CT and SPECT/CT

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We evaluate the energy dependent noise properties of monoenergetic images synthesized from dual-energy (DECT), or dual-kVp, CT acquisitions. These monoenergetic images can be used to estimate attenuation coefficients at energies suitable for PET and SPECT imaging. This is becoming more relevant with the increased used of quantitative imaging by PET/CT and SPECT/CT scanners. There are, however, significant variations in the noise properties of synthesized monoenergetic images as a function of energy. Methods: We used both analytic approximations and simulations to estimate the noise of synthesized monoenergetic images of a water-filled cylinder from 1 to 525 keV. The dual-energy spectra were based on the GE Lightspeed VCT scanner at 80 and 140 kVp, with added filtration of 1 mm Cu (80 kVp) and 1 mm Sn (140 kVp). Results: Both analytic calculations and simulations showed the expected minimum noise value for a synthesized monoenergetic image at an energy between the mean energies of the two spectra. In addition we found that the relative noise peaked near the 140 keV energy of 99mTc (i.e. SPECT) and then gradually decreased with increasing energy up to 511 keV and beyond (i.e. PET). As a check, the linear attenuation coefficients of

the synthesized monoenergetic images were within 1% of the known true values across the entire energy range. Conclusion: If DECT is being used for attenuation correction at higher energies, there is a noise amplification that is dependent on the energy of the synthesized monoenergetic image of linear attenuation coefficients.

7622-77, Session 15

Low dose, low noise and high resolution volume of interest (VOI) imaging in C-arm flat-detector CT

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A novel method for flat-detector computed tomography (FD-CT) was developed to provide images of the whole object which comprise an arbitrary, definable volume of interest (VOI) at high resolution and low noise. For this a low-dose overview scan of the whole object and a high-dose scan of the VOI are combined. The first scan is adequate for an overview to select the VOI and the second scan assures local high image quality in the VOI.

The combination of this consecutive scans is based on a forward projection of the reconstructed overview volume. After forward projecting, the artificial projection data of the overview scan is combined with the measured VOI data in the raw data domain. Different gray values are matched by an appropriate transformation and weighting.

By the combination of the two scans an image is generated which covers the whole object and provides the actual volume of interest at high image quality. In simulations, the resolution was evaluated and in measurements the effects of noise and dose reduction were shown. Outside the VOI a resolution of 1.6 lp/mm (line pairs per millimeter) and noise of 69 HU were determined. Inside the VOI, resolution was increased to 3.0 lp/mm and noise decreased to 48 HU. Measurements of an anthropomorphic head phantom were used to validate the proposed method for imaging stents. The effective dose for this two-scan procedure was significantly reduced in comparison to a standard high resolution scan.

7622-78, Session 15

4D-DSA and fluoroscopy: preliminary implementation

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Recently our group has achieved highly accelerated MRI using undersampled acquisition and approximate constrained reconstruction methods. One of these methods is a hybrid acquisition involving the constrained reconstruction of time dependent information by a separate scan of longer duration. Inspired by this approach we have developed modified reconstruction algorithms that combine a reconstructed rotational DSA volume with temporal information provided by either a separate single projection 2D-DSA examination or employs the intrinsic temporal information from projections used to form the rotational DSA volume. The result is the generation of time resolved 3D volumes with typical spatial resolution of 5123 at typical frame rates of 20 fps. Full rotation of the images is possible during each stage of the filling of the vasculature allowing for greatly simplified interpretation of vascular dynamics. Fluoroscopic information obtained from a single projection can be rotated for viewing at arbitrary angles without gantry rotation. The approximate reconstruction leads to shadowing artifacts due to occasional overlap of arteries and veins. These are greatly reduced when biplane acquisitions are used to derive temporal information. At the expense of frame rates, they are also diminished when separated angles from the intrinsic projections from the 3D-DSA are used. Since the reconstruction suppresses the parenchymal contrast, the utility for deriving indications of perfusion deficits based on the CBV values and vascular transit times needs further investigation. Successful studies have been conducted using various combinations of intravenous and intra-arterial injections.

7622-79, Session 15

Image reconstruction in cardiac interventions using a small flat-panel detector

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C-arm CT is used in neurovascular interventions where a large flat panel detector is used to acquire cone-beam projection data. In this case, data truncation problems due to the limited detector size are mild. When the cone beam CT method is applied to cardiac interventions severe data truncation artifacts reduce the clinical utility of the reconstructions. However, accurate reconstruction is still possible given a priori knowledge of the reconstruction values within a small region inside the FOV. Several groups have studied the case of the "interior problem" where data is truncated from all views. In this paper, we applied these new mathematical discoveries to C-arm cardiac cone-beam CT to demonstrate that accurate image reconstruction may be achieved for cardiac interventions. The method is applied to iteratively reconstruct the image volume such that it satisfies several physical conditions. In this work, the algorithm is applied to data from in-vivo cardiac canine studies collected using a clinical C-arm system. It is demonstrated that the algorithm converges well to the reconstruction values of non-truncated data reconstructed using the FDK algorithm. Furthermore, proper convergence is achieved by using only an estimate of the average value within a subregion as a priori information (i.e. the exact value at each pixel in the a priori region need not be known). In the context of cardiac imaging, airway and lung tissue regions are used since these structures are present in the neighborhood of the heart and their attenuation value can be approximated easily.

7622-80, Session 15

Investigating the dose distribution in the uncompressed breast with a dedicated CT mammotomography system

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A dual modality SPECT-CT system designed for uncompressed breast imaging is currently under development. The CT subsystem incorporates an ultra-thick K-edge filtration technique that optimizes the dose efficiency (SNR2/dose) of the system for lesion imaging. Here, we characterize the full-3D uncompressed breast dose under our standard tomographic cone beam imaging protocol using both ionization chamber-calibrated TLDs and radiochromic film. Two geometric phantoms and an anthropomorphic breast phantom are filled in turn with 1L of water and oil to simulate the effective density bounds of 100% glandular and fatty breast compositions. Volumetric dose measurements across the different breast equivalent materials and phantom shapes are generated. Point doses to the water-filled geometric phantoms and anthropomorphic breast phantoms for a single complete tomographic scan range from 1.3-7.3 mGy and 1.7-6.3 mGy, respectively, with a mean whole-breast dose of 4.5 mGy. Trends indicate lower doses in the centers of the volumes and the posterior "breast" towards the chest wall along with higher doses near the nipple regions. Measured doses to the oil-filled phantoms are less due to the smaller mass energy-absorption coefficient of oil relative to water. These results completely characterize the 3D dose distributions in

various shaped volumes in a dedicated breast imaging paradigm, and confirm the advantages of using the novel ultra-thick K-edge beam to minimize the dose to the breast during fully-3D imaging.

7622-81, Session 15

Optimization of system parameters for modulator design in x-ray scatter correction using primary modulation

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The impact of the modulator design parameters on X-ray scatter correction using primary modulation is studied; optimization of the modulator design is presented. Our scatter correction method for X-ray computed tomography (CT), which uses a checkerboard pattern of attenuating blockers (primary modulator) placed between the X-ray source and the object, has been developed and experimentally verified. The blocker size, d, and the blocker transmission factor, α, are critical to the performance of our method. In this work, an error caused by aliasing of the primary, which depends on the choices of d and α and the scanned object, is set as the object function to be minimized, with constraints including the X-ray focal spot, the physical size of the detector element, and the noise level. The optimization is carried out in two steps. In the first step, d is chosen to be as small as possible, while meeting lower bound conditions. In the second step, α is selected to balance the error in the scatter estimation and the noise in the reconstructed image. Our optimization approach is validated using a tabletop CT system. The lower bound of d is 0.83 mm. Numerical simulations suggest α should be between 0.6 and 0.8. Using a Catphan600 phantom, a copper modulator (d = 0.899 mm, $\alpha\approx0.7$) outperforms an aluminum modulator (d = 4.28 mm, $\alpha\approx0.9$), reducing the error of CT number from 371.4 to 21.9 HU, and increasing the contrast to noise ratio from 10.9 to 19.2.

7622-82, Session 15

Nanotechnology enabled desktop micro-CT system for 4D high-resolution micro-CT of mouse heart

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Micro-CT of small animals in vivo is increasingly used in biomedical research. In this paper a nanotechnology enabled desktop micro-CT system is presented for the purpose of in vivo micro-CT of mouse, especially for the 4D high-resolution micro-CT of mouse heart and lung under free-breathing setting. The micro-CT system is based on a rotating gantry of small diameter and a carbon nanotube field emission micro-focus x-ray tube of sufficient flux and compact size. The tube has not only a high flux (>100W peak power at 100um focal spot size) but also a compact design (7x3x3 inches), thus enabling the micro-CT system to have both a high spatial resolution and a high temporal resolution, as well as a compact geometry from a rotating source-detector pair and a stationary mouse bed. Another advantage from the field emission x-ray tube is its electronic programming and fast switching capability, allowing the micro-CT system to easily gate its imaging sequence with non-periodic physiological signals from free-breathing mice. The system's performance has been characterized in terms of MTF, CNR, linearity, and uniformity analysis. The system's application has been validated with 4D high-resolution (80um and 10ms) micro-CT of the mouse heart under free-breathing setting.

7623-01, Session 1

Modeling and segmentation of intra-cochlear anatomy in conventional CT

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Cochlear implant surgery is a procedure performed to treat profound hearing loss. Since the cochlea is not visible in surgery, the physician uses anatomical landmarks to estimate the pose of the cochlea. Research has indicated that implanting the electrode in a particular cavity of the cochlea, the scala tympani, results in better hearing restoration. The success of the scala tympani implantation is largely dependent on the point of entry and angle of electrode insertion. Errors can occur due to the imprecise nature of landmark-based, manual navigation as well as inter-patient variations between scala tympani and the anatomical landmarks. In this work, we use point distribution models of the intra-cochlear anatomy to study the inter-patient variations between the cochlea and the typical anatomic landmarks, and we implement an active shape model technique to automatically localize intra-cochlear anatomy in conventional CT images, where intra-cochlear structures are not visible. This fully automatic segmentation could aid the surgeon to choose the point of entry and angle of approach to maximize the likelihood of scala tympani insertion, resulting in more substantial hearing restoration.

7623-02, Session 1

Manifold parameterization of the left lentricle for a statistical modeling of its complete anatomy

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Distortion of Left Ventricle (LV) external anatomy is related to some dysfunctions, such as hypertrophy. The architecture of myocardial fibers determines LV electromechanical activation patterns as well as mechanics. Thus, their joined modelling would allow the design of specific interventions (such as peacemaker implantation and LV remodelling) and therapies (such as resynchronization). On one hand, accurate modelling of external anatomy requires either a dense sampling or a continuous infinite dimensional approach, which requires non-Euclidean statistics. On the other hand, computation of fiber models requires statistics on Riemannian spaces. Most approaches compute separate statistical models for external anatomy and fibers architecture.

In this work we propose a general mathematical framework based on differential geometry concepts for computing a statistical model including, both, external and fiber anatomy. Our framework provides a continuous approach to external anatomy supporting standard statistics. We also provide a straightforward formula for the computation of the Riemannian fiber statistics. We have applied our methodology to the computation of complete anatomical atlas of canine hearts from diffusion tensor studies. The orientation of fibers over the average external geometry agrees with the segmental description of orientations reported in the literature.

7623-03, Session 1

Fully automatic cardiac segmentation from 3D CTA data: a multi-atlas based approach

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Computed tomography angiography (CTA), a non-invasive technique, is becoming increasingly popular for cardiac examination, mainly due to its superior spatial resolution compared to MRI. This imaging modality is currently widely used for the diagnosis of coronary artery disease (CAD) but it is not commonly used for the diagnosis of ventricular and atrial function.

In this paper, we present a fully automatic method for segmenting the whole heart (i.e. the outer surface of the myocardium) and cardiac chambers from CTA datasets. Cardiac chamber segmentation is particularly valuable for the extraction of ventricular and atrial functional information, such as stroke volume and ejection fraction. With our approach, we aim to improve the diagnosis of CAD by providing functional information extracted from the same CTA data, thus not requiring additional scanning. In addition, the whole heart segmentation method we propose can be used for visualization of the coronary arteries and for obtaining a region of interest for subsequent segmentation of the coronaries, ventricles and atria. Our approach is based on multi-atlas segmentation, and performed within a non-rigid registration framework.

A leave-one-out quantitative validation was carried out on 8 images. The method showed a high accuracy, which is reflected in both a mean error of 1.05±1.30 mm and an average Dice coefficient of 0.93. The robustness of the method is demonstrated by successfully applying the method to 243 additional datasets, without any significant failure.

7623-05, Session 1

Model guided diffeomorphic demons for atlas based segmentation

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Using an atlas, an image can be segmented by mapping its coordinate space to that of the atlas in an anatomically correct way, a process commonly referred to as atlas based segmentation. In order to find this correct the diffeomorphic demons algorithm can be applied. Diffeomorphic demons offer the possibility to perform computationally efficient non-rigid registration. However, the demons registration algorithm is solely based on image information. Therefore this registration method is prone to image artifacts and image noise.

In order to overcome these limitations the efficiency of diffeomorphic demons and the stability of statistical models were combined in a new approach presented in this paper: A statistical deformation model that describes "anatomically correct" displacements vector fields for a specific registration problem is used to guide the demons registration algorithm. By projecting the current displacement vector field into the model space during any iteration of the registration process a regularized version of the displacement vector field is calculated. Using this regularized displacement vector field the demons registration algorithm can be guided by the deformation model.

The proposed method was evaluated on 21 CT datasets of the right hip. 120 different parameter configurations were tested for their capability to accurately segment the proximal femur. Measuring the average and maximum segmentation error for all 21 datasets and all 120 test configurations it could be demonstrated that the newly proposed algorithm leads to a reduction of the segmentation error of

up to 13% compared to using the conventional diffeomorphic demons algorithm.

7623-61, Session 1

A structural-functional MRI-based disease atlas: application to computer-aided-diagnosis of prostate cancer

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Population based atlases, derived from the integration of multiple imaging modalities and protocols into a common coordinate frame could reveal different pathological, structural, and functional aspects of disease. Most previous work on atlas construction has centered on models derived from normal or healthy subjects, either explicitly or implicitly, where it is assumed that the inter-patient pathological variation is not large. Such atlas construction methods are not suitable for constructing a diseased atlas across patient studies, where significant inter-patient pathological variation can be expected. We present a novel framework for the construction of a disease atlas from multi-protocol, structural and functional in vivo MR imaging data. Our framework comprises 3 distinct modules: (a) registration of multi-protocol and multi-functional data for each patient, (b) registration of data across multiple patients, and (c) parametric representations of the multi-protocol atlas disease data, which could provide a useful tool for clinicians to quantitatively study the correlations between structural and functional imaging data so as to make better, more informed diagnoses. In our preliminary data so far we have developed an atlas framework comprising 6 prostate cancer patient studies imaged via a 3 Tesla in vivo T2 and dynamic contrast enhanced (DCE) MRI with corresponding whole mount histology specimens. The parametric representations of the structural (T2) and functional (DCE) disease data suggest that our atlas model allows for definition of integrated structural-functional disease signatures that enable better discrimination between normal and diseased tissue compared to any individual modality (i.e. structural or functional data alone).

7623-06, Session 2

Deformable multimodal image registration by maximizing Renyi's statistical dependence measure

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We present a novel variational framework for deformable multi-modal image registration. Our approach is based on Renyi's statistical dependence measure of two random variables with the use of reproducing kernel Hilbert spaces associated with Gaussian kernels to simplify the computation. The popularly used method of maximizing mutual information based optimization algorithms are complex and sensitive to the quantization of the intensities, because it requires the estimation of continuous joint probability density function (pdf). The proposed model does not deal with joint pdf but instead observed independent samples. Experimental results are provided to show the effectiveness of the model.

The proposed model in this paper uses Renyi's statistical dependence measure for multimodal image registration. It has shown effectiveness on larger deformation and robustness to noise. Furthermore, to compute this measure we do not deal with the joint pdf of S and T, but instead observed samples drawn independently according to them. This avoids problems in continuous joint pdf estimation encountered in MI based registration algorithms. The proposed model shows more stability to different quantization compared with MI based model.

7623-08, Session 2

Tissue volume and vesselness measure preserving nonrigid registration of lung CT images

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In registration-based analyses of lung biomechanics and function, high quality registrations are essential to obtain meaningful results. Various criteria have been suggested to find the correspondence mappings between two lung images acquired at different levels of inflation. In this paper, we describe a new metric, the sum of squared vesselness measure difference (SSVMD), that utilizes the rich information of blood vessel locations and matches similar vesselness patterns in two images. Preserving both the lung tissue volume and the vesselness measure, a registration algorithm is developed to minimize the sum of squared tissue volume difference (SSTVD) and SSVMD together. We compare the registration accuracy using SSTVD + SSVMD with that using SSTVD alone by registering lung CT images of two normal human subjects. After adding the new SSVMD metric, the improvement of registration accuracy is observed by landmark error and fissure positioning error analyses. The average values of both errors are reduced by more than 20%. The mean landmark error is on the order of 1 mm. Statistical testing of landmark errors shows that there is a statistically significant difference between two methods with p values < 0.05 in both subjects. Visual inspection shows there are obvious accuracy improvement in the lung regions near the thoracic cage after adding SSVMD.

7623-09, Session 2

Multimodal registration of MR images with a novel least-squares distance measure

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In this work we evaluate a novel method for multi-modal image registration of MR images. The key feature of our approach is a new distance measure that allows for comparing modalities that are related by an arbitrary gray-value mapping. The novel measure is formulated as least square problem for minimizing the sum of squared differences of two images with respect to changing gray-values of one of the images.

With this approach, we overcome drawbacks from cross-correlation based registration that assumes an affine linear dependency of gray-values. Furthermore, it turns out that the novel measure can be computed explicitly and allows for very simple and efficient implementation. We compare our new approach to rigid registration with cross-correlation, mutual information, and normalized gradient fields as distance measures.

As a result of our experiments, we found that the novel distance measure is a simple and very effective alternative to MI and NGF for multi-modal image registration.

7623-10, Session 2

Extending the quadratic taxonomy of regularizers for nonparametric registration

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In the mathematical sense, nonrigid image registration algorithms are procedures for optimizing a functional over a specified class of deformable transformations. The functional typically contains two terms: an image similarity term, which is used to gauge the degree of similarity between the two images, and a regularizer, which is used to guarantee a unique solution to the optimization problem. The class

of transformations can be parameterized in terms of basis functions (such as B-splines or thin-plate splines), or it can be nonparametric, containing any deformation field that satisfies prescribed boundary conditions.

Modersitzki provides a taxonomy of homogeneous regularizers that have been used for medical image registration problems: the taxonomy includes the diffusion, elastic, fluid, and curvature regularizers. Two important features of these regularizers are whether they account for coupling of the spatial components of the deformation (elastic/fluid do; diffusion/curvature do not) and whether they are robust to initial affine misregistrations (curvature is; diffusion/elastic/fluid are not). In this article, we show how the Modersitzki taxonomy can be extended to include a second-order regularizer (the second-order elastic regularizer) that exhibits the best of both features: it accounts for coupling of the spatial components of the deformation and contains affine transformations in its kernel. We illustrate how the extended taxonomy relates to other work on regularizers, including Cachier and Ayache's differential quadratic forms and Arigovindan's family of rotationally invariant regularizers. We then describe two computationally efficient paradigms for performing nonparametric registration with the proposed regularizer, based on Fourier methods and on the Demons algorithm. Finally, we illustrate the performance of the regularizers in the extended Modersitzki taxonomy on serial 3-D CT exams of patients with lung nodules.

7623-11, Session 2

Coupling tumor growth with brain deformation: a constrained parametric non-rigid registration problem

A. Mang, S. Becker, A. Toma, T. M. Buzug, Univ. zu Lübeck (Germany)

A novel approach for coupling brain tumor mass effect with a continuous model of cancer progression is proposed. The purpose of the present work is to devise an efficient approximate model for the mechanical interaction of the tumor with its surroundings in order to aid registration of brain tumor images with statistical atlases as well as the generation of atlases of brain tumor disease.

To model tumor progression a deterministic reaction-diffusion formalism, which describes the spatio-temporal dynamics of a coarse-grained population density of cancerous cells, is discretized on a regular grid. Tensor information obtained from a probabilistic atlas is used to account for the anisotropy of the diffusion of malignant cells within white matter. To account for the expansive nature of the tumor a parametric deformation model is linked to the computed net cell density of cancerous cells. To this end, we formulate a constrained optimization problem that allows for approximating physical properties of brain tissue. The described coupling model can in general be applied to estimate mass effect of non-convex, diffusive as well as multifocal tumors so that no simplification of the growth model has to be stipulated.

The present work has to be considered as a proof-of-concept. Visual assessment of the computed results demonstrates the potential of the described method. We conclude that the analogy to the problem formulation in image registration potentially allows for a sensible integration of the described approach into a unified framework of image registration and tumor modeling.

7623-45, Session 2

Image processing and registration in a point set representation

Y. Gao, A. R. Tannenbaum, Georgia Institute of Technology (United States)

An image, being a continuous function, is commonly discretely represented as a set of sample values, namely the intensities, associated with the spatial grids. After that, all types of the operations are then carried out there in. We denote such representation as the

discrete function representation (DFR). In this paper we provide another discrete representation for images using the point sets, called the point set representation (PSR). Essentially, the image is normalized to have the unit integral and is treated as a probability density function of some random variable. Then the PSR is formed by drawing samples of such random variable. In contrast with the DFR, here the image is purely represented as points and no values are associated. Besides being an equivalent discrete representation for images, we show that certain image operations benefit from such representation in the numerical stability, performance, or both. Examples are given in the Perona-Malik type diffusion where in the PSR there is no such problem as the numerical instability. Furthermore, PSR naturally bridges the fields of image registration with the point set registration. This helps handle some otherwise difficult problems in image registration such as partial image registration, with much faster convergence speed.

7623-12, Session 3

Correspondence free 3D statistical shape model fitting to sparse x-ray projections

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In this paper we address the problem of 3D shape reconstruction from sparse X-ray projections. We present a correspondence-free method to fit a statistical shape model to two X-ray projections, and illustrate its performance in 3D shape reconstruction of the femur. The method alternates between 2D segmentation and 3D reconstruction, where 2D segmentation is guided by dynamic programming along the model projection on the X-ray plane. 3D reconstruction is based on the iterative minimization of the 3D distance between a set of support points and the back-projected silhouette with respect to the pose and model parameters. We show robustness of the reconstruction on simulated X-ray projection data of the femur, varying the field of view; and in a pilot study on cadaveric femora.

7623-13, Session 3

4D reconstruction of cardiac gated SPECT images using a content-adaptive deformable mesh model

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In this work, we present a four-dimensional reconstruction technique for cardiac gated SPECT images using a content-adaptive deformable mesh model. Clinical cardiac gated SPECT images are affected by a high level of noise and motion blur artifacts which decrease diagnostic accuracy. Noise reduction approaches have been proposed but they usually do not account for cardiac motion. Additionally, advanced methods offering motion compensation typically rely on Cartesian grid representations of images. The proposed method utilizes a mesh representation of the images in order to utilize the benefits of content-adaptive nonuniform sampling. The mesh model allows for accurate representation of important regions while significantly compressing the data. The content-adaptive deformable mesh model is generated by combining nodes generated on the full torso using pre-reconstructed emission and attenuation images with nodes accurately sampled on the left ventricle. Ventricular nodes are further displaced according to cardiac motion using our previously introduced motion estimation technique. The resulting mesh structure is then used to perform iterative image reconstruction using a mesh-based maximum-likelihood expectation-maximization algorithm. Finally, motion-compensated post-reconstruction filtering is applied using the deformable mesh model. Reconstructed images as well as quantitative evaluation show that the proposed method offers improved image quality while reducing the data size.

7623-14, Session 3

3D shape reconstruction of bone from two x-ray images using 2D/3D non-rigid registration based on moving least-squares deformation

T. Cresson, D. Branchaud, R. Chav, B. Godbout, J. A. de Guise, Univ. du Québec (Canada)

Several studies based on biplanar radiography technologies are foreseen as great systems for 3D-reconstruction applications for medical diagnoses. This paper proposes a non-rigid registration method to estimate a 3D personalized shape of bone models from two planar x-ray images using an as-rigid-as-possible deformation approach based on a moving least-squares optimization method. Based on interactive deformation methods, the proposed technique has the ability to let a user improve readily and with simplicity a 3D reconstruction which is an important step in clinical applications. Experimental evaluations of six anatomical femur specimens demonstrate good performances of the proposed approach in terms of accuracy and robustness when compared to CT-scan.

7623-15, Session 3

Abdominal arteries recognition in x-ray using a structural model

O. Nempont, R. Florent, Philips France (France)

The fully automatic recognition of vascular trees is a challenging task required for roadmapping or advanced visualization. For instance, during an endovascular aneurysm repair (EVAR), the recognition of abdominal arteries in angiograms can be used to select the appropriate stent graft. This choice is based on a reduced set of arteries (aorta, renal arteries, iliac arteries...) whose relative position is quite stable.

We propose in this article a recognition process based on a rough model of the target vessels. Their centerline is represented by a set of control points whose relative position is constrained. To position them in the angiogram, we enhance the target vessels and extract for each control point a set of possible positions. Then, a constraint propagation algorithm based on the model prunes those candidates, removing inconsistent ones. We present preliminary results on 5 cases, illustrating the potential of this approach and especially its ability to handle the high variability of that anatomy.

7623-16, Session 3

Robust extraction of the aorta and pulmonary artery from 3D MDCT image data

W. E. Higgins, P. Taeprasartsit, The Pennsylvania State Univ. (United States)

Accurate definition of the aorta and pulmonary artery from three-dimensional (3D) multi-detector CT (MDCT) images is important for pulmonary applications. This work presents robust methods for defining the aorta and pulmonary artery in the central chest. The methods work on both contrast and non-contrast enhanced 3D MDCT image data. The automatic methods use a common approach employing model fitting and selection and adaptive refinement. During the occasional event that more precise vascular extraction is desired or the method fails, we also have an alternate, semi-automatic, fail-safe method. This semi-automatic method is intuitive and requires little user effort. The semi-automatic method extracts the vasculature by extending the medial axes into a user-guided direction. Results over a series of human 3D MDCT images demonstrate the efficacy and accuracy of the methods. Further application of the results show the utility of the extracted vasculature to central-chest lymph-node station definition and to the guidance of safe bronchoscopic biopsy.

7623-17, Session 4

Combining short-axis and long-axis cardiac MR images by applying a super-resolution reconstruction algorithm

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In cardiac MR images the slice thickness is normally greater than the pixel size within the slices. In general, better segmentation and analysis results can be expected for isotropic high-resolution (HR) data sets. If two orthogonal data sets, e.g. short-axis (SA) and long-axis (LA) volumes are combined, an increase in resolution can be obtained. In this work we use a super-resolution reconstruction (SRR) for computing high-resolution data sets from two orthogonal SA and LA volumes. In contrast to a simple averaging of both data in the overlapping region, we apply a maximum a-posteriori approach. There, an imaging model is employed for estimating an HR image that best reproduces the two low-resolution input data sets. For testing the SRR approach we use clinical MRI data with an in-plane resolution of 1.5 mm x 1.5 mm and a slice thickness of 8 mm. We show that the results obtained with our approach are superior to currently used averaging techniques. Due to the fact that the heart deforms over the cardiac cycle, we investigate further, how the replacement of a rigid registration as pre-processing step by a deformable registration improves the quality of the final HR image data. We conclude that image quality is dramatically enhanced by applying a SRR technique especially for cardiac MR images where the resolution in slice-selection direction is about five times lower than within the slices.

7623-18, Session 4

Synthesizing MR contrast and resolution through a patch matching technique

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The magnetic resonance contrast and resolution of a neuroimaging data set have strong impacts on the utility of the data in clinical and neuroscience tasks such as registration and segmentation. Lengthy acquisition times typically prevent routine acquisition of multiple MR contrast images, and opportunities for detailed analysis using these data would seem to be irrevocably lost. This paper describes an example based approach using patch matching from a multiple resolution multiple contrast atlas in order to change an image's resolution as well as the MR contrast from one pulse-sequence to that of another. The use of this approach to generate different modalities (T2/PD/FLAIR) from a single T1 weighted image is demonstrated on both phantom and real images.

7623-19, Session 4

A variational approach for the correction of field-inhomogeneities in EPI sequences

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A wide range of medical applications in clinic and research exploit images acquired by fast magnetic resonance imaging (MRI) sequences such as echo-planar imaging (EPI), e.g. functional MRI (fMRI) and diffusion tensor MRI (DT-MRI). Since the underlying assumption of homogeneous static fields fails to hold in practical applications, images acquired by those sequences suffer from distortions in both geometry and intensity. In the present paper we propose a new variational image registration approach to correct those EPI distortions. To this end we acquire two reference EPI images without diffusion sensitizing and with inverted phase encoding gradients in order to calculate a rectified

image. The idea is to apply a specialized registration scheme which on the one hand mimics the elastic behavior of the underlying tissue and on the other hand compensates for the characteristical direction dependent image distortions. In addition the proposed scheme automatically corrects for intensity distortions. This is done by evoking a problem dependent distance measure incorporated into a variational setting. Unlike existing approaches we adjust not only the image volumes but also the phase encoding direction after correcting

for patients head-movements between the acquisitions. Finally, we present first successful results of the new algorithm for the registration of DT-MRI datasets.

7623-20, Session 4

Denoising arterial spin labeling MRI using tissue partial volume

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Arterial spin labeling (ASL) is a noninvasive MRI method that uses magnetically labeled blood to measure cerebral perfusion.

Spatial resolution of ASL is relatively small and as a consequence perfusion from different tissue types is mixed in each pixel.

An average ratio of gray matter (GM) to white matter (WM) blood flow is 3.2 to 1. Disregarding the partial volume effects (PVE) can thus cause serious errors of perfusion quantification. PVE also complicates spatial filtering of ASL images as apart from noise there is a spatial signal variation due to tissue partial volume.

Recently, an algorithm for correcting PVE has been published by Asllani et al. It represents the measured magnetization as a sum of different tissue magnetizations weighted by their fractional volume in a pixel.

With the knowledge of the partial volume obtained from a high-resolution MRI image, it is possible to separate the individual tissue contributions by linear regression on a neighborhood of each pixel.

We propose an extension of this algorithm by minimizing the total-variation of the tissue specific magnetization. This makes the algorithm more flexible to local changes in perfusion. We show that this method can be used to denoise ASL images without mixing the WM and GM signal.

7623-21, Session 4

An adaptive nonlocal means algorithm for medical image denoising

T. Thaipanich, C. J. Kuo, The Univ. of Southern California (United States)

Medical images obtained from Magnetic Resonance Imaging (MRI) and Computed Tomography (CT) are among the most common tools for diagnosis. These images are often affected by random noise arising in the image acquisition process. The presence of noise not only produces undesirable visual quality but also lowers the visibility of low-contrast objects. Image denoising is one of the classical problems in digital image processing, and has been studied for nearly half a century due to its important role as a pre-processing step in various applications. Its objective is to recover the best estimate of the original image from its noisy version. The recently proposed nonlocal means algorithm (NL-means) has offered remarkably promising results. In this work, we investigate an adaptive denoising scheme based on the NL-means algorithm for medical imaging applications. In contrast with the traditional NL-means algorithm, the proposed adaptive NL-means (ANL-means) denoising scheme has three unique features. First, it employs the singular value decomposition (SVD) method and the K-means clustering (K-means) technique for robust classification of blocks in noisy images. Second, the local window is adaptively adjusted to match the local property of a block. Finally, a rotated block matching algorithm is adopted for better similarity matching.

Experiment results are given to demonstrate the superior performance of the proposed ANL denoising technique, where the selected benchmark algorithms include the Gaussian filtering (GF), techniques based on the partial differential equation (PDE), total variation (TV) minimization and the traditional NL-means algorithm.

7623-22, Session 4

Noise filtering in thin-slice 4D cerebral CT perfusion scans

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Patients suffering from cerebral ischemia or subarachnoid hemorrhage, undergo a 4D (3D+time) CT Perfusion (CTP) scan to assess the cerebral perfusion and a CT Angiography (CTA) scan to assess the vasculature. The aim of our research is to extract the vascular information from the CTP scan. This requires thin-slice CTP scans that suffer from a substantial amount of noise. Therefore noise reduction is an important prerequisite for further analysis. So far, the few noise filtering methods for 4D datasets proposed in literature deal with the time dimension as a 4th dimension similar to the 3 spatial dimensions, mixing temporal and spatial intensity information. We propose a bilateral noise reduction method based on time-intensity profile similarity (TIPS), which reduces noise while preserving temporal intensity information. TIPS was compared to 4D bilateral filtering on 10 patient CTP scans and, even though TIPS bilateral filtering is much faster, it results in better vessel visibility and higher image quality ranking (observer study) than 4D bilateral filtering.

7623-23, Session 5

Affinity-based constraint optimization for nearly-automatic vessel segmentation

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We present an affinity-based optimization method for nearly-automatic vessels segmentation in CTA scans. The desired segmentation is modeled as a function that minimizes a quadratic affinity-based functional. The functional incorporates intensity and geometrical vessel shape information and a smoothing constraint. Given a few user-defined seeds, the minimum of the functional is obtained by solving a single set of linear equations. The binary segmentation is then obtained by applying a user-selected threshold. The advantages of our method are that it requires fewer initialization seeds, is robust, and yields better results than existing graph-based interactive segmentation methods. Experimental results on 20 vessel segments including the carotid arteries bifurcation and noisy parts of the carotid yield a mean symmetric surface error of 0.54mm (std=0.28).

7623-24, Session 5

A new 3D tubular intensity model for quantification of thin vessels in 3D tomographic images

S. Wörz, H. von Tengg-Kobligk, K. Rohr, Ruprecht-Karls-Univ. Heidelberg (Germany)

We introduce a new 3D curved tubular intensity model in conjunction with a model fitting scheme for accurate segmentation and quantification of thin vessels in 3D tomographic images. The curved tubular model is formulated based on principles of the image formation process, and we have derived an analytic solution for the model function. In contrast to previous straight models, the new model allows to accurately represent curved tubular structures, to directly estimate the local curvature by model fitting, as well as to more accurately estimate the shape and other parameters of tubular structures. We

have successfully applied our approach to 3D synthetic images as well as 3D MRA and 3D CTA vascular images of the human. It turned out that we achieved more accurate segmentation results in comparison to using a straight model.

7623-25, Session 5

Imaging the brain's connectome

J. W. Lichtman, Harvard Univ. (United States)

Connectional maps of the brain may have value in developing models of both how the brain works and how it fails when subsets of neurons or synapses are missing or misconnected. Such maps might also provide the first detailed information about how brain circuits develop and age. I am especially eager to obtain such maps from the developing nervous system because of a longstanding interest in the neuromuscular circuit changes during mammalian early postnatal life. In the neuromuscular system most axonal input to muscle fibers is pruned in early postnatal life. This so called 'synapse elimination' may be part of the process whereby the nervous system molds itself to a particular epigenetic landscape. The loss is driven by competition between multiple axons that temporarily share the same junction. The amount of resources available to each axon at a particular synapse may influence the competitive outcome. Because each axon has many branches all competing roughly at the same time, the resources available at one site are likely affected by the outcome of synaptic competitions at other neuromuscular junctions that are innervated by the same axons. We have developed techniques to observe all these synaptic interactions at different sites simultaneously by computer assisted axonal tracing and the generation of transgenic mice in which different axons are labeled different colors. These Brainbow mice (Livet et al., 2007) give us an opportunity to see the entire connectional maps (or 'connectomes') for muscles and other neuronal circuits. Thin sectioning is required however to disambiguate the many overlapping axons. My colleagues Ken Hayworth and N. Bobby Kasthuri have developed a new kind of microtome (and an electron imaging strategy) that allows automated high resolution imaging of thousands of ultra thin (<30 nm) sections that are very large (~4 mm2). This approach aims at making large scale serial microscopic analysis of volumes routine.

7623-26, Session 6

Artifact aware tracking of left ventricular contours in 3D ultrasound

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Analysis of echocardiograms, whether visual or quantitative, has traditionally been complicated by ultrasound artifacts such as reverberations and shadowing. These artifacts often obscure parts of the myocardial wall, causing difficulties in motion detection. In this study, a novel method is presented to recognize these artifacts, to accurately track left ventricular (LV) borders in three-dimensional images. A fast expectation-maximization method is used to distinguish between visible and artifact-obscured myocardium. This algorithm assigns probabilities to image voxels, to separate stationary (artifact) and moving (cardiac) components. In areas where the myocardium is obscured by artifacts, the LV motion is inferred from surrounding myocardium which is clearly visible, using a tracking method which integrates a statistical model of cardiac motion. In regions where the myocardium is visible, the motion detection relies more on a data-driven optical flow approach. Tracking using the proposed probabilistic scheme is compared with a tracking approach which does not distinguish between visible and obscured myocardium. Evaluation on 35 three-dimensional clinical-quality sequences reveals a considerable improvement in tracking results. Point-to-surface errors decrease from 1.49±0.52 to 1.19±0.47mm (p<<0.01). Also, smaller volume (3.9±8.0 vs. 1.4±6.7ml) and ejection fraction (4.8±5.5 vs. 0.9±4.8%) errors are found. The results using the proposed tracking approach compare very favorably with those in the literature. To conclude, the new method allows more accurate tracking, by taking into account the visibility of the myocardium. Since in vivo images often contain ultrasound artifacts, we anticipate that this method will aid in the quantitative analysis of echocardiograms in the clinical setting.

7623-27, Session 6

Classification in medical images using adaptive metric KNN

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This paper presents a new approach to perform classification in medical images using adaptive metric k-nearest neighbors (KNN) algorithm. A distance function is needed in order to identify the k nearest neighbors in feature space, and the standard Euclidean distance is commonly used. Instead of using the standard Euclidean distance, we propose to use the Mahalanobis distance metric so that the structure of samples is better represented. The covariance matrix of Mahalanobis distance can be estimated in different ways. In this paper, Mahalanobis distance metrics based on three different covariance matrices are estimated for our proposed adaptive metric KNN: the empirical covariance matrix based on the data set itself, the theoretical covariance matrix based on Brownian Image Model (BIM), and a novel optimized covariance matrix obtained by minimizing a smooth energy function. In order to validate this approach, a set of leave-one-out experiments have been performed on cardiovascular disease (CVD) data and mammogram data. The results show that the proposed adaptive metrics improve on the standard Euclidean one, especially for CVD data, where the empirical, theoretical and even preliminary optimized metric KNN classifiers have better areas under ROC curve (AUC) of 0.9137, 0.9023 and 0.8902 respectively, as compared to 0.8270 from the standard Euclidean one.

7623-28, Session 6

Partial volume correction for volume estimation of liver metastases and lymph nodes in CT scans using spatial subdivision

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In oncological therapy monitoring, the estimation of tumor growth from consecutive CT scans is an important aspect in deciding whether the given treatment is adequate for the patient. This can be done by measuring and comparing the volume of a lesion in the scans based on a segmentation. However, simply counting the voxels within the segmentation mask can lead to significant differences in the volume, if the lesion has been segmented slightly different by various readers or in various scans, due to the limited spatial resolution of CT and due to partial volume effects.

We present a novel algorithm for measuring the volume of liver metastases and lymph nodes which considers partial volume effects at the surface of a lesion. Our algorithm is based on a spatial subdivision of the segmentation. We have evaluated the algorithm on a phantom and a multi-reader study. Our evaluation has shown, that our algorithm allows determining the volume more accurately even for larger slice thicknesses. Moreover it reduces inter-observer variability of volume measurements significantly. The calculation of the volume takes 2 seconds for a 50³ voxels on a single 2.66GHz Intel Core2 CPU.

7623-29, Session 6

Microaneurysms detection with the radon cliff operator in retinal fundus images

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Diabetic Retinopathy (DR) is one of the leading causes of blindness in Western countries. Early detection is key to provide effective treatment. However, the current number of trained ophthalmologists is not enough to screen the increasing number of diabetic patients. In these years, automatic and semi-automatic systems to detect DR with color fundus images have been developed with encouraging, but not fully satisfactory results. In this study we present the initial results of a new technique for the detection and localization of microaneurysms, the very first sign of DR.

The algorithm is based on two steps, a background removal process that employs wavelets and the actual microaneurysms detection. In this second phase, we introduce the new Radon Cliff operator which is our main contribution to the field. Making use of the Radon transform, the operator is able to detect single noisy Gaussian-like circular structures regardless of their size or position in a window. The advantages over existing microaneurysms detectors are manifold: the size of the lesions can be unknown, it automatically distinguishes lesions from the vasculature and it provides a fair microaneurysms localization even without post-processing the candidates with machine learning techniques, facilitating the training phase.

The algorithm performance will be evaluated on an internal collection of images from a telemedicine network and another publicly available dataset.

7623-30, Session 6

Liver segmentation through combined EM clustering and GVF level sets over registered multiphase CT data sets

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In this study, clinical multiphase CT volumetric data sets are exploited to transcend the intrinsic limitations of single phase data sets for the robust and accurate segmentation of the liver in typically challenging cases. First, single phase volumes are registered to the arterial phase volume by a symmetric nonlinear registration method using mutual information as similarity metric. Once registered, the multiphase volumes are resampled and filtered through anisotropic diffusion. Under the assumption that the intensity vectors of different organs follow the Gaussian Mixture model, expectation maximization (EM) is then used to classify multiphase voxels into different clusters. The clusters for liver parenchyma, vessels and tumors are combined together and morphologically processed to provide the initial liver mask. This mask is then used to generate initial zeros level set and to reduce leakage in subsequent segmentation steps. Conversely, the voxels classified as non-liver by the EM algorithm are used to create a non-liver mask that will also guide the level sets for reducing leakage. Finally, geodesic level set using gradient vector flow (GVF) derived from the pre-contrast image is performed to extract the final liver segmentation estimate. The proposed method has been tested on several clinical datasets with relatively complex and/or extensive liver cancer or metastases. When compared to manual expert segmentation, a 94.1% dice similarity index demonstrates the performance and robustness of the proposed method - even for challenging cancer datasets - and confirms the potential of a more thorough computational exploitation of clinically available data sets.

7623-31, Session 6

Electric field theory based approach to search-direction line definition in image segmentation: application to optimal femur-tibia cartilage segmentation in knee-joint 3D MR

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Objective: Inspired by properties of electric field direction lines, a novel method is presented for definition of search lines in a variety of surface segmentation approaches. These search lines are 1) non-intersected, 2) easy to compute and 3) avoiding mis-segmentation due to the searching direction by expanding to any positions in the space. These properties are applicable to general-purpose n-D shape-based image segmentation tasks. Method: Its utility is demonstrated in graph construction and optimal segmentation of multiple mutually interacting objects. The properties of the electric field-based graph construction guarantee that inter-object graph connecting lines are non-intersecting and inherently covering the entire object-interaction space. When applied to inter-object cross-surface mapping, our approach generates one-to-one and all-to-all vertex correspondent pairs between the regions of mutual interaction. Experiments: We demonstrate the benefits of the electric field approach in examples ranging from relatively simple single-surface segmentation to complex multi-object multi-surface segmentation of femur-tibia cartilage. These optimal graph-based surface segmentation examples include: 1)iterative tibial surface detection and 2)fully automated femur-tibia cartilage segmentation. Results: The performance of our approach is first compared with graphs constructed from traditional normal-direction columns, in which our approach showed statistically significant improvement ($p<0.001$) when the new search lines were used. Then the performance is demonstrated in 30 MR images from the Osteoarthritis Initiative (OAI), in which our approach achieved a very good performance as judged by surface positioning errors (averagely 0.1 and 0.5 mm for signed and unsigned cartilage positioning errors respectively).

7623-32, Session 7

WCE video segmentation using textons

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Wireless Capsule Endoscopy (WCE) integrates wireless transmission with image and video technology. It has been used to examine the small intestine non invasively. WCE uses a small capsule whose front-end has an optical dome where a light illuminates the luminal surface of the intestine, and a colour camera sends images to a receiver worn by the patient. The camera takes 2 pictures per second. The stored data consist of about 50000 images. Medical specialists look for signicative events in the WCE video by direct visual inspection manually labelling, in tiring and up to one hour long sessions, clinical relevant frames. This limits the WCE usage. To automatically discriminate digestive organs such as esophagus, stomach, small intestine and colon is of great advantage. Mostly relevant is to find event boundaries that indicate either entrance to the next organ or to find unusual events within the same organ, such as bleedings, intestinal juices or obstructions, etc. All of these events are characterized by a sudden change in the video. In this paper we propose to use textons for the automatic discrimination of abrupt changes within a video. In particular, we consider, as features, for each frame hue, saturation, value, high-frequency energy content and the responseso to a bank of Gabor filters. The experiments have been conducted on 20 video segments extracted from WCE videos, in which the signicative events have been previously labelled by experts. Results have shown that the proposed method may eliminate up to 70% of the frames from further investigations.

7623-34, Session 7

Identification of post-menopausal patients with hip fracture by application of the radon transform to clinical radiographs of the proximal femur using three regions of interest

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Osteoporosis is a chronic condition characterized by demineralization and destruction of bone tissue. Fractures associated with the disease are becoming an increasingly relevant issue for public health institutions. Prediction of fracture risk is a major focus research and, over the years, has been approched by various methods.

Still, bone mineral density (BMD) obtained by dual-energy X-ray absorptiometry (DXA) remains the clinical gold-standard for diagnosis and follow-up of osteoporosis. However, DXA is restricted to specialized diagnostic centers and there exists considerable overlap in BMD results between populations of individuals with and without fractures. Clinically far more available than DXA is conventional x-ray imaging depicting trabecular bone structure in great detail.

In this paper, we demonstrate that bone structure depicted by clinical radiographs can be analysed quantitatively by parameters obtained from the Radon Transform (RT). RT is a global analysis-tool for detection of predefined, parameterized patterns, e.g. straight lines or struts, representing suitable approximations of trabecular bone texture.

The proposed algorithm differentiates between patients with and without fractures of the hip by application of various texture-metrics based on the Radon-Transform to standard x-ray images of the proximal femur. We consider three different regions-of-interest in the proximal femur (femoral head, neck, and inter-trochanteric area), and conduct an analysis with respect to correct classification of the fracture status. Performance of the novel approach is compared to DXA.

We draw the conclusion that performance of RT is comparable to DXA and may become a useful supplement to densitometry for the prediction of fracture risk.

7623-35, Session 7

Retinal atlas statistics from color fundus images

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An atlas provides a reference anatomic structure and an associated coordinate system. An atlas may be used in a variety of applications, including segmentation and registration, and can be used to characterize anatomy across a population. We present a method for generating an atlas of the human retina from 500 color fundus image pairs. Using color fundus image pairs, we register image pairs to obtain a larger anatomic field of view. Key retinal anatomic features are selected for atlas landmarks; disk center, fovea, and vessel main arcade. An atlas coordinate system is defined based on the statistics of the landmarks. Images from the population are warped into the atlas space to produce a statistical retinal atlas which can be used automatic diagnosis, concise indexing, semantic blending, etc.

7623-36, Session 7

Automatic landmark detection and scan range delimitation for topogram images using hierarchical network

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The topogram is a 2D projection image of human body formed using a Computed Tomography (CT) scanner. It could be used to delimitate the desired scan range for further precise 3D CT scan. In this paper, we present a robust and efficient system for automatically determining scan ranges and their associated anatomical landmarks for topogram images. The system could handle the cases when only about 50% of the desired regions are visible. The robustness of our system can be attributed to three key ingredients:

1. The detection is based on a hierarchical network, which follows naturally the human perception: in the high level, regions are dominant and the network contains only a few nodes corresponding to anatomical regions like thorax and pelvis; while in the low level, each anatomical region has its associated local landmark network.

2. Network optimization is based on sequentially optimizing a set of subnetworks. This implementation is more efficient and scalable. In addition, the belief propagation from reliable landmarks to unreliable landmarks makes the solution more robust to noisy detection.

3. The detection probability is further refined based on the detection context, thus provides a more faithful measurement for the unary potential used in the MRF network. Extensive experiments (including external testing) on over 1000 topogram images show that our approach works robustly and efficiently even on very challenging data.

7623-37, Session 7

Graph-based pigment network detection in skin images

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Dermatoscopy, also known as dermoscopy is a simple and inexpensive diagnostic imaging technique that offers a completely new range of visual features. One such prominent feature is the pigment network which is one of the most important features used for making decision about the malignancy of a skin tumor. In this paper, we present a novel graph-based pigment network detection method that can find and visualize round structures belonging to the pigment network. After finding sharp changes of the intensity in the blue channel of an RGB image by an edge detection function (Laplacian of Gaussian), the result binary image is converted to a graph, and then all cyclic sub-graphs are detected. Theses cycles represent meshes that belong to the pigment network. After removing noise (undesired round structures such as globules and dots), we create a new graph of the cyclic structures based on their distance. According to the density ratio of the new graph of the pigment network, the image is classified as "Absent" or "Present". Being "Present" means that a pigment network is detected in the skin lesion. We validated the method by classifying and visualizing the pigment network structure and achieve a classification accuracy of 92.6% on the 2-class problem ("Absent" or "Present").

7623-38, Session 7

cervigram image segmentation based on reconstructive sparse representations

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We proposed an approached based on reconstructive sparse representations to segment tissues in optical images of the uterine cervix. Due to large variations in image appearance caused by the changing of illumination and specular reflection, the color and texture features in optical images are often overlapped with each other and not linearly separable. By leveraging sparse representations the data can be transformed to higher dimension with sparse constraints and become more separated. K-SVD algorithm is employed to find sparse representations and corresponding dictionaries. The data can be reconstructed from its sparse representations and positive and/or negative dictionaries.

Classification can be achieved based on comparing the reconstructive errors. In the experiments we applied our method to automatically segment the biomarker AcetoWhite (AW) regions in an archive of 60,000 images of the uterine cervix. Cervigram images from the NCI/NLM archive with multiple-expert boundary markings are available for training and validation purposes. 100 images of diverse appearance were selected for training and testing. 90 randomly selected images are used for training and the remaining 10 are used for testing and validation. Compared with other popular methods, our approach showed lower space and time complexity and higher sensitivity.

7623-140, Session 7

A weighted mean shift, normalized cuts initialized color gradient based geodesic active contour model: applications to histopathology image segmentation

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One major issue for active contour models is their sensitivity to initialization. In this paper, we present a weighted mean shift based normalized cut (WM-Ncut) initialization scheme for automated initialization of a geodesic active contour (GAC) model. A second limitation of edge-based active contour models is that the stopping function is usually defined as the gradient of the gray scale image. When applied to color images, the gray scale gradient results in broken edges and weak boundaries presented in this paper due to the lose of edge information from the other channels during the conversion process. The methodology involves first defining a color swatch (typically a few pixels) from the object of interest. A new weighted mean shift scheme coupled with the popular normalized cuts algorithm then yields rapidly an initial accurate detection of all objects in the scene corresponding to the color swatch. This detection result provides the initialization for a Geodesic Active Contour (GAC) which employs a local structure tensor based color gradient approach, which calculates the local min/max variations of contribution from each image channel. In this paper, we demonstrate the applicability of our scheme to segmenting histopathological imagery. We evaluate our new GAC on three different problems related to histological imagery: segmenting the lumen of the prostate, cancer nuclei in ovarian cancer samples, and lymphocytes in breast biopsy samples, respectively. The results of qualitative and quantitative evaluation for the problem of segmenting lymphocytes on 14 breast cancer histology images reveals that our scheme easily outperforms randomly initialized GAC models. Additionally, the GAC model using the color gradient approach yields a better segmentation result compared to a GAC with gray scale gradient.

7623-04, Poster Session

Segmentation of lymph node regions in head-and-neck CT images using a combination of registration and active shape model

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Segmenting the lymph node regions in head-and-neck CT images has been a challenging topic in the area of medical image segmentation. The method proposed herein implements an atlas-based technique constrained by an active shape model (ASM) to segment the level II, III and IV lymph nodes as one single structure. A comparative study performed on 15 data sets shows that the results obtained with this technique are better than those obtained with a pure atlas-based

segmentation method, in particular in regions of poor contrast.

7623-62, Poster Session

A groupwise mutual information metric for cost efficient selection of a suitable reference in cardiac computational atlas construction

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Computational atlases based on nonrigid registration have found much use in the medical imaging community.

To avoid bias to any single element of the training set, there are two main approaches: using a (random) subject to serve as an initial reference and posteriorly removing bias, and a true groupwise registration with a constraint of zero average transformation. Major drawbacks are the possible selection of an outlier on one side, potentially leading to problems with registration performance, and a final approximation of the average image in which the structure of interest is not at all like the population average, or on the other hand a prohibitive computational load.

We propose an inexpensive means of reference selection based on a groupwise correspondence measure which avoids the selection of outliers. Thus, it improves tractability of reference selection and robustness of automated atlas construction.

7623-63, Poster Session

Effect of inter-subject variation on the accuracy of atlas-based segmentation applied to human brain structures

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It has been shown that there are large variations in brain anatomical structures in human populations presenting a critical challenge to brain mapping process. This study investigates the major impact of these variations on the performance of atlas-based segmentation. It is based on two publicly available datasets[1], from each of which 17 T1-weighted brain atlases were extracted. Each subject was registered to every other subject using the Morphons[2]. The automatic segmentations, obtained by warping the segmentation of this template, were compared with the expert segmentations using Dice metric and the differences were statistically analyzed using Bonferroni multiple comparisons at significance level 0.05. The results showed that an optimum atlas for accurate segmentation of all structures cannot be found, and that the group of preferred templates, defined as being significantly superior to at least two other templates regarding the segmentation accuracy, varies significantly from structure to structure. Moreover, compared to other templates, a template giving the best accuracy in segmentation of some structures can provide highly inferior segmentation accuracy for other structures. It is concluded that there is no template optimum for automatic segmentation of all anatomical structures in the brain because of high inter-subject variation. Using a single fixed template for brain segmentation does not lead to good overall segmentation accuracy. This proves the need for multiple atlas based solutions in the context of atlas-based segmentation on human brain.

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7623-64, Poster Session

An analysis of methods for the selection of atlases for use in medical image segmentation

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The use of atlases has been shown to be a robust method for segmentation of medical images. In this paper we explore different methods of selection of atlases for the segmentation of the quadriceps muscles in MR images, although the results are pertinent for a wide range of applications. First, a set of readers were assigned the task of selecting atlases from a training population of images which were felt to be representative subgroups of the total population. This task was performed with no external knowledge besides the end goal of segmentation. Second, the same readers were given a subset of the training population stratified into modes of the population from which to select templates. Finally, every image in the training set was employed as an atlas, with no input from the readers, and the atlas which had the best initial registration, judged by an appropriate registration metric, was used in the final segmentation procedure. The results show that, for four out of five readers, the inclusion of modal information into the atlas selection process improved the final segmentation. However, the use of every image in the training set as an atlas far outperformed the manual atlas selection method, whether with or without modal information.

7623-65, Poster Session

Combining morphometric evidence from multiple registration methods using Dempster-Shafer theory

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In tensor-based morphometry (TBM) group-wise differences in brain structure are measured using deformable registration and some form of statistical test. However, it is known that TBM results are sensitive to both the registration method and statistical test used. Given the lack of an objective model of group variation is it difficult to determine a best registration method for TBM. The use of statistical tests is also problematic given the corrections required for multiple testing and the notorious difficulty in selecting and interpreting significance values. This paper presents an approach to address both of these issues by combining multiple registration methods using Dempster-Shafer evidence theory to produce belief maps of categorical changes between groups. This approach is used to compare brain morphometry in aging, a typical application of TBM, using the Jacobian determinant as a measure of volume change. We show that the Dempster-Shafer combination produces a unique and easy to interpret belief map of regional changes between and within groups without the complications associated with hypothesis testing.

In this paper, we demonstrate that for the same data set, emph{TBM results obtained from using various registration methods are not identical}. Thus, in the absence of an objective measure to systematically chose one registration method over another, considering results from only one registration method will present an incomplete picture. In this paper, emph{we propose a method to integrate the information from multiple registration methods using the Dempster-Shafer evidence theory}. By treating the various registration methods as independent, imprecise and conflicting information sources our method acts as an information fusion tool. This tool represents change as belief maps, reducing the ambiguity and subjectivity in interpreting results from a study and allows for easy incorporation of prior knowledge.

7623-66, Poster Session

T1- and T2-weighted spatially constrained fuzzy C-means clustering for brain MRI segmentation

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The segmentation of brain tissues in magnetic resonance imaging (MRI) plays an important role in clinical analysis and is useful for many applications including studding brain diseases, surgical planning, computer assisted diagnoses, etc. In general, accurate tissue segmentation is a difficult task, not only because of the complicated structure of the brain, but also because of the presence of noise and low tissue contrasts in the MRI images, especially in neonatal brain images.

Fuzzy clustering techniques have been widely used in automated image segmentation. However, since the standard fuzzy c-means (FCM) clustering algorithm does not consider any spatial information, it is highly sensitive to noise. In this paper, we present a novel extension of the FCM algorithm to overcome this drawback, by combining information from both T2-weighted (T2-w) and T1-weighted (T1-w) MRI scans and by incorporating spatial information. This new spatially constrained FCM (SCFCM) clustering algorithm better preserves the homogeneity of the regions than existing FCM techniques, which often have difficulties when tissues are overlapping in intensity.

The performance of the proposed algorithm is tested on simulated and real adult MRI with different noise levels, as well as on neonatal MR brain images with the gestational age of 39 weeks. Experimental quantitative and qualitative segmentation results show that the proposed method is effective and more robust to noise than other FCM-based methods. SCFCM appears as a very promising tool for complex and noisy image segmentation of neonatal brain.

7623-67, Poster Session

3D tensor-based blind multispectral image decomposition for tumor demarcation

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Blind decomposition of multi-spectral fluorescent image for tumor demarcation is formulated exploiting tensorial structure of the image. First contribution of the paper is identification of the matrix of spectral responses and 3D tensor of spatial distributions of the materials present in the image from Tucker3 or PARAFAC models of 3D image tensor. Second contribution of the paper is clustering based estimation of the number of the materials present in the image as well as matrix of their spectral profiles. 3D tensor of the spatial distributions of the materials is recovered through 3-mode multiplication of the multi-spectral image tensor and inverse of the matrix of spectral profiles. Tensor representation of the multi-spectral image preserves its local spatial structure that is lost, due to vectorization process, when matrix factorization-based decomposition methods (such as non-negative matrix factorization and independent component analysis) are used. Superior performance of the tensor-based image decomposition over matrix factorization-based decompositions is demonstrated on experimental low-intensity red-green-blue fluorescent images of the skin tumor (basal cell carcinoma).

7623-68, Poster Session

Knowledge-based quantification of pericardial fat in non-contrast CT data

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Recent studies show that pericardial fat is associated with vascular calcification and cardiovascular risk factors. It is imaged with

Computed Tomography (CT) as part of coronary calcium scoring but it is not included in routine clinical analysis due to lack of automatic tools for fat quantification. Previous attempts to create such an automated tool have the limitations of either assuming a preset threshold or a Gaussian distribution for fat. In order to overcome these limitations, we present a novel approach of using a classification-based method to discriminate fat from other tissues. The classifier is constructed from three binary SVM classifiers trained separately for multiple tissues (fat, muscle/blood and calcium), and a specific code word is assigned to each tissue type based on the number of classifiers. The decisions of these binary classifiers are combined and compared with previously determined code words using a minimum hamming decoding distance to identify fat. We also present an improved method for detection of a compact region-of-interest around the heart to reduce the number of false positives due to neighboring organs. The proposed classifier method attained a maximum overlap of 0.87, and an average overlap of 0.76 with expert annotations when tested on unseen data from 36 subjects. The present classification method can be improved by identifying additional discriminative features for fat and muscle/blood separation, or by using more advanced classification approaches such as cascaded classifiers to reduce the number of false detections.

7623-69, Poster Session

Quantification of myocardial perfusion stress-rest change using one-class clustering

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The aim of this work is to accurately quantify myocardial perfusion stress-rest changes in myocardial perfusion SPECT (MPS) studies for detection of coronary artery disease (CAD). 997 rest/stress 99mTc MPS studies, (651 consecutive cases with correlating angiography and 346 with < 5% likelihood (LLk) of CAD) were used in our study. In this application, abnormal changes can have large variations with regard to the extent and location of defects but the normal studies are relatively uniform. Therefore, the normal database consisting of additional LLk patients (40 females 40 males) were used as a one-class training data for modeling the detection of CAD. Initially, pairs of stress and rest images were co-registered and normalized to each other. Change polar maps of the left ventricle were then generated for each case in the normal database. The normal database consisted of change values for each radial coordinate of the polar map corresponding to each patient. One-class clustering attempts to find a useful subset by locating a dense region in the data. We attempt to model a dense region within the normal database by globally searching for a cluster with minimal cost defined by the average distance of all cluster points from a cluster representative. On the 997 cases, the area under the receiver-operating-characteristic curve was 0.91 using one-class cluster analysis. One-class cluster analysis resulted in a value of 83% for both sensitivity and specificity. In conclusion, one-class cluster analysis is a promising approach when training can be perfromed only on normal datasets.

7623-70, Poster Session

Automated detection of grayscale bar and distance scale in ultrasound images

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Computer assisted diagnosis algorithms are evaluated by testing them against wide-ranging sets of images arising from real clinical conditions. To assemble a sufficiently large and comprehensive data set, one may need to aggregate images acquired with different equipment, magnification, calibration procedures, etc. These variations need to be accounted for when comparing image pixel intensities and distances in such a heterogeneous data set. Detection of the distance scale and the reference grayscale present in most ultrasound images

can be used to automate the process of calibrating physical per-pixel distances and grayscale normalization over a heterogeneously acquired ultrasound datasets.

This work presents novel methods for automated detection of (i) the distance scale and the spacing between its gradations, (ii) the reference grayscale along with the identification of discrete intensities therein. The distance scale is detected by searching for regular peaks in the 1-D autocorrelation of image pixel columns. The grayscale bar is detected by searching for contiguous sets of columns with long sequences of monotonically changing intensity. In tests on over 1000 images the distance scale and gradation spacing detection rate was 95% and reference grayscale detection rate was 100%. A confidence measure is also introduced to indicate the certainty of the distance scale detection. An optimal confidence threshold for flagging low-confidence results for human intervention was established through ROC curve analysis.

7623-71, Poster Session

CT slice localization via instance-based regression

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Automatically determining the relative position of a single CT slice within a full body scan provides several useful functionalities. For example, it is possible to validate DICOM meta-data information. Furthermore, knowing the relative position in a scan allows the efficient retrieval of similar slices from the same body region in other volume scans. Finally, the relative position is often an important information for a non-expert user having only access to a single CT slice of a scan. In this paper, we determine the relative position of single CT slices via instance-based regression without using any meta data. Each slice of a volume set is represented by a feature vector that is computed from a sequence of image conversions and edge detection routines on rectangular subregions of the slices. Our new method is independent from the settings of the CT scanner and provides an average localization error of less than 4.5cm using cross-validation on a data set of 34 annotated volume scans. Thus, we demonstrate that instance-based regression is a suitable tool for mapping single slices to a standardized coordinate system and that our algorithm is competitive to other volume-based approaches with respect to runtime and prediction quality, even though only a fraction of the input information is required in comparison to other approaches.

7623-72, Poster Session

A robust model order estimation and segmentation technique for tissue classification

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The difficult problem of identifying dominant structures in unknown data sets has been elegantly addressed by a non-parametric information theoretic approach, the Jump method [1], which employs a suitable transformation function to the distortion rate curve, $D(R)$, estimated by the popular K means algorithm. Although this approach yields excellent results asymptotically for higher dimensional spaces, in many practical cases involving lower dimensional spaces, the above transformation function that applies a fixed power may not find the correct model order. The work presented here develops an objective function to derive a more suitable transformation function that minimizes classification error in low dimensional data sets. In addition, a number of carefully chosen initialization and pre-clustering methods have been applied to enhance the detection sensitivity and to provide more accurate yet fast estimation. The proposed method has been evaluated for a large variety of datasets and compared with the original

Jump method and other well-known methods such as Minimum Description Length (MDL), Bayes Information Criterion (BIC), and Consistent Akaike Information Criteria (CAIC), demonstrating superior performance of our modified Jump method. Our algorithm has been validated with the Wisconsin Diagnostic Breast Cancer Dataset [2], and the comparative results have been included. This modified information theoretic approach to model order estimation is expected to improve diagnostic classification and detection of cancerous and pre-cancerous lesions from uterine cervix images [3].

7623-73, Poster Session

Classification of cognitive states using functional MRI data

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A fundamental goal of the analysis of fMRI data is to locate areas of brain activation that can differentiate various cognitive tasks. Traditionally, researchers have approached fMRI analysis through characterizing the relationship between cognitive variables and individual brain voxels. In recent years, multivariate approaches (analyze more than one voxel at once) to fMRI data analysis have gained importance. But in majority of the multivariate approaches, the voxels used for classification are selected based on prior biological knowledge or discriminating power of individual voxels. We used sequential floating forward search (SFFS) feature selection approach for selecting the voxels and applied it to distinguish the cognitive states of whether a subject is doing a reasoning or a counting task. We obtained superior classifier performance by using the sequential approach as compared to selecting the features with best individual classifier performance. We analyzed the problem of over-fitting in this extremely high dimensional feature space with limited training samples. For estimating the accuracy of the classifier, we employed various estimation methods and discussed their importance in this small sample scenario.

7623-74, Poster Session

Surface smoothness: cartilage biomarkers for knee OA beyond the radiologist

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Fully automatic imaging markers may allow quantification of patho-physiological processes that a radiologist would not be able to assess reliably. This can introduce new insight but is problematic to validate due to lack of meaningful ground truth expert measurements. Rather than quantification accuracy, such novel markers must therefore be validated against clinically meaningful end-goals such as the ability to allow correct diagnosis.

We included 170 scans in this study from the low-field MRI. The scans were segmented by a radiologist by slice-wise delineation and automatically using a voxel classification approach. We present a method for automatic cartilage surface smoothness quantification in the knee joint. The quantification is based on a mean curvature flow method used on the medial tibial and femoral cartilage compartments. These smoothness estimates are validated for their ability to diagnose osteoarthritis and compared to smoothness estimates based on manual expert segmentations and to conventional cartilage volume quantification. We demonstrate that the fully automatic markers eliminate the time required for radiologist annotations, and in addition provide a diagnostic marker superior to the evaluated semi-manual markers. The marker has highest diagnostic ability in tibial and central femoral compartments.

7623-75, Poster Session

Changes of MR and DTI appearance in early human brain development

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Understanding myelination in early brain development is of clinical importance, as many neurological disorders have their origin in early cerebral organization and maturation. The goal of this work is to study a large neonate database acquired with standard MR imagery to illuminate effects of early development in MRI.

For this study 90 subjects were selected from a study of neonatal brain development in controls. All subjects were subjected to MR imagery a few weeks postnatally. MR acquisition included high-resolution structural and diffusion tensor images.

Unbiased atlases for structural and DTI data were generated and co-registered into the a single coordinate frame for voxel-wise comparison. All datasets were mapped into this frame and structural data was additionally intensity normalized. We also mapped myelinated white matter probabilistic segmentations from our neonate tissue segmentation to study how our segmentation results were affected by the changing intensity characteristics in early development. Linear regression maps and p-value maps were computed and visualized.

The resulting visualization of voxels-wise corresponding maps of all MR and DTI properties captures early development information in MR imagery, which we are currently in the process of interpreting. Surprisingly, we encountered regions of seemingly decreased myelinated WM probability over time even though we expected a confident increase for all of the brain. The regressional visualizations indicate that this is an effect of intensity changes in the T1w and T2w images due not solely to myelination but also likely brain "dehydration" processes in early postnatal development.

7623-76, Poster Session

Evaluation of DTI property maps as basis of DTI atlas building

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Compared to region of interest based DTI analysis, voxel-based analysis gives higher degree of localization and avoids the procedure of manual delineation with the resulting intra and inter-rater variability. One of the major challenges in voxel-wise DTI analysis is to get high quality voxel-level correspondence. For that purpose, current DTI analysis tools are building on nonlinear registration algorithms that deform individual datasets into a template image that is either precomputed or computed as part of the analysis. A variety of matching criteria and deformation schemes have been proposed, but often comparative evaluation is missing. In our opinion, the use of consistent and unbiased measures to evaluate current DTI procedures is of great importance and our work presents two possible measures.

Specifically, we propose the evaluation criteria generalization and specificity, originally introduced by the shape modeling community, to evaluate and compare different DTI nonlinear warping results. These measures are of indirect nature and have a population wise view. Both measures incorporate information of the variability of the registration results in the template space via a voxel-wise PCA model.

Thus far, we have used these measures to evaluate our own DTI analysis procedure employing fluid registration on scalar DTI maps. Generalization and specificity from fractional anisotropy (FA) maps as well as from tensor images in the template space were computed for 8 scalar property maps. We found that for our procedure an intensity-normalized FA feature outperformed the other scalar measurements. Also, using the tensor images rather than the FA maps as a comparison frame seemed to produce more robust results. In our necessary next

steps we will compare our procedure against other ones using these same approaches.

7623-77, Poster Session

Assessing fiber tracking accuracy via diffusion tensor software models

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In the last few years, clinicians have started using fiber tracking algorithms for pre- and intraoperative neurosurgical planning. In the absence of a ground truth, it is often difficult to asses the validity and precision of these algorithms. To this end, we develop a realistic DTI software model in which any number of fiber bundles may be specified, also allowing for scenarios in which fiber bundles cross or kiss and which are common bottlenecks of fiber tracking algorithms. Partial voluming, that is the contributions of multiple tissues to a voxel, is taken into account. The model gives us the possibility to compute the diffusion-weighted signal attenuation given certain tissue and scanner parameters. On the tissue side we can model the diffusion coefficients, the principal diffusion direction and the width of the fiber bundles. On the scanner side, we can model the diffusion time, the strength and direction of the applied diffusion gradient and the width of the diffusion pulse gradient. We also include the possibility to add noise and various artifacts such as aliasing and N/2 ghosting to the model. After specifying a fiber bundle, we determine the largest distance between the modeled fiber bundle and the tracked fibers, which because of accumulating errors is highly related to the distance of the fibers from the region which has been used to seed the tracking. Moreover, we give an indication about an appropriate safety margin for the tracked fiber bundle. Both measures are easily understood by a clinician.

7623-78, Poster Session

Automatic clustering of white matter fibers via symbolic sequence analysis

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Fiber clustering is a very important step towards tract-based quantitative analysis of white matter via diffusion tensor imaging (DTI). This work proposes a new computational framework for white matter fiber clustering based on a computational sequence analysis method. We first perform brain tissue segmentation in the DTI image space using multi-channel fusion method and parcellate the whole brain into anatomically labeled regions via a hybrid volumetric and surface warping algorithm. Then, we perform standard fiber tractography in the DTI image and encode each tracked fiber by a sequence of labeled brain regions. Afterwards, the similarity of any pair of anatomically encoded fibers is defined as the similarity of symbolic sequences, which is well studied and solved in the bioinformatics domain such as is used for gene and protein symbolic sequences comparisons. Finally, the well-known normalized graph cut algorithm is applied to cluster the fibers into bundles based on the above defined similarities between any pair of fibers. Our experiments show promising results for the proposed fiber clustering framework.

7623-79, Poster Session

Improving RESTORE for robust diffusion tensor estimation: a simulation study

L. Chang, The Catholic Univ. of America (United States)

Diffusion tensor magnetic resonance imaging (DT-MRI) is used more and more in clinical research and applications for its ability to depict white matter tracts and for its sensitivity to microstructural and architectural features of brain tissue. However, artifacts are common in clinical DT-MRI acquisitions. Signal perturbations produced by such artifacts can be severe and neglecting to account for their contribution can result in erroneous diffusion tensor values. The Robust Estimation of Tensors by Outlier Rejection (RESTORE) has been demonstrated to be an effective method for improving tensor estimation on a voxel-by-voxel basis in the presence of artifactual data points in the diffusion weighted images. Despite the very good performance of the RESTORE algorithm, there are some limitations and opportunities for improvement. Instabilities in tensor estimation using RESTORE have been observed in clinical human brain data. Those instabilities can come from the intrinsic high frequency spin inflow effects in non-DWIs or from excluding too many data points from the fitting. This paper proposed several practical constraints to the original RESTORE method. Results from Monte Carlo simulation indicate that the improved RESTORE method reduced the instabilities in tensor estimation observed from the original RESTORE method.

7623-80, Poster Session

White matter degeneration in schizophrenia: a comparative diffusion tensor analysis

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Schizophrenia is a serious and disabling mental disorder. Diffusion tensor imaging (DTI) studies performed on schizophrenia have demonstrated white matter degeneration either due to loss of myelination or deterioration of fiber tracts although the areas where the changes occur are variable across studies. Most of the population based studies analyze the changes in schizophrenia using scalar indices computed from the diffusion tensor such as fractional anisotropy (FA) and relative anisotropy (RA). The scalar measures may not capture the complete information from the diffusion tensor. In this paper we have applied the RADTI method on a group of 9 controls and 9 patients with schizophrenia. The RADTI method converts the tensors to log-euclidean space where a linear regression model is applied and hypothesis testing is performed between the control and patient groups. Results show that there is a significant difference in the anisotropy between patients and controls especially in the parts of forceps minor, superior corona radiata, anterior limb of internal capsule and genu of corpus callosum. To check if the tensor analysis gives a better idea of the changes in anisotropy, we compared the results with voxelwise FA analysis as well as voxelwise geodesic anisotropy (GA) analysis.

7623-81, Poster Session

Qualitative and quantitative analysis of probabilistic and deterministic fiber tracking

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Fiber tracking (FT) and quantification algorithms are approximations of reality due to limited spatial resolution, model assumptions, user-defined parameter settings, and physical imaging artifacts resulting from diffusion sequences. Until now, correctness, plausibility, and reliability of both FT and quantification techniques have mainly been verified using histologic knowledge and software or hardware phantoms. Probabilistic FT approaches aim at visualizing the uncertainty present in the data by incorporating models of the acquisition process and noise. The uncertainty is assessed by tracking many possible paths originating from a single seed point, thereby taking the tensor uncertainty into account. Based on the tracked paths, maps of connectivity probabilities can be produced, which may be used to delineate risk structures for presurgical planning.

In this paper, we explore the advantages and disadvantages of probabilistic approaches compared to deterministic algorithms and give both qualitative and quantitative comparisons based on clinical data. We focus on two important clinical applications, namely, on the reconstruction of fiber bundles within the proximity of tumors and on the quantitative analysis of diffusion parameters along fiber bundles. Our results show that probabilistic FT is superior and suitable for a better reconstruction at the borders of anatomical structures and is significantly more sensitive than the deterministic approach for quantification purposes. Furthermore, we demonstrate that an alternative tracking approach, called variational noise tracking, is qualitatively comparable with a standard probabilistic method, but is computationally less expensive, thus, enhancing its appeal for clinical applications.

7623-82, Poster Session

3D motion analysis of keratin filaments in living cells

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We present a novel and efficient approach for the 3D motion estimation of keratin intermediate filaments in vitro. Keratin filaments are elastic cables forming a complex scaffolding within epithelial cells. To understand the mechanisms of filament formation and network organisation under physiological and pathological conditions, quantitative measurements of dynamic network alterations are essential. Therefore we acquired time lapse series of 3D images using a confocal laser scanning microscope. Based on these image series, we show that a dense vector field can be computed such that the displacements from one frame to the next can be determined.

Our method is based on a two-step registration process: First, a rigid pre-registration is applied in order to compensate for possible global cell movement. This step enables the subsequent nonrigid registration to capture only the sought local deformations of the filaments. As the transformation model of the deformable registration algorithm is based on Free Form Deformations, it is well suited for modeling the flexibility of a filament. The optimization is performed using efficient linear programming techniques such that the huge amount of image data of a time series can be efficiently processed.

The evaluation of our results illustrates the potential of our approach.

7623-83, Poster Session

3D motion tracking of the heart using Harmonic Phase (HARP) isosurfaces

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Tags are non-invasive features implanted in the heart muscle that enable the tracking of heart motion. Every tag line, in fact, corresponds to a 3D tag surface that deforms with the heart muscle during the cardiac cycle. Tracking of tag surfaces deformation is useful for the analysis of left ventricular (LV) motion. Cardiac material markers (Kerwin et al, IPMI, 1997) can be obtained from the intersections of orthogonal surfaces which can be reconstructed from short- and long- axis tagged images. The proposed method uses Harmonic Phase (HARP) method for tracking tag lines, then the reconstruction of grid tag surfaces is achieved by a Delaunay triangulation-based interpolation for sparse tag points corresponding to a specific harmonic phase value. Having three different tag orientations from short- and long- axis images, the proposed method showed the deformation of 3D tag surfaces during the cardiac cycle. Previous work on tag surface reconstruction was restricted for the dark tag lines; however, using the HARP in our method enables the reconstruction of iso-surfaces based on their harmonic phase values. The use of HARP, also, provides a fast and accurate way for tag lines identification and tracking, and hence, generating the surfaces.

7623-84, Poster Session

Development of a particle filter framework for respiratory motion correction in Nuclear Medicine Imaging

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With recent improvements in scanner performance, it has become important to address the problem of patient motion during PET/SPECT imaging. This research aims to develop a methodological framework based on a data driven approach known as particle filters often found in computer vision problems to correct the effect of respiratory motion on Nuclear Medicine imaging data. Particles filters are a popular class of numerical methods for solving optimal estimation problems and we wish to use this property to make an adaptive framework. In this work we use the particle filter (PF) for estimating the deformation of an internal model of the human torso X over a discrete time index t. The PF approximates the distribution of how X can deform by generating many propositions, called particles. The posterior estimate is inferred from the observation Z of the external surface. Currently there are two preliminary approaches in tracking organ deformation. In the first approach the internal model X is a small set of organ surface points. In the second approach X is a set of affine organ registration parameters to a reference time index r. Both approaches are contrasted to a comparable technique using direct mapping to infer X from the observation Z. Simulations of both approaches using the XCAT phantom suggest that the PF-based approaches are on average better than direct mapping. Further work is discussed on more advanced implementations of the PF for use with real data and integration into an overall Nuclear Medicine respiratory motion correction system.

7623-85, Poster Session

A comparison of tracking methods for swimming C. elegans

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Tracking the swimming motion of C. elegans worms is of high interest for a variety of research projects on behavior in biology, ranging from aging to mating studies. We compare six different tracking methods, which are obtained by combinations of two types of image preprocessing, namely local and global thresholding methods, and three types of segmentation methods: low-level vision morphological operations, and articulated models of either constant or varying width; the tracking of worms itself is performed on successive frames by either matching low-level segmentation results, or by locally adjusting the articulated models. All these methods have been used in recent related works, although mostly for crawling-worm tracking: we implemented some modifications to adapt them for swimming motions, which are significantly harder to track from a computer vision perspective. We report a quantitative comparison of these methods on a manually labeled test set of 1660 worm-frames using standard computer-vision measures: true positive pixel ratio, pixel distance between borders, correctly tracked worms, and processing time. We discuss the relative strengths and weaknesses of the tracking methods in the light of three different scenarios of behavior studies, depending on the constraints of a C. elegans project, and we give suggestions as to which methods are more adapted to each case, and how to further improve them.

7623-86, Poster Session

A marker-less observation model for motion correction in nuclear medicine

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One of the current major challenges in nuclear emission tomography is respiratory motion correction. Respiratory motion during the emission data acquisition process leads to blurred images, thus challenging diagnosis, planning and follow-up processes. There is significant research focus in developing new approaches to monitor and track respiratory motion during data acquisition (Rahmim et al., 2007). This may involve techniques to correct motion during reconstruction e.g. (Reyes et al., 2007) or using a marker-based tracking system to monitor the body motion during data acquisition, e.g. (Nehmeh et al., 2003), (Boutchko et al., 2007) and (Wolthaus et al., 2005). However, much of the prior work assumes invariant cyclic respiratory motion, where in reality this behaviour is actually more complex.

This paper describes a method of using a marker-less tracking system to track the upper part of the torso during scanning for developing patient-specific models of respiration. This approach is a part of a larger data driven scheme (Wells et al.,2009) to achieve motion correction in nuclear medicine using a particle filtering frame work (Abd Rahni et al., 2009) that relaxes commonly used assumptions about respiratory motion. Moreover, Principal component analysis (PCA) is used to study the breathing morphology for each individual for characterizing the breathing behaviour.

7623-87, Poster Session

Image-based motion estimation for cardiac CT via 4D image registration

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Cardiac imaging using multi-slice computed tomography has great potential as a non-invasive imaging technique. Currently, the image quality is limited due to the cardiac motion and the temporal resolution of the imaging devices. One solution to the problem is to estimate the motion of the heart and to use this additional information in the reconstruction algorithm. We present an algorithm for the first part of this process, the estimation of a motion vector field for the cardiac cycle. The vector field is obtained through registration of image volumes from several time steps throughout the cardiac cycle to a reference volume at a chosen quiescent phase. In general, image registration is an ill-posed problem and leads to ambiguous results for the estimated motion. Smoothness in both 3D-space and time is ensured by registering the image data simultaneously in four dimensions and smoothing the vector field with a Gaussian kernel. We use the XCAT phantom, a realistic 4D computer simulation of the human body including cardiac motion, to provide an initial estimate of the motion vector field to the registration algorithm. We demonstrate the impact of the starting vector field by comparing the estimated motion after registration of patient data with and without an initial motion vector field.

7623-88, Poster Session

Assessment of motion correction for positron emission tomography: application to ABP688

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Since Positron Emission Tomography (PET) images are normally acquired over an hour to two hour period, some subject motion is inevitable. This motion can create artifacts in the measured PET signal and adversely affect the quantitative information obtained from PET. Currently, there are two main methods used to compensate for this motion. The first is to track the motion optically and incorporate motion measurements directly into the image reconstruction. This technique requires additional equipment and may not be feasible in all cases. The second, more widely used method, involves correcting for the subject's motion after the scan using image registration. Since the second method is an indirect way of compensating for motion, which is universally available and may be used in conjunction with optical techniques, it is important to evaluate the effects of using both methods in PET imaging studies. Motion effects may even be ligand-specific, as differences in ligand kinetics determine its susceptibility to noise. In this work, both motion correction techniques were applied to four sets of test-retest images using the ligand ABP688, a recently developed antagonist of the metabotropic glutamate receptor subtype 5. The test-retest paradigm allowed both comparison of motion correction results between methods and assessment of motion correction reliability within a given method.

7623-89, Poster Session

Third brain ventricle deformation analysis using fractional differentiation and evolution strategy in brain cine-MRI

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In this paper, we present an original method to evaluate the deformations in the third cerebral ventricle on a brain cine-MR imaging. First, a segmentation process, based on fractional differentiation method, is directly applied on a 2D+t dataset to detect the contours of the region of interest (i.e. lamina terminalis). Then, the successive segmented contours are matched using a procedure of global alignment, followed by a morphing process, based on Covariance Matrix Adaptation Evolution Strategy (CMAES). Finally, local measurements of deformations are derived from the previously determined matched contours. The validation step is realized by comparing our results to the measurements achieved on the same patients by an expert.

7623-90, Poster Session

Endoscopic egomotion computation

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Computer assistance in Minimally Invasive Surgery is a very active field of research. Many systems designed for Computer Assisted Surgery require information about the instruments' positions and orientations. Our main focus lies on tracking a laparoscopic ultrasound probe to generate 3D ultrasound volumes. State-of-the-art tracking methods such as optical or electromagnetic tracking systems measure pose with respect to a fixed extra-body coordinate system. This causes inaccuracies of the reconstructed ultrasound volume in the case of patient motion, e.g. due to respiration. We propose attaching an endoscopic camera to the ultrasound probe and calculating the camera motion from the video sequence with respect to the organ surface. We adapt algorithms developed for solving the relative pose problem to recreate the camera path during the ultrasound sweep over the organ. By this image-based motion estimation camera motion can only be determined up to an unknown scale factor, known as the depth-speed-ambiguity. We show, how this problem can be overcome in the given scenario, exploiting the fact, that the distance of the camera to the organ surface is fixed and known. Preprocessing steps are applied to compensate for endoscopic image quality deficiencies.

7623-91, Poster Session

Diffeomorphic demons using normalized mutual information, evaluation on multimodal brain MR images

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The demons algorithm is a fast non-parametric non-rigid registration method. Over the last few years great efforts have been made to improve the approach. The state of the art demons technique yields symmetric inverse-consistent large-deformation diffeomorphic transformations. However only limited work has discussed the potential for incorporation of inter-modal similarity metrics, with virtually no practical evaluation on inter-modal data.

We present an implementation of the diffeomorphic demons approach using the Normalised Mutual Information (NMI) together with its analytical derivatives and a conjugate gradient optimiser. To the best of our knowledge the current paper reports the first qualitative and quantitative assessment of the demons algorithm for inter-modal registration.

We perform experiments to spatially normalise real MR images, and to recover simulated deformation fields; both demonstrate (i) similar accuracy for the classical demons and our new NMI-demons when the former may be used, and (ii) similar accuracy for the NMI-demons on T1w--T1w and T1w--T2w registrations, demonstrating its future potential in multi-modal scenarios.

7623-92, Poster Session

evaluating five non-rigid image registration algorithms using NIREP framework

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Evaluating non-rigid image registration performance is a difficult problem since there is rarely a "gold standard" (i.e., known) correspondence between two images. This paper reports the analysis and comparison of five non-rigid image registration algorithms using the Non-Rigid Image Registration Evaluation Project (NIREP) framework. The NIREP framework evaluates registration performance using common databases of well-characterized images and standard evaluation criteria that is implemented in a software package that can be downloaded from the NIREP web site (www.nirep.org). The performance of five non-rigid registration algorithms (Affine, AIR, Demons, SLE and SICLE) was evaluated using 22 images from two NIREP neuroanatomical evaluation databases. Six evaluation statistics (Relative Overlap, Intensity Variance, Normalized ROI overlap, alignment of Calcarine Sulcus, Inverse Consistency Error and Transitivity Error) were used to evaluate and compare registration performance. User friendly tables, graphs, images and analysis reports were produced to help interpret registration performance and compare registration results. The results suggest that the demons registration algorithm produced the best registration results with respect to the relative overlap criteria but produced the nearly the worst registration results with respect to the inverse consistency criteria. The fact that one registration algorithm produced the best result for one criterion and nearly the worse for another, illustrates the need to use multiple evaluation criteria. It also illustrates the need to archive registration algorithm performance so that investigators can choose the best registration algorithm based on their own needs. Archiving registration results can also help drive future innovation in non-rigid image registration.

7623-93, Poster Session

Reliable fusion of knee bone laser scans to establish ground truth for cartilage thickness measurement

M. Chang, GE Global Research (United States); N. H. Trinh, B. B. Kimia, Brown Univ. (United States)

One major issue in validating medical imaging algorithms is the availability of ground truth. In particular we are interested in establishing ground truth data for validating morphology measurements of human knee cartilage from MR imaging. One promising method is to compare the high-accuracy 3D laser scans of dissected cadaver knees before/after the dissolution of their cartilage. This requires an accurate and reliable method to fuse the individual laser scans from multiple views of the cadaver knees. Unfortunately off-the-shell packages using the Iterative Closest Point (ICP) algorithm often yield unreliable fusion results. We identify two major sources of variation: (i) the depth measurements in the laser scans are significantly noisier than the spatial resolution, and (ii) the use of vertex-to-vertex ICP correspondence in fusion yields variable results due to sampling variation. We resolve the first problem by smoothing out the depth noise of individual laser scans prior to the fusion. We resolve the second problem by meshing a surface from the point cloud of each scan and adopting a vertex-to-mesh ICP scheme. These scans are then fused in the order maximizing mutual overlaps, which is indicated by the minimal spanning tree of their neighborhood adjacency graph. In experiments on 6 repeated scanning trials of a cadaver knee, our approach reduces the alignment error of point-based ICP by 30% and reduced coefficient of variation from 5% down to 1.4%, significantly improving the repeatability. This shows that the laser scan measurements are reliable and can be used to validate other imaging algorithms.

7623-94, Poster Session

Multicontrast MRI registration of carotid arteries in atherosclerotic and normal subjects

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Clinical studies on atherosclerosis agree that multi-contrast MRI is the most promising technique for in-vivo characterization of carotid plaques. Multi-contrast image registration is essential for this application, because it corrects misalignments caused by patient motion during MRI acquisition. To date, it has not been determined which automatic method provides the best registration accuracy in carotid MRI. This study tries to answer this question by presenting an iterative coarse-to-fine algorithm that co-registers multi-contrast images of carotid arteries using three similarity metrics: Correlation Ratio (CR), Mutual Information (MI) and Gradient MI (GMI). The registration algorithm is first applied on the entire images and then only on the Region of Interest (ROI) of the carotid arteries using sub-pixel accuracy. The ROI is defined by an automatic carotid detection algorithm, which was tested on a group of 20 patients with different types of atherosclerotic plaques (sensitivity 91% and specificity 88%). Automatic registration was compared with image alignment obtained by manual operators (clinically qualified vascular specialists). Registration accuracies were measured using a novel MRI validation procedure, in which the gold standard is represented by in-plane rigid transformations applied by the MRI system to mimic neck movements. Overall, automatic methods (GMI = 181 ± 104 μm) produced lower registration errors than manual operators (365 ± 102 μm). GMI performed slightly better than CR and MI, suggesting that anatomical information improves registration accuracy in the carotid ROI.

7623-95, Poster Session

Joint learning of parameters for MR/CT atlas registration and MR-based attenuation map estimation for PET

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In this work, a method for simultaneous estimation of model and MR/CT atlas registration parameters for probabilistic MR-based prediction of pseudo-CTs is presented. The pseudo-CTs are used for creation of attenuation maps for PET attenuation correction (AC).

Prediction of pseudo-CT images from MR scans and atlas data with subsequent registration to correspoding CT images is alternated with the estimation of model parameters for pseudo-CT prediction.

The atlas consists of multiple MR/CT image pairs of the same patient. Initial registration of MR/CT pairs is performed using three-step co-registration with Mutual Information as similarity measure.

CT images are then segmented into tissue classes. Using the resulting labeling, parameters of the conditional probability model of MR intensity values for each tissue class are estimated. A two-dimensional Gaussian distribution was used. The prior probabilities of tissue classes at each position in the image are estimated with kernel densities from the co-registered atlas images.

A pseudo-CT is generated for each MR/CT pair using the MR image data and the MR/CT atlas by maximizing the a-posteriori probability of each voxel. The CT images are then registered to the pseudo-CTs, which are spatially aligned to the MR images.

The presented method outperforms the standard Mutual Information approach on this specific registration task by using prior knowledge in form of atlas and multiple MR scans.

The pseudo-CTs can be converted to attenuation maps for PET AC via a bilinear transformation and used for AC in a combined whole body PET/MR scanner.

7623-96, Poster Session

Cylindrical affine transformation model for image registration

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This paper describes the development of a cylindrical affine transformation model for image registration.

The usefulness of the model for initial alignment was demonstrated for the application of registering prone and supine 3D MR images of the breast.

Final registration results visually improved when using the cylindrical affine transformation model instead of none or a Cartesian affine transformation model before non-rigid registration.

7623-97, Poster Session

An improved 3D shape context registration method for non-rigid surface registration

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Point matching based surface registration, using 3D shape context has recently emerged as an alternative to intensity bases non-linear registration. One of limitations of shape context for point matching is that the significant amount of point mismatching may occur between two surfaces while their similarity is low both globally and locally or there is the existence of outliers.

In this paper, we address the issue of point matching by correcting point correspondences prior to computing surface deformation. We classify point mismatch into two types: long geodesic distance mismatch and neighbors crossing mismatch. We propose to firstly correct long geodesic distance mismatch by topological structure correction method through comparing source points and matched points with a preserved topological structure from source surface. Then we apply a smoothing filter, which combines thin-plate spline interpolation and correspondence field smoothing, to correct neighboring mismatches. The result is a quasi topologically preserving correspondence mapping between source and target surfaces. A robust 3D shape context model is proposed and further combined with thin-plate spline model for non-rigid surface registration. The method was tested on phantoms and rat hind limb skeletons from micro CT images. The statistical results from phantom test showed the good performance of the improved model. The average registration errors from iterative closest point method, traditional 3D shape context method and the improved method on 10 pairs of rat hind limb skeletons demonstrated that the errors between registered surfaces were reduced by using the proposed non-rigid registration method.

7623-98, Poster Session

Optical flow based deformable volume registration using a novel second-order regularization prior

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Nonlinear image registration is an initial step for a large number of medical image analysis applications. Optical flow based intensity registration is often used for dealing with intra-modality applications involving motion differences. In this work we present an energy functional which uses a novel, second-order regularization prior of the displacement field. Compared to other methods our scheme is robust to non-Gaussian noise and does not penalize locally affine deformation fields in homogeneous areas. We propose an efficient and stable numerical scheme to find the minimizer of the presented energy. We implemented our algorithm using modern consumer graphics processing units and thereby increased the execution performance dramatically. We further show experimental evaluations on clinical CT thorax data sets at different breathing states and on dynamic 4D CT cardiac data sets.

7623-99, Poster Session

Estimation of registration parameters: image similarity and regularization

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The problem of image registration is well-known and several registration methods exist that address this problem. However, most of these methods require careful manual parameter tuning to a target application, which is a time-consuming, expert task. As a result, it is not feasible to tune parameters for each specific case, and instead domain-specific settings are used that work well on average but may

lead to sub-optimal results for individual cases.

In this paper we investigate the possibility to automatically fine-tune the level of regularization in registration methods that use B-spline driven deformation to elastically register images. We hypothesize that there is a relation between image similarity after affine registration and the best setting for regularization and propose to use this relation to estimate the best setting for the level of regularization.

To test this hypothesis, we performed registrations for 1000 image pairs with varying settings for the level of regularization, ranging from a very restrictive regularization to virtually no regularization. These registrations were performed using the registration package DROP, and were then repeated for validation purposes with the registration package Elastix. Using a regression analysis of the result, we constructed an estimation function for the regularization, which was then validated on a set of new images.

On the basis of these experiments we show that our hypothesis was confirmed and that an estimation of the level of regularization based on image similarity leads to better results than using an average-best setting for the regularization parameter.

7623-100, Poster Session

Multistep size demons with divergence term for liver MRI motion correction

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Contrast-enhanced liver MR image sequences acquired at multiple times before and after contrast administration have been shown to be critically important for the diagnosis and monitoring of liver tumors and may be used for the quantification of liver inflammation and fibrosis. However, over multiple acquisitions, the liver moves and deforms due to patient and respiratory motion. In order to analyze contrast agent uptake one first needs to correct for liver motion. In this paper we present a method for the motion correction of dynamic contrast-enhanced liver MR images. For this purpose we use a modified version of the Demons non-rigid registration method. Since the liver is nearly incompressible its displacement field has small divergence. For this reason we add a divergence term to the energy that is minimized in the Demons method. To improve the convergence of the method and reduce the execution time we use a symmetrized version of the Demons forces and three levels of the maximal displacement step size. We applied the method to four sequences of contrast-enhanced liver MR images. Each sequence had a pre-contrast scan and seven post-contrast scans. For each post-contrast scan we corrected for the liver motion relative to the pre-contrast scan. Quantitative evaluation showed that the proposed method improved the liver alignment relative to the non-corrected and translation-corrected scans and visual inspection showed no visible misalignment of the motion corrected contrast-enhanced scans and pre-contrast scan.

7623-101, Poster Session

Towards analysis of growth trajectory through multimodal longitudinal MR imaging

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The human brain undergoes significant changes in the first few years after birth, but knowledge about this critical period of development is quite limited. Previous neuroimaging studies have been mostly focused on morphometric measures such as volume and shape, although tissue property measures related to the degree of myelination and axon density could also add valuable information to our understanding of brain maturation. Our goal is to complement brain growth analysis via morphometry with the study of longitudinal tissue property changes as reflected in patterns observed in multi-modal structural MRI and DTI.

Our preliminary study includes eight healthy pediatric subjects with repeated scans at the age of two weeks, one year, and two years with T1, T2, PD, and DT MRI. Analysis is driven by the registration of multiple modalities and time points within and between subjects into a common coordinate frame, followed by image intensity normalization. Quantitative tractography with diffusion and structural image parameters serves for multi-variate tissue analysis. Different patterns of rapid changes were observed in the corpus callosum and the posterior and anterior internal capsule, structures known for distinctly different myelination growth. There are significant differences in central versus peripheral white matter, and also a wm/gm contrast flip in both T1 and T2 images but not diffusion parameters. We demonstrate that the combined longitudinal analysis of structural and diffusion MRI proves superior to individual modalities and might provide a better understanding of the trajectory of early neurodevelopment.

7623-102, Poster Session

A fast rigid-registration method of inferior limb x-ray image and 3D CT images for TKA surgery

F. Ito, K. Ito, O. D. A. Prima, A. Doi, Iwate Prefectural Univ. (Japan)

In this paper, we propose a fast rigid-registration method of inferior limb X-ray films (two-dimensional Computed Radiography (CR) images) and three-dimensional Computed Tomography (CT) images for Total Knee Arthroplasty (TKA) surgery planning. The position of the each bone, such as femur and tibia (shin bone), in X-ray film and 3D CT images is slightly different, and we must pay attention how to use the two different images, since X-ray film image is captured in the standing position, and 3D CT is captured in decubitus (face up) position, respectively. Though the conventional registration mainly uses cross-correlation function between two images,and utilizes optimization techniques, it takes enormous calculation time and it is difficult to use it in interactive operations. In order to solve these problems, we calculate the center line (bone axis) of femur and tibia (shin bone) automatically, and we use them as initial positions for the registration. We evaluate our registration method by using three patient's image data, and we compare our proposed method and a conventional registration, which uses down-hill simplex algorithm. The down-hill simplex method is an optimization algorithm that requires only function evaluations, and doesn't need the calculation of derivatives. Our registration method is more effective than the downhill simplex method in computational time and the stable convergence. We have developed the implant simulation system on a personal computer, in order to support the surgeon in a preoperative planning of TKA. Our registration method is implemented in the simulation system, and user can manipulate 2D/3D translucent templates of implant components on X-ray film and 3D CT images.

7623-103, Poster Session

Detection of stable mammographic features under compression using simulated mammograms

Y. Jafar, J. H. Hipwell, C. Tanner, D. J. Hawkes, Univ. College London (United Kingdom)

Stable features under simulated mammographic compressions which will become candidate landmarks for a temporal mammographic feature-based registration algorithm are discussed in this paper. Using these simulated mammograms, we explore the extraction of features based on standard projection images and local phase projection images. One approach to establishing corresponding features is by template matching using a similarity measure. Simulated mammographic projections from deformed MR volumes are employed as the mean projected 3D displacements are computed and therefore validation of the technique is performed. Tracking is done by template matching and normalized cross correlation as the similarity measure. The performance of standard projection images and local phase projection images is compared. The preliminary results reveal that

although the majority of the points within the breast are difficult to track, a small number may be successfully tracked, which is indicative of their stability and thus their suitability as candidate landmarks. Whilst matching using the standard projection images achieves an overall error of 16.2mm, the overall mean error drops to 10.7mm when computing local phase of the projection images. These results suggest that using local phase improves template matching and by extension, the identification of stable landmarks for feature-based mammogram registration.

7623-104, Poster Session

Improving fluid registration through white matter segmentation in a twin study design

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Robust and automatic non-rigid registration depends on many parameters that have not yet been systematically explored. Here we determined how tissue classification influences non-linear fluid registration of brain MRI. Twin data is ideal for studying this question, as volumetric correlations between corresponding brain regions that are under genetic control should be higher in monozygotic twins (MZ) who share 100% of their genes when compared to dizygotic twins (DZ) who share half their genes on average. When these substructure volumes are quantified using tensor-based morphometry, improved registration can be defined based on which method gives higher MZ twin correlations when compared to DZs, as registration errors tend to deplete these correlations. In a study of 92 subjects, higher effect sizes were found in cumulative distribution functions derived from statistical maps when performing tissue classification before fluid registration, versus fluidly registering the raw images. This gives empirical evidence in favor of pre-segmenting images for tensor-based morphometry.

7623-105, Poster Session

Direction-dependent regularization for improved estimation of liver and lung motion in 4D image data

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The estimation of respiratory motion is a fundamental requisite for many applications in the field of 4D medical imaging, for example for radiotherapy of thoracic and abdominal tumors. It is usually done using non-linear registration without further modelling of physiological motion properties. In this field, the accurate calculation of liver und lung motion is especially challenging because these organs are slipping along the surrounding tissue (i.e. the rib cage) during the respiratory cycle what leads to discontinuities in the motion field. Without incorporating this specific physiological characteristic, common smoothing mechanisms cause an incorrect estimation along the object borders.

In this paper, we present an extended diffusion-based model for incorporating physiological knowledge in image registration. By decoupling normal- and tangential-directed smoothing, we are able to estimate slipping motion at the organ borders while preventing gaps and ensuring smooth motion fields in the inside.

We evaluate our model for the estimation of lung and liver motion on the basis of 4D CT and 4D MRI data. The results show a considerable increase of registration accuracy with respect to the target registration error.

7623-106, Poster Session

An intensity-based approach to x-ray mammography: MRI registration

T. Mertzanidou, J. H. Hipwell, D. J. Hawkes, Univ. College London (United Kingdom); C. Tanner, ETH Zürich (Switzerland)

This paper presents a novel approach to X-ray mammogram - MRI registration. The proposed method uses an intensity-based technique and an affine transformation matrix to recover the 3D deformation of the breast resulting from the compression applied during mammogram acquisition. The registration is driven by a similarity measure that is calculated at each iteration of the algorithm between the target X-ray mammogram and a simulated X-ray image, created from the MR volume. Although the similarity measure is calculated in 2D, it is the 3D volume that is updated at each iteration. We have performed two types of experiments. In the first set, we used simulated X-ray target data, for which the ground truth deformation of the volume was known and thus the results could be validated. For this case, we examined the performance of 4 different similarity measures and we show that Normalized Cross Correlation and Gradient Difference perform best. The calculated reprojection error was for both similarity measures 4mm, for an initial misregistration of 15mm. In the second set of experiments, we present the initial results of registering real X-ray mammograms with MR volumes. The results indicate that the breast boundaries were registered well and the volume was deformed in 3D in a similar way to the deformation of the breast during X-ray mammogram acquisition. The experiments were carried out on five patients.

7623-107, Poster Session

Fast and accurate 3D ultrasound volume stitching using phase symmetry and Harris corner detection for orthopedic applications

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Stitching of volumes obtained from three dimensional (3D) ultrasound (US) scanners improves visualisation of anatomy in orthopaedic applications. Accurate but fast volume registration remains the key challenge in this area. In this paper, we have implemented a volume stitching method based on fast registration of 3D US orthopaedic volumes obtained from a tracked US probe. Parameters from the probe tracking enable coarse alignment of the two volumes with considerable overlap along the direction of the probe motion. Then central slices of the two overlapping regions contain similar structures. Thus, by identifying and matching key features in these structures and registering sub-volumes surrounding the best corresponding feature pair, we can rapidly obtain a set of registration parameters that could be used to register the full volumes. To robustly identify the actual structures and key features, we employ Phase Symmetry to enhance the signal to noise ratio of the structures of interest. The features are subsequently extracted using the Harris corner detector and matched using RANSAC. The proposed method has been tested on artificial and real, in-vivo human radius bones, an in-vitro bovine femur, an artificial human pelvis and an artificial human fetus. Fiducials on the artificial bones were used to quantitatively assess the efficacy of the registrations/stitching. The results show that, by searching for key corresponding points in just one pair of slices and then registering only small sub-volumes around these points, our proposed method achieves significant increases in registration speed while maintaining high accuracy.

7623-108, Poster Session

Multimodality fiducial marker for validation of registration of histology with medical images

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A multi-modality fiducial marker is presented in this work, which can be used for validating the correlation of histology images with medical images. This marker can also be used for landmark-based image registration. Seven different fiducial markers including a catheter, spaghetti, black spaghetti, cuttlefish ink, and liquid iron are implanted in a mouse specimen and then investigated based on visibility, localization, size, and stability. The black spaghetti and the mixture of cuttlefish ink and flour are shown to be the most suitable markers. Based on the size of the markers, black spaghetti is more suitable for big specimens and the mixture of the squid ink and flour injected in a catheter is more suitable for small specimens such as mouse tumours. These markers are visible on medical images and also detectable on histology and optical images of the tissue blocks. The main component in these agents which enhances the contrast is iron. In this work the iron concentration in each of these markers is also reported.

7623-109, Poster Session

Fast correspondences search in anatomical trees

T. R. dos Santos, I. Gergel, H. Meinzer, L. Maier-Hein, Deutsches Krebsforschungszentrum (Germany)

Registration of multiple medical images commonly comprises the steps feature extraction, correspondences search and transformation computation. In this paper, we present a new method for a fast and pose independent search of correspondences using as features anatomical trees such as the bronchial system in the lungs or the vessel system in the liver. Our approach scores the similarities between the trees' nodes (bifurcations) taking into account both, topological properties extracted from their graph representations and anatomical properties extracted from the trees themselves. The node assignment maximizes the global similarity (sum of the scores of each pair of assigned nodes), assuring that the matches are distributed throughout the trees. Furthermore, the proposed method is able to deal with distortions in the data, such as noise, motion, artifacts, and problems associated with the extraction method, such as missing or false branches. According to an evaluation on swine lung data sets, the method requires less than one second on average to compute the matching and yields a high rate of correct matches compared to state of the art work.

7623-110, Poster Session

Evaluation of an efficient GPU implementation of digitally reconstructed radiographs in 3D/2D image registration

C. Zhang, M. Villa-Uriol, A. F. Frangi, Univ. Pompeu Fabra (Spain)

Intensity-based three-dimensional to two-dimensional (3D/2D) X-ray image registration algorithms usually require generating digitally reconstructed radiographs (DRRs) in every iteration during their optimization phase. Thus a large part of the computation time of such registration algorithms is spent in computing these DRRs. In a 3D to multiple 2D image registration framework, where a sequence of DRRs is calculated in every iteration, not only the computation but also the memory cost is very high. We present an efficient DRR generation method to reduce both costs on the graphical processing units (GPU) implementation. The method relies on integrating a precomputation and a narrow-band region-of-interest calculation into the DRR generation. We have demonstrated its benefits on a previously proposed non-rigid 3D+t or 4D to multiple 2D image registration framework to estimate

cerebral aneurysm wall motion. Both tested two algorithms initially required several hours of highly intensive computation that involves generating a large number of DRRs in every iteration. In this paper, results on digital and physical pulsating cerebral aneurysm phantom datasets showed a speedup factor of around 50x in DRRs generation. Comparing both registration algorithms with respect to their equivalent CPU-based implementation, we also obtained speedup while maintaining estimation accuracy. This suggests that our method has the potential to complete the registration task within 5 minutes without degrading the performance.

7623-111, Poster Session

Markov random field optimization for intensity-based 2D-3D registration

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We propose a Markov Random Field (MRF) formulation for the intensity-based N-view 2D-3D registration problem. To our best knowledge, this is the first time that 2D-3D registration is modeled by MRFs and solved by discrete optimization. The 3D rigid transformation aligning the 3D volume to the 2D views is estimated by iterative updates obtained by discrete optimization of the MRF model. We demonstrate that the 2D-3D registration problem can be solved by a pairwise MRF model with a fully connected graph in which the nodes represent the parameter updates and the edges encode the image similarity costs resulting from variations of the values of adjacent nodes. A label space refinement strategy is employed to achieve sub-millimeter accuracy. The extensive evaluation on real and synthetic data and comparison to the state-of-the-art shows that our approach can compete with current methods in terms of robustness and quality, and is robust to noise and initialization. Due to the active development in discrete optimization, we see a strong potential of the proposed method, since it allows to transfer the advances in MRF optimization to 2D-3D registration, e.g. the integration of future fast methods for higher-order clique models.

7623-112, Poster Session

Image similarity metrics in image registration

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Measures of image similarity that inspect the intensity probability distribution of the images have proved extremely popular in image registration applications. The joint entropy of the intensity distributions and the marginal entropies of the individual images are combined to produce properties such as resistance to loss of information in one image and invariance to changes in image overlap during registration. However information theoretic cost functions are largely used empirically. This work attempts to describe image similarity measures within a formal mathematical metric framework. Redefining mutual information as a metric is shown to lead naturally to the standardised variant normalised mutual information.

7623-113, Poster Session

Registration-based interpolation applied to cardiac MRI

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Various approaches have been proposed for segmentation of cardiac MRI. An accurate segmentation of the myocardium and ventricles is essential to determine parameters of interest for the function of the heart, such as the ejection fraction. One problem with MRI is the poor resolution in one dimension.

A 3D registration algorithm will typically use a trilinear interpolation of intensities to determine the intensity of a deformed template image. Due to the poor resolution across slices, such linear approximation is highly inaccurate since the assumption of smooth underlying intensities is violated. Registration-based interpolation is based on 2D registrations between adjacent slices and is independent of segmentations. Hence, rather than assuming smoothness in intensity, the assumption is that the anatomy is consistent across slices. The basis for the proposed approach is the set of 2D registrations between each pair of slices, both ways. The intensity of a new slice is then weighted by (i) the deformation functions and (ii) the intensities in the warped images. Unlike the approach by Penney et al. 2004, this approach takes into account deformation both ways, which gives more robustness where correspondence between slices is poor.

We demonstrate the approach on a toy example and on a set of cardiac CINE MRI. Qualitative inspection reveals that the proposed approach provides a more convincing transition between slices than images obtained by linear interpolation. A quantitative validation reveals significantly lower reconstruction errors than both linear and registration-based interpolation based on one-way registrations.

7623-114, Poster Session

Automated atlas-based segmentation of the heart and pericardium from noncontrast CT

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Automated segmentation of the 3D heart region from non-contrast CT data is a key first step for automated quantification of coronary calcium and pericardial fat volume, which are important for cardiovascular risk stratification. We aimed to develop and validate an automated, efficient atlas-based method for segmentation of the heart and pericardium from non-contrast CT.

A non-contrast CT atlas is first created from multiple manually segmented co-registered non-contrast CT data. To segment each dataset, manual 2D contours are traced by an expert physician along the pericardium (including the heart) on all transverse slices; a 3D binary volume mask is generated from the contours. Non-contrast CT data included in the atlas are co-registered to each other using iterative, rigid registration with sum of squared differences as the cost function, followed by a deformable transformation using Thirion's "demons" algorithm; the final transformation is also applied to the binary volume mask. New CT datasets are segmented by co-registration to an atlas image, and subsequently by voxel classification using a weighted decision function based on comparison to all co-registered/pre-segmented atlas images. This automated segmentation method was applied to 12 CT datasets, with a 3D atlas created from 8 datasets.

The total time was <15 seconds on 2.5 GHz computer with 3.5 GB memory. For the target datasets, the method achieved a maximum voxel overlap of 0.91 and an average overlap of 0.80 compared to expert manual segmentation. Fast automated atlas-based 3D segmentation of the heart and pericardium from non-contrast CT is feasible.

7623-115, Poster Session

Mosaicing of microscope images in the presence of large areas with insufficient information content

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In virtual microscopy, multiple overlapping fields of view are acquired from a large slide using a motorized microscope stage that moves and focuses the slide automatically. A virtual slide is reconstructed by combining digitally saved fields of view into an image mosaic. A seamless reconstruction requires the correction of unknown positioning errors of the stage. This is usually done by automatically estimating alignment parameters of the tiles in the image mosaic. But finding accurate alignment parameters can be inhibited by the presence of tiles that lack information content in the areas of overlap. In this work we propose a new mosaicing method that accesses information content of each overlap and performs pairwise registrations of adjacent tiles only if the content of their overlap is deemed sufficient for successful registration. For global positioning of tiles an optimal stitching path is found by tracing such content-rich overlaps. We tested the proposed algorithm on bright field and fluorescence microscope images and compared the results with those of an existing algorithm based on simultaneous estimation of global alignment parameters. It is shown that the new algorithm improves perceived image quality at boundaries between tiles. Our method is also computationally efficient since it performs no more than one pairwise registration per tile on average.

7623-116, Poster Session

Volume-constrained image registration for pre- and post-operative CT liver data

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The resection of a tumor is one of the most common tasks in liver surgery. Here, it is of particular importance to resect the tumor and a safety margin on the one hand and on the other hand to preserve as much healthy liver tissue as possible. To this end a preoperative CT scan is taken in order to come up with a sound resection strategy. It is the purpose of this paper to compare the preoperative planning with the actual resection result. Obviously the pre- and postoperative data is not straightforward comparable, a meaningful registration is required. In the literature one may find a rigid and a landmark-based approach for this task. Whereas the rigid registration does not compensate for nonlinear deformation the landmark approach may lead to an unwanted overregistration. Here we propose a fully automatic nonlinear registration with volume constraints which seems to overcome both aforementioned problems and does lead to satisfactory results in our test cases.

7623-117, Poster Session

Medical image registration using the modified conditional entropy measure combining the spatial and intensity information

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Due to the strengths and weaknesses of previous methods, several researchers recently proposed intensity based methods. Therefore, in this paper, we propose an image registration technique via area intensities. The registration is followed by the use of a measure based on the entropy of conditional probabilities. To achieve the registration,

we define a modified conditional entropy (MCE) computed from the joint histograms for the area intensities of two given images. To evaluate the performance of the proposed registration method, we conduct various experiments with our method as well as existing method based on the mutual information (MI) criteria. We evaluate the precision of MI- and MCE-based measurements by comparing the registration obtained from magnetic resonance (MR) images and transformed MR/transformed CT images. The experimental results show that our proposed method was fast and an accurate technique.

7623-118, Poster Session

Improving arterial spin labeling data by temporal filtering

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Arterial spin labeling (ASL) is an MRI method for imaging brain perfusion by magnetically labeling blood in brain feeding arteries. The perfusion is obtained from the difference between images with and without prior labeling.

Image noise is one of the main problems of ASL as the difference is around 0.5-2% of the image magnitude. Usually, 20-40 pairs of images need to be acquired and averaged to reach a satisfactory quality.

The images are acquired shortly after the labeling to allow the labeled blood to reach the imaged slice. A sequence of images with multiple delays is more suitable for quantification of the cerebral blood flow as it gives more information about the blood arrival and relaxation.

Although the quantification methods are sensitive to noise, no filtering or only Gaussian filtering is used to denoise the data in the temporal domain prior to quantification.

In this article, we propose an efficient way to use the redundancy of information in the time sequence of each pixel to suppress noise. For this purpose, the vectorial NL-means method is adapted to work in the temporal domain. The proposed method is tested on simulated and real 3T MRI data. We demonstrate a clear improvement of the image quality as well as a better performance compared to Gaussian and normal spatial NL-means filtering.

7623-119, Poster Session

Compact rotation invariant descriptors for non-local means

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Non-local means is a recently proposed denoising technique that better preserves image structures than other methods. However, the computational cost of non-local means is prohibitive, especially for large 3D medical images. Modifications have previously been proposed to reduce the cost, which result in image artifacts. This paper proposes a compact rotation invariant block descriptor, which reduces the computational cost but without artifacts occurring. The descriptor consists of the mean intensities along the orthogonal axes of lowest gradient and the weighted mean intensity of all axes. The short descriptor allows the use of a hashed approach, boosting speed and allowing all pairs of voxels in the image to be globally compared.

Testing demonstrates that improved denoising performance is obtained with an order of magnitude improvement in speed over the state-of-the-art optimized non-local means method.

7623-120, Poster Session

Novel registration-based image enhancement for x-ray fluoroscopy

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Introduction: High image noise is a major concern that discourages the inclusion of low-dose x-ray fluoroscopy images in patient medical records, typically necessitating additional higher-dose exposures to the patient. We report an image registration based approach for generating high-quality x-ray images from a sequence of low-dose fluoroscopy images.

Method: The described method involved weighted temporal averaging of consecutively acquired x-ray fluoroscopy images representing diagnostically vital information. A key algorithmic feature involved motion-correction of the individual images by registering to a reference image provided a priori or selected from the same sequence. Motion correction helped avoid generating lag artifacts during temporal averaging, which is vital in fluoroscopy applications due to the importance of clinical evaluation of fine image features. The registration algorithm corrected for rigid and non-rigid inter-frame differences using global and regional inter-frame motion information derived from motion vector maps and intensity-based image correlation metric. The relative influence of vector maps and intensity-based correlation metric was determined based on a priori information about the specific clinical application, including the anatomy imaged and expected patient motion during imaging.

Results: Tests on several image sequences acquired using an anthropomorphic phantom demonstrated visually impressive results with reduced noise and no appearance of lag artifacts. Local image noise was reduced on average by 37%, and CNR in selected regions improved by 45-89%.

Conclusion: The proposed approach provides a method to effectively improve image quality of fluoroscopy, enabling its use for image archive and diminishing the need for additional higher-dose exposures for patient record.

7623-121, Poster Session

Application of a modified regularization procedure for estimating oxygen tension in large retinal blood vessels

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Phosphorescence lifetime measurement based on a frequency domain approach is used to estimate oxygen tension in large retinal blood vessels. The classical least squares (LS) estimation was initially used to determine oxygen tension indirectly from intermediate variables. A spatial regularized least squares (RLS) method was later proposed to reduce the high variance of oxygen tension estimated by LS method. In this paper, we provide a solution using a modified RLS (MRLS) approach that utilizes prior knowledge about retinal vessels oxygenation based on expected oxygen tension values in retinal arteries and veins. The performance of MRLS method was evaluated in simulated data by determining the bias, variance, and mean absolute error (MAE) of oxygen tension measurements and comparing these parameters with those derived with the use of LS and RLS methods.

7623-122, Poster Session

Automated extraction method for the center line of spinal canal and its application to the spinal curvature quantification in torso x-ray CT images

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X-ray CT images have been widely used in clinical routine in recent years. CT images scanned by a modern CT scanner can show the details of various organs and tissues. This means various organs and tissues can be simultaneously interpreted on CT images. However, CT image interpretation requires a lot of time and energy. Therefore, support for interpreting CT images based on image-processing techniques is expected. The interpretation of the spinal curvature is important for clinicians because spinal curvature is associated with various spinal disorders. We propose a quantification method of the spinal curvature based on the center line of spinal canal on CT images. The proposed method consists of five steps: (1) Automated extraction of the skeleton region based on CT number thresholding. (2) Automated extraction of the center line of spinal canal. (3) Generation of the median plane image of spine, which is reformatted based on the spinal canal. (4) Automated detection of the spinous process. (5) Quantification of the spinal curvature. The proposed scheme was applied to 10 cases, and compared with the Cobb angle, which is commonly used by clinicians. As a result, strong correlation (for the 95% confidence interval, lumbar lordosis: 0.81-0.99) between values obtained by the proposed method and Cobb angle was found. Also, we confirmed the proposed method can provide the reproducible result (Inter- and intra-observer variability: within 2°). These experimental results suggested a possibility that the proposed method was effective for quantifying the spinal curvature using CT images.

7623-123, Poster Session

Closing of interrupted vascular segmentations: an automatic approach based on shortest paths and level sets

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Automatic approaches for cerebrovascular segmentation suffer from several problems. One of the major problems which can be observed are interruptions in the vascular segmentation, especially in case of small vessels represented by low intensities. These breaks are problematic for the outcome of several applications e.g. FEM-simulations and quantitative vessel analysis. In this paper we propose an automatic post-processing method to connect broken vessel segmentations. The approach proposed consists of 4 steps. Based on an existing vessel segmentation the 3D skeleton is computed first and used to detect the dead ends of the segmentation. In a following step possible connections between these dead ends are computed using a graph based approach based on the vesselness parameter image. After a consistency check is performed, the detected paths are used to obtain the final segmentation using a level set approach.The evaluation of the results yielded by the method proposed based on two Time-of-Flight MRA datasets showed that in mean 45 connections between dead ends per dataset were found. A quantitative comparison with semi-automatic segmentations by medical experts using the Dice coefficient revealed that a mean improvement of 0.0229 per dataset was achieved. The approach presented can considerably improve the accuracy of vascular segmentations needed for following analysis steps.

7623-124, Poster Session

Multiscale topo-morphologic opening of arteries and veins: a validation study on phantoms and CT imaging of pulmonary vessel casting of pigs

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Distinguishing pulmonary arterial and venous (A/V) trees via in vivo imaging is a critical first step in quantification of vascular geometry for purposes of determining, for instance, pulmonary hypertension, detection of pulmonary emboli and more. A multi-scale topo-morphologic opening algorithm has recently been introduced by us separating A/V trees in pulmonary multiple-detector X-ray computed tomography (MDCT) images without contrast. The method starts with two sets of seeds - one for each of A/V trees and combines fuzzy distance transform, fuzzy connectivity, and morphologic reconstruction leading to multi-scale opening of two mutually fused structures while preserving their continuity. The method locally determines the optimum morphological scale separating the two structures. Here, a validation study is reported examining accuracy of the method using mathematically generated phantoms with different levels of fuzziness, scale, resolution, noise, and geometric coupling and MDCT images of pulmonary vessel casting of pigs. After exsanguinating the animal, a vessel cast was generated using rapid-hardening methyl methacrylate compound with additional contrast by 10cc of Ethiodol in the arterial side which was scanned in a MDCT scanner at 0.5mm slice thickness and 0.47mm in plane resolution. True segmentations of A/V trees were computed from these images by thresholding. Subsequently, effects of distinguishing A/V contrasts were eliminated and resulting images were used for A/V separation by our method. Experimental results show that 98% accuracy is achieved using only one seed for each object in phantoms while 90.04% accuracy is achieved in MDCT cast images using ten seeds for each of A/V trees.

7623-125, Poster Session

Image segmentation using the student's t-test and the divergence of direction on spherical regions

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We have developed a new framework for analyzing images called Shells and Spheres (SaS) based on a set of spheres with adjustable radii, with exactly one sphere centered at each image pixel. This set of spheres is considered optimized when each sphere reaches, but does not cross, the nearest boundary of an image object. Statistical calculations at varying scale are performed on populations of pixels within spheres, as well as populations of adjacent spheres, in order to determine the proper radius of each sphere. In the present work, we explore the use of a classical statistical method, the student's t-test, within the SaS framework, to compare adjacent spherical populations of pixels. We present results from various techniques based on this approach, including a comparison with classical gradient and variance measures at the boundary. A number of optimization strategies are proposed and tested based on pairs of adjacent spheres whose size are controlled in a methodical manner. A properly positioned sphere pair lies on opposite sides of an object boundary, yielding a direction function from the center of each sphere to the boundary point between them. Finally, we develop a method for extracting medial points based on the divergence of that direction function as it changes across medial ridges, reporting not only the presence of a medial point but also the angle between the directions from that medial point to the two respective boundary points that make it medial. Although demonstrated here only in 2D, these methods are all inherently n-dimensional.

7623-126, Poster Session

Aorta segmentation in non-contrast cardiac CT Images using an entropy-based cost function

O. C. Avila-Montes, U. Kukure, I. A. Kakadiaris, Univ. of Houston (United States)

Studies have shown that aortic calcification is associated with increased risk of cardiovascular disease. In this paper, we present an entropy-based method for segmentation of the ascending aorta in non-contrast Computed Tomography (CT) images towards aortic calcification detection. Previous approaches formulated the problem of aorta segmentation as an optimal path detection problem, which is solved using dynamic programming principles in a polar coordinate system. However, owing to the lack of contrast in the non-contrast CT images, the edge features used in the previous approaches are insufficient to characterize the aorta boundary. We propose a local entropy-based feature, defined as a measure of local disorder, to characterize the aorta boundary features. This feature is used as an indicator of the edge characteristics overcoming the limitation of previously used edge feature. Furthermore, we present an iterative, narrow-band method to compute a locally optimal boundary path using dynamic programming. Instead of using the polar coordinate system, we define a modified coordinate system bounded within a narrow band. This formulation allows the boundary contour to deviate from the circular shape, and the narrow-band restricts the search space locally avoiding unexpected contour deformations. The iterative nature of the method allows the deforming contour to reach the real boundary of the aorta, irrespective of its shape. The results from the proposed method compare well with the manually traced aorta boundaries and outperform the previous approach in terms of boundary distance error.

7623-127, Poster Session

A skull segmentation method for brain MR images for combined PET/MRI applications

X. Yang, Emory Univ. School of Medicine (United States); H. Wang, Case Western Reserve Univ. (United States); B. Fei, Emory Univ. School of Medicine (United States)

We present an automatic segmentation method for the skull on brain MR images for attenuation correction in combined PET/MRI applications. Our method transforms T1-weighted MR images to the Random domain and then detects the feature of the skull. In the Random domain, the "sonogram" signals are filtered using two filters with different kernels along the vertical direction. After combining the two filtered sinogram, the reciprocal binary sinogram of the skull is obtained for the reconstruction of the skull image. We use filtered back projection (FBP) or order subset expectation maximization (OSEM) methods to get the segmented skull image. We define six metrics to evaluate our segmentation method. The method has been tested with brain phantom data, simulated brain data (PET-SORTEO), and patient MRI and CT data sets. Evaluation results showed that our method is robust and accurate, which is useful for skull segmentation and subsequently for attenuation correction in combined PET/MRI applications.

7623-128, Poster Session

A skull stripping method using deformable surface and tissue classification

X. Tao, M. Chang, GE Global Research (United States)

Many neuroimaging applications require an initial step of skull stripping to extract the cerebrum, cerebellum, and brain stem. We approach this problem by combining deformable surface models and a fuzzy tissue classification technique. Our assumption is that contrast exists between brain tissue (gray matter and white matter) and cerebrospinal fluid, which separates the brain from the extra-cranial tissue. We first analyze the intensity of the entire image to find an approximate centroid of the brain and initialize an ellipsoidal surface around it. We then perform a fuzzy tissue classification with bias field correction within the surface. Tissue classification and bias field are extrapolated to the entire image. The surface iteratively deforms under a force field computed from the tissue classification and the surface smoothness. Because of the bias field correction and tissue classification, the proposed algorithm depends less on particular imaging contrast and is robust to inhomogeneous intensity often observed in magnetic resonance images. We tested the algorithm on all T1 weighted images in the OASIS database, which includes skull stripping results using Brain Extraction Tool; the Dice scores have an average of 0.948 with a standard deviation of 0.017, indicating a high degree of agreement. The algorithm takes on average 2 minutes to run on a typical PC and produces a brain mask and membership functions for gray matter, white matter, and cerebrospinal fluid. We also tested the algorithm on T2 images to demonstrate its generality, where the same algorithm without parameter adjustment gives satisfactory results.

7623-129, Poster Session

Intracranial aneurysm segmentation in 3D CT angiography: method and quantitative validation with and without prior noise filtering

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Accurately quantifying aneurysm shape parameters is of clinical importance, as it is an important factor in choosing the right treatment modality (i.e. coiling or clipping), in predicting rupture risk and operative risk and for pre-surgical planning. The first step in aneurysm quantification is to segment it from other structures present in the image. As manual segmentation is a tedious procedure and prone to inter- and intra-observer variability, there is a need for an automated method which is accurate and reproducible. In this paper a novel semi-automated method for segmenting aneurysms in Computed Tomography Angiography (CTA) data based on Geodesic Active Contours is presented and quantitatively evaluated. Three different image features are used to steer the level set to the boundary of the aneurysm, namely intensity, gradient magnitude and variance in intensity. The method requires minimum user interaction, i.e. clicking a single seed point inside the aneurysm which is used to estimate the vessel intensity distribution and to initialize the level set. Furthermore it is investigated whether prior smoothing may improve results; hereto three different smoothing filters have been evaluated: Gaussian filtering, Edge Enhancing Diffusion and a regularized Perona-Malik nonlinear diffusion. The results show that the developed method is reproducible, and performs in the range of inter-observer variability in terms of accuracy. Furthermore, applying nonlinear diffusion prior to segmentation, slightly improves segmentation accuracy.

7623-130, Poster Session

Segmentation of the thalamus in multispectral MR images using a combination of atlas-based and gradient graph cut methods

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Two popular segmentation methods used today are atlas based registration and the graph cut algorithm. The atlas based method deforms a manually segmented image onto a target image, resulting in

an automatic segmentation. The spectral gradient graph cut algorithm is a segmentation method that merges three image modalities into a single RGB-like MRI and uses the graph cut paradigm to classify each pixel.

The atlas based registration method uses both spatial and textural information, often resulting in a good segmentation. However, the search space is much too large to be comprehensively searched and, thus, some segmentations may have errors. The graph cut algorithm on the other hand is quick to compute and is able to use information from three separate image modalities, but it does not use any spatial information and can often be confused by organs that have a similar appearance. Also, the graph cut algorithm has the limitation of being semi-automatic.

Therefore, the goal of this paper is to combine both of these methods, creating better segmentations. The registration algorithm is used to automate and initialize the graph cut algorithm as well as add needed spatial information.

Results show that the new method performs statistically better segmentations than the atlas-based registration alone (mean Dice Similarity Coefficient (DSC) 0.837 versus 0.818 for registration), especially in the case of images that have not been denoised where the registration is not as precise (mean DSC 0.829 for graph cut versus 0.800 for registration).

7623-131, Poster Session

Automated lung tumor segmentation for whole body PET volume based on novel downhill region growing

C. G. Ballangan, X. Wang, S. Eberl, M. Fulham, D. Feng, The Univ. of Sydney (Australia)

We propose an automated lung tumor segmentation method based on a novel downhill region growing (DRG) technique, which regards homogeneous tumor hotspots as 3D monotonically decreasing functions. The method has three major steps: thoracic slice extraction with K-means clustering of the slice features; hotspot segmentation with DRG; and decision tree analysis based hotspot classification. To overcome the common problem of leakage into adjacent hotspots in an automated lung tumor segmentation system from PET volumes, DRG employs the monotonicity features of tumors' SUV. DRG also uses gradient magnitude of tumors' SUV to improve tumor boundary definition. We evaluated our approach in 14 PET volumes from patients with primary NSCLC with pre-segmented tumors in CT as the gold standard. The thoracic region extraction step achieved good and consistent results for all 14 patients despite marked differences in size and shape of the lungs and the presence of large tumors. The DRG technique was able to avoid the problem of leakage into adjacent hotspots and produced a volumetric overlap fraction of 0.61 +/- 0.13 which outperformed four other methods where the overlap fraction varied from 0.40 +/- 0.24 to 0.59 +/- 0.14. Of the 18 tumors in 14 NSCLC studies, 15 lesions were classified correctly, 2 were false negative and 15 were false positive.

7623-132, Poster Session

'Active contour without edges', on parametric manifolds

Y. Gao, A. R. Tannenbaum, Georgia Institute of Technology (United States)

Region based active contour model has been widely used in image segmentation on planar images. However while a photo picture or a medical image is defined on 2D or 3D Euclidean spaces, in many cases the information is defined on the curved surfaces, or more general manifolds. In this work we extend the region based active contour method to work on the parametric manifolds. Essentially, it was noticed that in some region based active contour segmentation methods, it were only the signs of the level set function values, instead of the value themselves, which contribute to the cost functional. Thus a binary

state function is enough to represent the two phase segmentation. This gives an alternative view of the level set based optimization and it is especially useful when the image domain is curved because the signed distance function and its derivative are relative difficult to be evaluated in a curved space. Based on this, the segmentation on the curved space is proceed by consecutively changing the binary state function, to optimize the cost functional. Finally, the converged binary function gives the segmentation on the manifold. The method is stable and fast. We demonstrate the applications of this method, with the cost functional defined using the Chan-Vese model, in neuroimaging, fluid mechanics and geographic fields where the information is naturally defined on curved surfaces.

7623-133, Poster Session

Blood vessel segmentation using line-direction vector based on Hessian analysis

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For decision of the treatment strategy, grading of stenoses is important in diagnosis of vascular disease such as arterial occlusive disease or thromboembolism. It is also important to understand the vasculature in minimally invasive surgery such as laparoscopic surgery or natural orifice translumenal endoscopic surgery. Precise segmentation and recognition of blood vessel regions are indispensable tasks in medical image processing systems. Previous methods utilize only "lineness" measure, which is computed by Hessian analysis. However, difference of the intensity values between a voxel of thin blood vessel and a voxel of surrounding tissue is generally decreased by the partial volume effect. Therefore, previous methods cannot extract thin blood vessel regions precisely. This paper describes a novel blood vessel segmentation method that can extract thin blood vessels with suppressing false positives. The proposed method utilizes not only lineness measure but also line-direction vector corresponding to the largest eigenvalue in Hessian analysis. By introducing line-direction information, it is possible to distinguish between a blood vessel voxel and a voxel having a low lineness measure caused by noise. In addition, we consider the scale of blood vessel. The proposed method can reduce false positives in some line-like tissues close to blood vessel regions by utilization of iterative region growing with scale information. The experimental result shows thin blood vessel (0.5 mm in diameter, almost same as voxel spacing) can be extracted finely by the proposed method.

7623-134, Poster Session

Brain segmentation performance using T1-weighted images versus T1 maps

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The recent driven equilibrium single-pulse observation of T1 (DESPOT1) approach permits real-time clinical acquisition of large-volume and high-isotropic-resolution T1 mapping of MR tissue parameters with improved uniformity. It is assumed that the quantitative nature of maps will facilitate clinical applications such as disease diagnosis and comparison across subjects. However, there is not yet enough quantitative evidence on the actual benefit of adopting T1 maps, especially in computer-aided medical image analysis tasks. In this study, we compare methods with respect to two image types, T1-weighted images or T1 maps, for automatic brain MRI segmentation. Our experimental results demonstrate that, when using T1 maps, different segmentation algorithms show better agreement with each other, compared to that when using T1-weighted images. Further, the segmentation results using the same type of input images tend to better agree with each other, and thus all the segmentation results form two separate clusters. Finally, by comparing to a reference segmentation of brain-subregions produced by a neuroscientist, our results clearly show a better agreement with the reference when T1 maps are used. Our study demonstrates that using T1 maps lead to

better reliability in automatic brain MRI segmentation task than T1-weighted images.

7623-135, Poster Session

Detection of small human cerebral cortical lesions with MRI under different levels of Gaussian smoothing: applications in epilepsy

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The main objective of this study was to assess the effect of smoothing filter selection on Voxel-Based Morphometry studies of structural T1-weighted magnetic resonance images. VBM studies require smoothing the images to facilitate the gathering of image statistics. Commonly the preferred smoothing kernel is a Gaussian of 4 mm, 8 mm or 10 mm Full Width at High Maximum, based on the rule of thumb that the filter size should be at least twice the voxel size to get robust statistical results. Our hypothesis was that the selection of the smoothing kernel influences the detectability of small lesions in the brain. In particular, we were interested in studying this issue for the detection of Mesial Temporal Sclerosis associated with Mesial Temporal Lobe Epilepsy. For this purpose we used 20 T1-weighted simulated MRIs from the BrainWeb website. On each image a small spherical phantom lesion was placed in the amygdala, hippocampus, or parahippocampal gyrus with the guidance of the Anatomical Automatic Labelling mask. All the images were registered to the ICBM/MNI space and, after grey matter segmentation; a T-test was carried out to compare each image containing a phantom lesion with the rest of the images in the set. For each lesion the T-test was repeated under different Gaussian kernel sizes. VBM detected some of the phantom lesions. Interestingly, any phantom lesion smaller than 123 cubic millimetres was not detected, while a larger volume significantly increased the susceptibility of detection for the lesions.

7623-136, Poster Session

Automated method for tracing leading and trailing processes of migrating neurons in confocal image sequences

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Segmentation, tracking, and tracing of neurons in video imagery are important steps in many neuronal migration studies and can be inaccurate and time-consuming when performed manually. In this paper, we present an automated method for tracing the leading and trailing processes of migrating neurons in time-lapse image stacks acquired with a confocal fluorescence microscope. In our approach, we first locate and track the soma of the cell of interest by smoothing each frame and tracking the local maxima through the sequence. We then trace the leading process in each frame by starting at the center of the soma and stepping repeatedly in the most likely direction of the leading process. This direction is found at each step by examining second derivatives of fluorescent intensity along curves of constant radius around the current point. Tracing terminates after a fixed number of steps or when fluorescent intensity drops below a fixed threshold. We evolve the resulting trace to form an improved trace that more closely follows the approximate centerline of the leading process. We apply a similar algorithm to the trailing process of the cell by starting the trace in the opposite direction. We demonstrate our algorithm on time-lapse confocal imagery of migrating cerebellar granule neurons (CGNs). We show qualitatively that our automated traces closely approximate traces drawn manually by neurobiologists on the same images.

Additionally, we compute line intensity profiles of fluorescence along the automated traces and show their similarity to manually generated profiles in terms of fluorescence peak locations.

7623-137, Poster Session

Quantitative CT for volumetric analysis of medical images: initial results for liver tumors

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Quantitative CT for volumetric analysis of medical images is increasingly being proposed for monitoring patient response during chemotherapy trials. An integrated MATLAB GUI has been developed for an oncology trial at Georgetown University Hospital. This GUI allows for the calculation and visualization of the volume of a lesion. The GUI provides an estimate of the volume of the tumor using a semi-automatic segmentation technique. This software package features a fixed parameter adaptive filter from the ITK toolkit and a tumor segmentation algorithm to reduce inter-user variability and to facilitate rapid volume measurements. The system also displays a 3D rendering of the segmented tumor, allowing the end user to have not only a quantitative measure of the tumor volume, but a qualitative view as well. As an initial validation test, several clinical cases were hand-segmented, and then compared against the results from the tool, showing good agreement.

7623-138, Poster Session

Multiobject segmentation using coupled shape space models

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Due to noise and artifacts often encountered in medical images, segmenting objects in these is one of the most challenging tasks in medical image analysis. Model-based approaches like statistical shape models (SSMs) incorporate prior knowledge that supports object detection in case of in-complete evidence from image data. In this paper, we present a method to increase information of the object's shape in problematic image areas by incorporating mutual shape information from other entities in the image. This is done by using a common shape space of multiple objects as additional restriction. Two different approaches to implement mutual shape information are presented. Evaluation was performed on nine cardiac images by simultaneous segmentation of the epi- and endocardium of the left heart ventricle using the proposed methods. The results show that the segmentation quality is improved with both methods. For the better one, the average surface distance error is approx. 40% lower.

7623-139, Poster Session

Automatic recognition and validation of the common carotid artery wall segmentation in 100 longitudinal ultrasound images: an integrated approach using feature selection, fitting and classification

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We developed a completely automated segmentation algorithm for the detection of the 100 common carotid artery (CCA) in longitudinal B-Mode images. Considering the CCA as a low-intensity region (the lumen) surrounded by two bright stripes (the arterial walls), our algorithm first localizes all the local intensity maxima that are likely to belong to the adventitia layers. Specific features of these points (the intensity value and the neighborhood intensity breadth) are linearly combined and only the local maxima with higher energy are considered as seed points. The seed points are then combined to trace line segments. A final fitting and classification procedure discards false positive tracings to detect the line segments corresponding to the CCA adventitia layers. Our system is characterized as integrated approach.

We validated our algorithm on 100 longitudinal B-Mode images and compared the performances to those of a previously developed automatic algorithm. Human tracings of the arterial walls were considered as ground truth (GT). We showed that the integrated technique outperforms our previous technique: the average distance from GT is of 1.0 pixels for near wall and of 2.7 pixels for far wall. Of the 100 images, only 8 were discarded since not correctly processed (i.e., we obtained automatic tracings that did not follow the adventitial layers).

The new technique, based on an integrated approach consisting in feature extraction, fitting and classification, allows segmentation performances that are in line with the most performing user-driven techniques.

7623-141, Poster Session

Automated fat measurement and segmentation with intensity inhomogeneity correction

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Adipose tissue (AT) content, especially visceral AT (VAT), is an important indicator for risks of many disorders, including heart disease and diabetes. Measurement of fat by traditional means is often inaccurate and additionally does not separate subcutaneous fat and visceral fat. MRI offers a medium to obtain accurate measurements and segmentation between subcutaneous and visceral fat. This paper presents an approach to automatically label the voxels associated with adipose tissue and segment them between subcutaneous and visceral. First a body mask is extracted and image correction, including N3 inhomogeneity correction and anisotropic diffusion filtering, is applied to this body mask. Fuzzy c-means is then performed on the body mask to separate AT and other soft tissue. Then using fuzzy membership values to determine forces, active contours are used to separate subcutaneous AT (SAT) and VAT. Fuzzy c-means is performed again on the VAT mask and thresholds on membership values are used to label voxels as SAT and VAT. The method was validated against a manual method performed by two observers, which used thresholds and manual contours to separate SAT and VAT. We measured 25 patients, 22 of which were included in the final analysis and the other three had too much artifact for automated processing. For SAT and total AT, differences between manual and automatic measurements were comparable to manual inter-observer differences. VAT measurements showed slightly more variance in the automated methods.

7623-142, Poster Session

A novel fast liver segmentation method with graph cuts

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Liver segmentation remains a difficult problem in medical images processing, especially when accuracy and speed are both seriously considered. Graph Cuts is a powerful segmentation tool through which the optimal results are often got by considering both region and boundary information in images. However, the traditional Graph Cuts algorithms are always computationally expensive and inappropriate to

be applied to real clinical circumstance. Recently, the GPU (Graphics Processor Unit) had evolved to be a cheap and superpower general purpose computing instruments, especially when NVIDIA released its revolutionary CUDA (Compute Unified Device Architecture). In this paper, we introduce a novel method to segment 3D liver images in GPU, using the push-relable style 3D Graph Cuts implementation. This algorithm could run hundreds of time faster than traditional CPU methods, and it is well fitted to the GPU parallel computing capabilities. Extensive Experiments have been executed on human liver CT Data, including patients with or without liver tumors. These experiments show that the method obtains more accurate results in much less time compared to traditional methods, and it could speed up the processing 50-100 times faster than the same style CPU implement on the same computer. Several improvements to the traditional graph cuts algorithms are also introduced in this paper, which could better fit the method to the 3D volume segmentation problem and the clinical requirements. This method is integrated in several surgery planning and surgery navigation systems and has achieved good results in clinical circumstance.

7623-143, Poster Session

Thrombus segmentation by texture dynamics from microscopic image sequences

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The genetic factors of thrombosis are commonly explored by microscopically imaging the coagulation of blood cells induced by injuring a vessel of mice or of zebrafish mutants. The latter species is particularly interesting since skin transparency permits to non-invasively acquire microscopic images of the scene with a CCD camera and to estimate the parameters characterizing the thrombus development. These parameters are currently determined by manual outlining, which is both error prone and extremely time consuming. Even though a technique for automatic thrombus extraction would be highly valuable for gene analysts, little work can be found, which is mainly due to very low image contrast and spurious structures. In this work, we propose to semi-automatically segment the thrombus over time from microscopic image sequences of wild-type zebrafish larvae. To compensate the lack of valuable spatial information, our main idea consists of exploiting the temporal information by modeling the variations of the pixel intensities over successive temporal windows with a linear Markov-based dynamic texture formalization. We then derive an image from the estimated model parameters, which represents the probability of a pixel to belong to the thrombus. We employ this probability image to accurately estimate the thrombus position via an active contour segmentation incorporating also prior and spatial information of the underlying intensity images. The performance of our approach is tested on three microscopic image sequences. We show that the thrombus is accurately tracked over time in each sequence if the respective parameters controlling prior influence and contour stiffness are correctly chosen.

7623-144, Poster Session

Relaxed image foresting transforms for interactive volume image segmentation

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The Image Foresting Transform (IFT) is a framework for image partitioning, commonly used for interactive segmentation. Given an image where a subset of the image elements (seed-points) have been assigned user-defined labels, the IFT completes the labeling by computing minimal cost paths from all image elements to the seed-points. Each image element is then given the same label as the closest seed-point.

We propose a modified version of the IFT, featuring an additional parameter to control the smoothness of the segmentation boundary. The modified algorithm produces more intuitive segmentation results in the presence of noise, while maintaining a low computational complexity. We show an application of the method for interactive segmentation of back muscles in magnetic resonance images, where seed-points representing object and background are placed repeatedly until a desired segmentation result is obtained.

7623-145, Poster Session

Digital cleansing for virtual colonoscopy with probability map

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Identifying the residual fluid retained inside the colon is a major challenge for 3D virtual colonoscopy (VC). Digital cleansing aims to segment the colon lumen from a patient abdominal image acquired using an oral contrast agent for colonic material tagging. Then, the clean virtual colon model can be constructed and visualized for screening. We present a novel method for digital cleansing using probability map. The random walker algorithm is used to generate probability map for air (inside the colon), soft tissue, and residual fluid instead of segment colon lumen directly. The probability map is then used to remove residual fluid from the original CT data. The proposed method was tested using VC study data at National Cancer Institute at NIH. The performance of our VC system for polyp detection has been improved by providing radiologists more detail information of the colon wall.

7623-146, Poster Session

Optimal combination of multiple cortical surface parcellations

X. Hu, L. Guo, G. Li, Northwestern Polytechnical Univ. (China); T. Liu, The Univ. of Georgia (United States)

This paper presents an algorithm for simultaneous truth and performance estimation of various approaches for human cortical surface parcellation. The probabilistic true segmentation is estimated as a weighted combination of the segmentations resulted from multiple methods. An Expectation-Maximization (EM) algorithm is used to optimize the weighting depending on the estimated performance level of each method. Further, a spatial homogeneity constraint modeled by the Hidden Markov Random Field (HMRF) theory is incorporated to refine the estimated true segmentation into a spatially homogenous decision. The proposed method has been evaluated using both synthetic and real data. Also, it is used to generate reference sulci regions to perform a comparison study of methods for cortical surface parcellation.

7623-147, Poster Session

A multiscale approach to mass segmentation using level set method

H. Yu, L. Li, W. Xu, W. Liu, Hangzhou Dianzi Univ. (China)

As an important step of mass detection in mammograms, mass segmentation plays an important role in the computer-aided diagnosis (CAD) system. In this paper, we propose a novel scheme for breast mass segmentation, which is based on level set method and multi-scale analysis. In the proposed method, firstly mammogram is decomposed by Gaussian pyramid into a sequence of images from fine to coarse, the C-V model is applied at the coarse scale, and the obtained rough contour is used as the initial contour at the fine scale. The C-V model is able to obtain the mass contour roughly and easily because it is a region information based level set method. However, since most mammograms are inhomogeneous, while the C-V model assumes that an image consists of statistically homogeneous regions,

it could hardly segment the mass edge precisely. Thus, we develop a novel model (LAC) based on image local information, which can deal with the inhomogeneous images well. The LAC method is utilized to refine the rough contour locally at the fine scale. With the combination of global-information-based C-V method and local-information-based LAC method, the proposed method is able to take full advantage of image global and local information, thus the method we proposed is applicable to mass segmentation in mammograms perfectly. The experimental results demonstrate that the proposed method is an effective method for breast mass segmentation.

7623-148, Poster Session

Statistical fusion of surface labels provided by multiple raters

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Studies of the size and morphology of anatomical structures rely on accurate and reproducible delineation of the structures, obtained either by human raters or automatic segmentation algorithms. Measures of reproducibility and variability are vital aspects of such studies and are usually acquired using repeated scans and repeated delineations (in the case of human raters). Methods exist for simultaneously estimating the true structure and rater performance parameters from multiple segmentations and have been demonstrated on volumetric images. In this work, we extend the applicability of previous methods onto two-dimensional surfaces parameterized as triangle meshes. Label homogeneity is enforced using a Markov random field formulated with an energy that addresses the challenges introduced by the surface parameterization. The method was explored using both simulated raters and surface labels obtained from an atlas registration. Simulated raters are computed using a global error as well as a novel and more realistic boundary error model. We show that this method effectively estimates the true segmentation on both the simulated and real data sets.

7623-149, Poster Session

Ball-scale based multiobject recognition in a hierarchical framework

U. Bagci, The Univ. of Nottingham (United Kingdom); J. K. Udupa, X. Chen, The Univ. of Pennsylvania Health System (United States)

This paper investigates, using prior shape models and the concept of ball scale (b-scale), ways of automatically recognizing objects in 3D images without performing elaborate searches or optimization. That is, the goal is to place the model in a single shot close to the right pose (position, orientation, and scale) in a given image so that the model boundaries fall in the close vicinity of object boundaries in the image. This is achieved via the following set of key ideas: (a) A semi-automatic way of constructing a multi-object shape model assembly. (b) A novel strategy of encoding, via b-scale, the pose relationship between objects in the training images and their intensity patterns captured in b-scale images. (c) A hierarchical mechanism of positioning the model, in a one-shot way, in a given image from a knowledge of the learnt pose relationship and the b-scale image of the given image to be segmented. The evaluation results on a set of 10 routine clinical abdominal female CT data sets indicate the following: (1) Incorporating a large number of objects improves the recognition accuracy dramatically. (2) The recognition algorithm is more stable in a hierarchical framework. (3) Scale yields useful information about the relationship between the model assembly and any given image such that the recognition results in a placement of the model close to the actual pose without doing any elaborate searches or optimization. (4) Effective object recognition can make delineation most accurate.

7623-150, Poster Session

Automatic segmentation of the aorta and the adjoining vessels

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Diseases of the cardiovascular system are one of the main causes of death in the western world. For diagnosis, treatment and operation simulation, a reliable segmentation of cardiovascular structures, especially the aorta and its main descending vessels is crucial. In our approach, we present a method that allows to segment and classify aorta, carotides, and ostium (including coronary arteries) in one run, fully automatic and highly robust. The system tolerates changes in topology, streak artifacts in CT caused by calcification and inhomogeneous distribution of contrast agent. Both CT and MRI-Images can be processed. The underlying algorithm is based on a combination of Vesselness Enhancement Diffusion, Region Growing, and the Level Set Method. The system showed good results on noisy and 15 real patient data sets. Based on 15 data sets, both MRI and CT, the method succeeded in each case and the results are accurate up to two pixels.

7623-151, Poster Session

A completely automated processing pipeline for lung and lung lobe segmentation and its application to the LIDC-IDRI data base

T. Blaffert, R. Wiemker, H. Barschdorf, S. Kabus, T. Klinder, C. Lorenz, Philips Research (Germany); E. Dharaiya, Philips Medical Systems (United States)

Automated segmentation of lung lobes in thoracic CT images has relevance for various diagnostic purposes like localization of tumors within the lung or quantification of emphysema. Since emphysema is a known risk factor for lung cancer, both purposes are even related to each other. The main steps of the segmentation pipeline described in this paper are the lung detector and the lung segmentation based on a watershed algorithm, and the lung lobe segmentation based on mesh model adaptation. The segmentation procedure was applied to data sets of the data base of the Image Database Resource Initiative (IDRI) that currently contains over 500 thoracic CT scans with delineated lung nodule annotations. We visually assessed the reliability of the single segmentation steps, with a success rate of 97% for the lung detection and 86% for lung delineation. For 80% of the cases we found the lobe segmentation to be anatomically plausible. In 27% of the cases additional anatomical structures were erroneously included, mainly the trachea and in some cases parts of the bowel. For a demonstration of the segmentation method we studied the correlation between emphysema score and malignancy on a per-lobe basis.

7623-152, Poster Session

Gyral parcellation of cortical surfaces via coupled flow field tracking

G. Li, L. Guo, J. Nie, Northwestern Polytechnical Univ. (China); T. Liu, The Univ. of Georgia (United States)

This paper presents a novel method for parcellation of the cortical surface of human brain into gyral regions via coupled flow field tracking. The proposed method consists of two major steps. First, the cortical surface is automatically parcellated into sulcal based regions using several procedures: estimating principal curvatures and principal directions; applying the hidden Markov random field and the Expectation-Maximization (HMRF-EM) framework for sulcal region segmentation based on maximum principal curvature; diffusing the maximum principal direction field in order to propagate reliable and informative principal directions at gyral crests and sulcal bottoms to

other flat cortical regions with noisy principal directions by minimization of an energy function; tracking the flow field towards sulcal bottoms to segment the cortical surfaces into sulcal basins. The sulcal parcellation provides a very good initialization for the following steps of gyral parcellation. Second, based on the sulcal parcellation results, the cortical surface is further parcellated into gyral based regions using the following procedures: extracting gyral crest segments; dilating gyral crest segments; inverting the flow field and tracking the flow field towards gyral crests in order to partition the surface into a collection of gyral patches; merging gyral patches to obtain gyri based parcellation of the cortical surface. The proposed algorithm pipeline is applied to 9 randomly selected cortical surfaces of normal brains and promising results are obtained. The accuracy of the parcellated gyri is comparable to experts manually labeled gyri.

7623-153, Poster Session

Segmentation of deformable organs from medical images using particle swarm optimization and nonlinear shape priors

A. Afifi, T. Nakaguchi, N. Tsumura, Chiba Univ. (Japan)

In many medical applications, the automatic segmentation of deformable organs from medical images is indispensable and its accuracy is of a special interest. However, the automatic segmentation of these organs is a challenging task according to its complex shape. Moreover, the medical images usually have noise, clutter, or occlusion and considering the image information only often leads to meager image segmentation. In this paper, we propose a fully automated technique for the segmentation of deformable organs from medical images. In this technique, the segmentation is performed by fitting a nonlinear shape model with pre-segmented images. The kernel principle component analysis (KPCA) is utilized to capture the complex organs deformation and to construct the nonlinear shape model. The pre-segmentation is carried out by labeling each pixel according to its high level texture features extracted using the over-complete wavelet packet decomposition. Furthermore, to guarantee an accurate fitting between the nonlinear model and the pre-segmented images, the particle swarm optimization algorithm (PSO) is employed to adapt the model parameters for the novel images. In this paper, we demonstrate the competence of proposed technique by implementing it to the liver segmentation from computed tomography (CT) scans of different patients.

7623-154, Poster Session

Fuzzy affinity induced curve evolution

Y. Zhuge, National Cancer Institute/NIH (United States); J. K. Udupa, The Univ. of Pennsylvania Health System (United States); R. W. Miller, National Cancer Institute/NIH (United States)

Curve evolution methods have been widely used in image segmentation. These methods drive one or more initial curves to boundaries of objects of interest based on speed functions. For the numerical implementation of curve evolution, the level-set method has become popular because of its many advantages, such as the automatic handling of topological changes, general numerical schemes for high dimensions, etc. Typically, level-set implementation of the curve evolution process is based on the solution of partial differential equations (PDEs), which results in a high computation burden thus limiting its use in many applications with high efficiency requirement. In [1], an algorithm for the approximation of level-set-based curve evolution has been reported to reduce the computation time of typical level-set-based methods. The method does not need to solve PDEs and achieves real time results, while still keeping the main advantages of level-set-based methods. However, only very simple speed functions have been used in [1], and noise in the images has not been discussed. In this paper, we make use of fuzzy affinity that has been employed in fuzzy connectedness methods as a speed function for curve evolution. The fuzzy affinity consists of two components, namely homogeneity-based affinity and object-feature-based affinity, which

take account both boundary gradient and object region information. Ball scale - a local morphometric structure - has been used for image noise suppression. We use a similar strategy for curve evolution as the method in [1], but simplify the voxel switching mechanism where only one linked list is used to implicitly represent the evolving curve. We have presented several studies to evaluate the performance of the method based on brain MR and lung CT images. These studies demonstrate high accuracy and efficiency of the proposed method.

7623-155, Poster Session

Multi-structure segmentation of multi-modal brain images using artificial neural networks

E. Y. Kim, H. J. Johnson, The Univ. of Iowa Hospitals and Clinics (United States)

A method for simultaneously segmenting multiple anatomical brain structures from multi-modal MR images has been developed. An artificial neural network (ANN) was trained from a set of feature vectors created by a combination of high-resolution registration methods, atlas based spatial probability distributions, and a training set of 16 expert traced data sets. A set of feature vectors were adapted to increase performance of ANN segmentation; 1) a modified spatial location for structural symmetry of human brain, 2) neighbors along the priors' descent for directional consistency, and 3) candidate vectors based on the priors for the segmentation of multiple structures. The trained neural network was then applied to 8 data sets, and the results were compared with expertly traced structures for validation purposes. Comparing several reliability metrics, including a relative overlap, similarity index, and intraclass correlation of the ANN generated segmentations to a manual trace are similar or higher to those measures previously developed methods. The ANN provides a level of consistency between subjects and time efficiency comparing human labor that allows it to be used for very large studies.

7623-156, Poster Session

Segmentation of cervical cell images using mean-shift filtering and morphological operators

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Screening plays an important role within the fight against cervical cancer. One of the most challenging parts in order to automate the screening process is the segmentation of nuclei in the cervical cell images, as the difficulty for performing this segmentation accurately varies widely within the nuclei. We present an algorithm to perform this task. After background determination in an overview image, regions of interest at the full magnification level of 40x are extracted and processed. Subsequent to initial background removal, the image region is smoothed by mean-shift and median filtering. Then, a segmentation is generated by an adaptive threshold. The connected components in the resulting segmentation are filtered with morphological operators by characteristics such as shape, size and roundness. The algorithm was tested on a set of 50 images and was found to outperform other methods.

7623-157, Poster Session

Multilevel wireless capsule endoscopy video segmentation

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Wireless Capsule Endoscopy (WCE) is a relatively new technology (FDA approved 2002) allowing doctors to view most of the small intestine.

A tiny disposable video capsule is swallowed, and transmitting two images per second to a small data receiver worn by the patient on a belt. During an approximately 8-hour course, over than 55,000 images are recorded to a worn device, and then they are downloaded to a computer for the later examination. Typically, a medical clinician spends one or two hours to analyze a WCE video. To reduce the assessment time, it is critical to develop a technique to automatically discriminate digestive organs (esophagus, stomach, small intestinal and colon) and shots each of which consists of the same or similar shots. In this paper a multi-level WCE video segmentation methodology is presented to reduce the examination time. Our approach first divides the WCE image into regions using a region segmentation technique. We then create a feature vector combining color and texture information of the entire image and sub-regions. Based on the feature vector, each frame is evaluated to detect the boundaries of the digestive organs using the support vector machine. Finally the shot boundaries within each organ are detected using the graph matching technique. Our experimental results indicate that the proposed organ segmentation technique can segment its organ in most of cases, and the recall and precision of the proposed shot segmentation reach up to 91% and 72%, respectively.

7623-158, Poster Session

A probability tracking approach to segmentation of ultrasound prostate images using weak shape priors

R. S. Xu, O. Michailovich, Univ. of Waterloo (Canada)

Ultrasound imaging has been a prevalent medical diagnostic tool due to its properties of being non-invasive, harmless, widely accessible, and cost efficient. In particular, among its numerous applications is the detection of abnormalities within the prostate gland. In this case, ultrasound prostate images can be used for determining the size and volume of the gland - the parameters which are known to be indicative of the presence of pathology. This fact makes automatic procedures for segmenting the prostate images highly desirable. Unfortunately, the accuracy and reliability of such segmentation are still hampered by relatively low contrast of the prostate region with respect to its background. Consequently, many modern segmentation algorithms take advantage of prior information about the prostate shape to augment the segmentation. In this work, a novel approach to incorporating the shape priors is presented. Specifically, the latter are defined in the form of the probability density function (pdf) of the curvature of the prostate boundary. Subsequently, the actual segmentation boundary is constrained to have its curvature distribution similar to the model pdf. The proposed shape prior can be regarded as a weak constraint since it is used as a regularization force that complements the segmentation driven by other image-related forces. Nonetheless, it is demonstrated in the experimental results that the proposed shape prior is sufficient to render the segmentation stable and accurate.

7623-159, Poster Session

A new osteophyte segmentation method with applications to an anterior cruciate ligament transection rabbit femur model via micro-CT imaging

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Osteophyte is an additional bony growth on a normal bone surface limiting or stopping motion in a deteriorating joint. Detection and quantification of osteophytes is helpful in assessing disease status as well as treatment and surgery planning. However, it is difficult to separate osteophytes from healthy bones using simple thresholding or edge/texture features in CT imaging. Here, we present a new method, based on active shape model (ASM), to solve this problem and evaluate

its application to ACLT rabbit femur model via µCT imaging. The common idea behind most ASM based segmentation methods is to first build a parametric shape model from a training dataset and during application, find a shape instance from the model that optimally fits to target image. However, it poses a fundamental difficulty for the current application because a diseased bone shape is significantly altered at regions with osteophyte deposition misguiding an ASM method that eventually leads to suboptimum segmentation results. Here, we introduce a new partial ASM method that uses bone shape over healthy regions and extrapolate its shape over diseased region following the underlying shape model. Once the healthy bone region is detected, osteophyte is segmented by subtracting partial-ASM derived shape from the overall diseased shape. Also, a new semi-automatic method is presented in this paper for efficiently building a 3D shape model for rabbit femur. The method has been applied to micro-CT images of 2-, 4-, and 8-week ACLT and sham-treated rabbit femurs and both the qualitative and quantitative results are encouraging.

7623-160, Poster Session

Segmentation of blurry object by learning from examples

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Object with blurry boundary is a very common problem across image modalities and applications in medical field. Examples include skin lesion segmentation, tumor delineation in mammogram, tongue tracing in MR images, etc. To address blurry boundary problem, region-based active contour methods have been developed which utilize global image feature to address the problem of fuzzy edge. Image feature, such as texture, intensity histograms, or structure tensors, have also been studied for region-based models. On the other hand, trained domain experts have been much more effective in performing such tasks than computer algorithms that are based on a set of carefully selected, sophisticated image features. In this paper, we present a novel method that employs a learning strategy to guide active contour algorithm for delineating blurry objects in the imagery. Our method consists of two steps. First, using gold-standard examples, we derive statistical descriptions of the object boundary. Second, in the segmentation process, the statistical description is reinforced to achieve desired delineation. Experiments were conducted using both synthetic images and the skin lesion images. Our synthetic images were created with 2D Gaussian function, which closely resembles objects with blurry boundary. The robustness of our method with respect to the initialization is evaluated. Using different initial curve, similar results were achieved consistently. In experiments with skin lesion images, the outcome matches the contour in reference image, which are prepared by human experts. In summary, our experiments using both synthetic images and skin lesion images demonstrated great segmentation accuracy and robustness.

7623-161, Poster Session

Computer-aided detection of bladder tumors based on the thickness mapping of bladder wall in MR images

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Bladder cancer is reported to be the fifth leading cause of cancer deaths in the United States. Recent advances in medical imaging technologies, such as magnetic resonance (MR) imaging, make virtual cystoscopy a potential alternative with advantages as being a safe and non-invasive method for evaluation of the entire bladder and detection of abnormalities. To help reducing the interpretation time and reading fatigue of the readers or radiologists, we introduce a computer-aided detection scheme based on the thickness mapping of the bladder wall since locally-thickened bladder wall often appears around tumors. In the thickness mapping method, the path used to measure the thickness can be determined without any ambiguity by tracing the

gradient direction of the potential field between the inner and outer borders of the bladder wall. The thickness mapping of the three-dimensional (3D) inner border surface of the bladder is then flattened to a two-dimensional (2D) gray image with conformal mapping method. In the 2D flattened image, a blob detector is then applied to detect the abnormalities, which are actually the thickened bladder wall indicating bladder lesions. Such scheme was tested on two MR datasets, one from a healthy volunteer and the other from a patient with a tumor. The result is preliminary, but very promising with 100% detection sensitivity at 7 FPs per case.

7623-162, Poster Session

Validation and detection of vessel landmarks by using anatomical knowledge

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The detection of anatomical landmarks is an important prerequisite to analyze medical images fully automatically. Several machine learning approaches have been proposed to parse 3D CT datasets and to determine the location of landmarks with associated uncertainty. However, it is a challenging task to incorporate high-level anatomical knowledge to improve these classication results. We propose a new approach to validate candidates for vessel bifurcation landmarks which is also applied to systematically search missed or ambiguous landmarks. A knowledge base is trained providing human-readable geometric information of the vascular system, mainly vessel lengths, radii and curvature information, for validation of landmarks and to guide the search process. To analyze the bifurcation area surrounding a vessel landmark of interest, a new approach is proposed which is based on Fast Marching and incorporates anatomical information from the knowledge base. Using the proposed algorithms, an anatomical knowledge base has been generated based on 90 manually annotated CT images containing dierent parts of the body. To evaluate the landmark validation a set of 50 carotid datasets has been tested in combination with a state of the art landmark detector with excellent results. Beside the carotid bifurcation the algorithm is designed to handle a wide range of vascular landmarks, e.g. celiac, superior mesenteric, renal, aortic, iliac and femoral bifurcation.

7623-163, Poster Session

Automatic OD detection and segmentation based on image brightness and image contrast

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Untreated glaucoma leads to permanent damage of the optic nerve and resultant visual field loss, which can progress to blindness. As glaucoma often produces additional pathological cupping of the optic disc (OD), cup-disc-ratio is one measure that is widely used for glaucoma diagnosis. This paper presents an OD localization method that automatically segments the OD and so can be applied for the cup-disc-ratio based glaucoma diagnosis. The proposed OD segmentation method is based on the observations that the OD is normally much brighter and at the same time have a smoother texture characteristics compared with other regions within retinal images. Given a retinal image we first capture the OD's smooth texture characteristic by a contrast image that is constructed based on the local maximum and minimum pixel lightness within a small neighborhood window. The centre of the OD can then be determined according to the density of the candidate OD pixels that are detected by retinal image pixels of the lowest contrast. After that, an OD region is approximately determined by a pair of morphological operations and the OD boundary is finally determined by an ellipse that is fitted by the convex hull of the detected

OD region. Experiments over 71 retinal images of different qualities show that the OD region overlapping reaches up to 90.37% according to the OD boundary ellipses determined by our proposed method and the one manually plotted by an ophthalmologist.

7623-164, Poster Session

Segmentation of blood clot from CT pulmonary angiographic images using a modified seeded region growing algorithm method

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Pulmonary embolism (PE) is a medical condition defined as the obstruction of pulmonary arteries by a blood clot, usually originating in the deep veins of the lower limbs. PE is a common but elusive illness that can cause significant disability and death if not promptly diagnosed and effectively treated. CT Pulmonary Angiography (CTPA) is the first line imaging study for the diagnosis of PE. While clinical prediction rules have been recently developed to associate short-term risks and stratify patients with acute PE, there is a dearth of objective biomarkers associated with the long-term prognosis of the disease. Clot (embolus) burden is a promising biomarker for the prognosis and recurrence of PE and can be quantified from CTPA images. However, to our knowledge, no study has reported a method for segmentation and measurement of clot from CTPA images. Thus, the purpose of this study was to develop a semi-automated method for segmentation and measurement of clot from CTPA images. Our method was based on Modified Seeded Region Growing (MSRG) algorithm which consisted of two steps: (1) the observer identifies a clot of interest on CTPA images and places a spherical seed over the clot; and (2) a region grows around the seed on the basis of a rolling-ball process that clusters the neighboring voxels whose CT attenuation values are within the range of the mean ± two standard deviations of the initial seed voxels. The rolling-ball propagates iteratively until the clot is completely clustered and segmented. Our experimental results revealed that the performance of the MSRG was superior to that of the conventional SRG for segmenting clots, as evidenced by reduced degrees of over- or under-segmentation from adjacent anatomical structures. To assess the clinical value of clot burden for the prognosis of PE, we are currently applying the MSRG for the segmentation and volume measurement of clots from CTPA images that are acquired in a large cohort of patients with PE in an on-going NIH-sponsored clinical trial.

7623-165, Poster Session

Development of an acquisition protocol and a segmentation algortihm for wounds of cutaneous Leishmaniasis in digital images

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This paper proposes the development of an acquisition protocol and an automatic segmentation algorithm for digital images of cutaneous Leishmaniasis injuries. The image acquisition protocol uses indirect light to overcome glare, shadow and uneven illumination artifacts. Two digital images of the injury are taken: One with the injury alone and the other one with the injury covered with engineering paper to have a reference of the curvature of the skin. Combining the information from both pictures, the area of the wound is calculated. The difference obtained between the area measured with this protocol and by direct estimation is 8.74%. The automated segmentation algorithm is composed of three stages. First, the location of the ulcer is determined using threshold and mathematical morphology techniques to the H layer of the HSV color space. Then, the boundary of the ulcer is

estimated by analyzing the color characteristics in the YIQ space using the information of the first stage. Finally, the discrete dynamic contours algorithm is applied. The segmented regions obtained with the algorithm were compared with manual segmentations made by a medical specialist. The results show an overall accuracy of 98%, sensitivity of 89% and specificity of 99%.

7623-166, Poster Session

Interactive segmentation method with graph cut and SVM

X. Zhang, J. Tian, D. Xiang, Y. Wu, Institute of Automation (China)

Medical image segmentation is a prerequisite for visualization and diagnosis. State-of-the-art techniques of image segmentation concentrate on interactive methods which are more robust than automatic techniques and more efficient than manual delineation. In this paper, we present an interactive segmentation method for medical images which relates to graph cut based on support vector machine (SVM). The proposed method is a hybrid method that combines three aspects. First, the user selects seed points to paint foreground and background using a "brush", and then the labeled pixels/voxels data including intensity value and gradient of the sampled points are used as training set for SVM training process. Second, the trained SVM model was employed to predict the probability of which classifications each unlabeled pixel/voxel belongs to. Third, unlike traditional Gaussian mixture model (GMM) definition for region properties in graph cut method, negative log-likelihood of the obtained probability of each pixel/voxel from SVM model is used to define t-links in graph cut method and the classical max-flow/min-cut algorithm is applied to minimize the energy function. Finally, the proposed method is applied in 2D medical image segmentation. The experiment results demonstrate availability and effectiveness of the proposed method.

7623-167, Poster Session

Segmentation of light and dark hair in dermoscopic images: a hybrid approach using a universal kernel

N. H. Nguyen, Simon Fraser Univ. (Canada); T. K. Lee, The BC Cancer Research Ctr. (Canada); M. S. Atkins, Simon Fraser Univ. (Canada)

The main challenge in an automated diagnostic system for the early diagnosis of melanoma is the correct segmentation and classification of moles, often occluded by hair in images obtained with a dermoscope. Hair occlusion causes segmentation algorithms to fail to identify the correct nevus border, and can cause errors in estimating texture measures. We present a new method to identify hair in dermoscopic images using a universal approach, which can segment both dark and light hair without prior knowledge of the hair type. Our method uses a hybrid model of bottom-up, data-driven and top-down, knowledge-driven approaches to improve accuracy. First, the hair is amplified using a universal matched filtering kernel, which generates strong responses for both dark and light hair without prejudice. Then we apply local entropy thresholding on the response to get a raw binary hair mask. This hair mask is then refined and verified by a model checker. The model checker includes a combination of image processing (morphological thinning and label propagation) and mathematical (Gaussian curve fitting) techniques. The result is a clean hair mask which can be used to segment and disocclude the hair in the image, preparing it for further segmentation and analysis. Application on real dermoscopic images yields good results for thick hair of varying colours, from light to dark. The algorithm also performs well on skin images with a mixture of both dark and light hair, which was not previously possible with existing hair segmentation algorithms.

7623-168, Poster Session

Volumetric segmentation of trabecular bone into rods and plates: a new method based on local shape classification

E. C. Brun, J. Vicente, IUSTI (France); C. Chappard, Ctr. Hospitalier Régional d'Orléans (France)

Bone micro architecture is believed to play a key role in determining bone quality. We propose a new method of segmentation based on local shape classification. Bones samples are thus described into their basic elements (rods and plates). On each bone voxel we calculate the inertia moment of a neighborhood obtained by local geodesic dilation in the bone volume. The dilated volume is obtained through a homothopic dilation using the Fast Marching algorithms. We fix the size of the dilated volume from local aperture diameter in order to be scale independent. The bone cross-section is calculated using an optimized granulometry algorithm. The segmentation has been carried on a wide range of human trabecular bone with varied structure. We calculate the inertia moments of the dilated volumes; voxels are then classified according the ratio between these moments. This individualization process carried on a wide range of varied human trabecular bone allows statistical characterization of rod structures such as mean length, diameter, connectivity of the structure... An estimator based on ratio of plate volume versus bone volume and mean cross-section is proposed and compared to classical histomorphometrical parameters. Moreover the geodesic calculations allow us to propose a more pertinent geometrical estimator for bone mechanical quality. For a given direction, we compute the minimal centered paths and we report along them the bone cross-section. The segmentation into rods and plates and the estimation of the useful cross bone section permits a micro-scale characterization and constitutes a significant step for osteoporosis diagnose and understanding.

7623-169, Poster Session

Image enhancement and edge-based mass segmentation in mammogram

Y. Zhang, N. Tomuro, J. D. Furst, D. Stan Raicu, DePaul Univ. (United States)

This paper presents a novel automatic segmentation method for identifying the contour (boundary) for a suspicious mass region in mammograms. Our method is edge-based, and detects the mass contour from a pixel-level energy texture image of a region of interest (ROI) image. We applied our method to ROI-marked mammogram images from the Digital Database for Screening Mammography (DDSM). Our method first applies a contrast stretching function to adjust the image contrast, then uses a filter function to reduce image noise. Next, for each pixel in a ROI, the energy descriptor based on the co-occurrence matrix of the pixel is computed and the energy texture image of a ROI is obtained. Finally, the mass boundary is detected from the connected edges in the energy texture image. Preliminary results show that the contours detected by our algorithms outline the shape and boundary of a mass much more closely than the ROI markings made by human radiologists.

7623-170, Poster Session

Database guided detection of anatomical landmark points in 3D images of the heart

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Automated landmark detection may prove invaluable in facilitating the examination of real-time three-dimensional (3D) echocardiograms. By detecting 3D anatomical landmark points, the standard anatomical views can be extracted automatically in apically acquired 3D ultrasound images of left ventricle, for better standardization and objective diagnosis. Furthermore, the landmarks can serve as an initialization for other analysis methods, such as segmentation. The described algorithm consists of iteratively applying landmark detection in perpendicular planes of the 3D dataset. The landmark detection exploits a large database of expert annotated images, using an extensive set of Haar features for classification, resulting in fast detection times suitable for real-time applications. The detection is performed using a cascade of Adaboost classifiers in a coarse to fine scheme. The method is evaluated by measuring the total detection error for the landmark points. After the first detection stage, the average error over 25 patients in detecting the left ventricular position is 6.5±2.5mm. After the second detection stage, the detection error of the apex and the mitral valve points is 7.2±7mm and 5.6±5.2mm respectively. The results are very promising for iterative use.

7623-171, Poster Session

Partial volume correction using cortical surfaces

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Partial volume effect (PVE) in positron emission tomography (PET) leads to inaccurate estimation of regional metabolic activities among neighboring tissues with different tracer concentration. This may be one of the main limiting factors in the utilization of PET in the clinical practice.

Partial volume correction methods (PVC) have been widely studied to address this issue. MRI-based PVC methods are well-established now[1]. Their performance depend on the quality of the co-registration of the MR and PET dataset, on the correctness of the estimated point-spread function (PSF) of the PET scanner and largely on the performance of the segmentation method that divide the brain into brain tissue compartments.[1,2] In the present study a method for PVC is suggested, that utilizes cortical surfaces, extracted from MR images using FACE [3], to obtain detailed anatomical information. The objective is to improve the performance of PVC, facilitate a study of the relationship between metabolic activity in the cerebral cortex and cortical thicknesses and to obtain an improved visualization of PET data. The gray matter metabolic activity after performing PVC, in relation to the true activity was recovered by 99.7 - 99.8 % when testing on simple simulated data with different PSF and by 97.9 - 100 % when testing on simulated brain PET data at different cortical thicknesses. When studying the relationship between metabolic activities and anatomical structures it was shown, on simulated brain PET data, that it is important to correct for PVE in order to get the true relationship.

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7623-172, Poster Session

Adaptive model based pulmonary artery segmentation in 3D chest CT

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The extraction and analysis of the pulmonary artery in computed tomography (CT) of the chest can be an important, but time-consuming step for the diagnosis and treatment of lung disease, in particular in non-contrast data, where the pulmonary artery has low contrast and frequently merges with adjacent tissue of similar intensity. We here present a new method for the automatic segmentation of the pulmonary artery based on a novel adaptive model, Hough and Euclidean distance transforms, and spline fitting, which works equally well on non-contrast and contrast enhanced data. An evaluation on 40 patient data sets and a comparison to manual segmentations in terms of Jaccard index, sensitivity, specificity, and minimum mean distance shows its overall robustness.

7623-173, Poster Session

A combined voxel and surface based method for topology correction of brain surfaces

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Brain surfaces provide a reliable representation for cortical mapping. The construction of correct surfaces from magnetic resonance images (MRI) segmentation is a challenging task, especially when genus zero surfaces are required for further processing such as parameterization, partial inflation and registration. The generation of such surfaces has been approached either by correcting a binary image as part of the segmentation pipeline or by modifying the mesh representing the surface. During this task, the preservation of the structure may be compromised because of the convoluted nature of the brain and noisy/imperfect segmentations. In this paper, we propose a combined, voxel and surface-based, topology correction method which preserves the structure of the brain while yielding genus zero surfaces. The topology of the binary segmentation is first corrected using a set of topology preserving operators applied sequentially. This results in a white matter/gray matter binary set with correct sulci delineation, homotopic to a filled sphere. Using the corrected segmentation, a marching cubes mesh is then generated and the tunnels and handles resulting from the meshing are finally removed with an algorithm based on the detection of non-separating loops. The approach was validated using 20 young individuals' MRI from the OASIS database, acquired at two different time-points. Reproducibility and robustness were evaluated using global and local criteria such as surface area, curvature and point to point distance. Results demonstrated the method's capability to produce genus zero meshes while preserving geometry, two fundamental properties for reliable and accurate cortical mapping and further clinical studies.

7623-174, Poster Session

3D bone mineral density distribution and shape reconstruction of the proximal femur from a single DXA image

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Area Bone Mineral Density (BMD) measured by Dual X-ray Absorptiometry (DXA) is an established criterion in the evaluation of hip fracture risk. The evaluation from these planar images however is limited to 2D while it has been shown that proper 3D assessment of both the shape and the BMD distribution significantly improve the fracture risk estimation. In this work we present a method to reconstruct both the 3D bone shape and 3D BMD distribution of the proximal femur from a single DXA image. We automatically constructed a statistical model of shape and a separate statistical model of the BMD from a set of calibrated CT-scans. The reconstruction method incorporates a fully automatic intensity based 3D-2D registration process maximizing the similarity between the DXA and a Digitally Reconstructed Radiograph (DRR) of the model whereby the density model is deformed according to the shape model. Leave-one-out experiments evaluated the reconstruction method on 19 subjects with combined CT and DXA images. Comparisons between the reconstructions from DXA with the same subject CT-scans showed a mean shape error of 1.2 mm whereby 95% of the error is below 3.2 mm, and a mean density error of 6.2 mg/cm3 corresponding to 5.6% of the whole range of bone density values. This method allows an accurate reconstruction of the 3D shape and BMD distribution of the proximal femur from DXA images used in clinical routine, potentially improving the diagnosis of osteoporosis and fracture risk assessments at a low radiation dose and low cost.

7623-175, Poster Session

Model-based segmentation of pathological lymph nodes in CT data

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For the computer-aided diagnosis of tumor diseases knowledge about the position, size and type of the lymph nodes is needed to compute the tumor classification (TNM). For the computer-aided planning of subsequent surgeries like the Neck Dissection spatial information about the lymph nodes is also important. Thus, an efficient and exact segmentation method for lymph nodes in CT data is necessary, especially pathological altered lymph nodes play an important role here.

Based on prior work, in this paper we present a noticeably enhanced model-based segmentation method for lymph nodes in CT data, which now can be used also for enlarged and mostly well separated necrotic lymph nodes. Furthermore, the kind of pathological variation can be determined automatically during segmentation, which is important for the automatic TNM classification.

Our technique was tested on 21 lymph nodes from 5 CT datasets, among several enlarged and necrotic ones. The results lie in the range of the inter-personal variance of human experts and improve the results of former work again. Bigger problems were only noticed for pathological lymph nodes with vague boundaries due to infiltrated neighbor tissue.

7623-176, Poster Session

Evaluation of manual and computerized methods for the determination of axial vertebral rotation

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Axial vertebral rotation is among the most important parameters for the evaluation of spinal deformities, and several manual and computerized methods have been proposed for its measurement. Routine manual measurement of axial vertebral rotation from three-dimensional (3D) images is error-prone due to different properties of imaging techniques, variable characteristics of the observed anatomy, and difficulties in image navigation and representation. Computerized methods do not suffer from these limitations and may yield accurate results, however, they also require manual identification of multiple anatomical landmarks or neglect the sagittal and coronal inclinations of vertebrae, which may result in inaccurate measurements. The accuracy and reliability of

computerized methods have not been thoroughly investigated yet. In this study, we analyzed, compared and evaluated four different manual and a computerized method for measuring axial vertebral rotation of 56 normal and scoliotic vertebrae in images, acquired by computed tomography (CT) and magnetic resonance (MR). Using each method, multiple observers performed multiple measurements, which allowed the estimation of intra-observer, inter-observer and inter-method variabilities. The relatively low intra-observer (standard deviation of 0.84 and 0.67 degrees), inter-observer (standard deviation of 1.27 degrees) and inter-method (best standard deviation of 2.29 degrees) variabilities of the computerized method indicate that it is feasible for the determination of axial vertebral rotation and may represent an appropriate alternative to manual measurements.

7623-177, Poster Session

Sparse active shape models: influence of the interpolation kernel on segmentation accuracy and speed

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We analyze the segmentation of sparse data using the 3D variant of Active Shape Models by van Assen et al. (SPASM). This algorithm is designed to segment volumetric data represented by multiple planes with arbitrary orientations and with large undersampled regions. With the help of statistical shape constraints, the complicated interpolation of the sliced data is replaced by a mesh-based interpolation. To overcome large void areas without image information the mesh nodes are updated using a Gaussian kernel that propagates the available information to the void areas. Our analysis shows that the accuracy is mostly constant for a wide range of kernel scales, but the convergence speed is not. Experiments on simulated 3D echocardiography datasets indicate that an appropriate selection of the kernel can even double the convergence speed of the algorithm. Additionally, the optimal value for the kernel scale seems to be mainly related to the spatial frequency of the model encoding the statistical shape priors rather than to the sparsity of the sliced data. This suggests the possibility to pre-calculate the propagation coefficients which would reduce the computational load up to 40% depending on the spatial configuration of the input data.

7623-178, Poster Session

Smart manual landmarking of organs

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Statistical shape models play a very important role in most modern medical segmentation frameworks. In this work we propose a new approach for statistical shape model generation based on manual mesh deformation. Since the manual acquisition of ground truth segmentation data is a prerequisite for shape model creation, we developed a method that integrates a solution to the landmark correspondence problem in this particular step. This is done by coupling a user guided mesh adaptation for ground truth segmentation with a simultaneous real time optimization of the mesh in order to preserve point correspondences. First, a reference model with evenly distributed points is created that is taken as the basis of manual deformation. Afterwards the user adapts the model to the data set using a 3d Gaussian deformation of varying stiffness. The resulting meshes can be directly used for shape model construction. Furthermore, our approach allows the creation of shape models of arbitrary topology. We evaluate our method on CT data sets of the kidney and 4d MRI time series images of the cardiac left ventricle. A comparison with a standard ICP-based correspondence algorithm showed better results both in terms of generalization capability and specificity for the model generated by our approach. The proposed method can therefore be used to considerably speed up and ease the process of shape model generation as well as remove potential error

sources of landmark and correspondence optimization algorithms needed so far.

7623-179, Poster Session

Segmentation of the epicardial wall of the left atrium using statistical shape learning and local curve statistics

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Atrial fibrillation is caused by unsynchronized electrical activity in the atrial chambers of the heart. A possible treatment is catheter ablation in which the sources of electrical dyssynchrony are suppressed by ablating specific tissues in the left atrium using a special catheter. Magnetic resonance imaging has been used for both pre- and and post-ablation assessment of the atrial wall. Image processing techniques can be used for automatic segmentation of the atrial wall, which facilitates an accurate assessment of the region of interest. As a first step toward the general solution to the computer-assisted segmentation of the atrial wall, in this paper we propose a new scheme which uses statistical shape learning and segmentation driven by regional statistics to segment the epicardial wall of the left atrium. Our proposed method is composed of shape registration, shape learning, and image segmentation. Given a training set of binary images corresponding to the segmentations of the epicardial wall of the left atrium, each shape is registered to a fixed arbitrary shape in the training set using a mean-square error registration scheme. Next, we use principal component analysis to learn the shapes. Finally, the shape information available from the learning stage is used to segment the epicardial wall, where the segmentation is driven by local regional statistics. More specifically, a new function is introduced in the energy functional governing the evolution of the 3D surface. This results in the surface evolution to be affected only by voxels in the adjacent region.

7623-180, Poster Session

Automated determination of vertebral centroids and intervertebral discs in CT and MR lumbar spine images

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The knowledge of the location of the centers of vertebral bodies and intervertebral discs is valuable for the analysis of the spine. Existing methods for the detection and segmentation of vertebrae in images acquired by computed tomography (CT) and magnetic resonance (MR) imaging are applicable only to a specific image modality and require prior knowledge of the location of vertebrae, usually obtained by manual identification or statistical modeling. We propose a completely automated framework for the detection of the centers of vertebral bodies and intervertebral discs in CT and MR images. The image intensity and gradient magnitude profiles are first extracted in each image along the pre-determined spinal centerline and therefore contain a repeating pattern representing the vertebral bodies and intervertebral discs. From the correlation of the extracted profiles, we compute the period of this repeating pattern, which models the distribution of image intensities and gradient magnitudes along the vertebral body. By comparing the obtained model to the extracted profiles, we obtain the centers of vertebral bodies and intervertebral discs. The method was evaluated on 29 CT and 13 MR images of lumbar spine with varying number of vertebrae from L1 to L5. The overall mean distance between the obtained and the ground truth centers was 2.8 ± 1.9 mm, and no considerable differences were detected between the results for CT, T1-weighted MR or T2-weighted MR images, or among different vertebrae. The proposed method may therefore be used to initialize the techniques for the detection and segmentation of vertebrae.

7623-181, Poster Session

Multiscale shape representation and learning using wavelet

Y. Gao, A. R. Tannenbaum, Georgia Institute of Technology (United States)

Population study of the biological shapes investigates the variances among the shapes of the same organ within the group. However when learning the shapes, usually the small scale variances are overwhelmed by the large ones and are not correctly captured. Previous literatures addressing such issues using the wavelet have the restrictions in the dimensionality and topology of the shapes. In this paper, a new multiscale shape representation and learning technique is proposed. Essentially, the shapes are represented as the wavelet coefficients of the embedding function. Hence there is no restrictions on the dimensionality and topology of the shape. Furthermore, the shape learning under the proposed representation is presented and the results clearly indicate that such representation is able to capture the shape variances from large to small scales.

7623-182, Poster Session

Construction of groupwise consistent shape parameterizations by propagation

M. Kirschner, S. Wesarg, Technische Univ. Darmstadt (Germany)

Prior knowledge can highly improve the accuracy of segmentation algorithms for 3D medical images. A popular method for describing the variability of shape of an organ are statistical shape models. One of the greatest challenges in statistical shape modeling is to compute a representation of the training shapes as vectors of corresponding landmarks, which is required to train the model. Many algorithms for extracting such landmark vectors work on parameter space representations of the unnormalized training shapes. These algorithms are sensitive to inconsistent parameterizations: If corresponding regions in the training shapes are mapped to different areas of the parameter space, convergence time increases or the algorithms even fail to converge. To improve robustness and decrease convergence time, it is crucial that the training shapes are parameterized in a consistent manner. We present a novel algorithm to produce groupwise consistent parameterizations for a set of training shapes with genus-0 topology. Our algorithm firstly computes an area-preserving parameterization of a single reference shape, which is then propagated to all other shapes in the training set. As the parameter space propagation is controlled by approximate correspondences derived from a shape alignment algorithm, the resulting parameterizations are consistent. Additionally, the area-preservation property of the reference parameterization is likewise propagated such that all training shapes can be reconstructed from the generated parameterizations with a simple uniform sampling technique. Though our algorithm also considers consistency as an additional constraint, it is faster than computing parameterizations for each training shape independently from scratch.

7623-183, Poster Session

A statistical shape and motion model for the prediction of respiratory lung motion

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We propose a method to compute a 4D statistical model of respiratory lung motion which consists of a 3D shape atlas, a 4D mean motion model and a 4D motion variability model. Symmetric diffeomorphic image registration is used to estimate subject-specific motion models, to generate an average shape and intensity atlas of the lung as anatomical reference frame and to establish inter-subject correspondence. The Log-Euclidean framework allows to perform statistics on diffeomorphic transformations via vectorial statistics on their logarithms. We apply this framework to compute the mean motion and motion variations by performing a Principal Component Analysis (PCA) on diffeomorphisms.

Furthermore, we present methods to adapt the generated statistical 4D motion model to a patient-specific lung geometry and to predict individual organ motion.

The prediction performance is evaluated with respect to landmark and tumor motion. The quantitative analysis results in a mean target registration error of 3.3 mm if lung dynamics are not impaired by large lung tumors or other lung disorders. The results show that the new method is able to provide valuable knowledge in many fields of application. We present two examples of possible applications in the fields of radiation therapy and image guided diagnosis.

7623-184, Poster Session

Assessing texture measures with respect to their sensitivity to scale-dependent higher order correlations in medical images using surrogates

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The quantitative characterization of images showing tissue probes being visualized by e.g. CT or MR is of great interest in many fields of medical image analysis. A proper quantification of the information content in such images can be realized by calculating well-suited texture measures, which are able to capture the main characteristics of the image structures under study. Using test images showing the complex trabecular structure of the inner bone of a healthy and osteoporotic patient we propose and apply a novel statistical framework, with which one can systematically assess the sensitivity of texture measures to scale-dependent higher order correlations (HOCs). To this end, so-called surrogate images are generated, in which the linear properties are exactly preserved, while parts of the higher order correlations (if present) are wiped out in a scale dependent manner. This is achieved by dedicated Fourier phase shuffling techniques. We compare three commonly used classes of texture measures, namely spherical Mexican hat wavelets (SMHW), Minkowski functionals (MF) and scaling indices (SIM). While the SMHW were sensitive to HOCs on small scales (Significance S=19-23), the MF and SIM could detect the HOCs very well for the larger scales (S = 39 (MF) and S = 29 (SIM)). Thus the three classes of texture measures are complimentary with respect to their ability to detect scale-dependent HOCs. The MF and SIM are, however, slightly preferable, because they are more sensitive to HOCs on length scales, which the important structural elements, i.e. the trabeculae, are considered to have.

7623-39, Session 8

Learning discriminative distance functions for valve retrieval and improved decision support in valvular heart disease

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Disorders of the heart valves constitute as a considerable health problem and often require surgical intervention. Recently various

approaches were published seeking to overcome the shortcomings of current clinical practice, that still relies on manually performed measurements for performance assessment. Clinical decisions are still based on generic information from clinical guidelines and publications and personal experience of clinicians. We present a framework for retrieval and decision support using learning based discriminative distance functions and visualization of patient similarity with relative neighborhood graphs based on shape and derived features. Alongside we propose several applications, including interventional suitability and prediction of outcomes in valves, which are geared to enrich the available source for clinical decision finding and assist its process. Initial experimental results of classification based applications, which are shape-based diagnosis and suitability for intervention, on a set of 63 and 50 valves models are as high as 93% and 91% respectively.

7623-40, Session 8

Shape based MRI prostate image segmentation using local information driven directional distance Bayesian method

Y. Gao, A. R. Tannenbaum, Georgia Institute of Technology (United States)

In this paper, we present a shape based segmentation methodology for magnetic resonance prostate images. We first propose a new way to represent shapes via the hyperbolic tangent of the signed distance function. This effectively corrects the drawbacks of the signed distance function and yields very reasonable results for the shape registration and learning. Secondly, under a Bayesian statistical framework, instead of computing the posterior using a uniform prior, a directional distance map is introduced in order to incorporate a priori knowledge of image content as well as the estimated center of target object. Essentially, the image is modeled as a Finsler manifold and the metric is computed out of the directional derivative of the image. Then the directional distance map is computed to suppress the posterior remote from the object center. Thirdly, in the posterior image, a localized region based cost functional is designed to drive the shape based segmentation. Such cost functional utilizes the local regional information and is robust to both image noise and remote/irrelevant disturbances. With these three major components, the entire shape based segmentation procedure is provided as a complete open source pipeline and is applied to magnetic resonance image (MRI) prostate data.

7623-41, Session 8

3D shape from silhouette points in registered 2D images using conjugate gradient method

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We describe a simple and robust algorithm for estimating 3D shape given a number of silhouette points obtained from two or more viewpoints and a parametric model of the shape. Our algorithm minimizes (in the least squares sense) the distances from the lines obtained by unprojecting the silhouette points to 3D to their closest silhouette points on the 3D shape. The solution is found using an iterative approach. In each iteration, we locally approximate the least squares problem with a degree-4 polynomial function. The approximate problem is solved using a nonlinear conjugate gradient solver that takes advantage of the structure of the problem to perform exact and global line searches. We tested our algorithm by applying it to reconstruct patient-specic femur shapes from simulated biplanar X-ray images.

7623-42, Session 8

A single scan squeletonization algorithm: an application on medical imaging of trabecular bone

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Shape description is an important step in image analysis. The skeleton is an efficient, compact representation of a shape. It is a powerful tool routinely used in image analysis.

The skeleton is also used in image compression because it is a simple description of the shape. In the 2D case, the skeleton represent the line centered in the shape and must be homotopic and one point wide.

The current Skeletonization algorithms compute the skeleton with several image scans.

The two main ways to compute the skeleton is the thinning algorithm and the skeletonization algorithm by the distance transform. In the first case, the principle is to delete points as one goes along, preserving the topology of the shape. In the second case, the maxima of the distance transform identifies the skeleton which is equivalent to calculate the medial axis. However, with this method, the obtained skeleton is disconnected so a further step is required to connect all the points of the medial axis to produce the skeleton.

In this study we introduce translated distance transform and adapt an existing distance driven homotopic algorithm to perform skeletonization with a single scan and thus allowing unbounded image processing.

This method is applied, in our study, on micro scanner imaging of trabicular bones.

In fact we will be able to characterize the bone micro architecture in order to qualify the bone quality.

7623-43, Session 8

Coupled level set segmentation using a point-based statistical shape model relying on correspondence probabilities

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In this article, we propose a unified statistical framework for image segmentation with shape prior information. The approach combines an explicitly parameterized point-based probabilistic statistical shape model (SSM) with a segmentation contour which is implicitly represented by the zero level set of a higher dimensional surface. These two aspects are unified in a Maximum a Posteriori (MAP) estimation where the level set is evolved to converge towards the boundary of the organ to be segmented based on the image information while taking into account the prior given by the SSM information. The optimization of the MAP formulation leads to an alternate update of the level set and an update of the fitting of the SSM. As the probabilistic SSM as well as the level set framework offer possibilities to adapt to more than one shape class in a straightforward manner, the approach is well-suited for multiple-object segmentation. Furthermore, non-spheric topologies can be modeled and segmented. We demonstrate the effectiveness of the method by experiments on kidney segmentation as well as on hip joint segmentation in CT images.

7623-07, Session 9

A modified ICP algorithm for normal-guided surface registration

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The ICP is probably the most popular algorithm for registration of surfaces. Among its key properties are: a simple minimization scheme, proofs of convergence as well as the easiness to modify and improve it in many ways (e.g. use of fuzzy point correspondences, incorporation of a priori knowledge, extensions to non-linear deformations while keeping the desirable properties of the original method. However, ICP-related registration methods suffer from the fact that they only consider the distance between the surfaces to register in the criterion to minimize, and thus are highly dependent on how the surfaces are aligned in the first place. This explains why these methods are likely to be trapped in local minima and to lead to erroneous solutions. A solution to partly alleviate this problem would consist in adding higher order information in the criterion to minimize (e.g. normals, curvatures, etc.), but previous works along these research tracks have led to computationally intractable minimization schemes. In this paper, we propose a new way to include the point normals in addition to the point coordinates to derive an ICP-like scheme for non-linear registration of surfaces and show how to keep the properties of the original ICP algorithm with adequate implementation choices (most notably the use of a local, continuous, parametrization of the surfaces and a locally affine deformation model). Then we experimentally show the strong added value of using the normals in a series of controlled experiments.

7623-44, Session 9

Validation of a nonrigid registration framework that accommodates tissue resection

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We present a 3D extension and validation of an intra-operative registration framework that accommodates tissue resection. The framework is based on the bijective Demons method where regularization is commonly performed by applying a Gaussian low-pass filter. We propose to exchange the Gaussian filter with an anisotropic diffusion filter where we model the estimated resected region as a diffusion sink. The diffusion sink prevents unwanted Demons forces that occur within the resected region from diffusing into the surrounding region. Another attractive property of the diffusion sink is the resulting continuous deformation field across the diffusion sink boundary.

This allow us to move the boundary of the diffusion sink without changing values in the deformation field. The area of resection is estimated by a level-set method evolving in the space of image intensity disagreements.

Validation of the proposed method was performed on a set of 25 synthetic images. Our experiments show a significant improvement in accommodating resection using the proposed method compared to two other Demons based methods.

7623-46, Session 9

Structural template formation with discovery of subclasses

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A major focus of computational anatomy is to extract the most relevant information to identify and characterize anatomical variability within a group of subjects as well as between different groups. The construction of atlases is central to this effort. An atlas is a deterministic or probabilistic model with intensity variance, structural, functional or biochemical information over a population. By now most algorithms to construct atlases have been based on a single subject assuming that the population is best described by a single atlas. However, we believe that in a population with a wide range of subjects multiple atlases may be more representative since they reveal the anatomical differences and similairities within the group. In this work, we propose to use the K-means clustering algorithm to partition a set of images into several subclasses, based on a joint distance which is composed of a distance quantifying the deformation between images and a dissimilarity measured from the registration residual. During clustering, the spatial transformations are averaged rather than images to form cluster centers, to ensure a crisp reference. At the end of this algorithm, the updated centers of the k clusters are our atlases. We demonstrate this algorithm on a subset of a public available database with whole brain volumes of subjects aged 18-96 years. The atlases constructed by this method capture the significant structural differences across the group.

7623-47, Session 9

A novel point based nonrigid registration method and its application for brain shift

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This paper presents a novel point based non-rigid registration (NRR) method. The purpose of point based NRR is to find mapping function, which generally requires to know correspondence. One kind of methods are to use some specific algorithm to find the correspondence and then solve mapping function. The other kind of methods do not rely on any specific algorithms to find correspondence, but solve them (correspondence and mapping function) simultaneously. The representative of this kind of methods is point matching method (RPM), which is an extension of well-known iterative closest point (ICP) algorithm. However, RPM employs thin-plate splines (TPS) as mapping function and therefore is incapable of estimating the deformation given sparse data because TPS is not compact support. Furthermore, RPM cannot deal with the outliers existing in both source and target point sets. To overcome these limitations, we combine biomechanical model with RPM framework to deal with sparse point sets and employ robust regression technique to to deal with partially overlapping point sets.

We formulate this registration problem as a two variables (Correspondence C and Mapping function F) functional minimization problem, which can be decomposed into a stress energy of biomechanical model and a similarity energy. Finite element method is used to discretize this functional and Expectation Maximization method is used to solve these two variables simultaneously.

For the consideration of computational efficiency and robustness again outliers, a Gaussian distribution-based search range is defined. Combined the search range with Least Trimmed Squared(LTS), this method can be effectively used to detect the outliers in both source and target point sets.

The experiment for compensating for brain shift shows the effectiveness of this method as dealing with the non-rigid registration only given sparse and even partially overlapping point sets.

7623-48, Session 9

Improved robust point matching with label consistency

R. Bhagalia, J. V. Miller, GE Global Research (United States); A. S. Roy, GE Global Research (India)

Robust point matching (RPM) jointly estimates correspondences and non-rigid warps between unstructured point-clouds. RPM does not, however, utilize information of the topological structure or group memberships of the data it is matching. In numerous medical imaging applications, each extracted point can be assigned group membership attributes or labels based on segmentation, partitioning, or clustering operations. For example, points on the cortical surface of the brain can be grouped according to the four lobes. Estimated warps should enforce the topological structure of such point-sets, e.g. points belonging to the temporal lobe in the two point-sets should be mapped onto each other.

We extend the RPM objective function to incorporate group membership labels by including a Label Entropy (LE) term. LE discourages mappings that transform points within a single group in

one point-set onto points from multiple distinct groups in the other point-set. The resulting Labeled Point Matching (LPM) algorithm requires a very simple modification to the standard RPM update rules.

We demonstrate the performance of LPM on coronary trees extracted from cardiac CT images. We partitioned the point sets into coronary sections without a priori anatomical context, yielding potentially disparate labelings (e.g. [1,2,3] -> [a,b,c,d]). LPM simultaneously estimated label correspondences, point correspondences, and a non-linear warp. Non-matching branches were treated wholly through the standard RPM outlier process akin to non-matching points. Results show LPM produces warps that are more physically meaningful than RPM alone. In particular, LPM mitigates unrealistic branch crossings and results in more robust non-rigid warp estimates.

7623-49, Session 9

A new combined surface and volume registration

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3D registration of brain MRI data is vital for many medical imaging applications. However, purely intensity-based approaches for inter-subject matching of brain structure are generally inaccurate in cortical regions, due to the complex network of sulci and gyri, which vary widely across subjects. Here we combine a surface-based cortical registration with a 3D fluid one for the first time, enabling precise matching of cortical folds, but allowing large deformations in the enclosed brain volume. The cortices are segmented and registered with the software Freesurfer. The deformation field is initially extended to the full 3D brain volume using a 3D harmonic mapping that preserves the matching between cortical surfaces. Finally, these deformation fields are used to initialize a 3D Riemannian fluid registration algorithm, that improves the alignment of subcortical brain regions. We validate this method on an MRI dataset from 92 healthy adult twins.

7623-50, Session 10

Fast Hamilton-Jacobi equation solver and neural fiber bundle extraction

Y. Gao, J. M. Melonakos, A. R. Tannenbaum, Georgia Institute of Technology (United States)

The Hamilton-Jacobi equation (HJE) appears widely in computer vision, control theory and medical imaging. While its analytical solution is rarely available, the numerical solver is indispensable. In this work, firstly we propose a novel numerical method, based on the fast sweeping scheme, for the static HJE. Comparing with the original fast sweeping method, our algorithm speeds up the solution up to 8 times in 3D. The efficiency is due to incorporating the ideas of the fast marching into the fast sweeping. Essentially, the sweeping origin is selected so that the sweeping direction is more consistent with the information flow direction and the regions where the two directions are against are avoided. Moreover, the successive-over-relaxation nonlinear iterative method is used for faster convergence. Secondly, we provide a complete pipeline for brain tractography, in which the proposed solver is the key component for finding the optimal fiber tracts. Besides, the pipeline contains components from orientation distribution function estimation, multiple fiber extraction to the final fiber bundle volumetric segmentation, completing the process from DW-MRI image to segmented fiber bundles. The pipeline is integrated into the publicly available software 3D Slicer. The new solver has been tested and

compared with the original scheme on various types of HJEs and the tractography pipeline was tested and performed consistently on all the 12 brain DW-MRI images.

7623-51, Session 10

Directional assessment of fiber integrity in Q-ball imaging

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Q-ball imaging (QBI) is a diffusion imaging technique that provides unique microstructural information and outperforms diffusion tensor imaging (DTI) in areas of fiber crossings. The generalized fractional anisotropy (GFA) is a widely accepted quantitative measure of fiber integrity for QBI.

In this paper we demonstrate a major drawback of the GFA occuring in crossing fiber regions: the fiber integrity is heavily underestimated here. We present a new, directional anisotropy measure and compare it to the GFA using custom-designed fiber phantoms. Furthermore, we present in-vivo data of the measure. The new measure allows a more reliable quantification of fiber bundles and yields additional information regarding non-dominant tracts within a voxel.

7623-52, Session 10

Resolution of crossing fibers with constrained compressed sensing using traditional diffusion tensor MRI

B. A. Landman, H. Wan, J. A. Bogovic, P. Bazin, J. L. Prince, The Johns Hopkins Univ. (United States)

Diffusion tensor imaging (DTI) is widely used to characterize tissue micro-architecture and brain connectivity. Yet, DTI suffers serious limitations in regions of crossing fibers because traditional tensor techniques cannot represent multiple, independent intra-voxel orientations. Compressed sensing has been proposed to resolve crossing fibers using a tensor mixture model (e.g., Crossing Fiber Angular Resolution of Intra-voxel structure, CFARI). Although similar in spirit to deconvolution approaches, CFARI uses sparsity to stabilize estimation with limited data rather than spatial consistency or limited model order. Here, we extend the CFARI approach to resolve crossing fibers through a strictly positive, parsimonious mixture model. Together with an optimized preconditioned conjugate gradient solver, estimation error and computational burden are greatly reduced over the initial presentation. Reliable estimates of intra-voxel orientations are demonstrated in simulation and in vivo using data representative of typical, low b-value (30 directions, 700 s/mm2) clinical DTI protocols. These sequences are achievable in 5 minutes at 3 T, and the whole brain CFARI analysis is tractable for routine analysis. With these improvements, CFARI provides a robust framework for identifying intra-voxel structure with traditional DTI and shows great promise in helping to resolve the crossing fiber problem in current clinical imaging studies.

7623-53, Session 10

Reconstruction of a geometrically correct diffusion tensor image of a moving human fetal brain

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Recent studies reported the development of methods to rigidly register 2D human fetal brain imaging data to correct for unconstrained fetal and maternal motion and allow the formation of a true 3D image

of conventional MRI anatomy. Diffusion tensor imaging provides a valuable additional insight into the developing brain anatomy, however the correction of motion artifacts in clinical fetal diffusion imaging is still a challenging problem. This is due to the additional presence of geometric distortions in EPI data which can vary with fetal movements, together with the problem of estimating a regular lattice of local diffusion models (e.g. tensor) given the changing orientation of the fetus with respect to the direction of diffusion measurements. In this work, we describe methods to both correct the motion and local geometric distortions, and to reconstruct the diffusion tensor image from irregularly distributed observation points and orientations. The motion and distortion correction are achieved by a combined rigid and non-rigid alignment of the diffusion weighted EPI slices to a conventional structural MRI scan which provides a geometrically correct reference image. After the spatial mapping of each diffusion slice a tensor representing the diffusion profile is estimated by a local optimization in a parametrized manifold space which ensures the formation of a positive definite diffusion tensor given the varying spatial and angular density of diffusion measurements in the acquired diffusion data. We evaluate the performance of the approach on example adult data acquired with and without motion and on typical clinical fetal brain studies.

7623-54, Session 10

Discriminant analysis of resting-state functional connectivity patterns on the Grassmann manifold

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Functional magnetic resonance imaging (fMRI) has been increasingly used for investigating functional connectivity patterns of the brain, which can be extracted from 4D (3 spatial dimensions plus one temporal dimension) fMRI images using independent component analysis (ICA). The functional connectivity patterns, represented by independent components, have been recently demonstrated to be informative for distinguishing brain states of neurological diseases. Unlike traditional discriminant analysis methods that focus on features computed by projecting images onto the functional connectivity patterns, i.e., independent components, we propose a novel discriminant analysis method to directly analyze the functional connectivity patterns on a Grassmann manifold whose elements are linear subspaces spanned by the functional connectivity patterns themselves in the Euclidean space. By adopting principal angle based distance metrics for subspaces, the functional connectivity patterns in the Grassmann manifold can be classified similarly as did in the Euclidian space. The discriminant analysis method has been applied to an fMRI based schizophrenia study with 31 schizophrenia patients and 31 healthy individuals. The experimental results demonstrate that the proposed method can achieve better classification performance than the traditional discriminant analysis techniques.

7623-55, Session 11

Automatic bone segmentation and alignment from MR knee images

L. Shan, C. Zach, M. A. Styner, The Univ. of North Carolina at Chapel Hill (United States); C. Charles, Duke Univ. (United States); M. Niethammer, The Univ. of North Carolina at Chapel Hill (United States)

Automatic image analysis of magnetic resonance (MR) images of the knee (e.g., to subsequently assess localized cartilage thickness in osteoarthritis (OA)) is simplified by bringing the knee into a reference position. While this can be accomplished during the imaging, alignment will typically not be perfect. To correct for these imperfections we propose a two step-process of bone segmentation followed by elastic tissue deformation.

Although many methods have been proposed for bone segmentation,

most of them require user-guidance. In our work, we propose a fully-automatic method to segment femur and tibia from T1 and T2* MR images. The segmentation algorithm is based on a continuous convex optimization problem, incorporating edge, regional, and shape information. The regional terms are included from a probabilistic viewpoint, which readily allows the inclusion of shape information. Segmentation of the outer boundary of the cortical bone is encouraged by adding simple appearance-based information to the optimization problem. The resulting segmentation without the shape alignment step is globally optimal.

Standard registration is problematic for knee bone alignment due to the distinct physical properties of the tissues constituting the knee (bone, muscle, etc.). In our work, we develop an alternative alignment approach based on a simple elastic deformation model combined with strict enforcement of similarity transforms for femur and tibia based on the obtained segmentations.

The automatic bone segmentation and alignment procedure will ultimately be applied to analyze knee magnetic resonance (MR) images to assess OA.

7623-56, Session 11

Subvoxel segmentation and representation of brain cortex using fuzzy clustering and gradient vector diffusion

M. Chang, X. Tao, GE Global Research (United States)

Segmentation and representation of human brain cortex from Magnetic Resonance (MR) images is an important step for visualization and analysis in many neuro imaging applications. We propose an automatic and fast algorithm to segment the brain cortex and to represent it as a geometric surface on which analysis can be carried out. The algorithm works on T1 weighted MR brain images with extracranial tissue removed. A fuzzy clustering algorithm with a parametric bias field model is applied to assign membership values of gray matter, white matter, and cerebrospinal fluid to each voxel. The cortical boundaries, namely the WM-GM and GM-CSF boundary surfaces, are extracted as iso-surfaces of functions derived from these membership functions. The central surface, which traces the peak values (or ridges) of the GM membership function, is then extracted using gradient vector diffusion. Our main contribution is to provide a generic, accurate, fast, yet fully-automatic approach to (i) produce a soft segmentation of the MR brain image with intensity field correction, (ii) extract both the boundary and the center of the cortex in a surface form, where the topology and geometry can be explicitly examined, and (iii) use the extracted surfaces to model the curvy, folding cortical volume, which allows an intuitive measurement of the thickness. As a demonstration, we compute cortical thickness from the surfaces and compared the results with what has been reported in the literature. The entire process from raw MR image to cortical surface reconstruction takes on average between five and ten minutes.

7623-57, Session 11

An expectation-maximization approach to joint curve evolution for medical image segmentation

M. Farzinfar, E. K. Teoh, Nanyang Technological Univ. (Singapore); Z. Xue, Methodist Hospital Research Institute (United States)

This paper proposes a new curve evolution algorithm for medical image segmentation. Standard level set algorithms perform poorly when image information is incomplete, missing or some objects are corrupted. In such cases, statistical model-based segmentation methods are widely used since they allow object shape variations subject to shape prior constraints to overcome the incomplete or noisy information. Although matching robustly in dealing with noise and low contrast, the shape parameters are estimated intractably through Maximum a Posterior framework as using incomplete image

features. In this paper, we present a statistical shape-based joint curve evolution for image segmentation based on the assumption that hidden features of the image as missing data can simplify the estimation problem and help to improve the matching performance. In our method, these hidden features are local voxel labelling determined based on the intensity distribution of the image and priori anatomical knowledge. Therefore, using an Expectation-Maximization formulation, both hidden features and object shapes can be extracted. In addition, both parameter and non-parameter shape models are used for more accurate segmentation. Comparative results on segmenting putamen and caudates shapes in MR brain images confirm both robustness and accuracy of the proposed curve evolution algorithm.

7623-58, Session 11

Simultaneous truth and performance level estimation with incomplete, over-complete, and ancillary data

B. A. Landman, Vanderbilt Univ. (United States) and The Johns Hopkins Univ. (United States); J. A. Bogovic, J. L. Prince, The Johns Hopkins Univ. (United States)

Image labeling and parcellation are critical tasks for the assessment of volumetric and morphometric features in medical imaging data. The process of image labeling is inherently error prone as images are corrupted by noise and artifact. Even expert interpretations are subject to subjectivity and the precision of the individual raters. Hence, all labels must be considered imperfect with some degree of inherent variability. One may seek multiple independent assessments to both reduce this variability as well as quantify the degree of uncertainty. Existing techniques exploit maximum a posteriori statistics to combine data from multiple raters. YetA current limitation with, these approaches historicallyis that they have required that each rater to generate a complete dataset, which is often impossible given both human foibles and the typical turnover rate of raters in a research or clinical environment. Herein, we propose a robust set of extensions that allow for missing data, account for repeated label sets, and utilize training/catch trial data. With these extensionsour technique, numerous raters can label small, overlapping portions of a large dataset, and rater heterogeneity can be robustly controlled while simultaneously estimating a single, reliable label set and characterizing uncertainty. The proposed approach enables parallel processing of labeling tasks and reduces the otherwise detrimental impacts of rater unavailability.

7623-59, Session 11

Fast globally optimal single surface segmentation using regional properties

X. Dou, X. Wu, The Univ. of Iowa (United States)

Efficient segmentation of globally optimal surfaces in volumetric images is a central problem in many medical image analysis applications. Intra-class variance has been successfully utilized, for instance, in the Chan-Vese model especially for images without prominent edges. In this paper, we study the optimization problem of detecting a region (volume) bounded by a smooth terrain-like surface, whose intra-class variance is minimized. A novel polynomial time algorithm is developed. Our algorithm is based on the shape probing technique in computational geometry and computes a sequence of $O(n)$ maximum flows in the derived graphs, where n is the size of the input image. Our further investigation shows that those $O(n)$ graphs form a monotone parametric flow network, which enables to solving the optimal region detection problem in the complexity of computing a single maximum flow. The method has been validated on computer-synthetic volumetric images. Its applicability to clinical data sets was demonstrated in 20 3-D airway wall CT images from 6 subjects. The achieved results were highly accurate with mean unsigned surface positioning errors of outer walls of the tubes of 0.258+/-0.297mm, given a voxel size of 0.39x0.39x0.6mm3. With its highly polynomial-time efficiency, our algorithm is ready to be extended to higher-dimensional image segmentation.

7623-60, Session 11

Lung fissure detection in CT images using global minimal paths

B. Das, GE Global Research (India); V. Appia, Georgia Institute of Technology (United States); U. Patil, Manipal Hospital (India)

Pulmonary fissures separate human lungs into five distinct regions called lobes. Detection of fissure is essential for localization of the lobar distribution of lung diseases, surgical planning and follow-up. Treatment planning also requires calculation of the lobe volume. This volume estimation mandates accurate segmentation of the fissures. Presence of other structures (like vessels) near the fissure, along with its high variational probability in terms of position, shape etc. makes the lobe segmentation a challenging task. Also, false incomplete fissures and occurrence of diseases add to the complications of fissure detection. In this paper, we propose a semi-automated fissure segmentation algorithm using a minimal path approach on CT images. An energy function is defined such that the path integral over the fissure is the global minimum. Based on a few user defined points on a single slice of the CT image, the proposed algorithm minimizes a 2D energy function on the sagital slice computed using (a) intensity (b) distance of the vasculature, (c) curvature in 2D, (d) continuity in 3D. The fissure is the infimum energy path between a representative point on the fissure and nearest lung boundary point in this energy domain. The algorithm has been tested on 10 CT volume datasets acquired from GE scanners at multiple clinical sites. The datasets span through different pathological conditions and varying imaging artifacts.

Conference 7624: Computer-Aided Diagnosis

Tuesday-Thursday 16-18 February 2010

SPIE
Medical Imaging

7624-01, Session 1

Computer-aided diagnosis in medical imaging: achievements and challenges

K. Doi, The Univ. of Chicago (United States)

Computer-aided diagnosis (CAD) has become one of the major research subjects in medical imaging and diagnostic radiology. Many different types of CAD schemes are being developed for detection and/or characterization of various lesions in medical imaging, including conventional projection radiography, CT, MRI and ultrasound imaging. Organs that are subjected to research for CAD include the breast, chest, colon, brain, liver, kidney, and the vascular and skeletal systems. More than 10,000 commercial CAD systems have been used at many hospitals, clinics, and screening centers for assisting radiologists in their task of detecting breast cancers. From prospective studies, CAD has provided a gain of approximately 10-20% in the early detection of breast cancers on mammograms. CAD may be defined as a diagnosis made by a physician who takes into account the computer output as a "second opinion". The purpose of CAD is to improve the quality and productivity of physicians in their interpretation of radiologic images. The computer output is derived from quantitative analysis of radiologic images by use of various methods and techniques in computer vision, artificial intelligence, and artificial neural networks. The computer output may indicate a number of important parameters such as the locations of potential lesions and the likelihood of malignancy of detected lesions. Because the basic concept of CAD is broad and general, CAD is applicable to all imaging modalities, and to all kinds of examinations and images.

7624-02, Session 1

Resampling method for balancing training data in video analysis

B. Giritharan, X. Yuan, Univ. of North Texas (United States)

Reviewing videos from medical procedures is a tedious work that requires concentration for extended hours and usually screens thousands of frames to find only a few positive cases that indicate probable presence of disease. Computational classification algorithms are sought to automate the reviewing process. The class imbalance problem becomes challenging when the learning process is driven by relative few minority class samples. The learning algorithms using imbalanced data sets generally result in large number of false negatives. In this article, we present an efficient rebalancing method for finding video frames that contain bleeding lesions. The majority class generally has clusters of data within them. Here we cluster the majority class and under-sample the each cluster based on its variance so that useful examples would not be lost during the under-sampling process. The balance of bleeding to non-bleeding frames is restored by the proposed cluster-based under-sampling and over-sampling using Synthetic Minority over-sampling Technique(SMOTE). Experiments were conducted on synthetic data, videos manually annotated by medical specialists for obscure bleeding detection, and our proposed method achieved a high average sensitivity and specificity.

7624-03, Session 1

Training variability in the evaluation of automated classifiers

W. Chen, B. D. Gallas, U.S. Food and Drug Administration (United States)

The evaluation of automated classifiers in CAD for medical images often involves a training dataset for classifier design and a testing dataset for performance (e.g., AUC) estimation. The traditional

approach to assess the uncertainty of the estimated AUC considers only the finite size of the testing set as the source of variability. However, a finite training set is also a random sample from the population and the AUC would generally fluctuate with varying training sets. The two sources of variability - training and testing - in automated classifiers are analogous to readers and cases in the MRMC ROC paradigm in reader studies. Taking into account training variability allows for a more general assessment of automated classifiers. Using the U-statistics theory, we derive nonparametric AUC variance estimators at three levels of generalizability: (1) training treated as fixed effect, performance generalizable only to the population of testing sets-the traditional approach; (2) training treated as random effect, performance generalizable to both the population of training sets and the population of testing cases; (3) performance averaged over training sets generalizable to both the population of training sets and the population of testing cases. We show the one-to-one analogy between the automated classifiers and human readers at these three levels.

7624-04, Session 2

Database-guided breast tumor detection and segmentation in 2D ultrasound images

J. Zhang, S. K. Zhou, Siemens Corporate Research (United States); S. S. Brunke, C. Lowery, Siemens Medical Solutions USA, Inc. (United States); D. Comaniciu, Siemens Corporate Research (United States)

Ultrasonography is a valuable technique for diagnosing breast cancer. Computer-aid tumor detection and segmentation in ultrasound images can reduce labor cost and streamline clinic workflows. In this paper, we propose a fully automatic system to detect and segment breast tumors in 2D ultrasound images. Our system, based on database-guided techniques, learns the knowledge of breast tumor appearance exemplified by expert annotations. For tumor detection, we train a classifier to discriminate between tumors and their background. For tumor segmentation, we propose a discriminative graph cut approach, where both the data fidelity and compatibility functions are learned discriminatively. The performance of the proposed algorithms is demonstrated on a large set of 347 images, achieving a mean contour-to-contour error of 4.35 pixels with about 4.33 seconds.

7624-05, Session 2

Perception-driven IT-CADe analysis for the detection of masses in screening mammography: initial investigation

G. D. Tourassi, M. A. Mazurowski, Duke Univ. (United States); E. A. Krupinski, The Univ. of Arizona (United States)

We have previously reported an interactive information-theoretic CADe system for the detection of masses in screening mammograms. The system operates in either traditional static mode or in interactive mode whenever the user requests a second opinion. In this study we report preliminary investigation of a new paradigm of clinical integration, guided by the user's eye-gazing and reporting patterns. An observer study was conducted in which 6 radiologists evaluated 20 mammographic cases while wearing a head-mounted eye-tracking device. For each radiologist-reported location, eye-gazing data were collected. Image locations that attracted prolonged dwelling (>1000msec) but were not reported were also recorded. Fixed size regions of interest (ROIs) were extracted around all above locations and analyzed using the IT-CADe system. The system compared the ROIs to a knowledge database of proven mass and normal templates using mutual information as the similarity metric. Preliminary analysis showed that IT-CADe correctly confirmed 100% of reported true mass locations while eliminating 12.5% of the reported false positive locations. For

unreported locations that attracted long dwelling, IT-CADe identified 3/6 false negative errors (i.e., errors of decision) while overcalling 6/84 TN decisions. Finally, for missed true masses that attracted short (i.e., errors of recognition) or no dwelling at all (i.e., errors of search), IT-CADe detected 5/8 of them. These results suggest that IT-CADe customization to the user's eye-gazing and reporting pattern could potentially help delineate the various sources of diagnostic error (search, recognition, decision) for each individual user and provide targeted decision support, thus improving the human-CAD synergy.

7624-06, Session 2

Joint segmentation and spiculation detection for ill-defined and spiculated masses in mammograms

Y. Tao, Virginia Polytechnic Institute and State Univ. (United States); S. B. Lo, M. T. Freedman, Georgetown Univ. Medical Ctr. (United States); J. Xuan, Virginia Polytechnic Institute and State Univ. (United States)

We presented a multi-level statistical learning-based approach for a very challenging segmentation task of mammographic mass with ill-defined margins and spiculation. The algorithm started with a multi-phase classification step in pixels, using a comprehensive group of features in intensity, texture, shape, to generate a conditional probability map (PM) of mass. Mass candidate along with spurious noisy clusters were then extracted from this PM. A multi-scale steerable ridge detection algorithm was investigated to detect possible spiculation pixels. Finally, all the object level findings, including mass candidate, noisy clusters, and the detected spiculation, along with the PM were integrated by the graph cut algorithm ensuring accurate segmentation while suppressing the noise in one single step. Our experimental results on 59 ill-defined and spiculated masses demonstrated the effectiveness of the proposed approach.

7624-07, Session 2

Detection of architectural distortion in prior mammograms using fractal analysis and angular spread of power

S. Banik, R. M. Rangayyan, J. E. L. Desautels, Univ. of Calgary (Canada)

This paper presents methods for the detection of architectural distortion in mammograms of interval-cancer cases taken prior to the diagnosis of breast cancer, using Gabor filters, phase portrait analysis, fractal dimension (FD), and analysis of the angular spread of power in the Fourier spectrum. In the estimation of FD using the Fourier power spectrum, only the distribution of power over radial frequency is considered; the information regarding the angular spread of power is ignored. In this study, the angular spread of power in the Fourier spectrum is used to generate features for the detection of spiculated patterns related to architectural distortion. Using Gabor filters and phase portrait analysis, a total of 4224 regions of interest (ROIs) were automatically obtained from 106 prior mammograms of 56 interval-cancer cases, including 301 ROIs related to architectural distortion, and from 52 prior mammograms of 13 normal cases. For each ROI, the FD and measures of the angular spread of power were computed. Feature selection was performed using stepwise logistic regression. The best results achieved, in terms of area under the receiver operating characteristics curve, is 0.75 ± 0.02 with an artificial neural network based on radial basis functions. Analysis of the performance of the methods with free-response receiver operating characteristics indicated a sensitivity of 0.82 at 7.7 false positives per image.

7624-08, Session 2

A comparative study of volumetric breast density estimation in digital mammography and magnetic resonance imaging: results from a high-risk population

D. Kontos, The Univ. of Pennsylvania Health System (United States); Y. Xing, The Univ. of Pennsylvania (United States); P. R. Bakic, E. F. Conant, A. D. A. Maidment, The Univ. of Pennsylvania Health System (United States)

We compared methods for volumetric breast density estimation in digital mammography (DM) and magnetic resonance imaging (MRI) using a high-risk population of women. DM and MRI images of the unaffected breast from 32 women with recently detected abnormalities and/or previously diagnosed breast cancer (age range 31-78 yrs, mean 50.3 yrs) were analyzed. The DM images were analyzed using an extension of the Highnam & Brady method (QuantraTM, Hologic Inc.). In the MRI images, the breast boundary was semi-automatically segmented using an active contour algorithm. The fibroglandular tissue was then segmented using a fuzzy-C-means algorithm based on the T1 map. Both methods were compared to the current gold-standard for mammographic breast density estimation (Cumulus, Univ. Toronto). Our results demonstrated strong correlation between the volumetric DM and MRI breast density estimates (r=0.90, p≤0.001). The MRI density measures were more strongly correlated with Cumulus (r=0.82, p≤0.001), than were the correlation of the volumetric DM measures with Cumulus (r=0.72, p≤0.001). MRI provided the lowest breast density estimates (mean=14.63%), followed by the volumetric DM estimates (mean=22.72%) and Cumulus, which provided the highest breast density estimates (mean=36.88%). Our results demonstrate that volumetric breast density measures from DM and MRI are highly correlated and are statistically significantly different from the corresponding area based breast density measures obtained from DM. Fully-automated volumetric breast density estimation in DM could provide a biomarker for breast cancer risk estimation during breast cancer screening. Further work is underway to extend this study in larger clinical datasets.

7624-09, Session 2

Association of a mammographic parenchymal pattern (MPP) descriptor with breast cancer risk: a case-control study

J. Wei, H. Chan, C. Zhou, M. A. Helvie, L. M. Hadjiiski, B. Sahiner, Univ. of Michigan (United States)

We are investigating the feasibility of improving breast cancer risk prediction by computerized mammographic parenchymal pattern (MPP) analysis. A case-control study was conducted to investigate the association of the MPP measures with breast cancer risk. The case group included 168 contralateral CC-view mammograms of breast cancer patients dated at least one year prior to cancer diagnosis, and the control group included 522 CC-view mammograms from one breast of normal subjects. We extracted and compared four types of statistical texture feature spaces that included RLS/RSS features, SGLD features, GLDS features, and the combined feature space. A linear discriminant analysis (LDA) classifier with stepwise feature selection was trained and tested with leave-one-case-out resampling to evaluate whether the breast parenchyma of future cancer patients could be distinguished from those of normal subjects in each feature space. The areas under ROC curves (Az) were 0.71, 0.72, 0.71 and 0.76 for the four feature spaces, respectively. The Az obtained from the combined feature space was significantly (p<0.05) higher than those from the individual feature spaces. Odd ratios (OR) were used to assess the association between breast cancer risk and four categories of MPP measures: <0.1 (C1), 0.1-0.15 (C2), 0.15-0.2 (C3), and >0.2 (C4) while patient age was treated as a confounding factor. The adjusted ORs of breast cancer for C2, C3 and C4 were 3.23, 7.77 and 25.43, respectively. The preliminary result indicated that our proposed computerized MPP measures were strongly associated with breast cancer risk.

7624-10, Session 3

Projection-based features for reducing false positives in computer-aided detection of colonic polyps in CT colonography

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A large number of false positives (FPs) generated by computer-aided detection schemes is likely to distract radiologists' attention and decreases their interpretation efficiency. Therefore, it is desirable to reduce FPs as many as possible to increase the detection specificity while maintaining the high detection sensitivity. In this paper, several features are extracted from the projected images of each initial polyp candidate to differentiate FPs from true positives. These features demonstrate the potential to exclude different types of FPs, like haustral folds, rectal tubes and residue stool by an evaluation using a database of 325 patient studies (from two different institutions) which includes 556 scans at supine and/or prone positions with 347 polyps sized from 5 to 60 mm. For comparison purpose, several well-established features are used to generate a baseline reference. At the by-polyp detection sensitivity level of 96% (no loss of detection sensitivity), the number of FPs per scan is 7.8 by the baseline and 3.75 if the new projection features are added, which is a reduction of 51.9% FPs from the baseline.

7624-11, Session 3

Dual-energy electronic cleansing for non-cathartic CT colonography: a phantom study

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Partial volume effect and inhomogeneity are two major causes of artifacts in electronic cleansing (EC) for non-cathartic CT colonography (CTC). Our purpose was to develop a novel method of EC for non-cathartic dual-energy CTC (DE-CTC) using a subvoxel multi-spectral material classifier and a regional material decomposition method for differentiation of residual fecal materials from colonic soft-tissue structures.

In this study, an anthropomorphic colon phantom, which was filled with a mixture of aqueous fiber (psyllium), ground foodstuff (cereal), and non-ionic iodinated agent (Omnipaque iohexol, GE Healthcare, Milwaukee, WI), was scanned by a dual-energy CT scanner (SOMATON, Siemens) with two photon energies: 80 kVp and 140 kVp. The DE-CTC images were subjected to a dual-energy EC (DE-EC) scheme, in which a multi-spectral material classifier was used to compute the fraction of each material within one voxel by an expectation-maximization (EM) algorithm. This was followed by a regional texture segmentation method for material decomposition to identify homogeneous sub-regions (tiles) as fecal materials from other tissue types by use of texture features from DE-CTC images. The results were compared with the registered CTC images of native phantom without fillings.

The classification accuracy of the multi-spectral material classifier was 94.7% for air-tagging boundary (AT-boundary) caused by the partial volume effect and 96.7% for residual materials (foodstuffs and air bubbles) caused by inhomogeneous tagging. The classification overall accuracy after the regional material decomposition was improved up to 99% for both AT-boundary and residual materials.

7624-12, Session 3

Prediction of polyp histology on CT colonography using content-based image retrieval

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Predicting the malignancy of colonic polyps is a difficult problem and in general requires an invasive polypectomy procedure. We present a less-invasive and automated method to predict the histology of colonic polyps under computed tomographic colonography (CTC) using the content-based image retrieval (CBIR) paradigm. For the purpose of simplification, polyps annotated as hyperplastic or "other benign" were classified as benign polyps (BP) and the rest (adenomas and cancers) were classified as malignant polyps (MP). The CBIR uses numerical feature vectors generated from our CTC computer aided detection (CTC-CAD) system to describe the polyps. These features relate to physical and visual characteristics of the polyp. A representative database of CTC-CAD polyp images is created. Query polyps are matched with those in the database and the results are ranked based on the similarity to the query. Polyps with a majority of representative MPs in their result set are predicted to be malignant and similarly those with a majority of BPs in their results are benign. For evaluation, the system is compared to the typical optical colonoscopy (OC) size based classification. Using receiver operating curve (ROC) analysis, we show our system is sufficiently better than the OC size method.

7624-13, Session 3

Matching colonic polyps using correlation optimized warping

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Computed tomographic colonography (CTC) combined with a computer aided detection system has the potential for improving colonic polyp detection and increasing the use of CTC for colon cancer screening. In the clinical use of CTC, a true colonic polyp will be confirmed with high confidence if a radiologist can find it on both the supine and prone scans. To assist radiologists in CTC reading, we propose a new method for matching polyp findings on the supine and prone scans. The method performs a colon registration using four automatically identified anatomical salient points and correlation optimized warping (COW) of colon centerline features. We first exclude false positive detections using prediction information from a support vector machine (SVM) classifier committee to reduce initial false positive pairs. Then each remaining CAD detection is mapped to the other scan using COW technique applied to the distance along the centerline in each colon. In the last step, a new SVM classifier is applied to the candidate pair dataset to find true polyp pairs between supine and prone scans. Experimental results show that our method can improve the sensitivity to 0.96 at 6 false positive pairs per patient compared with 0.70 for a competing method that uses the normalized distance along the colon centerline ($p<0.05$).

7624-14, Session 3

Automated segmentation of reference tissue for prostate cancer localization in dynamic contrast enhanced MRI

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For pharmacokinetic (PK) analysis of Dynamic Contrast Enhanced (DCE) MRI the arterial input function needs to be estimated. Previously, we demonstrated that PK parameters have a significant better discriminative performance when per patient reference tissue was

used, but required manual annotation of reference tissue. In this study we propose a fully automated reference tissue segmentation method that tackles this limitation and tested the method with our CADx system when discriminating prostate cancer from benign areas in the peripheral zone (PZ).

The proposed method automatically segments normal PZ tissue from DCE derived data. First, the bladder is segmented in the start-to-enhance map using the Otsu histogram threshold selection method. Second, the prostate is detected by applying a multiscale Hessian filter to the relative enhancement map. Third, normal PZ was segmented by threshold and morphological operators. The resulting segmentation was used as reference tissue.

In 39 consecutive patients carcinoma, benign and normal tissue were annotated on MR images by a radiologist and a researcher using whole mount step-section histopathology as reference. PK parameters were computed for each ROI and used to train a support vector machine as classifier. Prospective performance was estimated by means of leave-one-patient-out cross validation. A bootstrap resampling approach with 10,000 iterations was used for estimating the bootstrap mean AUCs and 95% confidence intervals.

In total 42 malignant, 29 benign and 37 normal regions were annotated. For all patients, normal PZ was successfully segmented. The diagnostic accuracy obtained for differentiating malignant from benign lesions using a conventional general patient plasma profile showed an accuracy of 0.64 (0.53-0.74). Using the automated segmentation per patient calibration method the diagnostic performance improved significantly to 0.76 (0.67-0.86, p=0.017) , whereas the manual segmentation per patient calibration showed a diagnostic performance of 0.79 (0.70-0.89, p=0.01).

Automated per-patient reference tissue PK modeling is feasible. A significantly better discriminating performance compared to the conventional fixed calibration was obtained and the diagnostic accuracy is similar to using manual per-patient calibration.

7624-15, Session 4

Automatic classification of pathological myopia in retinal fundus images using PAMELA

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Pathological myopia is the seventh leading cause of blindness. We introduce a framework based on PAMELA (PAthological Myopia dEtection through peripapilLary Atrophy) for the detection of pathological myopia from fundus images. The framework consists of a pre-processing stage which extracts a region of interest centered on the optic disc. Subsequently, three analysis modules focus on detecting specific visual indicators. The optic disc tilt ratio module gives a measure of the axial elongation of the eye through inference from the deformation of the optic disc. In the texture-based ROI assessment module, contextual knowledge is used to demarcate the ROI into four distinct, clinically-relevant zones in which information from an entropy transform of the ROI is analyzed and metrics generated. In particular, the preferential appearance of peripapillary atrophy (PPA) in the temporal zone compared to the nasal zone is utilized by calculating ratios of the metrics. The PPA detection module obtains an outer boundary through a level-set method, and subtracts this region against the optic disc boundary. Temporal and nasal zones are obtained from the remnants to generate associated hue and color values. The outputs of the three modules are used as in a SVM model to determine the presence of pathological myopia in a retinal fundus image. Using images from the Singapore Eye Research Institute, the proposed framework reported an optimized accuracy of 90% and a sensitivity and specificity of 0.85 and 0.95 respectively, indicating promise for the use of the proposed system as a screening tool for pathological myopia.

7624-16, Session 4

Effects of image compression and degradation on an automatic diabetic retinopathy screening algorithm

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Diabetic retinopathy (DR) is one of the leading causes of blindness among adult Americans. Automatic methods for detection of the disease have been developed in recent years, most of them depending on segmentation of bright and red lesions. In this paper we present an automatic DR screening system that does not require segmentation of features and it is only based on textural features obtained using multiscale Amplitude Modulation-Frequency Modulation (AM-FM) decompositions. From the AM-FM decompositions we extract the instantaneous amplitude, instantaneous frequency magnitude, and relative angle for each of the combinations of scales. These features are the inputs of a classification algorithm that uses k-means and partial least squares (PLS). The algorithm achieves an accuracy of detection of 0.88 area under the ROC curve (AROC) for a set of 280 images from the Messidor database. Testing is done using the cross-validation methods, with 168 images being used for training and 112 for testing. The original algorithm is then used to analyze the effects of image compression and degradation, which are expected to be present in an eventual implementation of the system on a clinical setting. Results show that the algorithm is insensitive to illumination variations, but that high rate of compression and large blurring effects degrade its performance.

7624-17, Session 4

Automatic determination of the artery vein ratio in retinal images.

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A lower ratio between the width of the arteries and veins (Arteriolar-to-Venular diameter Ratio, AVR) on the retina, is well established to be predictive of stroke and other cardiovascular events in adults, as well as an increased risk of retinopathy of prematurity in premature babies. This work presents an automatic method that detects the location of the optic disc, determines the appropriate region of interest (ROI), classifies the vessels in the ROI into arteries and veins, measures their widths and calculates the AVR. After vessel segmentation and optic disc location detection the system eliminates all vessels outside the ROI. The remaining vessels are thinned, vessel crossing and bifurcation points are removed leaving a set of vessel segments containing centerline pixels. Features are extracted from each centerline pixel that are used to assign each of them a soft label indicating the likelihood it is part of a vein. As all centerline pixels in a connected segment should be the same type we take the median of the soft labels and assign this median label to each centerline pixel in the segment. Next artery vein pairs are matched using an iterative algorithm and the width of the vessel pairs are calculated. We compared the AVR values produced by our system with those manually determined in 15 images and obtained promising results.

7624-18, Session 4

Automated detection and classification of major retinal vessels for determination of diameter ratio of arteries and veins

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Abnormalities of retinal vasculatures can indicate health conditions in the body, such as the high blood pressure and diabetes. Providing automatically determined width ratio of arteries and veins (a/v ratio) on retinal fundus images may help physicians in the diagnosis of hypertensive retinopathy, which can cause blindness. The purpose of this study was to detect and classify major retinal vessels into arteries and veins for the determination of a/v ratio. Images used in this study were obtained from the DRIVE database, which consisted of 20 cases each for training and testing the algorithm. Starting with manual vasculature segmentation provided in the database, two major blood vessels each in the upper and lower temporal regions were manually selected and determined as arteries or veins for establishing the gold standard. We applied the black top-hat transformation and double-ring filter to detect retinal blood vessels. From the extracted vessels, large vessels extending from the optic disc to temporal regions were selected. Image features were extracted from the first vessel segments at a certain distance away from the centers of optic discs. The first segments in the training cases were classified into arteries and veins by using the discriminant analysis, and the selected parameters were applied to those in the test cases. Based on the classification for the first segments, the connected vessel segments were traced. In our preliminary investigation, 70 out of 76 first segments (92%) were classified correctly. The result can be used for the automated calculation of a/v ratio.

7624-19, Session 4

Use of a twin dataset to identify AMD-related visual patterns controlled by genetic factors

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The mapping of genotype to the phenotype of age-related macular degeneration (AMD) is expected to improve the diagnosis and treatment of the disease in a near future. In this study, we focused on the first step to discover this mapping: we identified visual patterns related to AMD which seem to be controlled by genetic factors, without explicitly relating them to the genes. For this purpose, we used a dataset of eye fundus photographs from 41 twin pairs, either monozygotic twins, who have the same genotype, or dizygotic twins, whose genes responsible for AMD are less likely to be identical. If we are able to differentiate monozygotic twins from dizygotic twins, based on a given visual pattern, then this pattern is likely to be controlled by genetic factors. The main visible consequence of AMD is the apparition of drusen between the retinal pigment epithelium and Bruch's membrane. We developed two automated drusen detectors based on the wavelet transform: a shape-based detector for hard drusen, and a texture- and color- based detector for soft drusen. Forty visual features were evaluated at the location of the automatically detected drusen. These features characterize the texture, the shape, the color, the spatial distribution, or the amount of drusen. A distance measure between twin pairs was defined for each visual feature; a smaller distance should be measured between monozygotic twins for visual features controlled by genetic factors. The predictions of several visual features (65.9% accuracy) are comparable or better than the predictions of human experts.

7624-20, Session 5

Auto-biometric for M-mode echocardiography

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The M-mode echocardiogram is a spatial-temporal image of the human heart captured using an ultrasound device. It is used frequently in clinical practices to assess the functionality of anatomic structures (calipers) inside the heart like left ventricle and aortic root. The proposed system will automatically estimate the locations of those calipers. This is a challenging task because of the huge variation in their appearance.

We propose to address the problem in a progressive fashion using two modules. The first module is the coarse detection based on the intensity profile image, which is formed by integrating pixel values across time. The second module estimates the precise location of each caliper.

The benefit of the coarse detection module is two-fold: First, it is more robust to noises. By integrating the intensity across time, noise is suppressed. Second, it improves system speed considerably. This module contains two steps: 1. Individual calipers detection using the Marginal Space Learning framework. 2. Select most likely position for each caliper using MRF.

The precise localization module consists of 4 steps: 1.Individual caliper detection. 2.Select top 3 candidates for each calipers based on the Markov network. 3.Select top 30 configurations for both ED/ES lines, using network consist of calipers along that line. 4.Using a warping detector to select the best caliper configuration for each ED/ES line.

A large dataset containing 478 M-mode images are used to evaluate the system. We achieved a very high accuracy: average error 1.64 millimeter. The system could detect all calipers (over 50) in one image within 1 second, thanks to the progressive detection scheme.

7624-21, Session 5

Automatic coronary calcium scoring in low-dose non-ECG-synchronized thoracic CT scans

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A system is presented for automatic coronary calcium scoring and cardiovascular risk stratification in thoracic CT scans. Data was collected from a Dutch-Belgian lung cancer screening trial. In 121 low-dose, non-ECG synchronized, non-contrast enhanced thoracic CT scans an expert scored coronary calcifications manually. A key element of the proposed algorithm is that the approximate position of the coronary arteries was inferred with a probabilistic coronary calcium atlas. This atlas was created with atlas-based segmentation from 51 scans and their manually identified calcifications, and was registered to each unseen test scan. In the test scans all objects with density above 130 HU were considered candidates that could represent coronary calcifications. A statistical pattern recognition system was designed to classify these candidates using features that encode their spatial position relative to the inferred position of the coronaries obtained from the atlas registration. In addition, size and texture features were computed for all candidates. Two consecutive classifiers were used to label each candidate. The system was trained with 35 and tested with another 35 scans. The detected calcifications were quantified and cardiovascular risk was determined for each subject.

The system detected 71% of coronary calcifications with an average of 0.9 false positive objects per scan. Cardiovascular risk category was correctly assigned to 29 out of 35 subjects (83%). Five scans (14%) were one category off, and only one scan (3%) was two categories off.

We conclude that automatic assessment of the cardiovascular risk from low-dose, non-ECG synchronized thoracic CT scans appears feasible.

7624-22, Session 5

An hybrid CPU-GPU framework for quantitative follow-up of abdominal aortic aneurysm volume by CT angiography

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We developed an hybrid CPU-GPU framework to perform the segmentation of abdominal aortic aneurysm (AAA) for maximal diameter (D-max) and volume follow-up by Computed Tomography Angiography (CTA). In order to improve the workflow efficiency some segmentation tasks were implemented and executed on the graphic hardware (GPU). A GPU based algorithm is used to automatically segment the lumen of the aneurysm in a very low computing time. In a second step, the user interacted with the software to validate the boundaries of the intra-luminal thrombus (ILT) on GPU-based curved image reformation. Automatic computation of D-max and volume are performed on the 3D AAA model.

Clinical validation was conducted on 34 patients having 2 consecutive MDCT examinations within a minimum interval of 6 months. The AAA segmentation was performed twice by a proficient radiologist (gold standard) and once by 3 unsupervised technologists on all 68 MDCT. The ICC for intra-observer reproducibility was 0.992 (>/=0.987) for D-max and 0.998 (>/=0.994) for volume measurement. The ICC for inter-observer reproducibility was 0.985 (0.977-0.90) for D-max and 0.998 (0.996- 0.999) for volume measurement. Semi-automated AAA segmentation for volume follow-up is more than twice as sensitive than D-max follow-up, while providing an equivalent reproducibility.

7624-23, Session 5

Automated segmentation and tracking of coronary arteries in cardiac CT scans: comparison of performance with a clinically used commercial software

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Cardiac CT has been reported to be an effective means for diagnosis of coronary artery plaque disease. We are investigating the feasibility of developing a computer-aided detection (CAD) system to assist radiologist in detection of non-calcified plaques in coronary arteries in ECG-gated cardiac CT scans.

Vascular structures are first enhanced by 3D multi-scale filtering and analysis of the eigenvalues of Hessian matrices using a vessel enhancement response function specifically designed for coronary arteries. The enhanced vascular structures are then segmented by an EM estimation method. The segmented coronary arteries are tracked using a 3D rolling balloon vessel tracking (RBVT) method. Starting at two manually identified seed points located at the origins of the left and right coronary artery (LCA and RCA), the RBVT method automatically moves a sphere of adaptive diameter along the vessels, tracks the vessels, and identifies its branches to generate the left and right coronary arterial trees.

Twenty cardiac CT scans that contained various degrees of coronary artery diseases were used as test data set. The rendered volume of coronary arteries tracked by our method was displayed on a PC, placed next to a GE Advantage workstation on which the coronary arterial trees tracked by the GE software and the original CT scan were displayed. Two experienced thoracic radiologists visually examined the coronary arteries on the original CT scans and the segmented vessels to count untracked false-negative (FN) segments and false positives (FPs). A total of 19 and 38 artery segments were identified to be FNs, and 23 FPs and 20 FPs were found in the coronary trees tracked by our method and the GE software, respectively.

7624-24, Session 5

MACD: an imaging marker for cardiovascular disease

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Cardiovascular diseases (CVD) are the most common cause of death in Europe and the United States. This is the case despite general acceptance that a healthy lifestyle and the treatment of risk factors can prevent the development of CVD. It is known that abdominal aortic calcifications (AAC) are strong predictors of cardiovascular morbidity and mortality. They correlate strongly with coronary artery calcifications and can hence predict the risk of coronary artery problems. An early detection of aortic calcified plaques helps to predict the risk of related coronary diseases. Also since two thirds of the adverse events have no prior symptoms, possibilities to screen for risk in low cost imaging are important. To this end the Morphological Atherosclerotic Calcification Distribution (MACD) index was developed.

In the following several potential severity scores relating to the geometrical outline of the calcified deposits in the lumbar aortic region are introduced. Their individual as well as their combined predictive power is examined and the combined marker, MACD, is constructed. This is done using a Cox regression analysis, also known as survival analysis. Furthermore we show how the Cox regression yields MACD to be the most efficient marker. We also demonstrate that MACD has a larger individual predictive power than any of the other individual imaging markers described. Finally we present that by the use of the MACD index to predict death one can achieve a relative risk of dying from CVD of approximately four through all categories.

7624-25, Session 6

Automated classification of lymph nodes in USPIO-enhanced MR-images: a comparison of three segmentation methods

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Computer assisted detection (CAD) of lymph node metastases may help reduce reading time and improve interpretation of the large amount of image data in a 3-D pelvic MRI exam.

In this study, we compare the influence of using different segmentation methods on the performance of a CAD system for classification of normal and metastasized lymph nodes.

Our database consisted of pelvic MR images of 28 consecutive patients, containing 603 lymph nodes.

Each dataset included a T1-weighted and a T2*-weighted sequence, enhanced by a lymph node specific contrast medium based on Ultrasmall Superparamagnetic Particles of Iron Oxide (USPIO).

For each lymph node, one seed point was manually defined. Three automated segmentation methods were compared: 1. Confidence Connected segmentation, extended with automated Bandwidth Factor selection; 2. Conventional Graph Cut segmentation; 3. Segmentation by selecting a sphere around the seed point.

4. All lymph nodes were also manually segmented by a radiologist. For all methods, the resulting segmentations were used to calculate 2 features (mean T1 and T2*-signal intensity). Linear discriminant analysis was used for classification. The performance of the CAD system for all methods was assessed using ROC-analysis.

It was found that the diagnostic accuracy of the CAD-system (AUC) was: 0.95 (Confidence Connected); 0.95 (Graph Cut); 0.85 (sphere); and 0.95 (manual segmentations).

The CAD-performance of both the Confidence Connected and Graph Cut methods was as good as the manual segmentation. The substantially lower performance of the sphere segmentations demonstrates the need for accurate segmentations, even in USPIO-enhanced images.

7624-26, Session 6

CT liver volumetry using geodesic active contour segmentation with a level-set algorithm

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Automatic liver segmentation on CT images is challenging because the liver often abuts other organs of a similar density. Our purpose was to develop an accurate automated 3D liver segmentation scheme for measuring liver volumes. We developed an automated volumetry scheme for the liver in CT based on a 5 step schema. First, an anisotropic smoothing filter was applied to portal-venous phase CT images to remove noise while preserving the liver structure, followed by an edge enhancer to enhance the liver boundary. By using the boundary-enhanced image as a speed function, a 3D fast-marching algorithm generated an initial surface that roughly estimated the liver shape. A 3D geodesic-active-contour segmentation algorithm coupled with level-set contour-evolution refined the initial surface so as to more precisely fit the liver boundary. The liver volume was calculated based on the refined liver surface. Hepatic CT scans of eighteen prospective liver donors were obtained under a liver transplant protocol with a multi-detector CT system. Automated liver volumes obtained were compared with those manually traced by a radiologist, used as "gold standard." The mean liver volume obtained with our scheme was 1520 cc, whereas the mean manual volume was 1486 cc, with the mean absolute difference of 104 cc (7.0%). CT liver volumetrics based on an automated scheme agreed excellently with "gold-standard" manual volumetrics (intra-class correlation coefficient was 0.95) with no statistically significant difference (F=1.27), and required substantially less completion time. Our automated scheme provides an efficient and accurate way of measuring liver volumes.

7624-27, Session 6

Multi-class SVM model for fMRI-based classification and grading of liver fibrosis

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We present a supervised learning method for the automatic creation of a classification and grading model for liver fibrosis from fMRI scans. The method uses the hepatic hemodynamic changes to build a statistical model of the liver fibrosis grade. Hepatic hemodynamics are evaluated from an anatomical MRI image and three T*2-W fMRI signal intensity time-course scans acquired during the breathing of air, air-carbon dioxide, and carbogen. A statistical model is constructed using binary-based one-against-all multi class Support Vector Machine (SVM) classifier. We evaluated the performance of the resulting classification model with the leave-one out technique and compared it to full multi-class SVM classification. Our experimental results on 57 slice sets from 13 mice yield an accuracy of 98.2% for separation between healthy and low grade fibrotic subjects, and overall accuracy of 84.2% for fibrosis grading. These results outperform existing image-based methods which can only discriminate between healthy and high grade fibrosis subjects. Our method may be used for non-invasive classification and progression monitoring of liver fibrosis patients instead of more invasive approaches, such as biopsy, or contrast-enhanced imaging.

7624-28, Session 6

Semi-automatic central-chest lymph-node definition from 3D MDCT images

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Central-chest lymph nodes play a vital role in lung-cancer staging. The three-dimensional (3D) definition of lymph nodes from multidetector computed-tomography (MDCT) images, however, remains an open problem. This is because of the limitations in the MDCT imaging of soft-tissue structures and the complicated phenomena that influence the appearance of a lymph node in an MDCT image. In the past, we have made significant efforts toward developing (1) live-wire-based segmentation methods for defining 2D and 3D chest structures and (2) a computer-based system for automatic definition and interactive visualization of the Mountain central-chest lymph-node stations. Based on these works, we propose new single-click and single-section live-wire methods for segmenting central-chest lymph nodes. The single-click live wire only requires the user to select an object pixel on one 2D MDCT section and is designed for typical lymph nodes. The single-section live wire requires the user to process one selected 2D section using standard 2D live wire, but it is more robust. We applied these methods to the segmentation of 20 lymph nodes from two human MDCT chest scans (10 per scan) drawn from our ground-truth database. The single-click live wire segmented 75% of the selected nodes successfully and reproducibly, while the success rate for the single-section live wire was 85%. We are able to segment the remaining nodes, using our previously derived (but more interaction intense) 2D live-wire method incorporated in our lymph-node analysis system. Both proposed methods are reliable and applicable to a wide range of pulmonary lymph nodes.

7624-29, Session 6

Computer-aided lymph node detection in abdominal CT images

J. Liu, J. White, R. M. Summers, National Institutes of Health (United States)

Many malignant processes cause abdominal lymphadenopathy, and computed tomography (CT) has become the primary modality for its detection. A lymph node is considered enlarged (swollen) if it is more than 1 centimeter in diameter. Which lymph nodes are swollen depends on the type of disease and the body parts involved. Identifying their locations is very important to determine the possible cause. In the current clinical workflow, the detection and diagnosis of enlarged lymph nodes is usually performed manually by examining all slices of CT images, which can be error-prone and time consuming. 3D blob enhancement filter is a usual way for computer-aided node detection. We proposed a new 3D blob detector for automatic lymph node detection in contrast-enhanced abdominal CT images. Since lymph nodes are usually next to blood vessels, abdominal blood vessels were first segmented as a reference to set the search region for lymph nodes. Then a new detection response measure, blobness, is defined based on eigenvalues of the Hessian matrix and the object scale in our new blob detector. Voxels with higher blobness were clustered as lymph node candidates. Finally some prior anatomical knowledge was utilized for classification and false positive reduction. We applied our method to 5 patients and compared the results with the performance of the original blobness definition. Both methods achieved sensitivity of 83.3% but the false positive rates per patient were 24 and 60 for our method and the original method, respectively. Our results indicated that computer-aided lymph node detection with this new blob detector may yield a high sensitivity and a relatively low FP rate in abdominal CT.

7624-30, Session 6

Automated liver lesion characterization using fast kV switching dual energy computed tomography imaging

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Hypo-intense malignant metastatic tumors are not completely distinguishable from benign cysts in the liver using conventional Computer Tomography (CT) imaging, since both lesion types present similar intensities. To correctly characterize such lesions, a follow up PET or MR exam and in some cases, biopsy, is required beyond the initial CT finding. Fast kV switching Dual Energy CT (DECT) combined with projection-based material decomposition offers the opportunity to discriminate tissue types based on material attenuation and density using monochromatic images where beam hardening is reduced or eliminated and the images come inherently pre-registered. We present a supervised learning method for discriminating between cysts and hypo-dense metastatic liver lesions using monochromatic images derived from fast switching DECT imaging. Intensity-based statistical features extracted from inside the lesion are used to train an optimal and robust nonlinear classifier. Our algorithm only requires a region of interest inside the lesion to compute features and perform classification, eliminating the need for an accurate segmentation. We show that: (a) monochromatic images exhibit reduced pseudo-enhancement and provide better separation between cysts and tumors compared to conventional polychromatic CT images, (b) automated classification using monochromatic images derived from fast kV switching DECT is superior to conventional polychromatic CT images and (c) classification using a pair of monochromatic images (70 and 100 keV) shows improvement over a pair of conventional CT acquisitions (80 and 140 kVp). Classifier performance was evaluated using M-fold cross-validation on a lesion database with radiologist provided lesion location and labels (cyst or metastatic tumor).

7624-31, Session 7

Interactive annotation of textures in thoracic CT scans

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This study describes a system for complete interactive annotation of thoracic CT scans. Lung volumes in these scans were segmented and subdivided into roughly spherical volumes of interest (VOIs) with homogeneous texture with a clustering procedure. For each 3D VOI, 72 features were calculated. The observer inspects the scan to determine which textures are present and annotates several VOIs of each texture. Based on these annotations, a k-nearest-neighbor classifier is trained, which classifies all remaining VOIs in the scan. The algorithm then presents a section with suggested annotations to the user, in which he can correct mistakes. The classifier is retrained, taking into account these new annotations, and the user is presented another section for correction. This process continues until at least 50% of all lung voxels in the scan have been classified. The remaining VOIs are classified automatically. In this way, the entire lung volume is annotated. The system has been applied to scans of patients with usual and non-specific interstitial pneumonia. The results of interactive annotation are compared to a system in which the user annotates all predefined VOIs manually. The interactive system is 3.7 times as fast as complete manual annotation of VOIs and results are within interobserver variability. This is a first step towards precise quantitation of texture patterns in thoracic CT in clinical research and in clinical practice.

7624-32, Session 7

Rib suppression in chest radiographs to improve classification of textural abnormalities

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The computer aided diagnosis (CAD) of abnormalities on chest radiographs is difficult due to the presence of overlapping normal anatomy. Suppression of the normal anatomy is expected to improve performance of a CAD system, but such a method has not yet been applied to the computer detection of interstitial abnormalities such as occur in tuberculosis (TB). The aim of this research is to evaluate the effect of rib suppression on a CAD system for TB. Profiles of pixel intensities sampled perpendicular to segmented ribs were used to create a local PCA-based shape model of the rib. The model was normalized to the local background intensity and corrected for gradients perpendicular to the rib. Subsequently rib suppressed images were created by subtracting the models for each rib from the original image. The effect of rib suppression was evaluated using a CAD system for TB detection. Small square image patches were sampled randomly from 15 normal and 25 TB-affected images containing textural abnormalities. Abnormalities were outlined by a radiologist and were given a subtlety rating from 1 to 5. Features based on moments of intensity distributions of Gaussian derivative filtered images were extracted. A supervised learning approach was used to discriminate between normal and diseased image patches. The use of rib suppressed images increased the overall performance of the system, as measured by the area under the receiver operator characteristic (ROC) curve, from 0.75 to 0.78. For the more subtly rated patches (rated 1-3) the performance increased from 0.62 to 0.70.

7624-33, Session 7

What catches a radiologist's eye? a comprehensive comparison of feature types for saliency prediction

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Experienced radiologists are in short supply, and are sometimes called upon to read many images in a short amount of time. This leaves them with a limited amount of time to read images, and can lead to fatigue and stress which can be sources of error, as they overlook subtle abnormalities that they otherwise might not miss. Another factor in error rates is called satisfaction of search, where a radiologist misses a second (typically subtle) abnormality after finding the first. These types of errors are due primarily to a lack of attention to an important region of the image during the search. In this paper we discuss the use of eye tracker technology, in combination with image analysis and machine learning techniques, to learn what types of features catch the eye experienced radiologists when reading chest x-rays for diagnostic purposes, and to then use that information to produce saliency maps that predict what regions of each image might be most interesting to radiologists. We found that, out of 13 popular features types that are widely extracted to characterize images, 4 are particularly useful for this task: (1) Localized Edge Orientation Histograms (2) Haar Wavelets, (3) Gabor Filters, and (4) Steerable Filters.

7624-34, Session 7

Combinational feature optimization for classification of lung tissue images

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A novel approach to feature optimization for classification of lung carcinoma using tissue images is presented. The methodology uses a combination of three characteristics of computational features: F-measure, which is a representation of each feature towards classification, inter-correlation between features and pathology based information. The metadata provided from pathological parameters is used for mapping between computational features and biological information. Multiple regression analysis maps each category of features based on how pathology information is correlated with the size and location of cancer. Relatively the computational features represented the tumor size better than the location of the cancer. Based on the three criteria associated with the features, three sets of feature subsets with individual validation are evaluated to select the optimum feature subset. Based on the results from the three stages, the knowledgebase produces the best subset of features. An improvement of 5.5% was observed for normal Vs all abnormal cases with Az value of 0.731 and 74/114 correctly classified. The best Az value of 0.804 with 66/84 correct classification and improvement of 21.6% was observed for normal Vs adenocarcinoma.

7624-35, Session 7

Classification of interstitial lung disease patterns with topological texture features

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Topological texture features were compared in their ability to classify morphological patterns known as 'honey-combing' that are considered indicative for the presence of fibrotic interstitial lung diseases in high-resolution computed tomography (HRCT) images. For 14 patients with known occurrence of honey-combing, a stack of 70 axial, lung kernel reconstructed images were acquired from MDCT chest exams. 241 regions of interest of both healthy and pathological (89) lung tissue were identified by an experienced radiologist. Texture features were extracted using six properties calculated from gray-level co-occurrence matrices (GLCM), Minkowski Dimensions (MDs), three Minkowski Functionals (MFs, e.g. MF.euler). A k-nearest-neighbor (k-NN) classifier and a Multilayer Radial Basis Functions Network (RBFN) were optimized in a 10-fold cross-validation for each texture vector, and the classification accuracy was calculated on independent test sets as a quantitative measure of automated tissue characterization.

A Wilcoxon signed-rank test was used to compare two accuracy distributions including the Bonferroni correction. The best classification results were obtained by the MF features, which performed significantly better than all the standard GLCM and MD features ($p<0.005$) for both classifiers. The highest accuracy was found for MF.euler (97.5%, 96.6%; for the k-NN and RBFN classifier, respectively). The best standard texture features were the GLCM features 'homogeneity' (91.8%, 87.2%) and 'absolute value' (90.2%, 88.5%). The results indicate that advanced topological texture features can provide superior classification performance in computer-assisted diagnosis of interstitial lung diseases when compared to standard texture analysis methods.

7624-36, Session 8

3D segmentation of lung nodules in CT images based on improved level set method

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we present a novel approach of 3D lung nodule segmentation in computed tomography (CT) images for developing an effective computer aided diagnosis (CAD) system for the lung cancer,. The segmentation process contains three steps. First, we divide nodules into two types according to their gray levels, which include the high contrast type and the low contrast type. In the second step, we propose two improved level set methods for segmenting these two types of nodules. Differing from the traditional level set methods; we redefined the average gray value of the outside area of zero level set, which is more close to the value of the lung parenchyma around the nodule. Finally, we remove the over-segment volumes caused by the other tissues attaching to nodules. We test on two datasets from Lung Imaging Database Consortium (LIDC). The first dataset contains 23 CT scans, and the second dataset contains 64 CT scans. The average segmentation volume overlapping rate and average volume error rate between the segmentation results and the gold standards provided by radiologists are used to evaluate the algorithm. Experimental results demonstrate we are able to achieve the high overlap rate and low error rate. By comparing with the results from several other existing methods, we can find that our method gives more accurate segmentation results.

7624-37, Session 8

Standard moments based vessel bifurcation filter for computer-aided detection of pulmonary nodules

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This work describes a method that can discriminate between a solid pulmonary nodule and a pulmonary vessel bifurcation point from a given candidate location on a CT scan using the method of standard moments. The algorithm starts with the estimation of a spherical window around a nodule candidate center that best captures the local shape properties of the region. Then, given this window, the standard set of moments, invariant to rotation, translation and scale is computed over the geometrical representation of the region. Finally, a feature vector composed of the moment values is classified into either a nodule or a vessel bifurcation point.

The performance of this technique was evaluated on the dataset containing 276 intraparenchymal nodules and 276 selected vessel bifurcation points. The method resulted in 99% sensitivity and 80% specificity in identifying nodules, which makes this technique an efficient filter for false positives reduction. Its efficiency was further evaluated on the dataset of 656 low-dose chest CT scans. Inclusion of this filter into a design of an experimental detection system resulted in up to a 69% decrease in false positive rate in detection of intraparenchymal nodules with less than 1% loss in sensitivity.

7624-38, Session 8

Micro CT based truth estimation of nodule size

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With the advent of high-resolution CT, three-dimensional (3D) methods for nodule volumetry have been introduced, with the hope that such methods will be more accurate and consistent than currently used planar measures of size. However, the error associated with volume estimation methods still needs to be quantified. Volume estimation error is multi-faceted in the sense that there are contributions associated with the patient, the software tool and the CT system. A

primary goal of the research in our lab is to quantify the various sources of measurement error and, when possible, minimize their effects. One of the requirements for the determination of bias is knowledge of the actual nodule size. In the work reported here, we compare estimates of true volume obtained from micro CT to those obtained from measures of nodule density and precision weight. A potential advantage of micro CT over other truthing methods is that it may provide both volume and shape information in a single measurement. In the current study we compare micro CT volume truth to weight-density truth for spherical, elliptical, spiculated, and lobulated nodules with diameters = 5- 40 mm, and densities = -630 and +100 HU. The percent differences between micro CT and weight-density volume for -630 HU nodules ranged from -21.7%, to -1.5% (mean=-11.9%) and the differences for +100 HU nodules range from -0.9% to 3% (mean=1.7%).

7624-39, Session 8

Approximations of noise structures in helical multi-detector CT scans: application to lung nodule volume estimation

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We have previously developed a model-based approach for estimating lung nodule size from helical multi-detector CT (MDCT) images [1], in which we used a sum of squared differences (SSD) metric to match the simulated CT templates to the measured nodule CT images. A previous study showed the potential of this approach for reducing the bias and variance for nodule size estimation. However, minimizing SSD would not be statistically optimal because the noise in 3D helical CT images is correlated. The goal of this work was to investigate the noise properties and explore several approximated descriptions of the 3D noise covariance, including: variance only, noise power spectrum (NPS), axial correlation, 2D in-plane correlation and fully 3D correlation. We examined the effectiveness of these second-order noise approximations by applying them to our volume estimation approach with a simulation study. Our simulations showed that: the variance based pre-whitening and axial pre-whitening performed very similar to the non-prewhitening case, with accuracy (measured in RMSE) differences within 1%; the NPS based pre-whitening performed slightly better, with a 4% decrease in RMSE; the in-plane pre-whitening and 3D fully pre-whitening performed best, with about 10% decrease in RMSE over the nonprewhitening case. The simulation results suggest that the NPS or 2D transaxial based partial prewhitening are beneficial for lung nodule size estimation. The performance improvement associated with using the fully 3D prewhitening in the template-based volume estimation approach comes with a greater computational cost associated with the determination of these noise characterizations.

7624-40, Session 8

A shape-dependent variability metric for evaluating panel segmentations with a LIDC case study

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The segmentation of medical images is challenging because a ground truth is often not available. Computer-Aided Detection (CAD) systems are dependent on ground truth as a means of comparison; however, in many cases theground truth is derived from only experts' opinions. When the experts disagree, it becomes impossible to discern one ground truth. In this paper, we propose an algorithm to measure the disagreement among radiologists' delineated boundaries. The algorithm accounts for both the overlap and shape of the boundaries in determining the variability of a panel segmentation. After calculating the variability of 3788 thoracic computed tomography (CT) slices

in the Lung Image Database Consortium (LIDC), we found that the radiologists have a high consensus in a majority of lung nodule segmentations. However, our algorithm identified a number of segmentations that the radiologists significantly disagreed on. Our proposed method of measuring disagreement can assist others in determining the reliability of panel segmentations. We also demonstrate that it is superior to simply using overlap, which is currently one of the most common ways of measuring segmentation agreement. The variability metric presented has applications to panel segmentations, and also has potential uses in CAD systems.

7624-41, Session 8

FDA phantom CT database: a resource for the assessment of lung nodule size estimation methodologies and software development

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As part of a more general effort to probe the interrelated factors impacting the accuracy and precision of lung nodule size estimation, we have been conducting phantom CT studies with an anthropomorphic thoracic phantom containing a vasculature insert on which synthetic nodules were inserted or attached. The utilization of synthetic nodules with known truth regarding size and location allows for bias analysis as well as the acquisition of repeat CT scans for variance analysis, which would be prohibitive to acquire on patients because of radiation exposure considerations. Using a factorial approach to probe imaging (acquisition and reconstruction) parameters and nodule characteristics (size, density, shape, location), ten repeat scans have been collected for each protocol and nodule layout. The resulting database is incrementally becoming available as a public resource via the National Biomedical Imaging Archive to facilitate the assessment of lung nodule size estimation methodologies and the development of image analysis software among other possible applications. This manuscript describes the phantom CT database and associated information including image acquisition and reconstruction protocols, nodule layouts and nodule truth.

7624-63, Poster Session

Towards automatic determination of total tumor burden from PET images

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Quantification of potentially cancerous lesions from imaging modalities, most prominently from CT or PET images, plays a crucial role both in diagnosing and staging of cancer as well as in the assessment of the response of a cancer to a therapy, e.g. for lymphoma or lung cancer. For PET imaging, several quantifications which might bear great disciriminating potential (e.g. total tumor burden or total tumor glycolysis) involve the segmentation of all cancerous lesions. However, this particular task of segmenting all cancerous lesions might be very tedious if it has to be done manually, in particlar if the disease is scattered or metastasized and thus consists of numerous foci; this is one of the reasons why only few clinical studies on those quantifications are available. In this work, we investigate two components to aid the easy determination of all lesions in a PET image of a human.

The first component is designed to detect all hot spots within a PET image and rank their probability of being a cancerous lesion. The basis of this component is a modified watershed algorithm; the ranking is performed on a combination of several measures derived from the individual basins. The other component is an atlas matching which can be used in order to control the parameters of a segmentation according to the location within the body or to account for the location in the body in the probability ranking.

Both components are embedded in a software suite to assess response to a therapy based on PET images. As a preprocessing

step, potential lesions are segmented and indicated to the user, who can select the foci which constitute the tumor and discard the false positives. This procedure substantially simplifies the segmentation of the entire tumor burden of a patient.

The components of the automatic hot spot detection are evaluated on 17 clinical datasets.

7624-64, Poster Session

Development of CAD prototype system for Crohn's disease

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The purpose of this paper is to present a CAD prototype system for Crohn's disease. Crohn's disease causes inflammation or ulcers of the gastrointestinal tract. The number of patient of Crohn's disease is increasing in Japan. Symptoms of Crohn's disease include narrowed intestine, longitudinal ulcers, and fistulae. Optical endoscope cannot pass through narrowed intestines in some cases. We propose a new CAD system using abdominal fecal tagging CT images for efficient diagnosis of the narrowed intestine of Crohn's disease. The system displays virtual unfolded (VU) views of both large and small intestines. To achieve the VU views, we developed a large and small intestines extraction method and a simple electronic cleansing method. The intestine extraction is based on the region growing, which use a characteristic that tagged fluid neighbor air in the intestine. The electronic cleansing enables observation of intestine wall under tagged fluid. We change the height of the VU views according to the perimeter of the intestine. In addition, we developed a method to enhance the longitudinal ulcer on views of the system. We enhance small concavities on the intestine wall, which are caused by the longitudinal ulcer, based on eigenvalues of the Hessian matrix. We observed large and small intestines of five CT images using the proposed system. The VU views enabled efficient observation of the intestine wall. The height change of the VU views helps finding narrowed intestines on the VU views. The small concavity enhancement method made longitudinal ulcers clear on the views.

7624-65, Poster Session

Feature selection by adaptive weighting and reordering for computer-aided polyp detection in CT colonography

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With the development of computer-aided polyp detection towards virtual colonoscopy screening, the trade-off between detection sensitivity and specificity has gained increasing attention. An optimum detection, with least number of false positives and highest true positive rate, is desirable and involves interdisciplinary knowledge, such as feature extraction, feature selection as well as machine learning. Toward that goal, various geometrical and textural features, associated with each suspicious polyp candidate, have been individually extracted and stacked together as a feature vector. However, directly inputting these high-dimensional feature vectors into a learning machine, e.g., neural network, for polyp detection is time-consuming and may induce the curse of dimensionality. In this paper, we explored an indispensable building block of computer-aided polyp detection, i.e., principal component analysis (PCA)-weighted feature selection for neural network classifier of true and false positives. The major concepts proposed in this paper include (1) the use of eigenvalues, associated with PCA, to scale each principal component (PC) proportionally, and (2) the selection of new features (i.e., eigenvalue-weighted PC) via a sophisticated prioritization scheme, which originates from the constrained band selection in remotely-sensed image processing. As such, the curse of dimensionality with more than necessary number of

features can be greatly mitigated. Learned and tested by radial basis neural network, the proposed computer-aided polyp detection has achieved 100% sensitivity at a cost of average two false positives per polyp.

7624-67, Poster Session

Performance study of polycystic kidneys segmentation methods

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Polycystic kidney disease (PKD) is a disorder characterized by the growth of numerous fluid filled cysts in the kidneys. Measuring cystic kidney volume is thus crucial to monitoring the evolution of the disease.

While T2-weighted MRI delineates the organ, automatic segmentation is very difficult due to highly variable shape and image contrast. The interactive methods based on stereology used currently involve a compromise between segmentation accuracy and time.

We have investigated semi-automated methods: active contours, graph-cuts method and a sub-voxel morphology based algorithm.

Coronal T2-weighted images of 17 patients were acquired in one breath-hold using the HASTE sequence on a 1.5 Tesla MRI unit. The segmentation results were compared to ground truth kidney masks obtained as a consensus of experts.

Automatic active contour algorithm yielded an average 17% +/- 4.9% volume error. A recently developed method (BridgeBurner) based on thresholding and constrained morphology failed to separate PKD from the spleen, yielding 32%+/- 6.8% volume error.

Manual post-editing reduced the volume error to 3.0%+/- 0.79% for active contours and 3.49%+/- 0.56% for BridgeBurner. The total time (automated algorithm plus editing) was 16 min +/- 6.5 min for active contours and 23.2 min +/- 16.8 min for BridgeBurner. The average volume errors for interactive stereology method were 5.2%, 5.6%, 6.5% for mesh size 6, 10, 15 mm. The average processing times were 20, 9, 6 min.

These preliminary results suggest that nearly two-fold improvement in PKD segmentation accuracy over stereology technique can be achieved with a combination of active contours and post-editing.

7624-68, Poster Session

A model based method for recognizing psoas major muscles in torso CT images

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In aging societies, it is very important to analyze age-related hypokinesia. A psoas major muscle has many important functional capabilities such as capacity of balance and posture control. These functions can be measured by its cross sectional area (CSA), volume, and thickness. However, these values are calculated manually in the clinical situation. The purpose of our study is to propose an automated recognition method of psoas major muscles in X-ray torso CT images. The recognition process proposed involves three steps: 1) determination of anatomical points such as the origin and insertion of the psoas major muscle, 2) generation of an outer shape model for the psoas major muscle, and 3) recognition of the psoas major muscles by use of the shape model. The model was built using quadratic function, and was fit to the anatomical center line. The shape model was generated using 20 CT cases and tested by 20 other CT cases. The applied database consists of 12 male and 8 female cases from the ages of 40's to 80's. The averaged Jaccard similarity coefficient (JSC) value employed in the evaluation was 0.7. Our experimental results indicated that our method was effective for a volumetric analysis and could be possible to be used for a quantitatively automated analysis.

7624-69, Poster Session

Feature selection for computer-aided polyp detection using MRMR

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In building robust classifiers for computer-aided detection (CAD) of lesions, selection of relevant features is of fundamental importance. Typically one is interested in determining which, of a large number of potentially redundant or noisy features, are most discriminative for classification. Searching all possible subsets of features is impractical computationally. This paper proposes a feature selection scheme combining AdaBoost with the Minimum Redundancy Maximum Relevance (MRMR) to focus on the most discriminative features. A fitness function is designed to determine the optimal number of features in a forward wrapper search. Bagging is applied to reduce the variance of the classifier and make a reliable selection. Experiments demonstrate that by selecting just 11 percent of the total features, the classifier can achieve better prediction on independent test data compared to the 70 percent of the total features selected by AdaBoost.

7624-70, Poster Session

Accurate computation of motion parameters using a regression method for colonoscopy tracking

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Optical colonoscopy and virtual colonoscopy are two technologies that can be used to screen for colorectal cancer, a leading cause of cancer-related mortality in the United States. Our overall goal is to effectively and simultaneously use both technologies, and present this information during an optical colonoscopy procedure. In our earlier work, we presented an optical flow based approach to automatically track and co-locate sequences of colonoscopy video with CT based virtual colonoscopy images. This method used a combination of sparse and dense optical flow fields, and optimal spatial and temporal scales to accurately estimate motion parameters. In this work, we use a robust regression based method to further improve the accuracy of the motion parameter computation step. We use the Least Median of Squares(LMS) estimator to detect outliers among the feature point pairs, and compare this to the Least sum of Squares(LS) estimator, used in our earlier work. We illustrate the superiority of the LMS estimator via three colonoscopy sequences containing 320, 1310 and 1316 images. The first experiment demonstrates more accurate spatial positioning of the virtual camera, when compared to the LS estimator based method. In the remaining two experiments, LS based method fails after 300 and 410 images, while the LMS based approach is able to track the entire sequence. The primary reason for the superior performance of the LMS estimator is its ability to discard feature points that are determined to be outliers; this results in more accurate estimates of the rotation and translation parameters.

7624-71, Poster Session

Segmentation of liver portal veins by global optimization

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We have adapted and improved the robustness of a previously developed lung vessel tree segmentation algorithm so it can handle a more challenging problem: the segmentation of the liver portal veins from an arterial phase CT scan. The developed segmentation algorithm incorporates a physiological model that states that the vasculature pattern is organized such that the whole organ is perfused using minimal mechanical energy. This model is, amongst others,

applicable to the lungs, the liver, and the kidneys. The algorithm first locally detects probable candidate vessel segments in the image. The subset of these segments that generates the most probable vessel tree according the image and the physiological model is afterwards sought by a global optimization method. The algorithm has already been applied successfully to segment heavily simplified lung vessel trees from CT images. Now the general feasibility of this approach is illustrated by applying it to the segmentation of the liver portal veins from an arterial phase CT scan. This is more challenging, because the intensity difference between the vessels and the parenchyma is small. To cope with this the local detection of candidate vessel segments has been made more robust, using a support vector machines approach with a robust feature vector, and the global optimization method has been revised. This approach has already been applied on one image, and the results thus far look promising. More images will soon be processed. This algorithm is a first step towards an automatic segmentation of all of the liver vasculature.

7624-72, Poster Session

Haustral fold registration in CT colonography and its application to registration of virtual stretched view of the colon

E. Fukano, M. Oda, K. Mori, Nagoya Univ. (Japan); T. Kitasaka, Y. Suenaga, Aichi Institute of Technology (Japan); T. Takayama, Univ. of Tokushima (Japan); H. Takabatake, Minami Sanjyo Hospital (Japan); M. Mori, Sapporo Kosei Hospital (Japan); H. Natori, Keiwakai Nishioka Hospital (Japan); S. Nawano, International Univ. of Health and Welfare (Japan)

This paper presents a method for registering haustral folds extracted from CT volumes taken in the supine and prone positions for CT colonography. In CTcolonography, a physician needs to diagnose two CT volumes taken in the supine and prone positions. Registered display of the CT volumes will greatly reduce diagnosis time. Since large number of haustral fold exists in the colon and their relations of relative positions do not change among two CT volumes, haustral fold information can be used for registration of two CT volumes. In actual registration process, we divide the colon regions into four segments based on anatomical features. Locations of the centers of gravities of each haustral fold are projected onto the centerline of the colon. Haustral fold registration is implemented as a procedure finding corresponding point pairs on the centerlines of the two supine and prone positions. Our method was evaluated by three pairs of CT volumes taken in the supine and prone positions. By using information of registered haustral fold information, virtual stretched views for the supine and prone position are registered so that corresponding haustral folds are displayed at same position. Experimental results showed that the proposed method can register haustral folds and display registered virtual stretched views.

7624-73, Poster Session

An open source implementation of colon CAD in 3D slicer

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Most colon CAD (computer aided detection) software products, especially commercial products, are designed for use by radiologists in a clinical environment. Therefore, those features that effectively assist radiologists in finding polyps are emphasized in those tools. However, colon CAD researchers, many of whom are engineers or computer scientists, are working with CT studies in which polyps have already been identified using CT Colonography (CTC) and/or optical colonoscopy (OC). Their goal is to utilize that data to design a computer system that will identify all true polyps with no false positive (FP) detections. Therefore, they are more concerned with how to reduce FPs and to understand the behavior of the system than how to

find polyps. Thus, colon CAD researchers have different requirements for tools not found in current CAD software. We have implemented CAD in 3D Slicer to assist these researchers. As with clinical colon CAD implementations, the ability to promptly locate a polyp candidate in a 2D slice image and on a 3D colon surface is essential for researchers. Our software provides this capability, and uniquely, for each polyp candidate, the prediction value from a classifier is shown next to the 3D view of the polyp candidate, as well as its CTC/OC finding. This capability makes it easier to study each FP and identify its causes. In this work, we describe features in our colon CAD system that meet researchers' specific requirements. As an example, using our system, we identified the characteristics of several typical FPs in our data. Since our system uses an open source implementation of a 3D Slicer module, the software will be available to the pubic for use and for extension.

7624-74, Poster Session

Prostate cancer region prediction using MALDI mass spectra

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For the early detection of prostate cancer, the analysis of the Prostate-specific antigen (PSA) in serum is currently the most popular approach. However, previous studies show that 15% of men have prostate cancer even their PSA concentrations are low. MALDI Mass Spectrometry (MS) proves to be a better technology to generate molecular tools for cancer detection. The molecular tools or peptides are termed as biomarkers. Using MALDI MS data, prostate biomarkers can be identified by looking for peptides that can differentiate cancer tissue regions from normal ones that are annotated by pathologists. Unfortunately, histopathological examination is currently done on an adjacent slice because the MALDI imaging process will destroy the tissue slice under investigation. For this reason, only the most confident cancer region resulting from the histopathological examination will be used for the biomarker identification. It is obvious that a better cancer boundary delimitation on the MALDI imaging slice would be beneficial. In this paper, we proposed methods to predict the true cancer boundary, using the MALDI MS data, from the most confident cancer region given by pathologists on an adjacent slice.

7624-75, Poster Session

Automated scheme for measuring polyp volume in CT colonography using Hessian matrix-based shape extraction and 3D volume growing

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Current measurement of the single longest dimension of a polyp is subjective and has variations among radiologists. Our purpose was to develop an automated measurement of polyp volume in CT colonography (CTC). We developed a computerized segmentation scheme for measuring polyp volume in CTC, which consisted of extraction of a highly polyp-like seed region based on the Hessian matrix, segmentation of polyps by use of a 3D volume-growing technique, and sub-voxel refinement to reduce a bias of segmentation. Our database consisted of 34 polyp views (17 polyps) in CTC scans from 15 patients. Polyp sizes measured in optical colonoscopy (OC) ranged from 6-18 mm with a mean of 10 mm. To obtain "gold standard," a radiologist outlined polyps in each slice and calculated volumes by summation of areas. The measurement study was repeated three times at least one week apart for minimizing a memory effect bias. We used the mean volume of the three studies as "gold standard." Our measurement scheme yielded a mean polyp volume of 0.36 cc (range: 0.15-1.24 cc), whereas a mean "gold standard" manual

volume was 0.38 cc (range: 0.14-1.08 cc). The mean differences between automated and manual volumes for polyps ranging from 6-9 mm and those 10 mm or larger were 0.07 and 0.14 cc with standard deviations of 0.08 and 0.13 cc, respectively. The two volumetrics reached excellent agreement (intra-class correlation coefficient was 0.79) with no statistically significant difference (P = 0.61). Thus, our automated scheme efficiently provides accurate polyp volumes for radiologists.

7624-76, Poster Session

Computerized evaluation method of white matter hyperintensities related to subcortical vascular dementia in brain MR images

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It has been reported that the severity of subcortical vascular dementia (VaD) correlates with an area ratio of white matter hyperintensity (WMH) regions to the brain parenchyma (WMH area ratio). The purpose of this study was to develop a computer-aided evaluation method of WMH regions for diagnosis of subcortical VaD based on magnetic resonance (MR) images. A brain parenchymal region was segmented based on the histogram analysis of a T1-weigthed image. The WMH regions were segmented on the subtraction image between T1-weighted and fluid-attenuated inversion-recovery (FLAIR) images using two segmentation methods, i.e., a region growing technique and a level set method, which were automatically and adaptively selected on each WMH region based on its image features by using a support vector machine. We applied the proposed method to 33 slices of the three types of MR images with 245 lesions, which were acquired from 10 patients (age range: 64-90 years, mean: 78) with a diagnosis of VaD using a 1.5-T MR imaging scanner. The average similarity index between regions determined by a manual method and the proposed method was 93.5±2.0% for brain parenchymal regions and 78.2±11.0% for WMH regions. The WMH area ratio obtained by the proposed method correlated with that determined by a neuroradiologist with a correlation coefficient of 0.992. The results presented in this study suggest that the proposed method could effectively assist neuroradiologists in the evaluation of WMH regions related to the subcortical VaD.

7624-77, Poster Session

Prediction of brain tumor progression using a machine learning technique

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A machine learning technique is presented for assessing brain tumor progression by exploring two patients' complete MRI records scanned during their visits in the past two years. There are ten MRI series, including DTI, for each visit. After registering all series to the corresponding DTI scan at the first visit, annotated normal and tumor regions were overlaid. Intensity value of each pixel inside the annotated regions were then extracted across all of the ten MRI series to compose a 10-dimensional vector. Each feature vector falls into one of three categories: normal, tumor, and normal but progressed to tumor at a later time. In this preliminary study, we focused on the trend of brain tumor progression during three consecutive visits, i.e., visit A, B, and C. A machine learning algorithm was trained using the data containing information from visit A to visit B, and the trained model was used to predict tumor progression from visit A to visit C. Preliminary results showed that prediction for brain tumor progression is feasible. An average of 78.9% pixel-wise accuracy was achieved for tumor progression prediction at visit C.

7624-78, Poster Session

Parkinson's disease prediction using diffusion-based atlas

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We study a Parkinson's disease (PD) prediction system using a specialized diffusion-based atlas. A total of 150 subjects, among who 75 patients diagnosed clinically with PD and 75 control cases, underwent DTI imaging (TR/TE 4300/90; 12 directions; 4 averages; 4/0 mm sections; 1.2 x 1.2 mm in-plane resolution). According to our knowledge, this represents the biggest cohort of PD patients implicated in such a study. T2 images are mainly used by the neurologists for their anatomical detail. The EPIs have lower resolution but provide essential anisotropy information for the fiber tracking process. The two volumes of interest (VOI) are represented by the Substantia Nigra and the Putamen. We use the VOIs for the iconic based registration. For the fusion, we enhance the anatomical part from T2 image and consider the anisotropy from EPI. After 3D fibers growing, we compute the fiber density (FD), fiber volume (FV) and the fractional anisotropy (FA). Using content-based image retrieval, we compare patients based on the extracted fibers and evaluate them according to Hohen&Yahr (H&Y) scale. Our preliminary results show that the T-Test on H&Y correlated with FD on the left side has $p=0.019$ and on the right side $p=0.015$. Our approach is important from the clinical point of view, providing a new tool for the neurologists to evaluate and predict PD evolution. From the technical point of view the fusion approach takes the tensor based information (EPI) and the anatomical detail (T2) from different types of images.

7624-79, Poster Session

TBIdoc: 3D content-based CT image retrieval system for traumatic brain injury

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Traumatic brain injury (TBI) is a major cause of death and disability. Computed Tomography (CT) scan is widely used in the diagnosis of TBI. Nowadays, large amount of TBI CT data is stacked in the hospital radiology department. Such data and the associated patient information contain valuable information for clinical diagnosis and outcome prediction. However, current hospital database system does not provide an efficient and intuitive tool for the doctors to search out cases relevant to the current study case. In this paper, we present the TBIdoc system: a content-based image retrieval system which works on the TBI CT images. In this web-based system, user can query by uploading CT slices of one study case (in JPEG or DICOM format), retrieval result is a list of TBI cases ranked according to their 3D visual similarity to the query case. Specifically, cases of TBI CT images often present diffuse or focal lesions. In TBIdoc system, these pathological image features are represented as bin-based binary feature vectors. We use the Jaccard-Needham measure as the similarity measurement. Based on these, we propose a 3D similarity measure for computing the similarity score between two series of CT slices. nDCG is used to evaluate the system performance, which shows the system produces satisfactory retrieval results. The system is expected to improve the current hospital data management in TBI and to give better support for the clinical decision-making process. It may also contribute to the computer-aided education in TBI.

7624-80, Poster Session

Shape similarity analysis of regions of interest in medical images

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In this work, we introduce a new representation technique of 2D contour shapes and a sequence similarity measure to characterize 2D regions of interest in medical images. First, we define a distance function on contour points in order to map the shape of a given contour to a sequence of real numbers. Thus, the computation of shape similarity is reduced to the matching of the obtained sequences. Since both a query and a target sequence may be noisy, i.e., contain some outlier elements, it is desirable to exclude the outliers in order to obtain a robust matching performance. For the computation of shape similarity, we propose the use of an algorithm which performs elastic matching of two sequences. The contribution of our approach is that, unlike previous works that require images to be warped according to a template image for measuring their similarity, it obviates this need, therefore it can estimate image similarity for any type of medical image in a fast and efficient manner. To demonstrate our method's applicability, we analyzed a brain image dataset consisting of corpus callosum shapes, and we investigated the structural differences between children with chromosome 22q11.2 deletion syndrome and controls. Our findings indicate that our method is quite effective and it can be easily applied on medical diagnosis in all cases of which shape difference is an important clue.

7624-81, Poster Session

Population analysis of the cingulum bundle, for schizophrenia detection using the tubular surface model

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We propose a novel framework for population analysis of Direction-Weighted MRI (DW-MRI) data using the Tubular Surface Model. The framework has the twin objectives of schizophrenia detection as well as aiding clinicians in identifying local regions of white matter connections most affected by schizophrenia. We focus on studying the Cingulum Bundle (CB) - a major tract for the limbic System and the main connection of the Cingulate Gyrus, which has been associated with several aspects of schizophrenia symptomatology. The Tubular Surface Model represents a tubular surface as a center-line with an associated radius function at every point of the center-line. It provides a natural way to sample statistics along the length of the fiber bundle and further reduces the registration of fiber bundle surfaces to that of curves in 4D. We apply our framework to a population of 20 subjects (10 normal, 10 schizophrenic) and extract features that combine diffusion information (Fractional Anisotropy and Mean Diffusion) with shape information (curvature, cross-sectional area and center-shifted coordinates). We obtain excellent classification (90% sensitivity, 95% specificity) using neural networks, and the performance of the k-means clustering validates these results. We apply further statistical analysis to the feature data and also characterize the discrimination ability of local regions of the CB, as a step towards localizing CB regions most relevant to schizophrenia in a clinically useful manner.

7624-82, Poster Session

Robustness of interactive intensity thresholding based breast density assessment in MR-mammography

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The efficiency of breast density assessment using interactive intensity thresholding applied to intensity uniformity corrected T1-weighted MR images is investigated for 20 healthy women who attended the UK multi-centre study of MRI screening for breast cancer. Mammographic density is estimated on the medial-lateral oblique X-ray mammograms using CUMULUS. MR density assessment is performed using both high and low-resolution T1-weighted images. The left and the right breast regions anterior to the pectoral muscle were segmented on these images using active contouring. For each region, intensity uniformities were corrected using proton density images and a user selected uniformity factor. An interactively selected threshold is applied to the corrected images to detect fibrogulandular tissue. The breast density is calculated as the ratio of the classified fibroglandular tissue to the segmented breast volume.

There is no systematic difference, good consistency and a high correlation between the left and the right breast densities estimated from X-ray mammograms and the high and low-resolution MR images. The correlation is the highest and the consistency is the best for the low-resolution MR measurements (r=0.976, MeanAbsoluteDifference=2.12%). Mean breast densities calculated over the left and the right breasts on high and low-resolution MR images are highly correlated with mammographic density (r=0.923 and 0.903, respectively) but is approximately 50% lower.

Interactive intensity thresholding of T1-weighted MR images provides an easy, reproducible and reliable way to assess breast density. High and low-resolution measurements are both highly correlated with the mammographic density but the latter requires less processing and acquisition time.

7624-83, Poster Session

Repeatability and classifier bias in computer-aided diagnosis for breast ultrasound

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The purpose was to investigate the repeatability and bias of the output of two classifiers commonly used in computer-aided diagnosis for the task of distinguishing benign from malignant lesions. Classifier training and testing were performed within a bootstrap approach using a dataset of 125 sonographic breast lesions (54 malignant, 71 benign). The classifiers investigated were linear discriminant analysis (LDA) and a Bayesian Neural Net (BNN) with 5 hidden units. Both used the same 4 input lesion features. The bootstrap .632plus area under the ROC curve (AUC) was used as a summary performance metric. On an individual case basis, the variability of the classifier output was used in a detailed performance evaluation of repeatability and bias. The LDA obtained an AUC value of 0.87 with 95% confidence interval [0.81; 0.92]. For the BNN, those values were 0.86 and [.76; .93], respectively. The classifier outputs for individual cases displayed better repeatability (less variability) for the LDA than for the BNN and for the LDA the maximum repeatability (lowest variability) lied in the middle of the range of possible outputs, while the BNN was least repeatable (highest variability) in this region. There was a small but significant systematic bias in the LDA output, however, while for the BNN the bias appeared to be weak. In summary, while ROC analysis suggested similar classifier performance, there were substantial differences in classifier behavior on a by-case basis. Knowledge of this behavior is crucial for successful translation and implementation of computer-aided diagnosis in clinical decision making.

7624-84, Poster Session

Effect of variable gain on computerized texture analysis on digitalized mammograms

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Computerized texture analysis of mammographic images has emerged as a means to characterize breast parenchyma and estimate breast percentage density, thus, to assess the risk of developing breast cancer. However, during the digitization process, mammographic images may be modified and optimized for viewing purposes, or mammograms may be digitized with different scanners. It is not clear how computerized texture analysis will be affected by differences in the digital image acquisition. In this study, mammograms from 172 subjects, 30 women with the BRCA1/2 gene-mutation and 142 low-risk women, were retrospectively collected and digitized. Contrast enhancement based on a look-up table which simulates the histogram of a mixed breast was applied on very dense and very fatty breasts. Computerized texture analysis was performed on these transformed images, and the effect of variable gain on computerized texture analysis on mammograms was investigated. Area under the receiver operating characteristic curve (AUC) was used as a figure of merit to assess the individual texture feature performance in the task of distinguishing between the high-risk and the low-risk women for developing breast cancer. For those features based on coarseness measures and fractal measures, the histogram transformation (contrast enhancement) showed little effect on the classification performance of these features. However, for those features based on gray-scale histogram analysis, such as balance and skewnesss, and contrast measures, large variations were observed in terms of AUC values for those features. Understanding this effect will allow us to better assess breast cancer risk using computerized texture analysis.

7624-85, Poster Session

Breast MRI intensity non-uniformity correction using mean shift

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Current Computer Aided Diagnosis (CAD) systems for breast Magnetic Resonance (MR) Imaging are intended to help radiologists to visualize and analyze contrast enhancement patterns. For further development of these systems we are investigating methods for fully automated processing of breast MRI studies and automated detection of lesions. In this paper we focus on intensity non-uniformity (bias field) correction as a preprocessing step for segmentation. Most of the existing methods for intensity non-uniformity estimation were developed for brain MR. As we found that these methods did not perform well on breast MRI data, or were computationally too demanding for our application, we have developed a new method for breast MR non-uniformity estimation. The method employs clustering using the fast mean shift algorithm. Since the mean shift is non-parametric it allows to delineate arbitrary shaped clusters and obtain robust and reliable clustering. By taking a logarithmic transform of the image data we represent the unbiased (true) image and the bias field in additive form. On each iteration a residual image is calculated by subtraction of the clustered image from the input image. This residual image is low-pass filtered because the bias field has low-frequency nature. For validation of the method T1 breast MR volumes of 10 patients were manually segmented into six tissue classes. By computing intensity homogeneity of fatty tissue and the pectoral muscle before and after correction we compared the performance of our method with several well-known existing correction methods: PABIC, N3, FMRIB FAST, FCM estimation. For quantitative comparisons we used the scale invariant information measure, the coefficient of variation, and the coefficient of joint variations. The developed method proved to give comparable or better results and is faster.

7624-86, Poster Session

Assessment of performance and reliability of interactive CAD schemes

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An ICAD scheme allows observers to query suspicious abnormalities depicted on medical images. Once a suspicious region is queried, CAD segments the abnormal region, computes a set of image features, searches for and identifies the reference regions depicted on the verified lesions that are similar to the queried one. Based on the distribution of the selected similar regions, CAD generates a detection score of the queried region depicting true-positive disease. In this study, we assessed the performance and reliability of an ICAD scheme when using a database including total 1500 positive images depicted verified breast masses and 1500 negative images as well as the leave-one-out testing method. We conducted two experiments. In the first experiment, we tested the relationship between CAD performance and the size of reference database by systematically increasing the size of reference database from 200 to 3000 images. In the second experiment, we tested the relationship between CAD performance and the similarity level between the queried image and the retrieved similar references by applying a set of thresholds to systematically remove the queried images whose similarity level to their most "similar" reference images are lower than threshold. The performance was compared based on the areas under ROC curves (AUC). The results showed that (1) as the increase of reference database, AUC monotonically increased from 0.636 ± 0.041 to 0.854 ± 0.004 and (2) as the increase of similarity threshold values, AUC also monotonically increased from 0.854 ± 0.004 to 0.932 ± 0.016. The increase of AUC and the decrease of their standard deviations indicate the improvement of both CAD performance and reliability. The study suggested that (1) assembling a large database and (2) assessing the similarity scores are important in developing ICAD schemes.

7624-87, Poster Session

Automatic estimation of breast density using a combined information of histogram statistics and boundary gradients

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This paper presents a new method for automatic breast density estimation based on statistics and boundary information of a breast region in a mammogram. Breast density has found to be a strong indicator for breast cancer risk, but measures of breast density still rely merely on a qualitative judgment of the radiologist. Therefore, objective and quantitative measurement is necessary to derive the relation between breast density and cancer risk. In this paper, we first detect the breast region by the unique histogram shape of the mammogram, perform contrast stretching to maximize the difference between fat and dense region, and apply median filtering so as to eliminate the noise. Then, two features are extracted: statistical and boundary information. Statistical information is the standard deviation of fat and dense region in breast area. Boundary information is the gradient magnitude of a set of pixels with the same intensity. These features are calculated for all existing pixel level. By combining these two features, the optimal threshold is determined which best divides the fat and dense region. For evaluation purpose, the dataset composed of 80 cases of Full-Field Digital Mammography (FFDM) is utilized taken in Seoul National University Hospital by using GE Senograph. Two human observers conducted the performance evaluation. The correlation coefficients of the optimal threshold and estimated breast density between human observer and estimation were 0.9580 and 0.9869 on average, respectively. The experimental result suggests that the combination of statistic and boundary information is a novel method for automatic breast density estimation.

7624-88, Poster Session

Similarity based false-positive reduction for breast cancer using radiographic and pathologic imaging features

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Mammography reading by radiologists and breast tissue image interpretation by pathologists often leads to high False Positive (FP) Rates. Similarly, current Computer Aided Diagnosis (CAD) methods tend to concentrate more on sensitivity, thus increasing the FP rates. A novel method is introduced here which employs similarity based method to decrease the FP rate in the diagnosis of microcalcifications. This method employs the Principal Component Analysis (PCA) and the similarity metrics in order to achieve the proposed goal. The training and testing set is divided into generalized (Normal and Abnormal) and more specific (Abnormal, Normal, Benign) classes. The performance of this method as a standalone classification system is evaluated in both the cases (general and specific). In another approach the probability of each case belonging to a particular class is calculated. If the probabilities are too close to classify, the augmented CAD system can be instructed to have a detailed analysis of such cases. In case of normal cases with high probability, no further processing is necessary, thus reducing the computation time. Therefore, this novel method can be employed in cascade with CAD to reduce the FP rate and also avoid unnecessary computational time. Using this methodology, a false positive rate of 8% and 11% is achieved for mammography and cellular images respectively.

7624-89, Poster Session

Classification of mammographic masses: influence of regions used for feature extraction on the classification performance

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Computer-assisted diagnosis (CADx) for the characterization of mammographic masses as benign or malignant has the potential to help radiologists during the critical decision process. By default the characterization is performed by extracting features from a region of interest (ROI) depicting the mass. To investigate the influence of the region on the classification performance, textural, morphological, frequency- and moment-based features are calculated in subregions of the ROI. The subregions are a semi-automatically segmented region which includes only the core of the mass, the outer border region of the mass and the combination of outer and inner border region, referred to as mass margin. To extract the border region and the margin of a mass an extended version of the rubber band straightening transform (RBST) was developed. Furthermore the effectiveness of the features extracted from the RBST transformed border region and mass margin is compared to the effectiveness of the same features extracted from the untransformed regions. An optimal feature subset is selected for each feature extractor. The classification performance was evaluated on a DDSM data set using ROC analysis. Results showed that the manually drawn ROI lead to superior classification performances for the morphological feature extractors and that the transformed outer border region and the mass margin are not suitable for moment-based features but yield to promising results for textural and frequency-based features. Beyond that the mass margin, which combines the inner and the outer border region, lead to better classification performances compared to the outer border region for its own.

7624-90, Poster Session

An improved method for segmentation of mammographic masses

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Computer aided diagnosis (CADx) systems can support the radiologist in the complex task of discriminating benign and malignant mammographic lesions. Automatic segmentation of mammographic lesions in regions of interest (ROIs) is a core module of many CADx systems. Previously, we have proposed a novel method for segmentation of mammographic masses. The approach was based on the observation that the optical density of a mass is usually high near its core and decreases towards its boundary. In the work at hand, we improve this approach by integration of a pre-processing module for the correction of inhomogeneous background tissue and by improved selection of the optimal mass contour from a list of candidates based on a cost function. We evaluate the performance of the proposed approach using ten-fold cross-validation on a database of mass lesions and ground-truth segmentations. Furthermore, we compare the improved segmentation approach with the previously proposed approach and with implementations of two state of the art approaches. The results of our study indicate that the proposed approach outperforms both the original method and the two state of the art methods.

7624-91, Poster Session

Computer aided diagnosis of digital mammography images using unsupervised clustering and biclustering techniques

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A new methodology for computer aided diagnosis in digital mammography using unsupervised classification and class-dependent feature selection is presented. In spite of the success of the supervised classification methods in improving the overall diagnosis, the labeling of training image samples limits the classification to classes that are deemed independent ignoring the relationships between different pathology types and the progression of each. As a result, images that represent stage of transition between different types are often misclassified. Therefore, a technique that would look at the unlabeled data and provide unsupervised classes would provide an insight into that thus improving the overall effectiveness of the diagnosis. Moreover, using unsupervised classification methods can be extended to utilize biclustering methods which allow for definition of unsupervised clusters of both pathologies and features. That is, for each pathology type, a particular set of features that can diagnose this particular type are defined. This has potential to provide more flexibility, and hence better diagnostic accuracy, than the commonly used feature selection strategies. The proposed system consists of four stages: preprocessing, feature extraction, feature matrix visualization, and unsupervised clustering/biclustering. The developed methods are applied to diagnose digital mammographic images from the Mammographic Image Analysis Society (MIAS) database. This system leads to better classification results for the data based on the K-means method. The system has potential in providing more insight into data and show the value for exploratory data analysis methods.

7624-92, Poster Session

Multi-agent method for masses classification in mammogram

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In this paper we considered the problem of masses classification based on Multi-agent method in mammogram. Multi-agent method was a kind of method that fused the information coming from different single classifiers in order to obtain a better decision result. Every Agent received the measurement value of single classifiers to a sample and sent a message to the center. Then the center responded to this message and began to analyze the correlation information between these single classifiers and their decisions information. If the message conformed to its determination standard, the center then provided a final result, or the message of agent had to be modified continuously. 128 ROIs, including 64 benign masses and 64 malignant masses, coming from the DDSM, were taken in this experiment. The DDSM database, developed at the University of South Florida, is a resource for use by the mammographic image analysis research community. Compared with the Majority voting fusion method, we evaluated the performance in the task of distinguishing between malignant and benign masses of the multi-agent fusion approach. The experimental results demonstrated that the multi-agent method outperformed the Majority voting method. Multi-agent fusion method yielded an accuracy of 95.47%, while the Majority voting method only had an accuracy of 92.23%. It also showed that the Mulit-agent method has good TP (True positive) rate and TN (True negative) rate. The experiment showed us that the application of the Multi-agent method could provide a significantly higher classification performance.

7624-93, Poster Session

Interactive mammogram retrieval system based on eye-tracking and fuzzy perceptual relevance feedback

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Breast cancer is the most common malignant disease in women. Mammogram retrieval system can help radiologists to improve the diagnostic accuracy(especially for masses) by retrieving biopsy-proven cases which are similar with the diagnostic ones. In this paper, an interactive mammogram retrieval system based on eye-tracking and fuzzy perceptual relevance feedback is proposed. Firstly, 14 image features of the manually labeled or automatically segmented mass lesion were computed and compared to those previously computed for the biopsy-proven mass lesions in the database and returns the closest K1 samples. Secondly, radiologist wear a eye-tracker to read K1 samples. During his reading, eye-gazing data including fixation positions, dwelling times and pupil diameters will be recorded and clustered to find out K2 mass lesions which can most attract radiologist's attention. Finally, a fuzzy-radial basis function network(FRBFN) is used to model the radiologists' fuzzy interpretation of mass lesion similarity during relevance judgment process in interactive mammogram retrieval. During each feedback iteration, the K2 and (K1 - K2) mass lesions are the relevant and irrelevant samples, respectively. After K1 samples were selected from the database, there are NL samples left in the database. After computing the mutual information between the K2 and NL lesions, m samples with the highest mutual information scores from the NL lesions were chosen as the fuzzy samples. All relevant, irrelevant and fuzzy samples were used for FRBFN training. The trained FRBFN classifier is then used in the next sessions for mass lesions retrieval.

7624-94, Poster Session

Computer-aided breast calcification auto detection in cone beam breast CT

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In cone beam breast CT (CBBCT), breast calcifications have higher intensities than the surrounding tissues. Without compression and the superposition of breast structures, calcifications are not camouflaged by the glandular tissues. Hence, more calcifications can be detected. In our research, based on the fact that calcifications have higher contrast, we used local thresholding to select candidate calcification areas. Six intensity features were extracted from each candidate calcification: Average foreground CT number value, foreground CT number standard deviation, average background CT number value,

background CT number standard deviation, foreground-background contrast, and average edge gradient. To reduce the false positive candidate calcifications, a feed-forward artificial intelligence network was designed and trained with the radiologists confirmed calcifications. In our preliminary experiments, 90% of the calcifications in our testing data set were detected correctly with an average of 10 false positives per breast.

7624-95, Poster Session

Evaluation of a 3D lesion segmentation algorithm on breast tomosynthesis and breast CT images

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Purpose: Both breast tomosynthesis and breast CT are promising 3D modalities for breast imaging. Since each modality produces a fundamentally different representation of the breast volume, our goal was to investigate whether a 3D segmentation algorithm for breast masses could be applied to both breast tomosynthesis and breast CT images.

Methods: The seeded mass lesion segmentation algorithm is based on maximizing the radial gradient index (RGI) along a constrained region boundary. In tomosynthesis, the constraint function is a prolate spherical Gaussian, with a larger FWHM along the depth direction where the resolution is low, while it was a spherical Gaussian for breast CT.

For tomosynthesis, manual lesion outlines were obtained in the in-focus plane of the lesion, which was used to compute the overlap ratio with the computer segmentation. For breast CT, lesions were manually outlined in three orthogonal planes, and the average overlap ratio from the three planes was computed.

Results: In tomosynthesis, 81% of all lesions were segmented at an overlap ratio of 0.4 or higher, based on the in-focus slice of the lesion. In breast CT, 93% of all segmentations achieved an average overlap ratio of 0.4, based on the manual outlines in three orthogonal planes.

Conclusion: Our results indicate mass lesions in both breast CT and tomosynthesis images can be segmented with the proposed 3D segmentation algorithm, by selecting an appropriate set of parameters and after images have undergone specific pre-processing.

7624-96, Poster Session

Detection of breast masses and false positive reduction by bilateral analysis on whole breast ultrasound images

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Whole breast ultrasonography can be a useful screening tool in addition to mammography especially for women with dense breast. One of the advantages is that it facilitates side by side comparison of right and left breasts. We have been developing a computerized scheme for detection of breast masses on whole breast ultrasound images. In this study, bilateral analysis is incorporated to the scheme for the mass detection and false positive reduction. Images of breast volumes were obtained by a whole breast scanner, in which an ultrasound probe scans one breast in three separate axial paths. Fifty cases, including 24 cases with 31 masses and 26 cases without masses, were used in this study. For the registration of the right and left breasts, nipple positions and skin lines were detected, and the left breast volume was shifted

to match the right breast volume. The initial candidates of the masses were detected based on the edge information. Image features were extracted from the candidate regions and the corresponding regions in the contralateral breasts. The false positive candidates were removed by using the rule based method and discriminant analysis. In our preliminary study with the small number of cases, the number of false positives was reduced by 67% without reducing the sensitivity. The comparison of the right and left breasts can be effective for not only the radiologists but also for the computerized analysis in the detection of breast masses.

7624-97, Poster Session

Segmentation and analysis of pulmonary artery tree from CTA data

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This paper presents an efficient algorithm for segmenting pulmonary artery tree in 3D images from pulmonary Computed Tomography Angiography (CTA) scans. This algorithm uses two passes of 3D region growing. At first, the algorithm performs an up-to-down region growing to extract the superior vena cava and right atrium and right ventricle which are connected to pulmonary artery and with the similar intensity values. Second, A method based on region growing and slice marching is proposed to segment the pulmonary artery, section by section, and slice by slice; at the same time, label of vessel tree, center-line and other features can be extracted for other purposes.

To avoid the leakage and other false positive such as pulmonary vein, a feature map based on eigenvaules of hessian matrix which make the edge between different organs more obvious is applied to stop the propagation from blowing up the boundary of desired pulmonary artery close to other organs in the whole process. Moreover, vessel shape is rather long and cross section changes gently in each vessel segment, false positive vessel segments are removed in the growing process using these shape restricts leading to more effective propagation and accurate segmentation.

The proposed method was experimented on 10 clinical patient datasets from CTA scans. With regard to acceptability, a qualified radiologist conducted a visual judgment on the segmentation results in search of any gross miss segmentation.

7624-98, Poster Session

Automatic detection of plaques with severe stenosis in coronary vessels of CT angiography

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Coronary artery disease is the end result of the accumulation of atheromatous plaques within the walls of coronary arteries and is the leading cause of death worldwide. Computed tomography angiography (CTA) has been proved to be very useful for accurate noninvasive diagnosis and quantification of plaques. However, the existing methods to measure the stenosis in the plaques are not accurate enough in mid and distal segments where the vessels become narrower. To alleviate this, in this paper, we propose a method consists of three stages namely, automatic extraction of coronary vessels; vessels straightening; lumen extraction and stenosis evaluation.

In the first stage, the coronary vessels are segmented using a parametric approach based on circular vessel model at each point on the centerline. It is assumed that centerline information is available in advance. Vessel straightening in the second stage performs multi-planar reformat (MPR) to straighten the curved vessels. MPR view of a vessel helps to visualize and measure the plaques better. Next, on the straightened vessel, lumen and vessel wall are segregated using a nearest neighbor classification. Finally, to detect the plaques with severe stenosis in the vessel lumen, we propose a "Diameter Luminal

Stenosis" method analyzing the smaller segments of the vessel. Proposed measurement technique identifies the segments with plaques and reports the top three severely stenosed segments. Proposed algorithm is applied on 24 coronary vessels belonging to multiple cases acquired from Sensation 64 - slice CT and initial results are promising.

7624-99, Poster Session

Automatic lumen segmentation from intravascular OCT images

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In the last decade intravascular Optical Coherence Tomography (OCT) has known a tremendous progress. Its high resolution (5-10μm) allows coronary plaque characterization, vulnerable plaque assessment, and the guidance of intravascular interventions. However, one intravascular OCT sequence contains hundreds of frames, and their interpretation requires a lot of time and energy. Therefore, there is a strong need for automatic segmentation method to process this large amount of data. In this article, we present an A-scan based segmentation algorithm to extract automatically lumen contour from images obtained with intravascular OCT. Unlike existing methods, our algorithm requires no post- or pre-processing of the image. First, a sliding window is convolved with every A-scan to locate the artery tissue, this location being determined from the largest distribution of the grey level values. Once all the tissue is extracted from the image, every segmented A-scan is binarized independently from the others. For a single A-scan, the level of intensity often varies strongly across the tissue. A global threshold would cause low intensity parts of the tissue to be considered as belonging to the background. Our solution is to determine an adaptive local threshold for every A-scan. That is, instead of having a single global threshold, we allow the threshold itself to smoothly vary across the image. Subsequently, on the binarized image the Prewitt mask is moved from the detected tissue position toward the probe to segment the lumen. The proposed method has been validated qualitatively on images acquired under different conditions without changing the value of any parameter of the algorithm. Experimental results show that the proposed method is adequate and robust to extract lumen borders.

7624-100, Poster Session

Automated myocardial perfusion from coronary x-ray angiography

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Our purpose is the automated evaluation of the clinical relevance of lesions in coronary angiograms. We aim to extract as much as possible quantitative information about the physiological condition of the heart from standard angiographic image sequences. Coronary angiography is still a gold standard for diagnosis in cardiology as it is able to precisely locate the coronary artery lesions. The dimensions of single distinct stenosis can be assessed nowadays successfully with image processing based Quantitative Coronary Angiography (QCA) techniques. Our aim is to assess the clinical relevance of less conspicuous lesions such as in case of multiple angiopathy. We therefore analyze the myocardial perfusion as revealed in standard angiographic image sequences. We present the results of a small study of a group of 25 patients which have been catheterized following the standard protocol with one additional image run after the administering of a vasodilating drug (e.g. papaverine) mimicking exercise. The images are 8 bit (512 x 512 pixels) at 15 images / s. The frame lengths are somewhat longer than usual in order to include the registration of the perfusion. We trace and track the vascular tree in an automated way and detect the local myocardial response and compare the normal image sequence with the vasodilated images. The thus obtained flow reserve is evaluated and where relevant, the quantitative influence of the angiopathy is quantified. Special care is taken to compensate for

artifacts due to the Automatic Exposure Control (AEC) and the timing of the injection in the cardiac cycle.

7624-101, Poster Session

An adaptive 3D region growing algorithm to automatically segment and identify thoracic aorta and its centerline using computed tomography angiography scans

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Thoracic Aortic Aneurysm (TAA) is a localized swelling of the thoracic aorta. The progressive growth of an aneurysm may eventually cause a rupture if not diagnosed or treated. This necessitates the need for an accurate measurement which in turn calls for the accurate segmentation of the aneurysm regions. Computer Aided Detection (CAD) is a tool to automatically detect and segment the TAA in the Computer tomography angiography (CTA) images. The fundamental major step of developing such a system is to develop a robust method for the detection of main vessel and measuring its diameters. In this paper we propose a novel adaptive method to simultaneously segment the thoracic aorta and to indentify its center line. For this purpose, an adaptive parametric 3D region growing is proposed in which its seed will be automatically selected through the detection of the iliac artery and the parameters of the method will be re-estimated while the region is growing thorough the aorta. At each phase of region growing the initial center line of aorta will also be identified and modified through the process. Thus the proposed method simultaneously detect aorta and identify its centerline. The method has been applied on CT images from 20 patients with good agreement with the visual assessment by two radiologists.

7624-102, Poster Session

Filter learning and evaluation of the computer aided visualization and analysis (CAVA) paradigm for pulmonary nodules using the LIDC-IDRI database

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Computer Aided Detection has sometimes been received with a certain guardedness in radiological practice because explicit graphical markers such as arrows or circles may be felt to clutter the original image and distract the reader. In an alternative concept for 3D imagery such as CT or MR, a volume-rendering-like overview is offered in addition to the original image, without explicit graphical markers. Rather, the volume rendering enhances anomalous structures and color-codes them according to their conspicuity. Instead of providing a list of objects as in classical CAD approaches, the volume rendering can be used as a navigator such that a mouse-click on any point in the anomaly-enhancing rendering will mark the associated position in the original image volume for further inspection. In this approach (CAVA) no internal object lists or object segmentations are used, but all voxels are treated on equal footing.

We propose a rotatable maximum intensity projection of various multiscale differential geometry features (eigenvalues of structure and Hesse matrix, shape index, etc.) which enhance pulmonary nodules in thoracic CT datasets (Fig.1). In the projection, nodular and tubular structures (tumors and vessels) can be intuitively differentiated by their color so that nodules and lymph nodes stand out from other

anatomical structures.

As a surrogate for a clinical observer study, we have used the multi-observer IDRI lung nodule database (800 CT lung scans). Using the 3000 reader-drawn outlines of pulmonary nodules as well as their expert-rated dignity, ground-truth overview renderings have been produced from the multi-observer annotations. These ideal renderings have been then been correlated with the nodule-enhancing renderings produced from multiscale differential geometry features in order to evaluate the agreement, showing promising results and improvement by filter learning.

7624-103, Poster Session

Modeling uncertainty in classification design of computer aided detection

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A computerized image analysis technology suffers from imperfection, imprecision and vagueness of the input data and its propagation in all individual components of the technology including image enhancement, segmentation and pattern recognition. Furthermore, a Computerized Medical Image Analysis System (CMIAS) such as computer aided detection (CAD) technology deals with another source of uncertainty that is inherent in image-based practice of medicine. While there are several technology-oriented studies reported in developing CAD applications, no attempt has been made to address, model and integrate these types of uncertainty in the design of the system components, even though uncertainty issues directly affect the performance and its accuracy.

In this paper, the main uncertainty paradigms associated with CAD technologies are addressed. The influence of the vagueness and imprecision in the classification of the CAD, as a second reader, on the validity of ROC analysis results is defined. In order to tackle the problem of uncertainty in the classification design of the CAD, two fuzzy methods are applied and evaluated for a lung nodule CAD application. Type-1 fuzzy logic system (T1FLS) and an extension of it, interval type-2 fuzzy logic system (IT2FLS) are employed as methods with high potential for managing uncertainty issues. The novelty of the proposed classification methods is to address and handle all sources of uncertainty associated with a CAD system. The results reveal that IT2FLS is superior to T1FLS for tackling all sources of uncertainty and significantly, the problem of inter and intra operator observer variability.

7624-104, Poster Session

Usefulness of texture features for segmentation of lungs with severe diffuse interstitial lung disease

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Accurate segmentation of lungs in CT images is an important but challenging step for development of computer-aided diagnostic systems of diffuse interstitial lung disease (DILD). We developed in this study an automated method for the segmentation of lungs with severe DILD in multi-detector CT. Our database includes 31 normal cases and 45 abnormal cases with severe DILD. The outlines of lungs were manually delineated by a medical physicist and confirmed by an experienced chest radiologist. The outlines were used as reference standard for the evaluation of the segmentation results. We first employed a thresholding technique for CT value to obtain initial lungs, which contain normal and mildly abnormal lung parenchyma. We then used texture-feature images derived from co-occurrence matrix to further segment lung regions with severe DILD. The segmented lung regions with severe DILD were combined with the initial lungs to generate the final segmentation results. We used three metrics, i.e., overlap, volume agreement, and mean absolute distance (MAD) between automatically segmented lung and reference lung to evaluate

the performance of our segmentation method. Our segmentation method achieved a mean overlap of 97.7%, a mean volume agreement of 99.0%, and a mean MAD of 0.66 mm for the 31 normal cases; and a mean overlap of 96.1%, a mean volume agreement of 98.1%, and a mean MAD of 0.96 mm for the 45 abnormal cases. Our method achieved very good segmentation results for lungs with severe DILD and would be useful for the detection of DILD in CT.

7624-105, Poster Session

Realistic simulated lung nodule dataset for testing CAD detection and sizing

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The development of computer-aided diagnosis (CAD) methods for the processing of CT lung scans continues to become increasingly popular due to the potential of these algorithms to reduce image reading time, errors caused by user fatigue, and user subjectivity when screening for the presence of malignant lesions. This study seeks to address the critical need for a realistic simulated lung nodule CT image dataset based on real tumor morphologies that can be used for the quantitative evaluation and comparison of these CAD algorithms. The manual contouring of 17 different lung metastases was performed and reconstruction of the full 3D surface of each tumor was achieved through the utilization of an analytical equation comprised of a spherical harmonics series. 2D nodule slice representations were then computed based on these analytical equations to produce realistic simulated nodules that can be inserted into CT datasets with well-circumscribed, vascularized, or juxtapleural borders and also be scaled to represent nodule growth. The 3D shape and intensity profile of each simulated nodule created from the spherical harmonics reconstruction was compared to the real patient CT lung metastasis from which its contour points were derived through the calculation of a correlation coefficient, producing an average value of 0.8897 (±0.0609). This database of realistic simulated nodules can fulfill the need for a reproducible and reliable gold standard for CAD algorithms with regards to nodule detection and nodule sizing, especially given its virtually unlimited capacity for expansion to other nodule shape variants, organ systems, and imaging modalities.

7624-106, Poster Session

Predicting LIDC diagnostic characteristics by combining spatial and diagnostic opinions

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Computer-aided diagnostic characterization (CADc) aims to support medical imaging decision making by objectively rating the radiologists' subjective, perceptual opinions of visual diagnostic characteristics of suspicious lesions. This research uses the Lung Image Database Consortium (LIDC) collection of radiologists' outlines of nodules and ratings of boundary and shape characteristics: spiculation, margin, lobulation, and sphericity. The approach attempts to reduce the observed disagreement between radiologists on the extent of nodules by combining their spatial opinion using probability maps to create regions of interest (ROIs). From these ROIs, images features are extracted and combined using machine learning models to predict a combined opinion, the median rating and an associated binary version, of their diagnostic characteristics. Preliminary results are mixed on an early version of the LIDC database and work is underway on applying this to the larger publicly available version.

7624-107, Poster Session

Improving CAD performance in pulmonary embolism detection: preliminary investigation

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In this preliminary study, a new computer-aided detection (CAD) scheme for pulmonary embolism (PE) detection was developed. The scheme applies multiple steps including lung segmentation, candidate extraction using intensity mask and tobogganing method, feature extraction, false positive reduction using an artificial neural network, and a multi-feature based k-nearest neighbor (KNN) classifier, to detect and classify suspicious PE lesions. In particular, a new method to define the surrounding background regions of interest (ROI) depicting PE candidates was proposed and tested in an attempt to reduce the detection of false positive regions. In this study, the authors also investigated following methods to improve CAD performance, which include a grouping and scoring method, feature selection using genetic algorithm, and limitation on allowed suspicious lesions to be cued in one examination. To test the scheme performance, 20 chest CT examinations with various lung diseases were selected. Among them, 18 are positive cases depicted 44 verified PE lesions and the remaining 2 were negative cases. 9 examinations and 11 examinations were used as training data and testing data, respectively. The experimental results showed when applying to the testing dataset CAD scheme using tobogganing method alone achieved 2D region-based sensitivity of 72.1% (220/305) and 3D lesion-based sensitivity of 83.3% (20/24) with total 19653 2D false-positive PE regions (1786.6 per case or approximately 6.3 per CT slice). Applying the proposed new method to improve lung region segmentation and better define the surrounding background ROI, the scheme reduced the region-based sensitivity by 6.5% from 72.1% to 65.6% or lesion-based sensitivity by 4.1% from 83.3% to 79.2% while reducing the false positive rate by 65.6% from 19653 regions to 6752 regions. After applying the methods of grouping, the maximum scoring, a genetic algorithm (GA) to delete "redundant" features, and limiting the maximum number of cued-lesions in one examination, CAD scheme ultimately achieved 63.2% detection sensitivity with 18.4 false-positive per examination when applying to the testing dataset. This study investigated the feasibility of several methods applying to the CAD scheme in detecting PE lesions and demonstrated that CAD performance could depend on many factors including better defining candidate ROI and its background, optimizing the 2D region grouping and scoring methods, selecting the optimal feature set, and limiting the number of allowed cueing lesions per examination.

7624-108, Poster Session

Selective reduction of CAD false-positive findings

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Computer-Aided Detection (CAD) systems are becoming widespread supporting tools to radiologists' diagnosis, especially in screening contexts.

However, a large amount of false positive (FP) alarms would inevitably lead both to an undesired possible increase in time for diagnosis, and to a reduction in radiologists' confidence in CAD as a useful tool.

Most CAD systems implement as final step of the analysis a classifier which assigns a score to each entry of a list of findings; by thresholding this score it is possible to define the system performance on an annotated validation dataset in terms of a FROC curve (sensitivity vs. FP per scan).

The strategy proposed in this study is to choose an operative point with high sensitivity on the CAD FROC curve, then to implement in cascade a further classification step,

constituted by a smarter classifier.

The key issue of this approach is that the smarter classifier is actually a meta-classifier of more then one decision system, each specialized in rejecting a particular type of FP findings generated by the CAD.

We applied this approach to the VBNA lung CAD and it leads, on a dataset of 16 lung CT, to an improvement in juxtapleural nodules classification from18.5 FP/scan to 10.1 FP/scan at the same value of sensitivity (87.1%).

7624-109, Poster Session

A model for the relationship between semantic and content based similarity using LIDC

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There is considerable research in the field of content-based image retrieval (CBIR); however, few of the current systems incorporate radiologists' visual impression of image similarity. Our objective is to bridge the semantic gap between radiologists' ratings and image features. We have been developing a conceptual-based similarity model derived from content-based similarity to improve CBIR. Previous work in our lab reduced the Lung Image Database Consortium (LIDC) data set into a selection of 149 images of unique nodules, each containing nine semantic ratings by four radiologists and 64 computed image features. After evaluating the similarity measures for both content-based and semantic-based features, we selected 116 nodule pairs with a high correlation between both similarities. These pairs were used to generate a linear regression model that predicts semantic similarity with content similarity input with an R^2 value of 0.871. The characteristics and features of nodules that were used for the model were also investigated.

7624-110, Poster Session

Variation compensation and analysis on diaphragm curvature analysis for emphysema quantification on whole lung CT scans

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CT scans allow for the quantitative evaluation of the anatomical basis of emphysema. Previous work has established that density based metrics have several limitations, and thus should not be viewed as the sole methodology of choice for evaluating emphysema severity from CT. Recently, a non-density based geometric measurement of lung diaphragm curvature has been proposed as a novel method for the quantification of emphysema from CT. As with any measure to be used for the evaluation of progression, the underlying variability of this measure must be understood This work analyzes variability of diaphragm curvature and evaluates the effectiveness of a compensation methodology for the reduction of this variability as compared to the emphysema index. Using a dataset of 43 scan-pairs with less than a 100 day time-interval between scans, we find that the diaphragm curvature had a trend towards lower overall variability over emphysema index (95% CI: -9.7 to +14.7 vs. -15.8 to +12.0), and that the variation of both measures was reduced after compensation. We conclude that the variation of the new measure can be considered comparable to the established measure and the compensation can reduce the apparent variation of quantitative measures successfully.

7624-111, Poster Session

Adjacent slice prostate cancer prediction to inform MALDI imaging biomarker analysis

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Traditionally, prostate cancer diagnosis is made by the analysis of prostate-specific antigen (PSA) levels and histopathological images of biopsy samples under microscopes. Proteomic biomarkers can improve upon these methods. MALDI molecular spectra imaging is used to visualize protein/peptide concentrations across biopsy samples to search for biomarker candidates. Unfortunately, traditional processing methods require histopathological examination on one slice of a biopsy sample while the adjacent slice is subjected to the tissue destroying desorption and ionization processes of MALDI. The highest confidence tumor regions gained from the histopathological analysis are then mapped to the MALDI spectra data to estimate the regions for biomarker identification from the MALDI imaging. To provide a significantly better estimate of the cancer tumor mapped onto the MALDI imaging spectra coordinates, we use the high confidence region to predict the true area of the tumor on the adjacent MALDI imaged slice.

7624-113, Poster Session

Robust detection of the counting area in blood smears for computer aided hematology

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For medical diagnosis, blood is an indispensable indicator for a wide variety of diseases, i.e. hemic, parasitic and sexually transmitted diseases. A robust detection and exact segmentation of white blood cells (leukocytes) in stained blood smears of the peripheral blood provides the basis for a fully automatic, image-based preparation of the so called differential blood cell count in the context of medical laboratory diagnostics. Especially for the localization of the blood cells and in particular for the segmentation of the cells it is necessary to detect the working area of the blood smear. In this contribution we present an approach for locating the so-called counting area on stained blood smears that is the region where cells are predominantly separated and do not interfere with each other. For this multiple images of a blood smear are taken and analyzed in order to select the image corresponding to this area. The analysis involves the computation of an unimodal function from the image content. This requires a prior segmentation of the cells that is carried out by a binarization in the HSV color space. Finally, the indicator function is derived from the number of cells and the cells' surface area. Its unimodality guarantees to find a maximum value that corresponds to the counting area's image index, enabling a fast determination of the counting area on blood smears. For an evaluation the algorithm's performance on a number of blood smears was compared with the ground truth information that has been defined by adept hematologists.

7624-114, Poster Session

Automatic recognition of abnormal cells in cytological tests using multispectral imaging

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Cervical cancer is the leading cause of gynecologic-related death worldwide, but is almost completely preventable with regular screening. Cytological test is a method of choice for screening of women at risk for cervical dysplasia; in that thousands of intraepithelial cells on a slide have to be visually inspected. Although it has radically lowered the death rate from cervical cancer; it is plagued by low sensitivity

and interobsever variability. Moreover, applicability of the existing approaches to aid in this task is still restricted because the recognition of shape and morphology of nuclei is compromised by overlapping and clumped cells.

Multispectral imaging can offer enhanced cellular characteristic via spectrally resolved images of cytological specimens. New features including spectral intensity and texture reflecting relevant morphological differences between normal and abnormal cells can be derived from such images and utilized in a detection/classification scheme. Our automated processing of multispectral image cubes yields nuclear objects which are subjected to classification facilitated by a library of spectral signatures obtained from normal and abnormal cells marked by experts. Clumps are processed separately with reduced set of signatures. Implementation of this method yields high rate of successful detection and classification of nuclei into predefined malignant and premalignant types and correlates well with those obtained by an expert.

Our multispectral approach may have an impact on the diagnostic workflow of cytological tests. Abnormal cell and areas can be automatically highlighted and quantified, thus objectivity and performance of the reading can be improved in a way currently unavailable in clinical setting.

7624-115, Poster Session

Segmentation of follicular regions on H&E slides using a matching filter and active contour model

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TFollicular Lymphoma (FL) accounts for 20-25% of non-Hodgkin lymphomas in the US. The first step in follicular lymphoma grading is the identification of follicles. The goal of this paper is to develop a technique to segment follicular regions in H&E stained images. The method is based on a robust active contour model in which the centroid of the expanded curve is selected manually by the user. The novel aspect of this method is the introduction of matched filter for the flattening of background in the L channel of the Lab color space. The performance of the algorithm was tested by comparing it against the manual segmentations of trained readers using the Zijbendos similarity index. The mean accuracy of the final segmentation compared to the manual ground truth is 0.71 and with a standard deviation of 0.12.

7624-116, Poster Session

Optic disk detection using energy maximization on match filter surface

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The optic disk (OD) detection is the vital step for automatic diabetic retinopathy screening system. A new fast and robust approach to automatically detect the optic disk in the color fundus image is purposed in this paper. The purposed method starts by equalizing the contrast through out the image using the adaptive histogram equalization approach. Multiple erosion (cropping) operations are applied in the preprocessing stage in order to shrink image's region of interest(ROI).ROI is selected on the bases of region consisting of high intensity values in the image. So Binarization is applied to extract the region of interest from the image. Dilation is then applied to the ROI to bridge the gapes. Gradient intensity map of the blood vessels is generated by applying the twelve two dimensional, directional matched filters. Further a template match filter is generated by averaging the OD vicinity of randomly selected retinal images. Match filter is resized into nine different sizes in order to match the size of the images in the database. Fast Normalized cross-Correlation is applied on to the gradient intensity map and the nine resized match filters. Each correlation surface obtained is convolved with ROI and the refined surface image with the maximum response is selected from these

convolved surfaces. In the final step, Extracted peaks in the refined surface image are localized by energy based methodology (block based processing) in order to locate the final optic disk location. Purposed method showed both accuracy and speed. The purposed algorithm was evaluated using publicly available Drive database, containing 40 images of both normal and diseased retinas. OD centre was detected 39 out of 40 images. Moreover the OD centre was detected in 100 out of 101 images in DIARETDB0 database.

7624-117, Poster Session

Classification of left and right eye retinal images

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Retinal image analysis is used by clinicians to diagnose and identify, if any, pathologies present in a patient's eye. The usage, development and applications of computer-aided diagnosis (CAD) systems in medical imaging have been rapidly increasing over the years. In this paper, we propose a system to classify left and right eye retinal images automatically.

This paper describes an approach to classify left and right retinal images via the position of the central retinal vessel within the optic disc. The detection and location of the macula helps to reaffirm the accuracy of this classification.

The novelty lies in acquiring of the locations of the anatomical structures of the eye, mainly, the macular and the central retinal vessels within the optic disc. Our proposed system is able to detect the key physiological structures of the retinal image, the optic disc and macular, identify the ISNT regions of the optic disc and differentiate left and right retinal images. An advantage of this is that other image processing algorithms can be focused on regions where diseases or pathologies and more likely to occur, thereby increasing the efficiency and accuracy of the retinal CAD system/pathology detection.

We tested our system on 102 retinal images, consisting of 51 left and right images each and achieved and accuracy of 94.1176% (96/102). The high experimental accuracy of this system shows that there is potential for this system to be integrated and applied together with other retinal CAD system, such as ARGALI, for priori information in automatic mass screening and diagnosis of retinal diseases.

7624-118, Poster Session

Enhancement of optic cup detection through an improved vessel kink detection framework

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Glaucoma is a leading cause of blindness. The presence and extent of progression of glaucoma can be determined if the optic cup can be accurately segmented from retinal images. In this paper, we present a framework which improves the detection of the optic cup. First, a region of interest is obtained from the retinal fundus image, and a pallor-based preliminary cup contour estimate is determined. Patches are then extracted from the ROI along this contour. To improve the usability of the patches, adaptive methods are introduced to ensure the patches are within the optic disc and to minimize redundant information. The patches are then analyzed for vessels by an edge transform which generates pixel segments of likely vessel candidates. Wavelet, color and gradient information are used as input features for a SVM model to classify the candidates as vessel or non-vessel. Subsequently, a rigourous non-parametric method is adopted in which a bi-stage multi-resolution approach is used to probe and localize the location of kinks along the vessels. Finally, contenxtual information is used to fuse pallor and kink information to obtain an enhanced optic cup segmentation. Using a batch of 21 images obtained from the Singapore Eye Research Institute, the new method results in a 12.64% reduction in the average overlap error against a pallor only cup, indicating viable improvements in the segmentation and supporting the use of kinks for optic cup detection.

7624-119, Poster Session

Retinal blood vessel tortuosity: a prospective diagnostic tool for the analysis of retinopathies

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Abnormalities in the vascular pattern of the retina have been linked to retinal disease as well as have been found to be risk factors for cardiovascular disease and stroke. This two-dimensional vascular pattern is partly formed congenitally, but is then modified over life, in response to aging and disease of the retinal vessel wall and long term changes in blood flow and pressure. An important aspect of the vascular pattern is vascular tortuosity, i.e. how curved or kinked a vessel is along its course.

It has not been clear whether arterial and venous tortuosity respond differentially or in tandem to these changes. We have developed a quantitative metric for vascular tortuosity, based on the vessel's angle of curvature, length of the curved vessel over its chord length (arc to chord ratio) and the number of turn sign changes, and combined into a tortuosity index (TI). In comparison to other published methods for tortusotiy measurement, our can estimate TI for constant curvature vessels and vessels with equal arc to chord ratio. We applied our method to the retinal color images of 15 patients with FSHD, a collection of 15 cases, of which the arterial and venous tortuosity have also been quantified by 4 masked physicians (ophthalmologists).

The method produced exactly the same rank-ordered list of vessel tortuosity as produced with the assessment by 4 physicians. Accordingly, TI has potential to detect and evaluate abnormal retinal vascular structure in early diagnosis and prognosis of retinopathies.

7624-120, Poster Session

A new algorithm for detecting smaller retinal blood vessels in fundus images

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DESCRIPTION OF PURPOSE: About 4.1 million Americans suffer from diabetic retinopathy. To help automatically diagnose various stages of the disease, a new blood-vessel-segmentation algorithm based on spatial high-boost filtering was developed to automatically segment blood vessels, including the smaller ones, with low noise.

METHODS: Image Database: Forty, 584 x 565 images were collected from DRIVE image database.

Preprocessing: Because the green band contains the most pertinent amount of visual information and better contrast, it was extracted from the color images.

Spatial high-boost filtering: A spatial high-boost filter with mask-size 11 was applied.

Enhancement: A histogram stretch was performed to enhance contrast. A median filter was applied to mitigate noise.

Binary Thresholding: The gray scale image was converted to a binary image using a binary threshold. Then, a logical NOT operation was performed.

Post processing: The resulting image was AND-ed with a ring mask to remove the outer-ring photographic artifact. At this point, most of the major and minor vessels were extracted, with some intersections and bifurcations missing. Vessel segments were reintegrated using the Hough transform.

RESULTS: Average SNR and RMS error improved by 10% and average Pratt's Figure of Merit by 30% compared to the previous published study [4].

CONCLUSIONS: The algorithm successfully preserved the details of smaller blood vessels, while keeping them intact and effectively removing noise. The algorithm should prove successful as a segmentation step for automatically identifying diseases that affect retinal blood vessels.

7624-121, Poster Session

Vertical cup-to-disc ratio measurement for diagnosis of glaucoma on fundus images

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Glaucoma is a leading cause of permanent blindness. Retinal fundus image examination is useful for early detection of glaucoma. In order to evaluate the presence of glaucoma, the ophthalmologists determine the cup and disc areas. However, determination of the cup area is very difficult, thus we propose a method to measure the cup-to-disc ratio using a vertical profile on the optic disc. First, we used the outline of the disc drawn by an ophthalmologist as the gold standard. The blood vessels were extracted by using black top-hat transformation from the green channel of the color images. Next, the blood vessels were erased from the image and then erased pixels were interpolated by using the RGB values of pixels in surrounding region. Twenty profiles were then obtained around the center of the optic disc in the vertical direction on blue channel of the color image. These profiles were averaged so that the result would not depend on the specific line selected, and the profile was smoothed. After that, the edge of the cup area was determined by analyzing the second order differential values of the vertical profile on the disc area. Lastly, the vertical cup-to-disc ratio was calculated. Fifty images, including twenty five glaucoma images, were used to evaluate the proposed method for determination of glaucoma. The sensitivity of 80% and a specificity of 88% were achieved with this method. These results indicated that this method can be useful for the analysis of the optic disc in glaucoma examinations.

7624-122, Poster Session

3D reconstruction of the optic nerve head using stereo fundus images for computer-aided diagnosis of glaucoma

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The shape of the optic nerve head is reconstructed from stereo fundus images of the optic disc by a robust stereo matching algorithm, which is needed for a quantitative estimate of the amount of nerve fiber loss for patients with glaucoma. Compared to natural scene stereo, fundus images are noisy because of the limits on illumination conditions and imperfections of the optics of the eye, posing challenges to conventional stereo matching approaches. In this paper, multi scale pixel feature vectors which are robust to noise are formulated using a combination of both pixel intensity and gradient features in scale space. Feature vectors associated with potential correspondences are compared with a disparity based matching score. The deep structures of the optic disc are reconstructed with a stack of disparity estimates in scale space, which matches with theoretical and behavioral studies of the stereoscopic depth perception process in the human binocular vision system. Optical Coherence Tomography (OCT) data was collected at the same time with color stereo photographs, and depth information from 3D segmentation was registered with the stereo

fundus images to provide the ground truth for performance evaluation. In experiments, the proposed algorithm produces estimates for the shape of the optic nerve head that are close to the OCT based shape, and it shows great potential to help computer-aided diagnosis of glaucoma and other related retinal diseases.

7624-123, Poster Session

Fundus image registration for vestibularis research

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In research on vestibular nerve disorders, fundus images of both left and right eyes are acquired systematically to precisely assess the rotation of the optic disc that is induced by the rotation of entire head. The measurement is still carried out manually. Although various methods have been proposed for medical image registration, robust detection of rotation especially in images with varied quality in terms of illumination, aberrations, blur and noise is still challenging. This paper evaluates registration algorithms operating on different levels of semantics: (i) data-based using Fourier transform and log polar maps; (ii) point-based using scaled image feature transform (SIFT); (iii) edge-based using Canny edge maps; (iv) object-based detecting pupila and macula automatically; (v) object-based using matched filters for vessel detection and (vi) manually by two independent medical experts. For evaluation, a database of 22 patients is used, where each of left and right eye images is captured in upright head position and in lateral tilt of ±20°. For 66 pairs of images (132 in total), the results are compared with ground truth, and the performance measures are tabulated. The evaluation shows that for applications in computer-aided diagnosis involving a large set of images with varied quality, like in versibularis research, registration methods based on a single level of semantics are not sufficiently robust. However, a multi-level semantics approach will improve the results since failure occur on different images.

7624-124, Poster Session

Toward automatic phenotyping of retinal images from genetically determined mono- and dizygotic twins using amplitude modulation-frequency modulation methods

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The purpose of this paper is to present a new method for classifying retinal images based on features derived from the application of amplitude modulation-frequency modulation (AM-FM) methods. A set of retinal images from identical (monozygotic) and fraternal (dizygotic) twins who presented with age-related macular degeneration (AMD) were processed to determine whether AM-FM could be used to differentiate between the two types of twins. Genetic data were available for each of the twin pairs to use as the gold standard for the automatic classifier. Results of the automatic classifier agreed with the findings of other researchers in explaining the variation of the disease between the related twins. We show that the AM-FM features classify 72% of the twins correctly. Visual analysis by other investigators (Seddon et al.) found that genetics could explain between 46% and 71% of the variance.

7624-125, Poster Session

Interobserver variability effects on computerized volume analysis of treatment response of head and neck lesions in CT

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A computerized system for segmenting lesions in head and neck CT scans was developed to assist radiologists in estimation of the response to treatment of malignant lesions. The system performs 3D segmentation based on a level set model and uses as input an approximate bounding box for the lesion of interest. We investigated the effect of the interobserver variability of the bounding box marked on the automatic segmentation performance. In this preliminary study, CT scans from a pre-treatment exam and a post one-cycle chemotherapy exam of 34 patients with primary site head and neck neoplasms were used. For each tumor, an experienced radiologist marked the lesion with a bounding box and provided a reference standard by outlining the full 3D contour on both the pre- and post treatment scans. A second radiologist independently marked each tumor again with another bounding box. The correlation between the automatic and manual estimates for both the pre-to-post-treatment volume change and the percent volume change was r=0.95. Based on the bounding boxes by the second radiologist, the automatic and manual estimate for the pre-to-post-treatment volume change was r=0.89 and for the percent volume change r=0.91. The correlation for the automatic estimates obtained from the bounding boxes by the two radiologists was as follows: (1) pre-treatment volume r=0.92, (2) post-treatment volume r=0.88, (3) pre-to-post-treatment change r=0.89 and (4) percent pre-to-post-treatment change r=0.90. The difference between the automatic estimates based on the two sets of bounding boxes did not achieve statistical significance for any of the estimates (p>0.29). The preliminary results indicate that the automated segmentation system can reliably estimate tumor size change in response to treatment relative to radiologist's hand segmentation and different sets of input bounding boxes.

7624-126, Poster Session

Evaluation of universal plan-indices and quality-factor of treatment plans in radiation therapy treatment of cancer

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Radiotherapy treatments such as intensity modulation radiation therapy (IMRT) and stereotactic radiosurgery are planned in commercial treatment planning system. Researchers have presented various plan evaluation techniques for such treatments. The main objective of this work was to investigate a universal plan-indices evaluation technique for such treatments utilizing an open-source software system Histogram Analysis in Radiation Therapy (HART) [1]. Three different IMRT plans (PTV1; PTV2; and PTV3) at prescription doses (PDs: 1440 cGy; 1028 ± 78 cGy; and 525.7 ± 251 cGy respectively) and a PELVIS plan (PD: 4500 cGy) were designed for treatment of 10 prostate cancer patients. HART extracted dose-volume histogram (DVH) statistics from these plans [2]. DVH statistics were extracted for planning target volumes, rectum and bladder above various fractions of PD and tolerance dose (TD50). These statistics were utilized to evaluate a noble universal plan-index (UPI) set for IMRT plans. UPI set included critical organ scoring index (COSI), radiation conformity index (RCI), prescription isodose target volume (PITV), homogeneity index (HI), conformal number (CN), target volume ratio (TVR), dose gradient index (DGI), new conformity index (NCI), modified homogeneity index (MHI) and target conformity index (TCI) respectively. Quality-factor (QF) of each plan was also evaluated utilizing UPI set. Average UPI scores were found to be 1.0 for COSI, 0.99 for RCI, 1.14 for PITV, 1.1 for HI, 1.0 for CN, 0.84 for TVR, 0.99 for DG, 1.16 for NCI, 0.95 for MHI, and 0.99 for TCI, for IMRT plans. Overall QF was found to be 99% for all plans.

7624-127, Poster Session

Source separation on hyperspectral cube applied to dermatology

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This paper proposes a method of quantification of the components underlying the human skin that are supposed to be responsible for the effective reflectance spectrum of the skin over the visible wavelength. In our team, we have developed a spectral device suited to dermatology, called ASCLEPIOS. The result of each acquisition is a hyperspectral cube describing the skin reflectance of each element of the skin. The skin reflectance can be analyzed to determine the quantities of the pigments or skin chromophores that absorb certain wavelengths of light penetrating the skin. The method is based on independent component analysis (ICA) assuming the epidermal melanin and the dermal haemoglobin as primary skin chromophores and that their absorbance spectra are independent of each other. Prior knowledge of the nature of the absorbance spectra of melanin and haemoglobin revealed non-Gaussianity of the signals. Therefore, kurtosis maximization of the signals as a measure of non-Gaussianity has been employed as an optimization process. The optimization process in turn estimates the mixing quantities of the skin components in the mixture of skin reflectance. The method extracts the source component spectra that correspond to the ideal absorbance spectra of melanin and haemoglobin. The noisy melanin spectrum extracted is fixed using a polynomial fit and the quantifications associated with it are re-estimated in least-squares sense. The results produce feasible quantifications of melanin and haemoglobin in the examined skin patch.

7624-128, Poster Session

Segmentation of individual ribs from low-dose chest CT

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The bone structure in chest CT scans may serve as a reference for locating a region of interest. The segmentation of individual ribs and bones in chest CT images is important for anatomical analysis, as the segmented ribs may be used as a baseline reference for the location of organs within the chest as well as for identification and measurement of any geometric abnormalities in the bone. In this paper we present an algorithm to segment the individual rib structure from a low-dose chest CT scan. The proposed algorithm consists of three main stages. First, all the bone structure present in the scan is segmented. Second, the centerline of the spinal canal is identified using a distance transform of the bone segmentation. Finally, based on the identified centerline, the seed point for every rib is detected, and individual ribs are separated from the vertebrae using the seed point. This algorithm was evaluated using 115 low-dose chest CT scans with various slice thicknesses. The algorithm parameters were determined using 5 scans, and remaining 110 scans were used to evaluate the performance. The outcome of the algorithm was visually inspected for the correctness of the segmentation. The results indicate that over 98% of the individual ribs are correctly segmented with the proposed algorithm.

7624-129, Poster Session

A comparison of basic deinterlacing approaches for a computer assisted diagnosis approach of videoscope images

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In the near future, Computer Assisted Diagnosis (CAD) which is well

known in the area of mammography might be used to support clinical experts in the diagnosis of images derived from imaging modalities such as endoscopy. In the recent past, a few first approaches for computer assisted endoscopy have been presented already. These systems use a video signal as an input that is provided by the endoscopes video processor. Despite the advent of high-definition systems most standard endoscopy systems today still provide only analog video signals. These signals consist of interlaced images that can not be used in a CAD approach without deinterlacing. Of course, there are many different deinterlacing approaches known today. But most of them are specializations of some basic approaches. In this paper we present four basic deinterlacing approaches. We have used a database of non-interlaced images which have been degraded by artificial interlacing and afterwards processed by these approaches. The database contains regions of interest (ROI) of clinical relevance for the case of Barrett's esophagus. We compared the classification rates on these ROIs on the original images and after the deinterlacing. The results show that the Bobbing approach and the Motion Compensation approach achieved classification results close to the original images.

7624-130, Poster Session

Segmentation and classification of dermatological lesions

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Certain skin diseases are chronic, inflammatory and without cure. However, there are many treatment options that can clear them for a period of time. Measuring their severity and assessing their extent, it is a fundamental issue to determine the efficacy of the treatment under test. Two of the most important parameters of severity assessment are Erythema (redness) and Scaliness. Physicians classify these parameters into five grades on a scale from 0 to 4 (0 means no disease, 4 means maximal severity). The classification is made by visual grading method, therefore is a subjective measure. In this paper an objective assessment of erythema and scaliness of dermatological lesions is proposed. A color image segmentation and classification algorithm is developed. The algorithm separates lesion from healthy skin and the lesion is classified into the different grades of erythema and scaliness. Color digital photographs taken under an acquisition protocol form the database. Difference between green band and blue band of images in RGB color space shows two modes (healthy skin and lesion) with clear separation. Otsu's method is applied to this difference in order to isolate the lesion. After the skin disease is segmented, some color and texture features are calculated and they are the inputs to a Fuzzy-ARTMAP neural network. The neural network classifies them into the five grades of erythema and the five grades of scaliness. The method has been tested with 31 images with a success percentage of 83.87 % when the images are classified in erythema, and 77.42 % for scaliness classification

7624-131, Poster Session

Pathology detection in medical images based on oriented active appearance models

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In CAD, typically the classical pattern recognition approach of feature extraction followed by classification is employed. In this paper, we propose a novel, general paradigm based on creating a statistical geographic model of shape and appearance of normal body regions. Any deviations from the normality information captured in a given patient image are highlighted and expressed as a fuzzy pathology image. We study the feasibility of this idea in 2D images via Oriented Active Appearance Models (OAAM). The OAAM synergistically combines AAM and live-wire concepts. The approach consists of three main stages: model building, segmentation, and pathology detection. The model is built on image data from normal subjects. The model

currently includes shape and texture information. A variety of other information (functional, morphometric) can be added in the future. For segmentation, a novel automatic object recognition method is proposed which strategically combines the AAM with the live-wire method. A two level dynamic programming method is used to do the finer delineation. For segmentation, a multi-object strategy is used for improving recognition and delineation accuracy. For pathology detection, the model is first fit to the given image as well as possible via recognition and delineation of the objects included in the model. Subsequently a fuzzy pathology image is generated that expresses deviations in appearance of the given image form the texture information contained in the model. The proposed method was tested on two clinical CT medical image data sets each consisting of 40 images. Our preliminary results indicate high segmentation accuracy (TPVF>97%, FPVF<0.5%) for delineating objects by the multi-object strategy with good pathology detection results suggesting the feasibility of the proposed system.

7624-132, Poster Session

Automated segmentation of mucosal change in rhinosinusitis patients

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Rhinosinusitis is a sinonasal disease affecting ~16% of the population and is responsible for more than $5.8 billion in healthcare costs annually. Major symptoms include pain, fever, purulence, edema, and anosmia. Volumetric segmentation and measurement of mucosal change on serial CT scans of rhinosinusitis patients can provide objective data that is useful when determining stage and therapeutic response. Unfortunately, volumetric segmentation of mucosal change is time consuming when performed manually. The goal of this research was to develop an automated method for the volumetric segmentation and measurement of mucosal change. Four chronic rhinosinusitis patients underwent a baseline and follow-up CT scan. For each patient, five sections were randomly selected and two otolaryngologists independently outlined all mucosal change. The automated method was then applied to the same set of sections and the computer-generated outlines were recorded. For each section, the Dice coefficient was calculated between the two otolaryngologist's outlines and between each otolaryngologist-defined and automatically-generated outline. The Dice coefficient (D) is a measure of similarity between two sets and ranges from 0 (disjoint sets) to 1 (identical sets). The median Dice coefficient between the two otolaryngologists was 0.74, the first quartile coefficient was 0.50, and the third quartile coefficient was 0.87. The observer-defined and automated segmentations demonstrated excellent agreement with a median Dice coefficient of 0.61, first quartile coefficient of 0.45, and third quartile coefficient of 0.72. This automated method represents the first step in the creation of a system for the quantitative 3D analysis of chronic rhinosinusitis in CT.

7624-133, Poster Session

Diagnosis of disc herniation based on classifiers and features generated from spine MR images

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Low back pain is one of the major public health problems in industrialized countries. Besides, it has an enormous economic impact on suffering patients and their families. According to Ambulatory Health Care Data, more than 20 million MRI exams are conducted annually in the United States and 50% of them are related to spine. In recent years, it is reported that there is a concern about a shortage of diagnostic radiologists. Accordingly, the demand for computer-assisted image processing and diagnosis has grown in the diagnosis of low back pain problems. Though it is often considered that an anatomic diagnosis is not feasible, the cause of the problem may be found by

using non-invasive imaging such as computerized tomography (CT), and magnetic resonance imaging (MRI). In this paper, we present several classifiers that can accurately diagnose herniated discs from MR Images. Our approach of herniation detection consists of two stages. In the pre-processing stage, the segmentation of the lumbar vertebrae as well as the generation of a feature vector is performed. In the classification stage, three classifiers (a SVM classifier, a perceptron classifier, and a least-mean-square classifier) are used to diagnose disc herniation and the results are compared. Cross-validation experiments on 68 clinical cases with 340 lumbar disks show that our classifiers diagnose disc herniation with 97% accuracy. In the future, we plan to increase the size of patient data so that our classifiers work well with patients of all ages and genders.

7624-134, Poster Session

Skin lesion progression with optical spectroscopy navigation and tracking

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Cutaneous T-Cell Lymphoma (CTCL) is a cancer type externally characterized by alterations in the coloring of skin. Optical spectroscopy has been proposed for quantification of minimal changes in skin offering itself as an interesting tool for monitoring of CTCL in real-time. However, in order to be used in a valid way, measurements on the lesions have to be taken at the same position and with the same orientation in each session. Combining hand-held optical spectroscopy devices with tracking and acquiring synchronously spectral information with position and orientation, we introduce a novel computer-assisted scheme for valid spectral quantification of disease pro¬gression. We further present an implementation for an augmented reality guidance system that allows to find a point previously analyzed with an accuracy of 0.8[mm] and 5.0[deg] (vs. 1.6[mm] and 6.6[deg] with¬out guidance). The intuitive guidance, as well as the preliminary quantitative results shows that the presented approach has great potential towards innovative computer-assistance methods for quantification of disease progression.

7624-135, Poster Session

Computer aided diagnosis of osteoporosis using multislice CT images

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The patients of osteoporosis comprised of about 10 million people in Japan and it is one of the problems the aging society has. In order to prevent the osteoporosis, it is necessary to do early detection and treatment. Multi-slice CT technology has been improving three dimensional (3-D) image analysis with higher body axis resolution and shorter scan time. The 3-D image analysis using multi-slice CT images of thoracic vertebra can be used as a support to diagnose osteoporosis and at the same time can be used for lung cancer screening which may lead to early detection. We develop automatic extraction algorithm of vertebra, and the analysis algorithm of the vertebral body using shape analysis and a bone density measurement for the diagnosis of osteoporosis.

7624-42, Session 9

Toward the assessment of pelvic organs dynamic with shape descriptors

M. Rahim, M. Bellemare, Univ. Paul Cézanne (France); N. Pirró, Hôpital de la Timone (France) and Univ. de la Méditerranée (France); R. Bulot, Univ. Paul Cézanne (France)

Pelvic floor diseases cover pathologies of which physiopathology is not well understood. MRI sequences used in the clinical assessment allow to visualize the dynamic behavior of the main organs involved (bladder, uterus- vagina and rectum). A methodology, using shape descriptors, is proposed to intent a quantitative and ob jective characterization of the organs behavior under abdominal strain condition. This approach assesses overall organs movement through characteristic angles measurements (anorectal angle, uterovaginal angle) and anatomically significant points tracking (anorectal angle vertex, cervix, bladder neck) by using the curvature features of a structural shape descriptor (medial axis). Deformation estimation is performed thanks to the shape comparison using global approach-based shape descriptors. In this connection, space domain based-methods (signature, turning angle) have been used, in addition to transform domain based-descriptors (Fourier descriptors, Zernike moments). Typical results of organs deformations and displacement tracking are presented, where pathological organs can be distinguished from healthy ones. In addition, a shape descriptors stability analysis have shown the soundness and efficiency of this approach.

7624-43, Session 9

Computer aided segmentation of kidneys using locally shape constrained deformable models on CT images

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This work presents a novel approach for model based segmentation of the kidney in images acquired by Computed Tomography (CT). The developed computer aided segmentation system is expected to support computer aided diagnosis and operation planning. Addressing the drawbacks of statistical shape models and deformable surfaces, we have developed an approach based on local shape constraints that prevent the model from deforming into neighboring structures while allowing the global shape to adapt freely to the data. Those local constraints are derived from the anatomical structure of the kidney and the presence and appearance of neighboring organs. Our work flow consists of two steps: 1) a user guided positioning and 2) an automatic model adaptation using affine and free form deformation in order to robustly extract the kidney. In cases which show pronounced pathologies, the system also offers real time mesh editing tools for a quick refinement of the segmentation result. Evaluation results based on 30 clinical cases using CT data sets show a mean surface distance error of <0.6 mm and a dice correlation coefficient of 94% compared to the ground truth. This means an improvement to existing kidney segmentation methods of up to 5% in terms of the average dice correlation coefficient. The results are therefore in most cases comparable to manual delineation. Computation times of the automatic adaptation are smaller than 10 seconds which makes the proposed system suitable for an application in clinical practice.

7624-44, Session 9

Automatic diagnosis of lumbar disc herniation using shape and appearance features from MRI

R. S. Alomari, J. J. Corso, V. Chaudhary, Univ. at Buffalo (United States); G. S. Dhillon, ProScan Imaging Buffalo (United States)

Intervertebral disc herniation is a major reason for lower back pain (LBP), which is the second most common neurological ailment. Automation of herniated disc diagnosis reduces the large burden on radiologists who have to diagnose hundreds of cases each day using clinical MRI. We present a probabilistic classifier for automatic diagnosis of disc herniation from lower lumbar spine. We jointly model the disc shape, with an active shape model, and disc appearance, with a Gaussian model, to perform the diagnosis task. We utilize a Gibbs distribution forcombineing the features and inference on the images. We use the active shape model assuming that the underlying

manifold of variations in the disc shape (elliptical shape) is roughly linear. We also model the appearance of the disc with a Gaussian model based on empirical study of discs signal profiles. We present the details of the method in the extended abstract along with all the potentials of the method. We validate our classifier on 33 clinical MRI cases that contain both T1- and T2-weighted volumes manually co-registered at the acquisition time. Our gold standard is the actual clinical diagnosis reports that the radiologist submits to his referral doctor. We extract our needed information from these reports with the help of our collaborating radiologist. We perform preprocessing for the volumes to overcome the MR signal inhomogeinities and combine the signal of T1- and T2-weighted to produce better images for inference on our proposed model. We test our classifier with a cross validation experiments leaving 13 out each time and training on the other 20 cases. We achived over 91% accuracy for herniation detection.

7624-45, Session 9

Content-based image retrieval applied to bone age assessment

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Radiological bone age assessment is based on local image regions of interest (ROI), such as the epiphysis or the area of carpal bones. These are compared to a standardized reference and a score determining the skeletal maturity is calculated. For computer-assisted diagnosis, automatic ROI extraction and analysis is done so far mainly by heuristic approaches. Due to high variations in the imaged biological material and differences in age, gender and ethnic origin, automatic analysis is difficult and frequently requires manual interactions. On the contrary, epiphyseal regions (eROIs) can be compared to previous cases with known age by content-based image retrieval (CBIR). This requires a sufficient number of cases with reliable positioning of the eROI centers. In this first approach to bone age assessment by CBIR, we conduct leaving-one-out experiments on 1,102 left hand radiographs and 15,428 metacarpal and phalangeal eROIs from the USC hand atlas. The similarity of the eROIs is assessed by cross-correlation of 16x16 scaled eROIs. The effects of the number of eROIs, two age computation methods as well as the number of considered CBIR references are analyzed. The best results yield an error rate of 1.16 years and a standard deviation of below 0.74 years. As the appearance of the hand varies naturally by up to two years, these results clearly demonstrate the applicability of the CBIR approach for bone age estimation.

7624-46, Session 9

Computer-aided diagnosis of lumbar stenosis conditions

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Computer-aided diagnosis (CAD) systems are indispensable tools for patients' healthcare in modern medicine. Nevertheless, the only fully automatic CAD system available for lumbar stenosis today is for X-ray images. Its performance is limited due to the limitations intrinsic to X-ray images. In this paper, we present a system for magnetic resonance images. It employs a new machine learning classification technique to automatically recognize lumbar spine components. Features can then be extracted from these spinal components. Finally, diagnosis is done by applying a Multilayer Perceptron. This classification framework can learn the features of different spinal conditions from the training images. This trained Perceptron can then be applied to diagnose new cases for various spinal conditions. Our experimental studies based on 62 subjects indicate that the proposed system is reliable and significantly better than our older system for X-ray images.

7624-47, Session 10

Digital tomosynthesis mammography: computerized detection of microcalcifications in reconstructed breast volume using a 3D approach

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We are developing a computer-aided detection (CAD) system for clustered microcalcifications in digital breast tomosynthesis (DBT). In this preliminary study, we investigated the approach of detecting microcalcifications in the tomosynthesized volume. The DBT volume is first enhanced by 3D multi-scale filtering and analysis of the eigenvalues of Hessian matrices with a calcification response function and signal-to-noise ratio enhancement filtering. Potential signal sites are identified in the enhanced volume and local analysis is performed to further characterize each object. A 3D dynamic clustering procedure is designed to locate potential clusters using hierarchical criteria. We collected a pilot data set of two-view DBT mammograms of 39 breasts containing microcalcification clusters (17 malignant, 22 benign) with IRB approval. A total of 74 clusters were identified by an experienced radiologist in the 78 DBT views. Our prototype CAD system achieved view-based sensitivity of 90% and 80% at an average FP rate of 7.3 and 2.0 clusters per volume, respectively. At the same levels of case-based sensitivity, the FP rates were 3.6 and 1.3 clusters per volume, respectively. For the subset of malignant clusters, the view-based detection sensitivity was 94% and 82% at an average FP rate of 6.0 and 1.5 FP clusters per volume, respectively. At the same levels of case-based sensitivity, the FP rates were 1.2 and 0.9 clusters per volume, respectively. This study demonstrated that computerized microcalcification detection in 3D is a promising approach to the development of a CAD system for DBT. Study is underway to further improve the computer-vision methods and to optimize the processing parameters using a larger data set.

7624-48, Session 10

The reconstruction of microcalcification clusters in digital breast tomosynthesis

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We present a novel method for the 3D reconstruction and detections of microcalcifications (CAD) in digital breast tomosynthesis (DBT). From a list of microcalcification candidates (real microcalcification points or noise points) of each DBT projection detected using any microcalcification detection technique in a single projection, our approach (1) finds the correspondences of a microcalcification across multiple projections; (2) locates its 3D position in the breast; (3) highlights noise points and (4) identifies the failure of microcalcification detection in one or more projections, and in such cases predicts their locations in the images in which they are missed.

From the geometry of any DBT acquisition system, an epipolar curve is derived for the 2D positions in all projections generated at different angular positions for a microcalcification. Each epipolar curve represents a single microcalcification point in the breast. By examining the n projections in DBT, one expects ideally m epipolar curves of n points representing m microcalcification points can be obtained. Since each microcalcification point is at a different 3D position, each epipolar curve will be at different positions in the same 2D coordinate system. By plotting all the microcalcification candidates in the same 2D plane simultaneously, one can easily extract a representation of the number of microcalcification points in the breast (number of epipolar curves) and their 3D positions, the noise points detected (isolated points not forming any epipolar curve) and microcalcification points missed in some projections (epipolar curves with less than n points).

7624-49, Session 10

Digital breast tomosynthesis mammgoraphy: feasibility of automated detection of microcalcification clusters on projections views

L. M. Hadjiiski, H. Chan, J. Wei, B. Sahiner, C. Zhou, M. A. Helvie, Univ. of Michigan (United States)

We are developing a computer-aided detection (CAD) system to assist radiologists in detecting microcalcification clusters in digital breast tomosynthesis (DBT). The purpose of this study is to investigate the feasibility of a 2D approach using the projection-view (PV) images as input. In the first stage, automated detection of the microcalcification clusters on the PVs is performed. In the second stage, the detected cluster candidates on the individual PVs are back-projected to the 3D volume. The true clusters will therefore converge at their focal planes and ideally will result in higher cluster scores than the FPs. In the final step an analysis of the back-projected cluster candidates is performed to differentiate the true and false clusters. In this pilot study, a limited data set of 39 cases with biopsy proven microcalcification clusters (17 malignant, 22 benign) was used. The DBT scans were obtained in both CC and MLO views using a GE GEN2 prototype system which acquires 21 PVs over a 60° arc in 3° increments. In the 78 DBT volumes, a total of 74 clusters (33 malignant clusters in 34 breasts and 41 benign clusters in 44 breasts) were identified. The computer detected 93% (69/74) of the true clusters on the PVs. After back projection 70% (52/74) of the true clusters could be identified in the 3D volume. Study is underway to develop methods to reduce FPs and to compare this 2D approach with 3D or combined 2D and 3D approaches.

7624-50, Session 10

Analysis of breast lesions on contrast-enhanced magnetic resonance images using high-dimensional texture features

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Haralick texture features derived from gray-level co-occurrence matrices (GLCM) were used to classify the character of suspicious breast lesions as benign or malignant on dynamic contrast-enhanced MRI studies. Lesions were identified and annotated by an experienced radiologist on 57 MRI exams of female patients where histopathological reports were available prior to this investigation. GLCMs were then extracted from these 2D regions of interest (ROI) for four principal directions (0°, 45°, 90° & 135°) and used to compute Haralick texture features. A fuzzy k-nearest neighbor (k-NN) classifier was optimized in ten-fold cross-validation for each texture feature and the classification performance was calculated on an independent test set as a function of area under the ROC curve. The lesion ROIs were characterized by texture feature vectors containing the Haralick feature values computed from each directional-GLCM; and the classifier results obtained were compared to a previously used approach where the directional-GLCMs were summed to a non-directional GLCM which could further yield a set of texture feature values. The impact of varying the inter-pixel distance while generating the GLCMs on the classifier's performance was also investigated. Classifier's AUC was found to significantly increase when the high-dimensional texture feature vector approach was pursued, and when features derived from GLCMs generated using different inter-pixel distances were incorporated into the classification task. These results indicate that lesion character classification accuracy could be improved by retaining the texture features derived from the different directional GLCMs rather than combining these to yield a set of scalar feature values instead.

7624-51, Session 10

Heterogeneity of kinetic curve parameters as indicator for the malignancy of breast lesions in DCE MRI

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Dynamic contrast enhanced Breast MRI (DCE BMRI) has emerged as powerful tool in the diagnostic work-up of breast cancer. While DCE BMRI is very sensitive, specificity remains to be an issue. Consequently there is a need for features that support the classification of enhancing lesions into benign and malignant lesions. Traditional features include the morphology and the texture of a lesion, as well as the kinetic parameters of the time-intensity curves, i.e., the temporal change of image intensity at a given location. The kinetic parameters include initial contrast uptake of a lesion and the type of the kinetic curve. The curve type is usually assigned to one of three classes: persistent enhancement (Type I), plateau (Type II), and washout (Type III). While these curve types show a correlation with the tumor type (benign or malignant), only a small sub-volume of the lesion is taken into consideration and the curve type will depend on the location of the ROI that was used to generate the kinetic curve. Furthermore, it has been shown that the MR scanner and the scan parameters have a significant effect on the curve type.

Recently, it was shown that the heterogeneity of a given lesion with respect to spatial variation of the kinetic curve type is a clinically significant indicator for malignancy of a tumor. In this work we develop and compare three quantitative measures for the degree of heterogeneity of the kinetic curve parameters in a tumor and evaluate their ability of predicting the dignity of a tumor. All features are shown to have an area under the ROC curve of 0.72 or higher (for a single feature).

7624-52, Session 10

Optimization of a fuzzy C-means approach to determining probability of lesion malignancy and quantifying lesion enhancement heterogeneity in breast DCE-MRI

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Previous research has shown that a fuzzy C-means (FCM) approach to computerized lesion analysis has the potential to aid radiologists in the interpretation of dynamic contrast-enhanced MRI (DCE-MRI) breast exams. Our purpose in this study was to optimize the performance of the FCM approach with respect to binary (benign/malignant) breast lesion classification in DCE-MRI. We used both raw (calculated from kinetic data points) and empirically fitted kinetic features for this study. FCM was used to automatically select a "characteristic kinetic curve" (CKC) based on intensity-time point data of voxels within each lesion, using four different kinetic criteria: (1) maximum initial enhancement, (2) minimum shape index, (3) maximum washout, and (4) minimum time to peak. We extracted kinetic features from these CKC's, which were merged using linear discriminant analysis (LDA), and evaluated with receiver operating characteristic (ROC) analysis. There was comparable performance for methods 1, 2, and 4, while method 3 was inferior. Next, we modified use of the FCM method by calculating a feature vector for every voxel in each lesion and using FCM to select a "characteristic feature vector" (CFV) for each lesion. Using this method, we achieved slightly better (although p > 0.05) performance, compared with the four CKC methods. Additionally, we proposed a method for optimizing the number of FCM clusters based upon the spatial variance of kinetic features in each lesion. Finally, we generated lesion

color maps using FCM membership matrices, which facilitated the visualization of malignant voxels in a given lesion.

7624-53, Session 11

Computer-aided classification of patients with dementia of Alzheimer's type based on cerebral blood flow determined with arterial spin labeling technique

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Arterial spin labeling (ASL) is one of promising non-invasive magnetic resonance (MR) imaging techniques for measurement of cerebral blood flow (CBF). Some researchers reported that the ASL could classify patients with dementia of Alzheimer's type (DAT). The aim of this study was to develop a computer-aided classification system for DAT patients at early stages based on functional image features of the CBFs measured by the ASL technique. First, a CBF map image of each subject was segmented into 13 anatomical regions (frontal, temporal, limbic, occipital, parietal lobes, etc.) based on the Talairach atlas. For that purpose, a free-form deformation based on B-splines, between each ALS image and the Talairach atlas was performed as a non-rigid local registration. Second, an artificial neural network (ANN), which was trained by the average CBFs in 13 functional regions, was employed for distinguishing DAT patients from control subjects. In the ANN, a single three-layer feed-forward network was constructed with a Levenberg Marquardt algorithm. For evaluation of the proposed method, we applied it to CBF map image of ten patients with a diagnosis of DAT (age range: 60-89, mean age: 74.1, Mini-Mental State Examination (MMSE): 12-25, mean MMSE: 21) and ten control subjects (age: 68-86, 73.9, MMSE: 27-30, 29.2), who were scanned a 3.0-Tesla MR unit. Ten DAT patients and ten control subjects were correctly distinguished by the proposed method based on a resubstitution test. Our preliminary results suggest that the proposed method would be feasible for detection of patients with DAT at early stages.

7624-54, Session 11

Predictive modeling of neuroanatomic structures for brain atrophy detection

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This paper presents an approach of predictive modeling of neuroanatomic structures for the detection of brain atrophy based on cross-sectional MRI image. The underlying premise of applying predictive modeling for atrophy detection is that brain atrophy is defined as significant deviation of part of the anatomy from what the remaining normal anatomy predicts for that part. The proposed method is summarized as follows. The central cortical surface under consideration is reconstructed from brain tissue map and Regions of Interests (ROI) on it are predicted from correlated reliable anatomies. The vertex pair-wise distance between the predicted vertex and the true one within the abnormal region is expected to be larger than that of the vertex in normal brain region. Then change of white matter/gray matter ratio within a spherical region is used to identify the direction of vertex displacement. In this way, the severity of brain atrophy can be defined quantitatively by the displacements of those vertices. The proposed predictive modeling method has been evaluated by using both simulated atrophies and MRI images of Alzheimer's disease.

7624-55, Session 11

Spatial prior in SVM-based classification of brain images

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This paper introduces a general framework for spatial prior in Support Vector Machine (SVM) based classification of brain images based on Laplacian regularization. Most existing methods include spatial prior by adding a feature aggregation step before the SVM classification. The problem of the aggregation step is that the invididual information of each feature is lost. Our framework enables to avoid this shortcoming by including the spatial prior directly in the SVM. We demonstrate that this framework can be used to derive embedded regularization corresponding to existing methods for classification of brain images and propose an efficient way to implement them. This framework is illustrated on the classification of MR images from 55 patients with Alzheimer's disease and 82 elderly controls selected from the ADNI database. The results demonstrate that the proposed algorithm enables introducing straightforward and anatomically consistent spatial prior into the classifier.

7624-56, Session 11

Model-free functional MRI analysis for detecting low-frequency functional connectivity in the human brain

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Slowly varying temporally correlated activity fluctuations between functionally related brain areas have been identified by functional magnetic resonance imaging (fMRI) research in recent years. These low-frequency oscillations of less than 0.08 Hz appear to play a major role in various dynamic functional brain networks, such as the so-called "default mode" network. They also have been observed as a property of symmetric cortices, and they are known to be present in the motor cortex among others. These low-frequency data are difficult to detect and quantify in fMRI. Traditionally, user-defined regions of interests (ROI) or 'seed clusters' have been the primary analysis method. In this paper, we propose unsupervised clustering algorithms based on various distance measures to detect functional connectivity in resting state fMRI. The achieved results are evaluated quantitatively for different distance measures. The Euclidian metric implemented by the standard unsupervised clustering approaches is compared with a non-metric topographic mapping of proximities based on the mutual prediction error between pixel-specific signal dynamics time-series. It is shown that functional connectivity in the motor cortex of the human brain can be detected based on such model-free analysis methods for resting state fMRI.

7624-57, Session 11

Supervised method to build an atlas database for multi-atlas segmentation-propagation

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Multi-atlas based segmentation-propagation approaches have been shown to obtain accurate parcelation of brain structures. However, this approach requires a large number of manually delineated atlases, which are often not available. We propose a supervised method to build a population specific atlas database, using the publicly available Internet Brain Segmentation Repository (IBSR). The set of atlases grows iteratively as new atlases are added, so that its segmentation capability may be enhanced in the multi-atlas based approach. Using a dataset of 210 MR images of elderly subjects (170 elderly control, 40 Alzheimer's disease) from the Australian Imaging, Biomarkers and Lifestyle (AIBL) study, 40 MR images were segmented to build a population specific atlas database for the purpose of multi-atlas segmentation-propagation. The population specific atlases were used to segment the elderly population of 210 MR images, and were evaluated in terms of the agreement among the propagated labels. The agreement was measured by using the entropy H of the probability image produced when fused by voting rule and the partial moment μ of the histogram. Compared with using IBSR atlases, the population specific atlases obtained a higher agreement when dealing with images of elderly subjects.

7624-58, Session 12

Reproducibility of airway wall thickness measurements

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Airway remodeling and accompanying changes in wall thickness are known to be a major cause of chronic obstructive pulmonary disease (COPD), causing reduced lung function in diseased individuals. Further investigation of this disease and monitoring of disease progression and treatment effect demand for accurate and reproducible automatic assessment of airway wall thickness in CT datasets. With wall thicknesses in the sub-millimeter range, this task remains challenging even with today's high resolution CT datasets. To provide accurate measurements, taking partial volume effects into account is mandatory. It has been shown, that Full-Width-at-Half-Maximum (FWHM) is not appropriate for small airways ([1]) and several improved algorithms for objective quantification of airway wall thickness have been proposed ([2-4]). In this paper, we describe an algorithm based on the closed form solution in [2]. We locally estimate the lung density parameter required for the closed form solution to account for varying lung densities between different lung regions, inspiration states and contrast agent concentrations. The general accuracy of the algorithm is evaluated using basic tubular software and hardware phantoms. For longitudinal observations within individual subjects for disease monitoring, reproducibility of quantifications under clinical conditions is crucial. We therefore evaluate reproducibility of the algorithm on patient data with respect to varying reconstruction kernels and repeated low dose scans. Finally we investigate wall thickness and wall area variations between paired inspiratory and expiratory scans.

7624-59, Session 12

Automated volumetric segmentation method for computerized-diagnosis of pure nodular ground-glass opacity in high-resolution CT

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Recently, pure nodular ground-glass opacity (PNGGO) has been reported to increasing aspect in the CT screening and has considerable portion of benign diseases. Therefore accurate diagnosis of PNGGO

is important in order to reduce the number of unnecessary surgeries. Computer-aided diagnosis of PNGGO is less studied then other pulmonary nodules (solid-type nodule, mixed-type nodule). In this research, we propose an automated volumetric segmentation method for PNGGO and evaluate the segmentation method. Our segmentation method starts with noise-filtering and removal lung wall as a pre-processing step. Histogram modeling approach is applied to the automatically determining the threshold value between PNGGO and surrounding lung tissue. PNGGO regions are then segmented by region-growing technique. The elimination of vessel-like structure around the nodules was performed using morphological image operations. Our results indicate that the automated segmentation method produce acceptable results on a database of 26 cases.

7624-60, Session 12

Analysis of computer quantification of emphysema distribution and measurement variability using low-dose whole-lung CT scans from a large cohort

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Computed Tomography allows for the quantitative assessment of pulmonary emphysema through whole-lung scanning. Multiple image-based measures, such as emphysema index, have been proposed in the literature as being indicative of the severity emphysema present. This work looks to simultaneously examine the four most commonly reported emphysema measures in a large cohort and determine measure distribution and variation over a standard screening interval, as well as inter-score correlations and relationship between inspiration level changes and measurement changes in relation to one another. Using a cohort of 626 scan-pairs (1252 total scans) acquired at a 1.25mm slice thickness, we compute the distribution and variability of the emphysema index, histogram percentile, fractal dimension, and mean lung density. We also compute the pair-wise inter-measure correlation between the various metrics as well as the relationship between the measures and inspiration change. We find that while using emphysema index as a baseline, the other three measures tend to over-report severity. We also find that emphysema index and fractal dimension have similar, slightly reduce variability versus the other measures. It was also seen that that the four measures correlate highly to one another (r: 0.81-0.93), with histogram percentiles and fractal dimension having the least overall correlation. Finally, it was found that a moderate correlation exists between most measures and inspiration volume change (r2: 0.44-0.72), with mean lung density being most related to inspiration volume changes.

7624-61, Session 12

Semi-automated method to measure pneumonia severity in mice through computed tomography (CT) scan analysis

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Imaging is a crucial clinical tool for diagnosis and assessment of pneumonia, but quantitative methods are lacking. Micro-computed tomography (micro CT), designed for lab animals, provides opportunities for non-invasive radiographic endpoints for pneumonia studies.

HYPOTHESIS: In vivo micro CT scans of mice with early bacterial pneumonia can be scored quantitatively by semi-automated imaging methods, with good reproducibility and correlation with bacterial dose inoculated, pneumonia survival outcome, and radiologists' scores.

METHODS: Healthy mice had intratracheal inoculation of E. coli bacteria (n=24) or saline control (n=11). In vivo micro CT scans were performed 24 hours later with microCAT II (Siemens). Two independent

radiologists scored the extent of airspace abnormality, on a scale of 0 (normal) to 24 (completely abnormal). Using the Amira 5.2 software (Mercury Computer Systems), a histogram distribution of voxel counts between the Hounsfield range of -510 to 0 was created and analyzed, and a segmentation procedure was devised.

 RESULTS: A t-test was performed to determine whether there was a significant difference in the mean voxel value of each mouse in the three experimental groups: Saline Survivors, Pneumonia Survivors, and Pneumonia Non-survivors. It was found that the voxel count method was able to statistically tell apart the Saline Survivors from the Pneumonia Survivors, the Saline Survivors from the Pneumonia Non-survivors, but not the Pneumonia Survivors vs. Pneumonia Non-survivors. The segmentation method, however, was successfully able to distinguish the two Pneumonia groups.

CONCLUSION: We have pilot-tested an evaluation of early pneumonia in mice using micro CT and a semi-automated method for lung segmentation and scoring system. Statistical analysis indicates that the system is reliable and merits further evaluation.

7624-62, Session 12

Quantitative analysis of airway abnormalities in CT

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Algorithms that focus on the segmentation and measurement of airway lumen and wall area in computerized tomography images can help in the diagnosis and treatment of Chronic Obstructive Pulmonary Disease (COPD). A coupled surface graph cut algorithm is presented and evaluated along with cost functions that highlight both inner and outer wall borders. The method combines the search for both inner and outer airway wall border into one graph cut. Additionally a new measure of airway wall thickening is proposed called Normalized Wall Intensity Sum (NWIS).

The accuracy of the proposed method is evaluated on manually segmented data and concluded to be an improvement over similar existing algorithms and the Full Width at Half Maximum (FWHM) algorithm (37% and 62% less wrongly segmented pixels compared to FWHM and similar graph cut methods without coupled contours).

Additionally the use of the algorithm as a COPD diagnostic tool is demonstrated by successfully correlating the outcomes of pulmonary function tests with lumen area or Interior Area (IA), Wall Area percentage (WA%) and NWIS.

The proposed method is able to statistically separate healthy subjects from COPD (Stage II and higher) patients and repeatability is confirmed by using follow up scans. NWIS is shown to correlate better with lung function parameters and be more consistent than previous measures such as lumen area and wall area percentage.

Conference 7625: Visualization, Image-Guided Procedures, and Modeling

7625-01, Session 1

The OCT penlight: in-situ image guidance for microsurgery

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We have developed a new image-based guidance system for microsurgery using optical coherence tomography (OCT) that presents a virtual image in its correct location inside the scanned tissue. Applications include surgery of the cornea, skin, and other surfaces below which shallow targets may advantageously be displayed for the naked eye or low-power magnification by a surgical microscope or loupes (magnifying eyewear). OCT provides real-time high-resolution (3 micron) images at video rates within the first two millimeters of soft tissue, and is therefore suitable for guidance to various shallow targets such as Schlemm's canal in the eye (for treating Glaucoma) or melanoma in the skin. A series of prototypes of the "OCT penlight" has produced virtual images with sufficient resolution and intensity to be useful under magnification, while the geometrical arrangement between the OCT scanner and display optics (including a half-silvered mirror) does not impede surgical access. The two prototypes constructed thus far have used, respectively, a miniature organic light emitting diode (OLED) display and a reflective liquid crystal on silicon (LCoS) display. The OLED has the advantage of relative simplicity, satisfactory resolution (15 micron), and color capability, whereas the LCoS can produce an image with much higher intensity and superior resolution (12 micron), although it is monochromatic and more complicated optically. Intensity is an important limiting factor, since light flux is greatly diminished with increasing magnification, thus favoring the LCoS as the more practical system.

7625-02, Session 1

Fusion of intraoperative cone-beam CT and endoscopic video for image-guided procedures

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Methods for accurate registration and fusion of intraoperative cone-beam CT (CBCT) with endoscopic video have been developed and integrated into a system for surgical guidance that accounts for intraoperative anatomical deformation and tissue excision. The system is based on a prototype mobile C-Arm for intraoperative CBCT that provides low-dose 3D image updates on demand with sub-mm spatial resolution and soft-tissue visibility, and also incorporates subsystems for real-time tracking and navigation, video endoscopy, deformable image registration of preoperative images and surgical plans, and 3D visualization software. The position and pose of the endoscope are geometrically registered to 3D CBCT images by way of real-time optical tracking (NDI Polaris) for rigid endoscopes (e.g., head and neck surgery), and electromagnetic tracking (NDI Aurora) for flexible endoscopes (e.g., bronchoscopes, colonoscopes). The intrinsic (focal length, principal point, non-linear distortion) and extrinsic (translation, rotation) parameters of the endoscopic camera are calibrated from images of a planar calibration checkerboard (5x5 mm2 squares)

obtained at different perspectives. Video-CBCT registration enables a variety of 3D visualization options (e.g., oblique CBCT slices at the endoscope tip, augmentation of video with CBCT images and planning data, virtual reality representations of CBCT [surface renderings]), which can reveal anatomical structures not directly visible in the endoscopic view - e.g., critical structures obscured by blood or behind the visible anatomical surface. Video-CBCT fusion is evaluated in pre-clinical experiments (sinus / skull base surgery, lung biopsy), and is currently being incorporated into an ongoing prospective clinical trial in CBCT-guided head and neck surgery.

7625-03, Session 1

Integrating the visualization concept of the medical imaging interaction toolkit (MITK) into the XIP-builder visual programming environment

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The Medical Imaging Interaction Toolkit (MITK) and the eXtensible Imaging Platform (XIP) both aim at facilitating the development of medical imaging applications, but provide support on different levels. MITK offers support from the toolkit level, whereas XIP comes with a visual programming environment.

XIP is strongly based on Open Inventor. Open Inventor with its scene-graph-based rendering paradigm was not specifically designed for medical imaging, but focuses on creating dedicated visualizations.

MITK has a visualization concept with a model-view-controller-like design that assists in implementing multiple, consistent views on the same data, which is typically required in medical imaging. In addition, MITK defines a unified means of describing position, orientation, bounds, and (if required) local deformation of data and views, supporting e.g. images acquired with gantry tilt and curved reformations. The actual rendering is largely delegated to the Visualization Toolkit (VTK).

This paper presents an approach of how to integrate the visualization concept of MITK with XIP, especially into the XIP-Builder. This is a first step of combining the advantages of both platforms. It enables experimenting with algorithms in the XIP visual programming environment without requiring a detailed understanding of Open Inventor. Using MITK-based add-ons to XIP, any number of data objects (images, surfaces, etc.) produced by algorithms can simply be added to an MITK DataStorage module and rendered into any number of slice-based (2D) or 3D views.

Both, MITK and XIP, are open-source, C++ platforms. The extensions presented in this paper will be available as part of MITK from www.mitk.org.

7625-04, Session 1

High-accuracy registration of intraoperative CT imaging

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Image-guided interventions using intraoperative 3D imaging can be less cumbersome than systems dependent on preoperative images, especially by needing neither potentially invasive image-to-patient registration nor a lengthy process of segmenting and generating a 3D surface model.

In this study, a method for computer-assisted surgery using direct

navigation on intraoperative imaging is presented. In this system the registration step of a navigated procedure was divided into two stages: preoperative calibration of images to a ceiling-mounted optical tracking system, and intraoperative tracking during acquisition of the 3D medical image volume. The preoperative stage used a custom-made multi-modal calibrator that could be optically tracked and also contained fiducial spheres for radiological detection; a robust registration algorithm was used to compensate for the very high false-detection rate that was due to the high physical density of the optical light-emitting diodes. Intraoperatively, a tracking device was attached to plastic bone models that were also instrumented with radio-opaque spheres; A calibrated pointer was used to contact the latter spheres as a validation of the registration.

Experiments showed that the fiducial registration error of the preoperative calibration stage was approximately 0.1mm. The target registration error in the validation stage was approximately 0.45mm.

This study suggests that direct registration is potentially a highly accurate means of performing image-guided interventions in a fast, simple manner.

7625-05, Session 1

Intraoperative positioning of mobile C-arms using artificial fluoroscopy

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In trauma and orthopedic surgery, imaging through X-ray fluoroscopy with C-arms is ubiquitous, leading to an increase in ionizing radiation. Placing these devices in the desired position to visualize the required region of interest is a challenging task, requiring both skill of the surgical staff and numerous X-rays. We propose an extension to C-arms for which position data is available that provides the surgeon with so called artificial fluoroscopy. This is achieved by computing digitally reconstructed radiographs (DRRs) from pre- or intraoperative CT data. The approach is based on C-arm motion estimation, for which we employ a Camera Augmented Mobile C-arm(CAMC) system, and a rigid registration of the patient to the CT data. Using this information we are able to generate DRRs and simulate fluoroscopic images. For positioning tasks, this system appears almost exactly like conventional fluoroscopy, however simulating the images from the CT data without the application of ionizing radiation. Furthermore, preoperative planning can be done on the CT data and then visualized during positioning, e.g. defining drilling axes for pedicle approach techniques. Our method does not require external tracking. This makes it suitable to deploy in clinical environments and day-to-day routine. An experiment with six drillings into a lumbar spine phantom showed reproducible accuracy in positioning the C-arm.

7625-06, Session 2

3D model-based catheter tracking for motion compensation in EP procedures

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Atrial fibrillation is the most common sustained heart arrhythmia today. It affects about 2% of the general population. One approach to cure atrial fibrillation is to (electrically) isolate the pulmonary veins attached to the left atrium. Related procedures usually involve C-arm X-ray imaging devices for fluoroscopic catheter navigation inside the heart. As the heart is not visible under X-ray fluoroscopy, catheter navigation can benefit from fluoro overlay images. They can be rendered from static 3-D data sets obtained, e.g., using C-arm CT techniques such as syngo DynaCT Cardiac (Siemens AG, Healthcare, Forchheim,

Germany). Unfortunately, static 3D overlays need not necessarily match the true patient anatomy due to respiratory motion and cardiac motion. Procedure inaccuracies caused by motion could potentially lead to sub-optimal outcomes. In such a situation, image-based navigation may be difficult. To improve the situation, we present an image-based 3-D motion estimation technique based on tracking a circumferential mapping catheter on a biplane X-ray C-arm system. This mapping catheter is fixed at the ostium of the pulmonary vein being ablated to measure residual electrical signals. Catheter tracking is performed using a 2-D/3-D registration method. It involves a 3-D catheter model, which is calculated at the beginning of the procedure by reconstruction from two views. In this paper, we explain our technique and evaluate its performance using real clinical data. On a test data set comprising 231 biplane fluoroscopy frames, an average 3-D error of 1.2 mm was achieved.

7625-07, Session 2

Respiratory motion compensated overlay of surface models from cardiac MR on interventional x-ray fluoroscopy for guidance of cardiac resynchronization therapy procedures

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Various multi-center trials have shown that cardiac resynchronization therapy (CRT) is an effective procedure for patients with end-stage drug invariable heart failure (HF). Despite the encouraging results of CRT, at least 30% of patients do not respond to the treatment. Detailed knowledge of the cardiac anatomy (coronary venous tree, left ventricle), functional parameters (i.e. ventricular synchronicity) is supposed to improve CRT patient selection and interventional lead placement for reduction of the number of non-responders.

As a pre-interventional imaging modality, cardiac magnetic resonance (CMR) imaging has the potential to provide all relevant information. With functional information from CMR optimal implantation target sites may be better identified. Pre-operative CMR could also help to determine whether useful vein target segments are available for lead placement. Fused with X-ray, the mainstay interventional modality, improved interventional guidance for lead-placement could further help to increase procedure outcome.

In this contribution, we present novel and practicable methods for a) pre-operative functional and anatomical imaging of relevant cardiac structures to CRT using CMR, b) 2D-3D registration of CMR anatomy and functional meshes with X-ray vein angiograms and c) real-time capable breathing motion compensation for improved fluoroscopy mesh overlay during the intervention based on right ventricular pacer lead tracking. With these methods, enhanced interventional guidance for left ventricular lead placement is provided.

7625-08, Session 2

Estimating heart shift and morphological changes during minimally invasive cardiac interventions

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Image-guided interventions rely on the common assumption that pre-operative information can depict intra-operative morphology with sufficient accuracy. Nevertheless, in the context of minimally invasive cardiac therapy delivery, this assumption loses ground; the heart is a

soft-tissue organ prone to changes induced during access to the heart and especially intracardiac targets. In addition to its clinical value for cardiac interventional guidance and assistance with the image- and model-to-patient registration, here we show how ultrasound imaging may be used to estimate changes in the heart position and morphology of structures of interest at different stages in the procedure. Using a magnetically tracked 2D transesophageal echocardiography transducer, we acquired in vivo images of the heart at different stages during the procedural workflow of common minimally invasive cardiac procedures, including robot-assisted coronary artery bypass grafting, mitral valve replacement/repair, or model-enhanced US-guided intracardiac interventions, all in the coordinate system of the tracking system. Anatomical features of interest (mitral and aortic valves) used to register the pre-operative anatomical models to the intra-operative coordinate frame were identified from each dataset. This information allowed us to identify the global position of the heart and also characterize the valvular structures at various peri-operative stages, in terms of their orientation, size, and geometry. Based on these results, we can estimate the differences between the pre- and intra-operative anatomical features, their effect on the model-to-subject registration, and also identify the need to update or optimize any pre-operative surgical plan to better suit the intra-operative procedure workflow.

7625-09, Session 2

Artifact reduction method for improved visualization of 3D coronary artery reconstructions from rotational angiography acquisitions

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High quality and high resolution three dimensional reconstruction of the coronary arteries from clinically obtained rotational X-ray images during contrast injection has recently been attained through the use of advanced image processing techniques, including gating, optimal heart phase selection, motion compensation, and iterative reconstruction. While these strategies have produced excellent results despite severe angular under-sampling, the volumes that result from these techniques contain artifact/background signal features which impede both the qualitative as well as the quantitative analysis. This paper details a method for artifact removal from reconstructed 3D coronary angiograms that uses a priori image content information to maximize the background removal while minimizing influence on the reconstructed vessels. A variety of parameters are explored, as well as potential modifications which may improve the methodology. Results indicate that this method can greatly improve visualization for use in the catheterization laboratory as well as reduce the impact of the visualization grey scale on qualitative and quantitative evaluation of the data.

7625-10, Session 2

Semi-automatic segmentation of major aorto-pulmonary collateral arteries (MAPCAs) for image-guided procedures

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Manual segmentation of pre-operative volumetric dataset is generally time consuming and results are subject to large inter-user variabilities. Level-set methods have been proposed to improve segmentation consistency by finding interactively the segmentation boundaries by respect to some priors. However, in thin and elongated structures, such as major aorto-pulmonary collateral arteries (MAPCAs), edge-based level set methods might be subject to flooding whereas region-based

level set methods may not be selective enough. The main contribution of this work is to propose a novel expert-guided technique for the segmentation of the aorta and of the attached MAPCAs that is resilient to flooding while keeping the localization properties of an edge-based level set method. In practice, a two stages approach is used. First, the aorta is delineated by using manually inserted seed points at key locations and an automatic segmentation algorithm. The latter includes an intensity likelihood term that prevents leakage of the contour in regions of weak image gradients. Second, the origins of the MAPCAs are identified by using another set of seed points, then the MAPCAs' segmentation boundaries are evolved while being constrained by the aorta segmentation. This prevents the aorta to interfere with the segmentation of the MAPCAs. Our preliminary results are promising and constitute an indication that an accurate segmentation of the aorta and MAPCAs can be obtained with reasonable amount of effort.

7625-11, Session 2

Endoclamp balloon visualization and automatic placement system

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The European research network "Augmented Reality in Surgery" (ARIS*ER) developed a system that supports minimally invasive cardiac surgery based on augmented reality (AR) technology. The system supports the surgical team during aortic endoclamping where a balloon catheter has to be positioned and kept in place within the aorta. The presented system addresses the two biggest difficulties of the task: lack of visualization and difficulty in manoeuvring the catheter.

The system was developed using a user centred design methodology with medical doctors, engineers and human factor specialists equally involved in all the development steps. The system was implemented using the AR framework "Studierstube" developed at TU Graz and can be used to visualize in real-time the position of the balloon catheter inside the aorta. The spatial position of the catheter is measured by a magnetic tracking system and superimposed on a 3D model of the patient's thorax. The alignment is made with a rigid registration algorithm. Together with a user defined target, the spatial position data drives an actuator which adjusts the position of the catheter in the initial placement and corrects migrations during the surgery.

Two user studies with a silicon phantom show promising results regarding usefulness of the system: the users perform the placement tasks faster and more accurately than with the current restricted visual support. Animal studies also provided a first indication that the system brings additional value in the real clinical setting. This work represents a major step towards safer and simpler minimally invasive cardiac surgery.

7625-12, Session 3

Evaluation of popular volume rendering algorithms revisited

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For today's medical diagnostic systems the ability to interactively explore large three-dimensional data sets is of foremost importance. In the last years a significant improvement in the flexibility and performance of consumer level graphics cards has been achieved. Several programming APIs are being developed that promise easy access to the potential of these cards.

In this paper four popular algorithms for direct volume rendering on rectilinear grids, namely ray casting, splatting, shear-warp, and 3D texture mapping will be evaluated with respect to these advances. In order to allow for a direct comparison of these four algorithms, a framework was developed that features interactive switching between

the different rendering modules, while keeping all other parameters unchanged. Each algorithm was programmed as a reference implementation using standard C++ and the CG shader programming language where applicable. These reference implementations were then parallelized using CUDA and subsequently optimized for performance. The main focus of the evaluation is performance and image quality for medical imaging. In order to concentrate on the algorithmic performance and to exclude memory transfer bias, medical test data sets were chosen to fit entirely into the graphics card memory of the selected test machine.

An evaluation of the programming effort and the performance benefits of each implementation is presented for each algorithm. Suggestions are made on how to integrate more than one of these algorithms into a hybrid rendering framework for next generation 3D medical imaging systems to take full advantage of the merits of each method.

7625-13, Session 3

Bladder wall flattening with conformal mapping for MR cystography

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Magnetic resonance visual cystoscopy or MR cystography (MRC) is an emerging tool for bladder tumor detection, where two-dimensional (2D) MR slice images are acquired and the 3D inner surface of the bladder wall in the images is routinely examined by radiologists in 2D slice displays. Such process is often time consuming and wearing, and even leads to fatigue error in bladder evaluation and diagnosis. Therefore, 3D endoscopic views on the inner surface are being investigated by researchers. In this paper, we further investigate an innovative strategy of visualizing the inner surface by flattening the 3D surface into a 2D display, where conformal mapping, a mathematically-proved algorithm with shape preserving, is used. The original morphological, textural and even geometric information can be visualized in the flattened 2D image. Therefore, radiologists do not have to manually control the view point and angle to locate the possible abnormalities like what they do in the 3D endoscopic views. Once an abnormality is detected on the 2D flattened image, its locations in the original MR slice images and in the 3D endoscopic views can be retrieved since the conformal mapping is an invertible transformation. In such a manner, the reading time needed by a radiologist can be expected to be reduced. In addition to the surface information, the bladder wall thickness can be visualized with encoded colors on the flattened image. A normal volunteer and a patient studies were performed to test the whole pipeline. The patient dataset shows a noticeable difference on the wall thickness distribution than that of the volunteer's dataset.

7625-14, Session 3

General approach to error prediction in rigid point registration

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Rigid, point registration is typically based on the alignment of localized fiducials. The alignment is achieved by finding a rigid transformation that brings the localized positions in one space as close as possible in the least-squares sense to their corresponding positions in the second space. The optimal transformation is the one that minimizes a weighted sum of squares of the distances between corresponding fiducials. The prediction of error in point registration requires that statistics, typically root-mean-square values, of either fiducial registration error (FRE) and/ or target registration error (TRE) be derived from fiducial configuration, target location, and the distributions of fiducial localization error (FLE). Derivations for FRE and TRE statistics have been published for a variety of forms of the FLE distribution and of weightings schemes, but they are complex and difficult to relate to one another. This paper extends a method, announced at Medim 2009, which is limited to homogeneous, isotropic FLE and uniform weighting. The extended method is a general approach to error prediction that encompasses all these earlier forms simultaneously. The result is a much simpler

derivation and a much more general result. In addition, analysis of correlation between FRE and TRE, which was shown at Medim 2009 to be zero for homogeneous, isotropic FLE with uniform weighting, is extended to the general case, and a hitherto unknown effect of weighting is revealed.

7625-15, Session 3

Correlation of hemodynamical forces and atherosclerotic plaque components

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Local hemodynamic forces in atherosclerotic carotid arteries are thought to trigger cellular and molecular mechanisms that determine plaque vulnerability to rupture. The introduction of image-based computational fluid dynamics (CFD) has allowed researchers to obtain time-resolved wall shear stress (WSS) information of atherosclerotic carotid arteries in vivo. With in vivo WSS information available, a deeper understanding of the mechanisms of initiation and progression of atherosclerosis can be obtained through the comparison of WSS and plaque composition distribution. Magnetic resonance imaging (MRI) has been shown to be able to detect intraplaque hemorrhage, which is an established factor in plaque progression and destabilization. In this study, we proposed comparing 2D representations of the WSS and the thickness between intraplaque hemorrhage and lumen as an effort to determine relationships between WSS patterns and plaque vulnerability. 2D flattened map of a bifurcating artery is especially attractive because it provides a single unobstructed view of the artery, and it allows for an efficient comparison between the 3D distribution of flow patterns and plaque composition, as they are displayed in a 2D fashion.

7625-16, Session 3

Aortic valve and ascending aortic root modeling from 3D and 3D+t CT

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Aortic valve disorders are the most frequent form of valvular heart disorders (VHD) affecting nearly 3% of the global population. A large fraction among them are aortic root diseases, such as aortic root aneurysm, often requiring surgical procedures (valve-sparing) as a treatment. Visual non-invasive assessment techniques could assist during pre-selection of adequate patients, planning procedures and afterward evaluation of the same. However state of the art approaches try to model a rather short part of the aortic root, insufficient to assist the physician during intervention planning. In this paper we propose a novel approach for morphological and functional quantification of both the aortic valve and the ascending aortic root. A novel physiological shape model is introduced, consisting of the aortic valve root, leaflets and the ascending aortic root. The model parameters are hierarchically estimated using robust and fast learning-based methods. Experiments performed on 63 CT sequences (630 Volumes) and 21 single phase CT volumes demonstrated an accuracy of 1.39mm and a speed of 30 seconds (3D+t series) for this approach. To the best of our knowledge this is the first time a complete model of the aortic valve (including leaflets) and the ascending aortic root, estimated from CT, has been proposed.

7625-17, Session 4

Trajectory planning method for reduced patient risk in image-guided neurosurgery: concept and preliminary results

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We present a new preoperative planning method to quantify and reduce the risk of tools trajectories in image-guided keyhole neurosurgery. The goal is to quantify the risk of a proposed straight trajectory and to find the trajectory with the lowest risk to nearby brain structures based on pre-operative CT/MRI images. The method automatically computes the trajectory with the lowest risk to nearby brain structures based on preoperative image segmentation and on a risk volume. The surgeon can then revise the suggested trajectory, and add new ones using interactive 3D visualization and quantitative risk assessment. The trajectory's risk is evaluated based on the tool placement uncertainty, on the proximity of brain structures, and on a table of quantitative geometric risk measures. Our preliminary results on one clinical dataset show a reduction in trajectory risk and planning time when compared to the conventional method.

7625-18, Session 4

Enhancement of subsurface brain shift model accuracy: a preliminary study

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Biomechanical models that describe soft-tissue deformations provide a relatively inexpensive way to correct registration errors in image guided neurosurgical systems caused by non-rigid brain shifts. Quantifying the factors that cause this deformation to sufficient precision is a challenging task. To circumvent this difficulty, atlas-based method have been developed recently which allow for uncertainty yet still capture the first order effects associated with brain deformations. More specifically, the technique involves building an atlas of solutions to account for the statistical uncertainty in factors that control the direction and magnitude of brain shift. The inverse solution is driven by a sparse intraoperative surface measurement. Since this subset of data only provides surface information, it could bias the reconstruction and affect the subsurface accuracy of the model prediction. Studies in intraoperative MR have show that the deformation in the midline, tentorium, and contralateral hemisphere is relatively small. The falx cerebri and tentorium cerebelli, two of the important dural septa, act as rigid membranes supporting the brain parenchyma and compartmentalizing the brain. Accounting for these structures in models may be an important key to improving subsurface shift accuracy. The goals of this paper are to describe a novel method developed to segment the tentorium cerebelli, develop the procedure for modeling the dural septa and study the effect of those membranes on subsurface brain shift.

7625-19, Session 4

Evaluating the feasibility of C-arm CT for brain perfusion imaging: an in vitro study

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Conebeam C-arm CT (CBCT) is being used to supplement 2D real-time data with 3D information. Temporal resolution of the 3D volumes is currently limited by the mechanical rotation speed of the C-arm, and is too slow for imaging contrast dynamics in brain perfusion CT (PCT). We present a novel protocol where multiple scans are obtained at different start times with respect to the start of contrast injection. The data is interleaved temporally and interpolated before 3D reconstruction. To evaluate this protocol we developed a phantom that generates the range of temporal frequencies relevant for PCT. The highest frequencies are seen in the arterial input function (AIF), which can be modeled as a gamma-variate; Fourier transform analysis showed

that 90% of the spectral energy is below ~0.06-0.08Hz. A sinusoidal contrast phantom was built by partitioning an acrylic cylinder into 25 sections, each of length 1cm and filled with iodinated contrast diluted to provide a half sinusoid over the length of the phantom. The phantom was moved linearly at speeds from 0.5cm/s to 4cm/s (temporal frequencies of 0.01Hz to 0.07Hz) and imaged using a C-arm system (6x6 sweeps, 4.3s/sweep, offset -4.6s to +4.6s in increments of 1.8s). Phantom CT numbers in a slice at iso-center were measured and fitted to sinusoids. The fitted sinusoids had frequencies within 3±2% of the actual temporal frequencies of the moving phantom sinusoid. These results show that the offset imaging protocol is adequate for PCT; the impact of scan number reduction on accuracy is under investigation.

7625-20, Session 4

Demons deformable registration for cone-beam CT guidance: registration of pre and intraoperative images in the presence of excised tissue

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The accuracy of fast 3D deformable registration of preoperative images and planning data to intraoperative cone-beam CT (CBCT) was investigated for guiding head and neck surgery. A series of cadaveric surgical procedures were performed to induce a range of deformations and excisions with intraoperative 3D images acquired using a prototype high-performance CBCT capable C-arm. A multi-scale Demons deformable registration algorithm was developed for CBCT-guided head and neck procedures and used to register preoperative images and planning data while accounting for anatomical changes present in each intraoperative image such that the surgeon could navigate within the augmented intraoperative CBCT. Studies were performed under varying degrees of deformation and/or tissue excision. Registration accuracy was quantified in terms of normalized cross correlation and target registration error (TRE). Registration accuracy with deformable registration was far superior to rigid registration alone; however, in the presence of excisions, TRE was found to degrade near the excision site. Approaches were investigated to mitigate this effect and obtain more uniform registration accuracy throughout the volume of interest; a two-pronged approach allowed more robust and accurate registration, including: spatially varying Gaussian smoothing constraints and filtering of the resultant deformation field. Obtaining a high level of registration accuracy quickly throughout the volume of interest facilitates online deformable registration as a means of augmenting intraoperative CBCT with surgical planning data defined preoperatively while accounting for anatomical changes.

7625-21, Session 4

Biomechanical based image registration for head and neck radiation treatment

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A deformable image registration of a head and neck cancer patient is conducted using biomechanical based model. A patient specific 3D finite element model has been developed using CT image data of two radiation treatment sessions. The model consists of seven vertebrae (C1 to C7), mandible, larynx, left and right parotid glands, tumor and body. Different combinations of boundary conditions are applied to the model in order to evaluate the best configuration with a minimum registration error. Each vertebra in the first session is aligned with its correspondence in the second session. Rigid alignment is used for each individual vertebra since little deformation is expected in the bones. In addition, the effect of deformable registration of the external body and rigid registration of the mandible are investigated. The

accuracy of the registration is evaluated using the tumor and left and right parotid glands by comparing the calculated residual difference between the surfaces of these structures following deformation in relation to their true surface defined in the image of the second session. The registration with the smallest residual error is obtained when the vertebrae and mandible are aligned in the two sessions. The vector values of registration error are reduced from 5.4±0.3, 4.1±0.4 and 3.1±0.7 mm using rigid registration of the entire image to 0.7±0.2, 0.7±0.2, and 1.7±0.4 mm in the tumor, left and right parotid glands, respectively.

7625-22, Session 4

Real-time fiber selection using the Wii remote

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In the last few years, fiber tracking tools have become popular in clinical contexts, e.g., for pre- and intraoperative neurosurgical planning. The efficient, intuitive, and reproducible selection of fiber bundles still constitutes one of the main issues. In this paper, we present a framework for a real-time selection of axonal fiber bundles using a Wii remote control, a wireless controller for Nintendo's gaming console. It enables the user to select fiber bundles without any other input devices. To achieve a smooth interaction, we propose a novel space-partitioning data structure for efficient 3D range queries in a data set consisting of precomputed fibers. The data structure which is adapted to the special geometry of fiber tracts allows for queries that are many times faster compared with previous state-of-the-art approaches. In order to extract reliably fibers for further processing, e.g., for quantification purposes or comparisons with preoperatively tracked fibers, we developed an expectation-maximization clustering algorithm that can refine the range queries. A user study has shown that white matter fiber bundles can be reliably selected within a few seconds by the Wii, which has been placed in a sterile plastic bag to simulate usage under surgical conditions.

7625-23, Session 5

Multi-slice to volume registration of ultrasound data to a statistical atlas of human pelvis

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Identifying the proper orientation of the pelvis is a criticaltep in accurate placement of the femur prosthesis in the acetabulum in Total Hip Replacement (THR) surgeries. The general approach to localize the orientation of the pelvis coordinate system is to use X-ray fluoroscopy to guide the procedure. An alternative can be employing intra-operative ultrasound (US) imaging with pre-operative CT scan or fluoroscopy imaging. In this paper, we propose to replace the need of pre-operative imaging by using a statistical shape model of the pelvis, constructed from several CT images. We then propose an automatic deformable intensity-based registration of the anatomical atlas to a sparse set of 2D ultrasound images of the pelvis in order to localize its anatomical coordinate system. In this registration technique, we first extract a set of 2D slices from a single instance of the pelvic atlas. Each individual 2D slice is generated based on the location of a corresponding 2D ultrasound image. Next, we create simulated ultrasound images out of the 2D atlas slices and calculate a similarity metric between the simulated images and the actual ultrasound images. The similarity metric guides an optimizer to generate an instance of the atlas that best matches the ultrasound data. We demonstrate the feasibility of our proposed approach on two male human cadaver data. The registration has been able to instantiate a patient-specific shape with an average

registration error of 6.28 mm and 9.48 mm for the two cadavers, respectively.

7625-24, Session 5

An image-guided femoroplasty system: development and initial cadaver study

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This paper describes the development and initial cadaver study with our image-guided surgical execution system for femoroplasty, which is a prospective alternative treatment option for reducing the risk of fracture in patients with severe osteoporosis. Our goal is to develop an integrated surgical-system that will allow surgeons to augment the femur using patient specific biomechanical planning and analysis tools. This paper focuses on the intraoperative module, which navigates an injection device with reference to the preoperative plan and estimates the distribution of the injected material. Patient registration is performed using intensity-based 2D/3D registration of X-ray images and preoperative CT data. To co-register intraoperative X-ray images and optical tracker coordinates, we implemented a custom optically-tracked fluoroscope fiducial. This fiducial allows real-time visualization of the optically tracked injection device with respect to the patient's femur. During the procedure, X-ray images are acquired to estimate the 3-dimensional distribution of the injected augmentation material. Using this feedback, the injection plan can be adjusted to achieve optimal distribution. In phantom experiments, the average target registration error at the center of the femur head was 1.4 mm and the rotational error was 0.8 degrees when two images were used. The cadaveric study demonstrated efficacy of the navigation system. Our preliminary simulation study of the 3D shape reconstruction algorithm demonstrated that the 3D distribution of the augmented material can adequately be estimated from six X-ray images.

7625-25, Session 5

Active self-calibration of thoracoscopic images for assisted minimally invasive spinal surgery

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Registration of thoracoscopic images to a preoperative 3D model of the spine is a prerequisite for minimally invasive surgical guidance. We propose an active self-calibration method of thoracoscopic image sequences acquired by an angled monocular endoscope with varying focal length during minimally invasive surgery of the spine. The extrinsic parameters are updated in real time by a motion tracking system while the intrinsic parameters are determined from a set of geometrical primitives extracted from the image of the surgical instrument tracked throughout the thoracoscopic sequence. A particle filter was used for the tracking of the instrument on the image sequence that was preprocessed to detect and correct reflexions due to the light source. The proposed method requires undertaking a pure rotation of the endoscope to update the focal length and exploits the inherent temporal rigid motion of the instrument through consecutive frames. A pure rotation is achievable by undertaking a rotation of the scope cylinder with respect to the head of the camera. Therefore, the surgeon may take full advantage of an angled endoscope by adjusting focus and zoom during surgery. Simulation experiments have assessed the accuracy of the obtained parameters and the optimal number of geometrical primitives required for an active self-calibration of the angled monocular endoscope. Finally, an in vitro experiment demonstrated that 3D reconstruction of rigid structures tracked throughout a monocular thoracoscopic image sequence is feasible and its accuracy is adequate for the registration of thoracoscopic images to a preoperative MRI 3D model of the spine.

7625-26, Session 5

Group-wise feature-based registration of CT and ultrasound images of spine

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A method for group-wise registration of pre-operative CT and intra-operative freehand 2-D ultrasound images of the lumbar spine is presented. The approach utilizes a point-based registration technique based on the unscented Kalman filter, taking as input segmented vertebrae surfaces in both CT and ultrasound data. Ultrasound images are automatically segmented using a dynamic programming approach, while the CT images are semi-automatically segmented using thresholding. Since the curvature of the spine is different between pre-operative and intra-operative data, the registration approach is designed to simultaneously align individual groups of points segmented from each vertebra in the two imaging modalities. A biomechanical model is used to constrain the vertebrae transformation parameters during registration and to ensure convergence. The mean target registration error achieved for individual vertebrae is 2.43 mm with standard deviation of 2.26 mm.

7625-27, Session 5

Plan to procedure: combining 3D templating with rapid prototyping to enhance pedicle screw placement

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Spinal fusion procedures involving the implantation of pedicle screws have steadily increased over the past decade because of demonstrated improvement in biomechanical stability of the spine. However, current methods of spinal fusion carries a risk of serious vascular, visceral, and neurological injury caused by inaccurate placement or inappropriately sized instrumentation, which may lead to patient paralysis or even fatality. 3D spine templating software developed by the Biomedical Imaging Resource (BIR) at Mayo Clinic allows the surgeon to virtually place pedicle screws using pre-operative 3D CT image data. With the template plan incorporated, a patient-specific 3D anatomic model is produced using a commercial rapid prototyping system. The pre-surgical plan and the patient-specific model then are used in the procedure room to provide real-time visualization and quantitative guidance for accurate placement of each pedicle screw, significantly reducing risk of injury. A pilot study was conducted at Mayo Clinic by the Department of Radiology, the Department of Orthopedics, and the BIR, involving six complicated pediatric spine cases. In each case, pre-operative 3D templating was carried out and patient specific models were generated. The plans and the models were used intra-operatively, providing precise pedicle screw starting points and trajectories. Post-operative assessment by the surgeon confirmed all six operations were successful. Results from the study suggest that patient-specific, 3D anatomic models successfully acquired from 3D templating tools are valuable for planning and conducting pedicle screw insertion procedures.

7625-28, Session 6

Validation platform for ultrasound-based monitoring of thermal ablation

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PURPOSE: A ground-truth validation platform was developed to provide spatial correlation between US, temperature measurements and histopathology images to validate US based thermal ablation monitoring methods. METHOD: The apparatus consists of a container box with integrated fiducial lines. The box is filled with gel, with the suspended tissue sample inside. Following US imaging, the gel block is sliced and pathology images are acquired. Interactive software segments the fiducials and structures of interest in the pathology and US images. The software reconstructs the regions in 3D space and performs analysis and comparison of the features identified from pathology and ultrasound. RESULTS: The apparatus and software were constructed to meet technical requirements. Shapes were contoured, reconstructed and registered in the common coordinate system of fiducials. There was agreement between the shapes, but systematic shift of several millimeters was found between histopathology and US. This indicates that during pathology slicing shear forces tend to dislocate the fiducial lines. Softer fiducial lines and harder gel material can eliminate this problem. CONCLUSION: Viability of concept was presented. Despite our straightforward approach, further experimental work is required to optimize all materials and customize software.

7625-28, Session 6

The potential of focused ultrasound for brain treatments

K. H. Hynynen, Sunnybrook Health Sciences Ctr. (Canada)

Focused Ultrasound is a noninvasive method to deliver highly concentrated mechanical energy deep in the body and it has been explored for tissue ablation for over half a century. Safe clinical use requires that the focus is guided by an imaging method. Magnetic Resonance Imaging (MRI) provides such features as excellent soft tissue contrast, which make it well suited for the guidance of focused energy delivery.

Animal experiments have shown that focused ultrasound exposures can induce transient and local increase in the cell membrane or blood vessel wall permeability. This may allow localization of the treatment based on imaging information. This potential for delivering large molecules into an image defined location has especially high potential in the brain where the Blood-Brain barrier (BBB) prevents the diffusion of most therapeutic and imaging agents into the brain from the blood vessels. Focused ultrasound has now been explored by several research groups for the disruption the blood-brain barrier for targeted delivery of therapy agents. This method coupled with the development of phased array methods for focusing ultrasound exposures through intact skull may have significant potential in future clinical patient care.

In this talk the basic concepts of ultrasound induced BBB disruption will be reviewed. The animal experiments conducted so far for the utilization of the method for the treatment of brain will be summarized.

7625-29, Session 6

Development of an MRI-compatible focused-ultrasound system for the investigation of novel therapeutic applications in preclinical animal models

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MRI-guided focused-ultrasound therapy is being investigated as a non-invasive method to improve the delivery of therapeutic agents in the body. The goal of this work was to develop a focused-ultrasound system, for preclinical investigations, that is capable of operating within a closed-bore MRI. The system uses piezoelectric actuators and optical encoders to position a focused-ultrasound transducer to targeted tissues under MRI guidance. The actuator and encoder signals are transmitted through low-pass-filtered connectors on a grounded RF-penetration panel to prevent signals from the drive electronics

from corrupting image acquisition. The transducer is attached to the positioning system by a rigid beam and is submerged within a closed water tank. The beam passes into the tank through flexible bellows to ensure that the system remains sealed. An RF coil acquires high-resolution images in the vicinity of the target tissue. An aperture on the water tank, centered about the RF coil, provides an access point for target sonication. Registration between ultrasound and MRI coordinates involves sonicating a temperature-sensitive phantom and measuring the centroid of the thermal focal zone in 3D. A 5 cm linear travel with a positioning resolution of 0.05 mm was achieved for each axis. The entire system was constructed with non-magnetic components and operation of the system within the bore of clinical MRI scanners of different manufacturers was feasible. Simultaneous motion during imaging did not result in any mutual interference or image artifacts. This system can be used for high-throughput small-animal experiments to study the efficacy of ultrasound-enhanced drug delivery.

7625-29, Session 6

Calibration of temperature measurements with CT for ablation of liver tissue

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Purpose: It was the aim of this study to calculate the relationships between the CT value and temperature for the range of ablation therapy.

Materials and Methods: Bovine liver was heated by different methods concerning only steady heat growth on the sample. Image acquisition was performed with a clinical multi-slice CT scanner before and during ablation. Real time temperature was measured and stored using calibrated thermal sensors. Images were analyzed at CT workstation.

Results: It was feasible to validate the spatial and temporal temperature growth during heating by means of declining CT values in the performed images. The change of CT value with respect to temperature rise was found to be linear. The thermal sensitivity for liver tissue was -0.54±0.10 HU/ °C.

Conclusion: It is shown that CT can be calibrated to predict temperature distribution during heating.

7625-30, Session 6

The ACUSITT ultrasonic ablator: the first steerable needle with an integrated interventional tool

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Steerability in percutaneous medical devices is highly desirable, enabling the needle to avoid sensitive structures (e.g. nerves or blood vessels), access obstructed anatomical targets, and compensate for the inevitable errors induced by registration accuracy thresholds and tissue deformation during insertion. Thus, mechanisms for needle steering have been of great interest to the engineering community in the past few years, and several have been proposed. While many interventional applications have been hypothesized for steerable needles (essentially anything deliverable via a regular needle), none have yet been demonstrated as far as the authors are aware. Instead,

prior papers focus on model validation and accuracy assessment. In this paper, we present the first integrated steerable needle-interventional device. The ACUSITT integrates a multi-tube steerable Active Cannula (AC) with an Ultrasonic Interstitial Thermal Therapy ablator (USITT) to create a steerable percutaneous device that can deliver a spatially and temporally controllable (both mechanically and electronically) thermal dose profile. We present our initial experiments toward applying the ACUSITT to treat large liver tumors through a single insertion. This involves repositioning the ablator tip to several different locations, without withdrawing it from the liver capsule, under 3D Ultrasound image guidance. In our experiments, the ACUSITT was deployed to three positions, each 2cm apart in a conical pattern to demonstrate the capability of ablating large liver tumors 7cm in diameter through a single entry point into the liver capsule.

7625-30, Session 7

Respiratory effects in PET/CT imaging: impact on diagnosis, quantitative estimation, and therapy

P. E. Kinahan, Univ. of Washington (United States)

Multi-modality imaging with PET/CT scanners has had a tremendous impact on cancer management over the last decade. Future roles include treatment planning, cardiac imaging, and quantitative estimation of response to therapy. However, respiratory motion introduces several confounding aspects that can limit the utility of PET/CT imaging procedures. We review the current and potential uses of PET/CT imaging and the impact of respiratory motion from both the CT and PET components of an imaging study. The small amount of data on respiratory patterns during extended imaging procedures and methods of acquisition will be reviewed. A hierarchy of available and potential respiratory motion compensation methods is outlined, where the cost and complexity of the method can depend on the diagnostic or therapeutic task.

7625-31, Session 7

Particle filtering for respiratory motion compensation during navigated bronchoscopy

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Although the field of navigated bronchoscopy is gaining increasing attention in literature, robust guidance in the presence of respiratory motion and electromagnetic noise remains challenging. In previous work, we introduced a motion compensation approach which continuously matches incoming tracking data to the centerline of the bronchial tree, extracted from a pre-interventional planning image according to a nearest neighbor approach (centerline matching). The purpose of this study is to increase the robustness of the existing method by taking into account the already traveled trajectory of the instrument within the lung. For this purpose, we integrate the particle filtering method with the centerline matching method and evaluate the performance of the combined method in a virtual environment, which accounts for respiratory motion and electromagnetic noise. The simulation is based on a deformation field computed from human computed tomography data. According to the results, the proposed method outperforms the original centerline matching method and is suitable for lung motion compensation during electromagnetically guided interventions.

7625-32, Session 7

Structured light 3D tracking system for measuring motions in PET brain imaging

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Positron emission tomography (PET) imaging has changed the impact and standards of nuclear medicine. In the last decade PET image quality has improved considerably. The High Resolution Research Tomograph (HRRT, Siemens) is a brain dedicated scanner, with a resolution down to 1.4 mm. If no corrections for patient head movements are performed, head movements lead to degradation of image-quality especially during long acquisitions. This degradation increases with increasing scanner resolution and thus head movements end up counteracting the technological advances of high resolution scanners. In this paper a new proposal of a 3D head tracking system for high resolution PET brain imaging is demonstrated. A prototype of a tracking system based on structured light with a DLP projector and CCD camera is set up on a model of the HRRT PET scanner. Fringe projection is used to reconstruct a 3D point cloud of simple surfaces. Four patterns are captured for each point cloud. Three shifted sinus patterns and a center line cross to generate an absolute phase-map. Corresponding CCD pixels and lines on the DMD (digital micromirror device) are associated by the phase-map. The phase image is unwrapped using path integration of each line. The captured images are corrected for the non-linearity of the projector output. The results are convincing and a first step toward a fully automated tracking system for measuring of head movements in PET imaging.

7625-33, Session 7

Model-based Lasso catheter tracking in monoplane fluoroscopy for 3D breathing motion compensation during EP procedures

R. Liao, Siemens Corporate Research (United States)

Presentation of detailed anatomical structures via 3-D CT and/or MR volumes helps visualization and navigation in electrophysiology procedures (EP). Unfortunately, respiratory motion may impair the utility of static overlay of the volume with fluoroscopy for catheter navigation. In this paper, we propose a B-spline based method for tracking the circumferential catheter (lasso catheter) in monoplane fluoroscopy. The tracked motion can be used for the estimation of the 3-D trajectory of breathing motion and for subsequent motion compensation. A lasso catheter is typically used during EP procedures and is pushed against the ostia of the pulmonary vein (PV) to be ablated. Hence this method does not require additional instruments, and achieves motion estimation right at the site of ablation. The performance of the proposed tracking algorithm was evaluated on 340 monoplane frames with an average error of 0.68 ± 0.36 mms. Our contributions in this work are twofold. First and foremost, we show how to design an effective, practical, and workflow-friendly 3-D motion compensation scheme for EP procedures in a monoplane setup. In addition, we develop an efficient and accurate method for model-based tracking of the circumferential lasso catheter in the low-dose EP fluoroscopy.

7625-34, Session 7

Four dimensional MRI of respiratory organ motion using an intersection profile method

Y. Masuda, H. Haneishi, Chiba Univ. (Japan)

We propose an intersection profile method for reconstructing a four-dimensional magnetic resonance (4D-MR) image of respiratory organ motion from time sequential images of two-dimensional (2D-) MRI. In the proposed method, first, time sequential MR images in many coronal planes set to widely cover the lung area are acquired as data slices. Second, time sequential MR images in a proper sagittal plane are acquired as a navigator slice. 2D spatio-temporal (2D-ST) images, which are the time sequential array of profiles along the intersection of two kinds of slices, are generated for both the navigator slice and the data slices. After a proper respiratory pattern (template) is extracted from the 2D-ST images of the navigator slice, the template matching by a normalized cross-correlation is carried out to find a similar respiratory pattern from the 2D-ST images of data slices. 4DMR images are reconstructed by applying this process to each data slice.

Two volunteers were scanned using the 1.5T Intera Achiva Nova-dual (Philips Medical Systems). Reconstructed 4D-MR images were visualized by a volume rendering technique implemented in Osirix. Very natural motion of lung was observed. The accuracy of the reconstruction was evaluated by comparing the real navigator slice and the corresponding sagittal slice cut from the 4D-MRI. Three marked points on the diaphragm were chosen and the displacement between the navigator slice and a sagittal slice cut from 4D-MR images was calculated. Then mean error ranged from 0.8 to 1.5 mm. This is sufficiently accurate for clinical use.

7625-57, Poster Session

3D visualization of medical imaging using static volumetric display, Cspace

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We present a stereoscopic static volumetric display called CSpace, which is capable of projecting three-dimensional (3D) medical imaging data set in 3D world coordinates. The displayed 3D data set can be viewed in the optical medium, without the use of any headset and from any perspective angle, when dual infrared (IR) laser beams intersect with each other at specified volume elements, or voxels, according to the object's geometry. Our display does not utilize any mechanical parts, instead it implements two digital light projection (DLP) systems to render the 3D object. Thus, it has the ability of achieving high refreshing rate at large spatial resolution which makes it dominant over the other 3D displays for telemedicine and medical visualization. The design of CSpace allows us to perform a volume rendering technique by which we display the surface and the interior of any organ of the human body. Therefore, the adjacent tissues can be monitored in a 3D aspect and diseases' diagnosis will be more accurate. In this paper, we explain the optical concepts of visualizing the 3D object and describe the hardware specifications used in the CSpace display. Also, we have developed a novel software architecture that can read various medical imaging files' extensions, acquire the imaging parameters that specify how these images have been captured by ultrasound, magnetic resonance imaging (MRI) and computed tomography (CT) scanners from the files' header, then applying these parameters on the rendered 3D object to be displayed exactly as it was captured. The animation concept implemented in CSpace software that enables us to demonstrate many 3D scenes, each of them represents the organ at specific time, is fully addressed in the paper.

7625-58, Poster Session

Cross modality registration of video and magnetic tracker data for 3D appearance and structure modeling

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The paper reports a fully-automated, cross-modality sensor data registration scheme between video and magnetic tracker data. This registration scheme is intended for use in computerized imaging systems to model the appearance, structure, and dimension of human

anatomy in three dimensions (3D) from endoscopic videos, particularly colonoscopic videos, for cancer research and clinical practices. The proposed

cross-modality calibration procedure operates this way: Before a colonoscopic procedure, the surgeon fixes the tracker's position on the scope. The surgeon then maneuvers the scope-tracker assembly to view a checkerboard calibration pattern from a few different viewpoints for a few seconds. The calibration procedure is then completed, and the relative pose (translation and rotation) between the reference frames of the magnetic tracker and the scope is determined. During the colonoscopic procedure, the readings from the magnetic tracker are used to automatically deduce the pose of the scope's reference frame over time, without complicated image analysis. Knowing the scope movement over time then allows us to infer the 3D appearance and structure of the organs and tissues in the scene. While there are other well-established mechanisms for inferring the movement of the camera from images, they are often sensitive to mistakes in image analysis, error accumulation, and structure deformation. The proposed method using a magnetic tracker to establish the camera motion parameters thus provides a robust and efficient alternative for 3D model construction. Furthermore, the calibration procedure does not require special training nor use expensive calibration equipment except for a checkerboard pattern.

7625-59, Poster Session

Reconstruction and visualization of model-based volume representations

Z. Zheng, K. D. Mueller, Stony Brook Univ. (United States)

In modern medical CT, the primary source of data is a set of X-ray projections acquired around the object, which are then used to reconstruct a discrete regular grid of sample points. Conventional volume rendering methods use these reconstructed regular grid to estimate unknown off-grid values via interpolation. However, these interpolated values may not match the values that would have been generated had they been reconstructed directly with CT. The consequence can be simple blurring, but also the omission of fine object detail which usually contains precious information. To avoid these problems, in the method we propose, instead of reconstructing a lattice of volume sample points, we derive a high-fidelity object model directly from the reconstruction process, fitting a localized object model to the acquired raw data within tight tolerances. This model can then be easily evaluated both for slice-based viewing as well as in GPU 3D volume rendering, offering excellent detail preservation in zooming operations Furthermore, the model-driven representation also supports high-precision analytical ray tracing. Finally, the framework is also well suited to support more complex reconstruction algorithms.

7625-60, Poster Session

automatic feature detection for 3D surface reconstruction in HDTV endoscopic images

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Computer-assisted laparoscopic surgery could benefit considerably from accurate 3D reconstruction of organ surfaces derived from 2D endoscopic images. Typically, the reconstruction requires detection and tracking of characteristic features in multiple 2D images. Unfortunately, the proposed methods still suffer from the generally low resolution of the applied endoscopes, which makes robust and accurate feature tracking challenging. In this paper, we assess the dependency of the quality of feature detection and tracking by applying several state-of-the art feature descriptors to both, standard PAL endoscopic images and HDTV endoscopic images.

7625-61, Poster Session

Parameter space visualizer: an interactive parameter selection interface for iterative CT reconstruction algorithms

W. Xu, K. D. Mueller, Stony Brook Univ. (United States)

Previous work indicated that using ordered subsets (OS-SIRT) for iterative CT can optimize the reconstruction performance once optimal settings for parameters such as number of subsets and relaxation factor have been identified. However, recent work also indicated that the optimal settings have dependent relations with regards to the quality of the projection data (such as SNR-level), which are hard to obtain a-priori. In addition, users may also have preferences in trading off between the dependent parameters, such as reconstruction speed and quality, which makes these (independent) parameters even more difficult to determine in an automated manner. Therefore, we devise an effective parameter space navigation interface allowing users to interactively assist parameter selection for iterative CT reconstruction algorithms (here for OS-SIRT). It is based on a 2D scatter plot with six display modes to show different features of the reconstruction results based on the user preferences. It also enables a dynamic visualization by gradual parameter alteration for illustrating the rate of impact of a given parameter constellation. Finally, we note the generality of our approach, which could be applied to assist any parameter selection related systems.

7625-62, Poster Session

Real-time simulation of dynamic fluoroscopy of ERCP

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This paper discusses the methods for real-time rendering of time-varying dynamic fluoroscope images including fluid flow for the ERCP (Endoscopic Retrograde Cholangiopancreatography) simulation. A volume rendering technique is used to generate virtual fluoroscopy images. The paper proposes an image-overlapping method which overlaps the time-varying images onto the constant background image. The full size fluoroscopy image is computed from the initial volume data set during the pre-processing stage, which is then saved as the background image. Only the time-varying images are computed from the time-varying volume data set during the actual simulation. This involves relatively small computation compared with the background image. The time-varying images are then overlapped onto the background image to obtain the final images. The method reduces computation by removing redundant computations. A simplified particle dynamics model is employed for fast simulation of fluid flow. The fluid model, a collection of particles, interacts only with the ducts based on principles of a complete elastic collision. Hence, the velocity of the particles when they collide with the duct can be computed by simple algebraic equations. The methods are implemented for a simulation of the ERCP.

7625-126, Poster Session

PIRATE: Pediatric imaging response assessment and targeting environment

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By combining the strengths of various imaging modalities, the multimodality imaging approach has potential to improve tumor staging, delineation of tumor boundaries, chemo-radiotherapy regime design, and treatment response assessment in cancer management. To address the urgent needs for efficient tools to analyze large-scale clinical trial data, we have developed an integrated multimodality,

functional and anatomical imaging analysis software package for target definition and therapy response assessment in pediatric radiotherapy (RT) patients. Our software provides quantitative tools for automated image segmentation, region-of-interest (ROI) histogram analysis, spatial volume-of-interest (VOI) analysis, and voxel-wise correlation across modalities. To demonstrate the clinical applicability of this software, histogram analyses were performed on baseline and follow-up 18F-fluorodeoxyglucose (18F-FDG) PET images of nine patients with rhabdomyosarcoma enrolled in an institutional clinical trial at St. Jude Children's Research Hospital. In addition, we combined 18F-FDG PET, dynamic-contrast-enhanced (DCE) MR, and anatomical MR data to visualize the heterogeneity in tumor pathophysiology with the ultimate goal of adaptive targeting of regions with high tumor burden. Our software is able to simultaneously analyze multimodality images across multiple time points, which could greatly speed up the analysis of large-scale clinical trial data and validation of potential imaging biomarkers.

7625-63, Poster Session

3D automatic anatomy recognition based on iterative graph-cut-ASM

X. Chen, J. K. Udupa, The Univ. of Pennsylvania Health System (United States); U. Bagci, The Univ. of Nottingham (United Kingdom); A. Alavi, D. A. Torigian, The Univ. of Pennsylvania Health System (United States)

We call the computerized assistive process of recognizing, delineating and quantifying organs and tissue regions in medical imaging, occurring automatically during clinical image interpretation, automatic anatomy recognition (AAR). The AAR system we are developing includes five main parts: model building, object recognition, object delineation, pathology detection, and organ system quantification. In this paper, we focus on the delineation aspect. For the modeling part, we employ the ASM strategy. For recognition and delineation, we are integrating several hybrid strategies of combining purely image based methods with ASM. In this paper, an iterative Graph-Cut ASM (IGCASM) method is proposed for object delineation. An algorithm called GC-ASM was presented at this symposium last year for object delineation in 2D images which attempted to combine synergistically ASM and GC. Here, we extend this method to 3D medical image delineation. The IGCASM method effectively combines the rich statistical shape information embodied in ASM with the globally optimal delineation capability of the GC method. We propose a new GC cost function, which effectively integrates the specific image information with the ASM shape model information. The proposed methods are tested on a clinical abdominal CT data set. The preliminary results show that: (a) it is feasible to explicitly bring prior 3D statistical shape information into the GC framework; (b) the 3D IGCASM delineation method improves on ASM and GC and can provide practical operational time on clinical images.

7625-64, Poster Session

Catheter tracking in asynchronous biplane fluoroscopy images by 3D b-snakes

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Minimally invasive catheter ablation procedures are guided by biplane fluoroscopy images visualising the interventional scene from two different orientations. However, these images do not provide direct access to their inherent spatial information. A three-dimensional measurement and visualisation of the catheters from such projections therefore has the potential to support quick and precise catheter navigation. It enhances the perception of the interventional situation and provides means of three-dimensional catheter pose documentation. In order to address this issue we developed an algorithm for tracking the three-dimensional pose of electro-physiological catheters in biplane fluoroscopy images. It is based on the B-Snake algorithm which had to be adapted to the biplane and

in particular the asynchronous image acquisition situation. A three-dimensional B-spline curve is transformed so that its projections are consistent with the catheter path enhancing feature images, while the information from the missing image caused by the asynchronous acquisition is interpolated from its sequence neighbours. In order to analyse the three-dimensional precision despite the acquisition situation, virtual images were created from patient data sets and three-dimensional ground truth catheter paths. The evaluation of the three-dimensional catheter pose reconstruction by means of our algorithm on 33 of such virtual image sets indicated a mean pose RMSE along the catheter path of 0.93 mm and a mean tip deviation of 2.40 mm.

The tracking capability of the algorithm was evaluated on 10 patient data sets. In 94% of all images our algorithm followed the catheter projections.

7625-65, Poster Session

A gold-standard dataset for 2D/3D image registration evaluation

S. Ardjo Pawiro, Medizinische Univ. Wien (Austria); P. Markelj, Univ. of Ljubljana (Slovenia); C. Gendrin, M. Figl, M. Stock, C. Bloch, C. Weber, E. Unger, I. Noebauer-Huhmann, F. Kainberger, H. Bergmeister, D. Georg, H. Bergmann, W. Birkfellner, Medizinische Univ. Wien (Austria)

A gold standard data set for evaluation of 2D/3D image registration algorithms is presented. We propose a standard data set using a pig head with attached fiducial markers. Several imaging modalities common in diagnostic imaging or radiotherapy were used. Radiographic data was acquired using kV and MV imaging techniques. The 3D and 2D images were segmented using Analyze 9.0 (AnalyzeDirect, Inc)and in-house software. Precise marker positions are provided alongside with the image data. The expected target registration error was found less than 2 mm for CT, MR with T1 weighted, MR with T2 weighted, and MR with proton density weighted to X-ray registration. A new gold standard data set, obatined with state-of-art imaging technology, has the potential to improve the validation of 2D/3D registration algorithm for image guided therapy.

7625-66, Poster Session

A comment to the rank correlation merit function for 2D/3D registration

M. Figl, C. Bloch, W. Birkfellner, Medizinische Univ. Wien (Austria)

Lots of procedures in computer assisted interventions register pre-interventionally generated 3D data sets to the intraoperative situation using fast and simply generated 2D images, e.g. from a C-Arm, a B-mode Ultrasound, etc. Registration is typically done by generating a 2D image out of the 3D data set, comparison to the original 2D image using a planar similarity measure and subsequent optimisation. As these two images can be very different, a lot of different comparison functions are in use.

In a recent article Stochastic Rank Correlation, a merit function based on Spearman's rank correlation coefficient was presented.

By comparing randomly chosen subsets of the images, the authors wanted to avoid the computational expense of sorting all the points in the image.

In the current paper we show that, because of the limited grey level range in medical images, full image rank correlation can be computed almost as fast as Pearson's correlation coefficient.

A run time estimation is illustrated with numerical results using a 2D Shepp-Logan phantom at different sizes, and a sample data set of a pig.

7625-67, Poster Session

Influence of intensity standardization on medical image registration

U. Bagci, The Univ. of Nottingham (United Kingdom); J. K. Udupa, The Univ. of Pennsylvania Health System (United States)

Acquisition-to-acquisition signal intensity variations (non-standardness) are inherent in MR images. Intensity standardization is a post processing method for correcting inter-subject intensity variations through transforming all images from the given image gray scale into a standard gray scale so that similar intensities achieve similar tissue meanings. The lack of a standard image intensity scale in MRI leads to many difficulties in tissue characterizability, image display, and analysis, including image segmentation. The influence of standardization on these tasks has been documented well; however, the effects of standardization on medical image registration have not been studied yet. In this paper, we investigate the role of intensity standardization in registration tasks with systematic and analytic evaluations involving clinical MR images. We conducted nearly 20,000 clinical MR image registration experiments and evaluated the registrations both quantitatively and qualitatively. The evaluations show that intensity variations between images degrade the accuracy of registration performance. The results imply that the accuracy of image registration not only depends on spatial and geometric similarity but also on the similarity of the behavior of intensity values for the same tissues in different images.

7625-68, Poster Session

Non-rigid registration for quantification of intestinal peristalsis on dynamic MRI data

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Diseases of the intestinal tract often begin with changes altering the bowel tissue elasticity. Therefore, quantification of bowel motion would be desirable for diagnosis, treatment monitoring and follow-up. Dynamic MRI can capture such changes, but quantification requires non-rigid registration.

Towards a computer-assisted quantification for bowel diseases, two innovative methods for detection of bowel motility restrictions have been developed and evaluated. Therefore a coronal 2D+t image will be extracted from a dynamic 3D MRI dataset and registered non-rigidly over multiple time steps. The first method generates a new image from the resulting motion maps by adding the absolute value of the vector for each pixel to the corresponding values in following time steps. The second method calculates the absolute values only from the lateral part of the vectors, skipping the coronal part, and thus removes large distortions due to movements caused by breathing. In this preliminary evaluation both methods will be compared in regard to 5 healthy subjects (volunteers) and 5 patients with proven restrictions in bowel motility.

It was shown, that for the first method with respiration a classification of volunteers and patients is only partly possible. However, the second method turns out to be capable of classifying normal and restricted bowel peristalsis. For the second method the mean motion from patients motion maps are about 34.4% lower than that from volunteers motion maps. Therefore, for the first time such a classification is possible.

7625-69, Poster Session

Pre-tuned resonant marker for iMRI using aerosol deposition on polymer catheters

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New advances in MRI technology enable fast acquisition of high-resolution images. In combination with the new open architecture this scanners are entering the surgical suite being used as intra-operative imaging modality for minimally invasive interventions. However, for a usage on a large scale the major issue of availability of appropriate surgical tools is still unsolved. Such instruments, i.e. needles and catheters have to be MR-safe and -compatible but in contrast still have to be visible within the MRI image. This usually is solved be integration of markers onto non-magnetic devices. For reasons of MR-safety, work-flow and cost effectiveness semi-active markers without any connection to the outside are preferable. The challenge in development and integration of such resonant markers is to precisely meet the MRI frequency by keeping the geometrical dimensions of the interventional tool constant. This paper focuses on the reliable integration and easy fabrication of such resonant markers on the tip of an interventional instrument. Starting with a theoretical background for resonant labels a self-sufficient pre-tuned marker consisting of a standard capacitor and a thin-film inductor is presented. A prototype is built using aerosol deposition for the inductor on a 6-F polymer catheter and by integration of an off-the-shelf capacitor into the lumen of the catheter. Due to the fact that the dielectric materials of some capacitors lead to artifacts in the MRI image different capacitor technologies are investigated. The prototypes are scanned by an interventional MRI device proving the proper functionality of the tools.

7625-70, Poster Session

Robotically assisted small animal MRI-guided mouse biopsy

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Small mammals, namely mice and rats, play an important role in biomedical research. Imaging, in conjunction with percutaneous biopsies, have tremendous value in small animal research since it enables serial, non-destructive testing of animals and facilitates the study of biomarkers of disease progression. The small size of organs in mice lends some difficulty to accurate biopsies. Image-guidance with the use of robotic devices enable more accurate and repeatable biopsies, as well as the ability to acquire tissue from a pre-specified location based on imaging outcome. This paper presents the results of our effort to integrate a robotic needle guide device, specialized stereotaxic mouse holder and magnetic resonance imaging, to perform accurate and repeatable biopsies in anesthetized mice studies.

7625-71, Poster Session

A rapid method for compensating registration error between tracker and endoscope in flexible neuroendoscopic surgery navigation system

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This paper presents a rapid method for compensating registration error between tracker and endoscope in flexible neuroendoscopic surgery navigation system. Recently, flexible neuroendoscopic surgery navigation systems have been developed utilizing an electromagnetic tracker (EMT). In such systems, an electromagnetic tracker sensor is fixed at the tip of flexible endoscope to get the position and orientation of the endoscope camera by using the relationship between camera and sensor. Usually, the relationship is estimated by a registration method via a calibration chart. Then, the virtual images corresponding to real endoscopic views are generated by using the position and orientation of the camera. However, in the clinical application, the sensor has to be re-fixed before or during

the surgery due to its disinfection or breakage. Although the sensor can be re-fixed at the same position as the registered position, it is difficult to ensure the roll of sensor in the same because the senor is a cylinder. Furthermore, the sensor is also rotated by the operation of tools sometimes during the operation. As a result, the virtual images will be rotated and become greatly different from the real endoscopic views. In this case, the relationship between camera and sensor has to be re-estimated by registration methods or manually, which makes the operation of endoscope complicated and nonfeasible. In order to overcome this problem, we propose a rapid method for compensating the rotation error between real and virtual images. In the proposed method, epipolar geometry is used to estimate the epipole of the real endoscope views and corresponding virtual images in different view points. Then the rotation error of the registration is estimated by using the epipoles of real and virtual images. An evaluating method is also designed to evaluate the accuracy of the proposed method. According to the result of experiments, the proposed method can reduce the rotation error of registration to less than 10 degree.

7625-72, Poster Session

A system for advanced real-time visualization and monitoring of MR-guided thermal ablations

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In modern oncology, thermal ablations are increasingly used as a regional treatment option to supplement systemic treatment strategies such as chemotherapy and immunotherapy. The goal of all thermal ablation procedures is to cause cell death of disease tissue while sparing adjacent healthy tissue. Real-time assessment of thermal damage is the key to therapeutic efficiency and safety of such procedures. Magnetic resonance thermometry is capable of monitoring the spatial distribution and temporal evolution of temperature changes during thermal ablations. In this work, we present an advanced monitoring system for MR-guided thermal ablations that includes multiplanar visualization, specialized overlay visualization methods, and additional methods for correcting errors resulting from magnetic field shifts and motion. To ensure the reliability of the displayed thermal data, systematic quality control of thermal maps is carried out on-line. The primary purpose of this work is to provide clinicians with an intuitive tool for accurately visualizing the progress of thermal treatment at the time of the procedure. Importantly, the system is designed to be independent of the heating source. The presented system is expected to be of great value not only to guide thermal procedures but also to further explore the relationship between temperature-time exposure and tissue damage. The software application was implemented within the open source eXtensible Imaging Platform (XIP) and has been validated with clinical data.

7625-73, Poster Session

Evaluation of nonholonomic needle steering using a robotic needle driver

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Accurate needle placement is a common need in the medical environment. While the use of small diameter needles for clinical applications such as biopsy, anesthesia and cholangiography is preferred over the use of larger diameter needles, precision placement can often be challenging, particularly for needles with a bevel tip. This is due to deflection of the needle shaft caused by asymmetry of the needle tip. Factors such as the needle shaft material, bevel design, and properties of the tissue penetrated determine the nature and extent to which a needle bends. In recent years, several models have been developed to characterize the bending of the needle, which provides a method of determining the trajectory of the needle through tissue. This paper explores the use of a nonholonomic model to characterize needle bending while providing added capabilities of path planning, obstacle avoidance, and path correction for lung biopsy procedures. We used a ballistic gel media phantom and a robotic needle placement device to experimentally assess the accuracy of simulated needle paths based on the nonholonomic model. Two sets of experiments were conducted, one for a single bend profile of the needle and the second set of tests for double bending of the needle. The tests provided an average error between the simulated path and the actual path of 0.8mm for the single bend profile and 0.9mm for the double bend profile tests over a 110 mm long insertion distance. The maximum error was 7.4mm and 6.9mm for the single and double bend profile tests respectively. The nonholonomic model is therefore shown to provide a reasonable prediction of needle bending.

7625-74, Poster Session

Relative versus absolute error characterization of electromagnetic tracking accuracy

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Electromagnetic (EM) tracking systems are often used for real time navigation of medical tools in an Image Guided Therapy (IGT) system. They are specifically advantageous when the medical device requires tracking within the body of a patient where line of sight constraints prevent the use of conventional optical tracking. EM tracking systems are however very sensitive to electromagnetic field distortions. These distortions, arising from changes in the electromagnetic environment due to the presence of ferromagnetic surgical tools or other medical equipment, limit the accuracy of EM tracking. We describe a method to analyze the spatial distortion within the range over which EM tracking sensors are used. This method allows for characterization of relative measurement errors. As compared to absolute measurement errors, relative errors are less sensitive to distortions and indicate lower values.

In our approach, we employ a calibration phantom to assess distortion of the EM tracker and display the distribution of measurement errors, as well as the location and extent of the field associated with minimal spatial distortion. The relative accuracy is assessed based on known phantom characteristics. Error is computed for a reference point and consecutive measurement errors are displayed relative to the reference in order to characterize the accuracy. In an initial set-up phase, the phantom geometry is calibrated by analyzing data from a multitude of EM sensors in a clean (non-ferromagnetic) environment. The registration results in the locations of sensors with respect to each other and defines the geometry of the sensors in the phantom. In a measurement phase, the position and orientation data from all sensors are compared with the known geometry of the sensor spacing, and localization errors (displacement and orientation) are computed. The spatial distribution of relative localization errors are displayed to provide an understanding of the EM tracker space.

7625-75, Poster Session

Reducing depth uncertainty in large surgical workspaces, with applications to veterinary medicine

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This paper presents on-going research that addresses uncertainty along the Z-axis in image-guided surgery, for applications to large surgical workspaces, including those found in veterinary medicine. Veterinary medicine lags human medicine in using image guidance, despite MR and CT data scanning of animals.

The positional uncertainty of a surgical tracking device can be modeled as an octahedron with one long axis coinciding with the depth axis of the sensor, where the short axes are determined by CCD pixel resolution and the workspace dimensions. The further a 3D point is from this device, the more elongated is this long axis, and the greater the uncertainty along Z of this point's position, in relation to its components along X and Y. Moreover, for a triangulation-based tracker, its position error can be modeled as degrading with the square of distance.

Our approach is to exploit the ability to use two or more Micron Trackers (Claron Technology, Inc.) to communicate with each other, and combine this feature with flexible positioning, e.g.: a programmable linear positioner. In theory, prior knowledge of the type of surgical procedure, and if applicable, the species of animal that determines the scale of the workspace, would allow the surgeon to pre-operatively configure the trackers in the OR for optimal accuracy in 3D. From a geometrical perspective, this flexible approach promises to outperform a rigidly spaced sensor configuration, optimized for the scale of the majority of human surgical procedures. Our research also leverages the open source Image Guided Surgery Toolkit.

7625-77, Poster Session

Exploring the clinical validity of predicted TRE in navigation

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In a detailed laboratory investigation we performed a series of experiments in order to assess the validity of the widely used TRE concept to predict the application accuracy. On base of 1mm CT scan a plastic skull, a cadaver head and a volunteer were registered to an in house navigation system. We stored the position data of an optical camera (NDI Polaris) for registration with pre-defined CT coordinates. For every specimen we choose 3, 5, 7 and 9 registration and 10 evaluation points, respectively, performing 10 registrations. The data were evaluated both with the Arun and the Horn approaches. The vectorial difference between actual and predefined position in the CT data set was stored and evaluated for FRE and TRE. Evaluation and visualization was implemented in Matlab. The data were analyzed, specifically for normal distribution, with MS Excel and SPSS Version 15.0.

For the plastic skull and the anatomic specimen submillimetric application accuracy was found experimentally and confirmed by the calculated TRE. Since for the volunteer no Titanium screws were implanted anatomic landmarks had to be used for registration and evaluation; an application accuracy in the low millimeter regime was found in all approaches. However, the detailed statistical analysis of the data revealed that the model predictions and the actual measurements do not exhibit a strong statistical correlation ($p < 0.05$). These data suggest that the TRE predictions are too optimistic and should be used with caution intraoperatively.

7625-78, Poster Session

Full automatic fiducial marker detection on coil arrays for accurate instrumentation placement during MRI guided breast interventions

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With its high sensitivity, dynamic contrast-enhanced MR imaging (DCE-MRI) of the breast is today one of the first-line tools for early detection and diagnosis of breast cancer, particularly in the dense breast of young women. However, many of these findings are very small or occult on targeted ultrasound images, so that MR-guided biopsy is the only option for a precise histological work-up [1]. State-of-the-art software tools for computer-aided diagnosis of breast cancer in DCE-MRI data offer also means for image-based planning of biopsy interventions. One step in the MR-guided biopsy workflow is the alignment of the patient position with the preoperative MR images. In these images, the location and orientation of the coil localization unit can be inferred from a number of fiducial markers, which for this purpose have to be manually or semi-automatically detected by the user.

In this study, we propose a method for precise, full-automatic localization of fiducial markers, on which basis a virtual localization unit can be subsequently placed in the image volume for the purpose of determining the parameters for needle navigation. The method is based on adaptive thresholding for separating breast tissue from background followed by rigid registration of marker templates. In an evaluation of 25 clinical cases comprising 4 different commercial coil array models and 3 different MR imaging protocols, the method yielded a sensitivity of 0.96 at a false positive rate of 0.44 per case. The mean distance between detected fiducial centers and ground truth information, appointed from a radiologist, was 0.94mm.

7625-79, Poster Session

Risk maps for navigation in liver surgery

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Currently, planning information for liver surgery is not optimally transferred onto the operative site. A common practice is to use preoperative 3D planning models as a printed output or presentation on a display in front of the surgeon. However, these models were not developed to provide information in complex workspaces such as the operating room.

Our aim is to reduce the visual complexity of 3D planning models by mapping surgically relevant information onto a 2D map, called a risk map. Therefore, we present methods for the identification and classification of critical anatomical structures in the proximity of a planned resection surface. Shadow-like distance indicators are introduced to encode the distance from the resection surface to these critical structures on the risk map. In addition, contour lines are used to accentuate shapes and encode the distance from the resection surface to the organ surface.

The resultant visualization is clear and intuitive, allowing for a fast mental mapping of the current cut surface to the risk map. Preliminary evaluations by liver surgeons indicate that the proposed methods may prevent a possible damage to risk structures and thus enhance patient safety during liver surgery.

7625-80, Poster Session

Real time planning, guidance and validation of surgical acts using 3D segmentations, augmented reality projections and surgical tools video tracking

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Laparoscopies and punctures are broadly used but the anatomic structures need to be precisely located. The medical challenge is to map the real situation with preoperative images. We present a PC-based software which helps plan and control surgical acts. From CT or MR, the software realizes 3D segmentations of regions of interest (organs, lesions, skin, and anatomical landmarks). A tilted plane is computed in real time and displays its intersection with voxel data and segmented volumes. The user chooses the appropriate puncture path using the tilted plane as visual help. This step helps determine whether or not the needle or trocars crosses the virtual organs and lesions. The planned path is displayed into the model. During the intervention, a standard video projector is used to display the segmented volumes over the patient's body using geometrical transformations. Landmarks on the patient are identified and drawn over his skin using a pencil; then they are mapped onto the model by scaling and tilting the virtual image. During the procedure a webcam is used to track the surgical tool. A fast 2D image processing algorithm has been developed to identify the tool in real time. The processed image, with the tool identified, is mapped onto the tilted plane displayed on the computer. The user realizes the insertion using the on-screen images. The planning takes about 15 minutes and the intervention time is broadly reduced. No surgical protocol is modified. We present the procedure in cases of liver and renal punctures and in PCNL.

7625-81, Poster Session

Treatment planning and delivery of shell dose distribution for precision irradiation

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The motivation for shell dose irradiation is to deliver a high therapeutic dose to the surrounding supplying blood-vessels of a lesion. Our approach's main utility is in enabling laboratory experiments to test the much disputed hypothesis about tumor vascular damage. That is, at high doses, tumor control is driven by damage to the tumor vascular supply and not the damage to the tumor cells themselves. There is new evidence that bone marrow derived cells can reconstitute tumor blood vessels in mice after irradiation. The ability to deliver a dose shell allows mechanistic research of how a tumor interacts with its microenvironment to sustain its growth and lead to its resistance or recurrence. Shell dosimetry is also of interest to study the effect of radiation on neurogenic stem cells that reside in a small niche surface of the mouse ventricles, a generalized form of shell. The type of surface that we are considering as a shell is a sphere which is created by intersection of cylinders. The results are then extended to create the contours of different organ shapes. Specifically, we present a registration routine to identify the 3-D structure of a mouse brain, project it into contours and convert the contours into trajectories that can be executed by our platform. We use the Small Animal Radiation Research Platform (SARRP) to demonstrate the dose delivery procedure. The SARRP is a portable system for precision irradiation with beam sizes down to 0.5 mm and optimally planned radiation with on-board cone-beam CT guidance.

7625-82, Poster Session

Correction of prostate misalignment in radiation therapy using US-CT registration

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Recent developments in radiation therapy promise to spare organs at risk by applying better dose distribution on the tumor.

For an effective application of these methods the exact positioning of the patient and the localization of the exposed organ is crucial. Depending on the filling level of rectum and bladder the prostate can move from several millimeters up to centimeters. That implies the need for daily determination and correction of the position of the prostate.

We calibrated a scan head of a B-mode US machine by means of an optical tracking system. 2D/3D registration was accomplished introducing the concept of attribute vectors. The elements of the vectors were chosen to be the intensity of the voxel, the magnitude of the gradient, and the Laplacian of the Gaussian with respect to the US image. The corresponding attribute vector for the CT image was built with voxel intensity and a median filtered image. To achieve US-CT image registration, the mutual information metric was maximized. The complete system setup was evaluated by means of a water-filled balloon embedded in a gelatine tank. For additional evaluation of the 2D/3D registration we used real patient data. The patient's prostate was drawn in by a physician on the US image and the reformatted CT slice. Then, the Hausdorff distance between the two structures was calculated.

The target registration error with respect to the balloon experiments amounted to 1.8 mm +/- 1.5 mm. The Hausdorff distance was found to be 2.8 mm.

7625-83, Poster Session

Computer-assisted targeted therapy (CATT) for prostate radiotherapy planning by fusion of CT and MRI

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We present a novel computer-aided diagnosis (CAD) and multimodal image registration framework for facilitating computer-assisted targeted therapy (CATT) of prostate cancer. The framework involves the fusion of planning CT with multiprotocol MRI, upon which cancer extent was determined via a texture and non-linear dimensionality reduction-driven CAD scheme. Treatment of prostate cancer by targeted radiotherapy requires the use of CT to formulate a dose plan, yet CT is ineffective for localizing intraprostatic lesions and inaccurate for delineation the prostate boundary. MR imagery on the other hand allows for greatly improved prostate segmentation. Further, several studies have demonstrated the utility of CAD for in vivo MRI of the prostate that are capable of identifying the location of tumors. Thus, with the availability of both MR and CT images of the prostate, it is possible to improve the accuracy of radiotherapy dose plans via multimodal fusion of these data. In this study, we present a scheme for CAD-assisted radiotherapy dose planning that operates by registration of MRI and CT, followed by mapping of tumor extent from diagnostic MRI to planning CT. First, an unsupervised CAD system is used to identify suspect regions within the prostate on high resolution diagnostic MRI. The CAD system achieves improved tumor characterization via novel texture features, embedding of feature space using normalized cuts, and classification via replicated k-means clustering. Using a novel elastic registration method for multiple images, we then align corresponding diagnostic MRI, planning MRI, and CT images of the prostate. Once MR and CT images are in alignment, the tumor map from CAD and the prostate boundary from MRI are directly mapped onto the planning CT images. , and a dose plan is calculated. The scheme is demonstrated on 79 corresponding sets of MR and CT images from 11 patient studies with cancer. The CAD-assisted dose plans are more disease focused, sparing the benign areas compared to the original plan.

7625-84, Poster Session

Shape-correlated deformation statistics for respiratory motion prediction in 4D lung

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4D image-guided radiation therapy (IGRT) for free-breathing lungs is

challenging due to the complicated respiratory dynamics. Effective modeling of respiratory motion is crucial to account for the motion affects on the dose to tumors. We propose a shape-correlated statistical model on dense image deformations for patient-specific motion estimation in 4D lung IGRT. Using the shape changes of the high-contrast lungs as the surrogate, the statistical model trained from the planning CTs can be used to predict the image deformation during delivery verification time. Dense deformation fields obtained by diffeomorphic registrations characterize the respiratory motion within a breathing cycle. A particle optimization algorithm is used to obtain the shape models of lungs with group-wise correspondences. Canonical correlation analysis (CCA) is adopted in training to maximize the linear correlation between the shape variations of the lungs and the corresponding dense image deformations. A leave-one-phase-out intra-session CT study is carried out on 5 lung cancer patients and evaluated in terms of the tumor and lung boundary location accuracies. The results suggest its potential for further research

7625-85, Poster Session

Automatic generation of boundary conditions using Demons non-rigid image registration for use in 3D modality-independent elastography

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Modality-independent elastography (MIE) is a method of elastography that analyzes images from any modality in a loaded and unloaded state. From image pattern alone, elastic properties of a biomechanical model of the loaded tissue are determined such that maximal similarity between the acquired deformed target (loaded state) image and model-deformed source (unloaded state) image is achieved. Boundary conditions are a critical input to the algorithm, and are often supplied by attached fiducials and point correspondence methods assisted by thin-plate spline interpolation for non-fiducial points. Unfortunately, generation of accurate boundary conditions for the biomechanical model is often difficult due to the challenge of accurately matching points between the source and target surfaces and consequently necessitates the use of large numbers of fiducial markers. This study presents a novel method of automatically generating boundary conditions by non-rigidly registering the two images with a Demons diffusion-based registration algorithm. The use of this method was successfully performed on a breast data set with known boundary conditions. These preliminary results have produced boundary conditions with approximately 7% error compared to the known conditions. Finally, the boundary condition data extracted from the automatic registration process was used within an elastographic reconstruction which used a priori information regarding the lesion extent but was tasked with determining the elastic property contrast among tissues. While still preliminary, it is encouraging that the properties were determined to within 30-40% of their true values (overshooting the ratio). The work reported significantly improves the automation level and viability of the method.

7625-86, Poster Session

Automation of a boundary element method approach for multimodality imaging of breast tissue

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Integrating various modalities of imaging helps reduce shortcomings of different methods and produce a powerful imaging tool to detect, diagnose and screen tissue abnormalities and even help outline therapeutic plans for cancer patients. Particularly, combining diffuse optical tomography (DOT) with standard imaging systems is of great interest. Boundary element method (BEM) as a numerical tool is used to solve the diffusion equation and recover light absorption and scatter properties within tissue, which can be related to vascular and metabolic conditions. Spatial and structural information contained in standard imaging methods (such as MRI, CT-Scan) can guide optical tomography in obtaining higher resolution images. To incorporate this a-prior information into BEM solution of DOT, establishing a spatial relation between surfaces of various tissues is required. An algorithm based on point containment test of general polyhedron is proposed and implemented. The algorithm is based on a Binary Space Partitioning method. BSP method, popular in computer graphics and gaming, can be modified to represent a closed volume by planes that split the volume into half. Using this method a solid-leaf BSP tree is constructed for every type of tissue surface (such as fibro-glandular, adipose or lesions). These surfaces are easily generated using 2D conventional images. Once the BSP trees are constructed, testing all the vertices of various surfaces for containment in another tissue volume is fast and robust. This enables us to further automate formation of BEM matrices and consequently have a smoother workflow for clinical image guided near infrared spectroscopy.

7625-88, Poster Session

Modeling tumor/polyp/lesion structure in 3D for computer-aided diagnosis in colonoscopy

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We describe a software system for building three-dimensional (3D) models from colonoscopic videos. The system is end-to-end in the sense that it takes as input raw image frames---shot during a colon exam---and produces the 3D structure of objects of interest (OOI), such as tumors, polyps, and lesions. We use the structure-from-motion (SfM) approach in computer vision which analyzes an image sequence in which camera's position and aim vary relative to the OOI. The varying pose of the camera relative to the OOI induces the motion-parallax effect which allows 3D depth of the OOI to be inferred. Unlike the traditional SfM system pipeline, our software system contains many check-and-balance mechanisms to ensure robustness, and the analysis from earlier stages of the pipeline is used to guide the later processing stages to better handle challenging medical data. The constructed 3D models allow the pathology (growth and change in both structure and appearance) to be monitored over time.

7625-89, Poster Session

Generation of smooth and accurate surface models for surgical planning and simulation

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We compare different methods to extract and postprocess triangle meshes from intensity data as well as from binary segmentations. The resulting surface meshes are evaluated regarding their smoothness, accuracy and mesh quality. We consider the local curvature, equi-angle-skewness, distances between two meshes (before and after processing), and volume preservation as measures. We discuss these results concerning the suitability for different applications in the field of surgical planning as well as finite element simulations and make recommendations on how to receive smooth and accurate surface meshes for exemplary cases. This involves the application of different reconstruction and smoothing algorithms to several models of characteristic anatomical structures. The paper presents suggestions on mesh generation and smoothing for surgical planning and simulations.

7625-90, Poster Session

Multi-contact model for FEM-based surgical simulation

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This paper presents a novel method to treat multi-contacts of deformable objects modeled by the finite-element method. There are two main approaches for contact models in the finite-element method. One is the penalty method and the other is the constraint method. Penalty method creates a force at the collision nodes, which is proportional to inter-penetration depth or volume. But this method fails to guarantee the non-penetration condition. Displacement of the collision nodes is determined in the constraint method. Imposition of multiple position constraints on arbitrary points of the surface, caused by the multi-contacts, can be either deterministic or non-deterministic depending on the contact configurations. Infinite number of solutions exists in most cases. The proposed method uses a deformable membrane using the mass-spring method to determine the position constraints to obtain a unified solution regardless of the contact configurations. The membrane is generated at the local region where contacts occur, which is identical to the local triangular surface mesh of the finite-element model. The membrane is then deformed by the contacts with rigid objects. The displacements of the mass points of the deformed membrane at the equilibrium state are applied to the finite-element model as the position constraints. The simulation result shows realism of the deformation and the real-time performance of the proposed method. The proposed method prevents penetration of the rigid object into the deformable object and provides realistic deformation. The method can be applied to interactions between tools and organs of arbitrary shapes.

7625-91, Poster Session

3D TEE registration with pre-operative MR for interventional cardiac applications

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Pre-operative patient-specific anatomy obtained from MRI and live three-dimensional trans-esophageal echocardiography (TEE) can provide complementary information to guide cardiac image-guided interventions. The pre-operative MRI contains more detailed anatomical information (i.e. segmentation of organ, the location of scar or substrate region) whereas three-dimensional real-time TEE is an emerging and promising technique that offers soft tissue contrast and volumetric imaging enabling the feasibility of real-time (i.e., 30 fps) and easy visualization of complex cardiac anatomy for interventional guidance during minimally invasive surgery.

In this work, we present a fully automated and fast multi-modal image registration of 3D TEE with MR using global and local feature-based statistics. When comparing with other imaging modalities, TEE has large differences due to low SNR, speckle noise and limited field-of-view, which makes the registration task challenging. Mutual information (MI) based approach is known as gold standard for multi-modal image registration. Although successful results have been reported when MI was used, MI measure has limitations in that the statistics that are computed from overlap region cannot reflect the local characteristics of salient regions (e.g., corners, edges or ridge) thereby ignoring spatially meaningful information. To remedy difficulties mentioned above, we propose to localize the salient region first using scale-space gradient magnitude to calculate local statistics, followed by a registration method based on combined cost functional using both global and feature-based local statistics. We validated the proposed method using phantom data and preliminary results show the potential of the proposed approach to be used for near real-time cardiac image-guided intervention.

7625-92, Poster Session

Realistic colon simulation in CT colonography using mesh skinning

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Realistic colon simulations do not exist but would be valuable for CT colonography (CTC) CAD development and validation of new colon image processing algorithms. The human colon is a convoluted tubular structure and very hard to model physically and electronically. In this investigation, we propose a novel approach to generate realistic colon simulation using mesh skinning. It has three stages. First, a digital phantom of a cylindrical tube modeled with haustral folds and teniae coli is built. Second, a centerline equipped with rotation-minimizing frames (RMF) and distention values is computed. Third, mesh skinning is applied to warp the tube around the centerline and generate realistic colon simulation. Colonic polyps in the shape of ellipsoids are also modeled. Results show that the simulated colon highly resembles the real colon. This is the first colon simulation that incorporates most colon characteristics in one model, including curved centerline, variable distention, haustral folds, teniae coli and colonic polyps.

7625-93, Poster Session

Ground truth and CT image model simulation for pathophysiological human airway system

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Recurrent problem in medical image segmentation and analysis, establishing a ground truth for assessment purposes is often difficult.

Facing this problem, the scientific community orients its efforts towards the development of objective methods for evaluation, namely by building up or simulating the missing ground truth for analysis.

This paper focuses on the case of human pulmonary airways and develops a method 1) to simulate the ground truth for different pathophysiological configurations of the bronchial tree as a mesh model, and 2) to generate synthetic 3D CT images of airways associated with the simulated ground truth. The airway model is here built up based on the information provided by a medial axis (describing bronchus shape, subdivision geometry and local radii), which is computed from real CT data to ensure realism and matching with a patient-specific morphology. The model parameters can be further on adjusted to simulate various pathophysiological conditions of the same patient (longitudinal studies).

Based on the airway mesh model, a 3D image model is synthesized by simulating the CT acquisition process. The image realism is achieved by including textural features of the surrounding pulmonary tissue which are obtained by segmentation from the same original CT data providing the airway axis. By varying the scanning simulation parameters, several 3D image models can be generated for the same airway mesh ground truth.

Simulation results for physiological and pathological configurations are presented and discussed, illustrating the interest of such a modeling process for designing computer-aided diagnosis systems or for assessing their sensitivity, mainly for follow-up studies in asthma and COPD.

7625-94, Poster Session

Endoscope-magnetic tracker calibration via trust region optimization

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Minimally invasive surgical techniques and advanced imaging

systems are gaining prevalence in modern clinical practice. Using magnetic trackers during these procedures can help physicians with instrument guidance in graphical displays, 3D reconstruction of anatomy, and other applications. Magnetic trackers are often used with other instruments such as endoscopes and optical trackers. In such applications, calibration procedures are required to align the coordinate systems of the devices to produce accurate results. Our application in 3D reconstruction of the colon requires the endoscope and magnetic tracker to be registered in a common reference frame to track the endoscope's viewing location and orientation in real time. Unfortunately, current calibration procedures developed for augmented reality are cumbersome and unsuitable for repeated use in a clinical setting.

This paper presents a simple and efficient scope-tracker calibration algorithm and preliminary 3D reconstruction results from endoscopic video. The algorithm is based on a novel application of a state-of-the-art trust region optimization method and requires minimal intervention from the endoscope operator. The only input is a short video of a calibration pattern taken with the endoscope and attached magnetic tracker. The three stage calibration process uses camera calibration to determine the intrinsic and extrinsic parameters of the endoscope. Then the endoscope is registered in the tracker's reference frame using a novel linear estimation method and a trust region optimization algorithm. This innovative method eliminates the need for complicated calibration procedures and facilitates the use of magnetic trackers in clinical settings.

7625-95, Poster Session

A GPU based high-definition ultrasound digital scan conversion algorithm

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Digital scan conversion algorithm is the most computational intensive part of ultrasound imaging. Traditionally, in order to meet the requirements of real-time imaging, digital scan conversion algorithm often traded off image quality for speed, such as the use of simple image interpolation algorithm, the use of look-up table to carry out polar coordinates transform and logarithmic compression. This paper presents a GPU-based high-definition real-time ultrasound digital scan conversion algorithm implementation. By rendering appropriate proxy geometry, we can implement a high precision digital scan conversion pipeline, including polar coordinates transform, bi-cubic image interpolation, high dynamic range tone reduction, line average and frame persistence FIR filtering, 2D post filtering, fully in the fragment shader of GPU at real-time speed. The proposed method shows the possibility of updating exist FPGA or ASIC based digital scan conversion implementation to low cost GPU based high-definition digital scan conversion implementation.

7625-96, Poster Session

Precisely shaped acoustic ablation of tumors utilizing steerable needle and 3D ultrasound image guidance

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Many recent studies have demonstrated the efficacy of interstitial ablative approaches for the treatment of hepatic tumors. Despite these promising results, current systems remain highly dependent on operator skill, and cannot treat many tumors because there is little control of the size and shape of the zone of necrosis, and no control over ablator trajectory within tissue. Additionally, tissue deformation and target motion make it extremely difficult to place the ablator device precisely into the target. Irregularly shaped target volumes typically

require multiple insertions and several overlapping thermal lesions, which are even more challenging to accomplish in a precise and timely manner without causing excessive damage to surrounding normal tissues.

In answer to these problems, we have developed a steerable acoustic ablator called the ACUSITT with the ability to directionally deliver energy to precisely shape the thermal dose delivered. In this paper, we address image guidance for this device, proposing an innovative method for accurate tracking and tool registration to spatially-registered intaoperative three-dimensional US volumes, without relying on an external tracking device. This method is applied to guidance of the flexible, snake-like, lightweight, and inexpensive ACUSITT to facilitate precise placement of its ablator tip within the liver, with ablation monitoring via strain imaging. Recent advancements in interstitial high-power ultrasound applicators enable controllable and penetrating heating patterns which can be dynamically altered. This paper summarizes the design and development of the first synergistic system that integrates a novel steerable interstitial acoustic ablation device with a novel trackerless 3DUS guidance strategy.

7625-97, Poster Session

A probabilistic framework for ultrasound image decomposition

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A number of important applications of medical ultrasound imaging, such as image segmentation and tissue characterization, require computing local statistics of ultrasound images as the first step in the process of feature extraction. Typically, these statistics are computed directly based on local segments of acquired images. However, the process of formation of the images suggests that such an approach could result in biased estimates of the local statistics in the case when the image segments contain several (statistically) distinct regions. This may result in a variety of unwanted artifacts such as excessive smoothing of segmentation boundaries and misclassification. On the other hand, more accurate estimates of the local statistics could be obtained if the images were first decomposed into their quasi-stationary components. It would then be possible to use each image component separately to extract a set of its corresponding local statistics (or features). Accordingly, this work introduces a computationally efficient method for decomposition of ultrasound images for the purpose of robust feature extraction. The method is derived based on the maximum-a-posteriori (MAP) framework, which allows us to perform the decomposition using convex optimization. Examples of in silico simulations and in vivo experiments are provided to illustrate the usefulness of the proposed technique.

7625-98, Poster Session

Dynamic tracking of tendon elongation in ultrasound imaging

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Measuring tendon strains is of particular clinical importance since it enables understanding of mechanical properties of tendon. This is achieved by looking at the changing position of Myotendenious Junction (MTJ) using ultrasound. Ophir et al. introduced Elastography to measure elasticity and motion of soft tissue using time domain speckle tracking to estimate one dimensional longi-tudinal axial strain elastograms. A method of measuring longitudinal nerve movement using Cross Correlation algorithm for tracking an area of interest in B-mode ultrasound images was reported by Dilley which demonstrated to be successful method to study dynamics of soft tissue.

Magnaris and Paul et al. developed a method to measure tendon tensile properties non-invasively in vivo. The method involves three steps: first, measuring the isometric plantarflexion maximum voluntary

contraction. Second, the Gastronomies tendon elongation during maximum voluntary force and third, measuring the tendon's cross-sectional area. This method calculates tendon stiffness manually at certain frame intervals.

Oliveira and colleagues have developed cross correlation algorithm for estimation of MTJ displacement in sequence of US images at 5 frames/s sampling rate. However, this method is sensitive to noise channel and can be affected by speckle noise varying in intensity values. This can be solved by denoising the image through optimizing signal oscillation using image diffusion in scale-space theory of computer vision. This toolbox integrates the contrast of image edges while reducing the effect of speckle noises. Our priliminary results have been accepted in ASB2009 conference where we have developed a dynamic method in MATLAB which applies cross-correlation using an adaptive mask to track the related movement of MTJ on a sequence of de-noised binarized images.

7625-99, Poster Session

Mechanically assisted 3D prostate ultrasound imaging and biopsy needle-guidance system

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The prostate biopsy procedure is currently limited to using 2D transrectal ultrasound (TRUS) imaging to guide the biopsy needle. Being limited to 2D causes ambiguity in needle guidance and provides an insufficient record to allow guidance to the same suspicious locations or avoid regions that are negative during subsequent biopsy sessions. We have developed a mechanically assisted 3D ultrasound imaging and needle tracking system, which supports a commercially available TRUS probe and integrated needle guide for prostate biopsy. The mechanical device is fixed to a cart and the mechanical tracking linkage allows its joints to be manually manipulated while fully supporting the weight of the ultrasound probe. The computer interface is provided in order to track the potential needle trajectory and display this path on a corresponding 3D TRUS image, allowing the physician to aim the needle-guide at predefined targets within the prostate. The system has been designed for use with several end-fired transducers that can be swept about the longitudinal axis of the probe in order to generate 3D image for 3D navigation. Using the system, 3D TRUS prostate images can be scanned and reconstructed in approximately 10 seconds. The system reduces most of the user variability from conventional hand-held probes that render them unsuitable for precision biopsy, while preserving the user familiarity and procedural workflow. In this paper, we describe the 3D TRUS guided biopsy system and report on the initial clinical use of this system for prostate biopsy.

7625-100, Poster Session

Multiparametric MRI-pathologic correlation of prostate cancer using tracked biopsies

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MRI is currently the most promising modality for prostate cancer diagnosis due to its high resolution and multi-parametric nature. However, currently there is no standard for integration of information

from different MRI sequences due to the difficulties of MRI/Pathology correlation for patients under radical prostatectomy. We propose a method to increase the diagnostic accuracy of MRI by correlating biopsy specimens with four MRI sequences including T2w, DWI, DCE and MRS. This method uses device tracking and image fusion to locate the specimen's position on MRI images. The proposed method is unbiased and has low cost. It does not substantially interfere with the standard biopsy workflow, allowing it to be easily accepted by physicians. A study of 41 patients was carried out to validate the approach. The performance of all four MRI sequences in various combinations is reported. Guidelines are given for multi-parametric imaging and tracked biopsy of prostate cancer.

7625-101, Poster Session

A multi-threaded mosaicking algorithm for fast image composition of fluorescence bladder images

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The treatment of urinary bladder cancer is usually carried out using fluorescence endoscopy. A narrow-band bluish illumination activates a tumor marker resulting in a red fluorescence. Because of low illumination power the distance between endoscope and bladder wall is kept low during the whole bladder scan, which is carried out before treatment. Thus, only a small field of view (FOV) of the operation field is provided, which impedes navigation and relocating of multi-focal tumors. Although off-line calculated panorama images can assist surgery planning, the immediate display of successively growing overview images composed from single video frames in real-time during the bladder scan, is well suited to ease navigation and reduce the risk of missing tumors. Therefore we developed an image mosaicking algorithm for fluorescence endoscopy. Due to fast computation requirements a flexible multi-threaded software architecture based on our RealTimeFrame platform is developed. Different algorithm tasks, like image feature extraction, matching and stitching are separated and applied by independent processing threads. Thus, different implementation of single tasks can be easily evaluated. In an optimization step we evaluate the trade-off between feature repeatability and total processing time, consider the thread synchronization, and achieve a constant workload of each thread. Thus, a fast computation of panoramic images is performed on a standard hardware platform, preserving full input image resolution (780x576) at the same time. Displayed on a second clinical monitor, the extended FOV of the image composition promises high potential for surgery assistance.

7625-102, Poster Session

Automatic segmentation of seeds and fluoroscope tracking (FTRAC) fiducial in prostate brachytherapy x-ray images

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C-arm fluoroscopy-based radioactive seed localization for intraoperative dosimetry of prostate brachytherapy is an active area of research. The fluoroscopy tracking (FTRAC) fiducial is an image-based tracking device composed of radio-opaque BBs, lines, and ellipses that provides an effective means for three-dimensional reconstruction of the implanted seeds from multiple fluoroscopic images in relation to the ultrasound-computed prostate volume. Both the FTRAC features and the brachytherapy seeds must be segmented quickly and accurately during the surgery, but current segmentation algorithms are inhibitory in the operating room (OR). The first reason is that current algorithms require operators to manually select a region of interest (ROI), preventing automatic pipelining from image acquisition

to seed reconstruction. Secondly, these algorithms fail often, requiring operators to manually correct the errors. We propose a fast and effective ROI-free automatic FTRAC and seed segmentation algorithm to minimize such human intervention. The proposed algorithm exploits recent image processing tools to make the goal of seed reconstruction as easy and convenient as possible. Preliminary results on 162 patient images show this algorithm to be fast, effective, and accurate for all features to be segmented. With near perfect success rates and subpixel differences to manual segmentation, our automatic FTRAC and seed segmentation algorithm shows promising results to save crucial minutes in the OR while reducing errors.

7625-103, Poster Session

Trans-rectal interventional MRI (TRIM): initial experience

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Dynamic contrast-enhanced imaging of the prostate gland when evaluated along with T2-weighted images, diffusion-weighted images (DWI) and their corresponding apparent diffusion coefficient (ADC) maps can yield valuable information in patients with rising or elevated serum prostate-specific antigen (PSA) levels1. In some cases, patients present with multiple negative trans-rectal ultrasound (TRUS) biopsy, often placing the patient into a cycle of active surveillance. Recently more patients are undergoing TRIM for targeted biopsy of suspicious findings with a cancer yield of ~59% (compared to 15% for second TRUS biopsy2) to solve this diagnostic dilemma and plan treatment and/or therapy.

7625-104, Poster Session

MRI-guided prostate motion tracking by means of multislice-to-volume registration

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We developed an algorithm for tracking prostate motion during MRI-guided prostatic needle placement, with the primary application in prostate biopsy. Our algorithm has been tested on simulated patient and phantom data. The algorithm features a robust automatic restart and a 12-core biopsy error validation scheme. Simulation tests were performed on four patient MRI pre-operative volumes. Three orthogonal slices were extracted from the pre-operative volume to simulate the intra-operative volume and a volume of interest was defined to isolate the prostate. Phantom tests used six datasets, each representing the phantom at a known perturbed position. These volumes were registered to their corresponding reference volume (the phantom at its home position). Convergence tests on the phantom data showed that the algorithm demonstrated accurate results at 100% confidence level for initial misalignments of less than 5mm and at 73% confidence level for initial misalignments less than 10mm. Our algorithm converged in 95% of the cases for the simulated patient data with 0.66mm error and the six phantom registration tests resulted in 1.40mm error.

7625-105, Poster Session

Planning of vessel grafts for reconstructive surgery in congenital heart diseases

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The Fontan operation is a surgical treatment in cases of severe congenital heart diseases, where the biventricular anatomy of the heart can't be retained and must be replaced by a uni-ventricular system. During surgery a tunnel segment is placed to connect the inferior caval vein directly with the pulmonary artery, bypassing the right atrium and ventricle. Thus both atriums and ventricles can work for the body circulation.

Fontan tunnels can be planned intra- and extra-cardially. The location, length and shape of the tunnel must be planned accurately: the remaining blood pressure in the vena cava must be high enough to press the blood through the tunnel into the lung. Furthermore, if the tunnel is placed extra-cardially, it must be placed between other anatomical structures without constraining them. If the tunnel is placed intra cardially inside the right atrium, it must not interfere with structures like valves or the conductive system.

We developed a software system to support planning of the tunnel location, shape, and size, allowing for pre-operative preparation of the tunnel material. The system allows for interactive placement and planning of the tunnel, affords a three dimensional visualization of the virtual Fontan tunnel inside the thorax, and provides a quantification of the length, circumferences and diameters of the tunnel segments. The visualization and quantification can be used to plan and prepare the tunnel material for the surgery in order to reduce the intra-operative time and to improve the fitting of the sewed tunnel patch.

7625-106, Poster Session

A robotic assistant system for cardiac interventions under MRI guidance

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Purpose: MRI-guided transapical aortic valve (tAoV) placement is challenging because of the limited scanner space and the angle and distance to reach to the target area. We developed a robotic surgical assistant system for delivering a prosthetic valve under MRI guidance, in a beating heart.

Methods: The system integrates three sub-systems: imaging, robot, and interface. The MRI compatible robotic system comprises a 5-DoF Innomotion arm and a 3-DoF valve delivery module. The 3-DoF module is developed for delivering both balloon-expandable and self-expanding prosthesis. Under MRI and rtMRI guidance, the user can place this delivery module on a pre-planned trajectory. The delivery module consists of one rotational and two linear joints. Simultaneously motion of the two linear joints at same velocity deploys the self-expanding prosthesis, whereas, independent motion of the linear joints deploys the balloon-expandable prosthesis.

Results: The accuracy and repeatability of the delivery module for prosthesis deployment was tested using a phantom. The average position error based on nine trials of a self-expanding prosthesis was 0.8+/-0.4 mm; whereas that of a balloon-expandable prosthesis was 1.5+/-0.2 mm. The observed SNR loss in MRI images was less than 10% when the robotic system was in motion.

Conclusion: Preliminary results in ex-vivo experiment shows the robotic system may provide sufficient capabilities to perform precise positioning of a bioprosthetic aortic valve using either balloon-expandable or self-expanding stent inside a beating heart under MRI guidance in animal and clinical models.

7625-107, Poster Session

Integration of trans-esophageal echocardiography with magnetic tracking technology for cardiac interventions

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Trans-esophageal echocardiography (TEE) is a standard component of patient monitoring during most cardiac surgeries. In recent years magnetic tracking systems (MTS) have become sufficiently robust to function effectively in appropriately structured operating room environments. The ability to track a conventional multiplanar 2D TEE transducer in 3D space offers incredible potential by greatly expanding the cumulative field of view of cardiac anatomy beyond the limited field of view provided by 3D TEE technology. For example, by tracking the TEE peri-operatively it is possible to quantify cardiac tissue shift (due to collapsing a lung in robotic surgery). This information can be of immense importance in predicting optimal port locations for minimally invasive cardiac surgeries based on preoperative CT image data. Intraoperatively, tracking the surgeon's tools and the TEE probe makes it possible to integrate virtual models of tools and anatomy with the real time US images, thus creating a powerful augmented reality environment for image guided interventions. However, there is currently no TEE manufactured with MTS technology embedded in the transducer which means sensors must be attached to the outer surface of the TEE. This leads to potential safety issues for patients, as well as potential damage to the sensor during procedures. This paper describes the creation, assessment and application of a TEE device fully integrated with MTS technology. We demonstrate an RMS point localization accuracy of 3.68mm, and successful implementation in a clinical operating room with a first generation TEE probe.

7625-108, Poster Session

2D/3D registration using only single-view fluoroscopy to guide cardiac ablation procedures: a feasibility study

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Introduction: The CARTO XP is an electroanatomical cardiac mapping system that provides 3D color-coded maps of the electrical activity of the heart, however it is expensive and it can only use a single costly magnetic catheter for each patient intervention. Aim: To develop an affordable fluoroscopic navigation system that could shorten the duration of RF ablation procedures and increase its efficacy. Methodology: A novel 4-step filtering technique was implemented in order to project the tip electrode of an ablation catheter visible in single-view X-ray images in order to calculate its width. The width is directly proportional to the depth of the catheter. Results: For phantom experimentation, when displacing a 7-French catheter at 1cm intervals away from an X-ray source, the recovered depth using a single image was 2.05 ± 1.46 mm, whereas depth errors improved to 1.54 ± 1.29 mm when using an 8-French catheter. In clinic experimentation, twenty posterior and left lateral images of a catheter inside the left ventricle of a mongrel dog were acquired. The standard error of estimate for the recovered depth of the tip-electrode of the mapping catheter was 13.1 mm and 10.1 mm respectively for the posterior and lateral views. However, these depth errors did not alter significantly the all important isochronal maps that were registered directly on the 2D X-ray images, making them useful for assisting clinicians in guiding the ablation catheter towards the arrhythmogenic site. Conclusions: A novel filtering implementation using single-view C-arm images showed that it was possible to recover depth in phantom study and proved adequate in clinical experimentation.

7625-109, Poster Session

Segmentation of carotid arteries by graph-cuts using centerline models

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This paper presents a semi-automatic segmentation algorithm for extracting the lumen of carotid arteries in CE-CTA data. The proposed algorithm is based on the global graph-cut optimization algorithm using vessel centerlines extracted between the user-placed seed points. Centerline representations of blood vessels are extracted by a minimal path detection method working on a discrete grid where the cost of graph edges are computed from multi-scale medialness filters. Specifically, for the segmentation of carotid arteries, a user needs to place three seeds on each branch of carotid artery for the centerline extraction. In general, the graph-cuts algorithms are not suitable for segmenting elongated shapes such as blood vessels since the minimum energy surfaces often do not coincide with the boundaries of vessels. In this paper, we show that the integration of vessel centerlines makes the graph-cuts algorithm to be successfully used for the segmentation of vessels. Specifically, centerlines are important for three main reasons: (1) foreground seeds required by the graph-cuts algorithms are obtained from the location of centerlines. (2) The weights of discrete graph edges are normalized by the distance from the centerline representations. (3) The global optimization is limited to the vicinity of centerline by constructing a tubular graph for computational reasons and robustness. This algorithm is implemented by using the "max-flow" algorithm. The proposed algorithm has been tested on more than 40 CTA data sets successfully. It is shown that it can successfully segment the carotid arteries without including calcified and non-calcified plaques in the segmentation results.

7625-110, Poster Session

An evaluative tool for preoperative planning of brain tumor resection

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A patient specific finite element biphasic brain model has been utilized to codify a surgeon's experience by establishing quantifiable biomechanical measures to score orientations for optimal planning of brain tumor resection. When faced with evaluating several potential approaches to tumor removal during preoperative planning, the goal of this work is to facilitate selection of a patient head orientation such that tumor presentation and resection is assisted via favorable brain shift conditions rather than trying to allay confounding ones. Preliminary results for a frontal lobe theoretical tumor presentation show that the model predicts an ideal orientation that agrees within 10 degrees of the surgeon's orientation of the model for a non-optimized objective function.

7625-111, Poster Session

Computer-aided planning for endovascular treatment of intracranial aneurysms

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Endovascular treatment planning of intracranial aneurysms requires accurate quantification of patient-specific geometric parameters of these aneurysms, including the neck length, dome height and maximum diameter. Today, intracranial aneurysm geometry is typically quantified manually based on three-dimensional (3D) Digital Subtraction Angiography (DSA) images. Since the repeatability of manual measurements is not guaranteed and the accuracy depends on the experience of the treating physician, we propose a semi-automated approach for computer-aided measurement of these parameters. The approach fits a deformable model of a vessel segment to the parent artery of the aneurysm, initialized based on user-provided points inside the artery. An initial estimate of the aneurysm part of the vasculature is obtained based on differences between the vessel model and the input image. A 3D deformable contour model based on local surface curvature and distance from the vessel model is then used to localize the aneurysm neck and to separate its dome

surface from the parent artery. Finally, approaches for estimation of the clinically relevant geometric parameters are applied, based on the neck contour and dome surface. Results on 20 3D DSA datasets of saccular aneurysms indicate that, for maximum diameter and dome height, the error distributions are not different from the respective distributions of inter- rater variability between two independent manual sets of measurements obtained by experts. For the aneurysm neck length parameter, the results may be improved through the use of an image segmentation approach that generates a topologically correct segmentation of the aneurysm and the parent artery.

7625-112, Poster Session

A novel contrast for DTI visualization for thalamus delineation

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It has been recently shown that the thalamic nuclei can be automatically segmented using diffusion tensor images (DTI) under the assumption that principal fiber orientation is similar within a given nucleus and distinct between adjacent nuclei. Validation of these methods, however, is challenging because manual delineation is hard to carry out due to the lack of images showing contrast between the nuclei. In this paper, we present a novel gray-scale contrast for DTI visualization that accentuates voxels in which the orientations of the principal eigenvectors are changing, thus providing an edge map for thalamic nuclei. The method represents the 3-D orientation of principal eigenvectors in five dimensions vector to get rid of the arbitrary information of vector direction by Knutsson mapping. The gradient to the 3D spatial grid is computed to incorporate the edge information from all possible directions. At last, the gray scaled contrast based on the edge map comes from the Frobenius norm of the gradient matrix. We show in results that there are clear edges between large nucleus of the thalamus on the new contrast, making manual delineation of the thalamus nuclei possible. We describe briefly the process of the manual delineation of thalamus nuclei, including how this edge-map based contrast is used for the thalamus delineation.

7625-113, Poster Session

evaluating a visualization of uncertainty in probabilistic tractography

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This paper deals with interactive visualization of uncertainty information in probabilistic fiber pathways of the living human brain as measured by diffusion tensor imaging. Magnetic resonance diffusion tensor imaging (DTI) provides the currently most forward method for the assessment of white matter fiber pathways in the living human brain. We propose a customized direct volume rendering method through which the probabilities of fiber tracts are conveyed by colors and opacities. By rendering multiple scalar-valued data sets simultaneously we are able to visualize sections where multiple fiber tracts intersect which is an important methodological issue in DTI tractography (crossing fibers). We focus on real-time rendering and interaction techniques since interactivity is a crucial requirement for effective data analysis. Therefore, our proposed technique also runs on virtual reality systems. In the full paper we plan to conduct a user study with DTI domain scientist in order to quantify the effectiveness of our visualization. The study will hopefully reveal the benefits of our approach to commonly used visualization of fiber tracts (e.g. streamlines or isosurfaces). Furthermore, we hope that the use of virtual reality systems will further enhance the data analysis of three-dimensional structures and allow the use of direct manipulation.

7625-114, Poster Session

Graphical user interfaces for simulation of brain deformation in image-guided neurosurgery

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In image-guided neurosurgery, preoperative images are typically used for surgical planning and intraoperative guidance. The accuracy of preoperative images can be significantly compromised by intraoperative brain deformation. To compensate for brain shift, biomechanical finite element models have been used to assimilate intraoperative data to simulate brain deformation. The clinical feasibility of the approach strongly depends on its accuracy and efficiency. In order to facilitate and streamline data flow, we have developed graphical user interfaces (GUIs) to provide efficient image updates in the operating room (OR). The GUIs are organized in a top-down hierarchy with a main control panel that invokes and monitors a series of sub-GUIs dedicated to perform tasks involved in various aspects of computations of whole-brain deformation. The GUIs are used to segment brain, generate case-specific brain meshes, and assign and visualize case-specific boundary conditions (BC). Registration between intraoperative ultrasound (iUS) images acquired pre- and post-durotomy is also facilitated by a dedicated GUI to extract sparse displacement data used to drive a biomechanical model. Computed whole-brain deformation is then used to morph preoperative MR images (pMR) to generate a model-updated MR image set (i.e., uMR) for intraoperative guidance (accuracy of 1-2 mm). These task-driven GUIs have been designed to be fault-tolerant, user-friendly, and with sufficient automation. In this paper, we present the modular components of the GUIs and demonstrate the typical workflow through a clinical patient case.

7625-115, Poster Session

An integrated model-based neurosurgical guidance system

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Maximal tumor resection without damaging healthy tissue in open cranial surgeries is critical to the prognosis for patients with brain cancers. Because brain shifts significantly even at the start of surgery while surgical planning is based on preoperative images (e.g., preoperative magnetic resonance images (pMR)), compensating for brain shift while surgery progresses is desired to improve surgical accuracy. We have developed an integrated neurosurgical guidance system that intraoperatively incorporates three-dimensional (3D) tracking, volumetric true 3D ultrasound (iUS), stereovision (iSV) and computational modeling to provide near efficient updates of pMR for neurosurgical guidance. The system is based on real-time Labview to provide high efficiency in data acquisition and on Matlab to offer computational convenience in developing graphical user interfaces related to computational modeling. Patient in the operating room (OR) is first registered to pMR and sparse displacement data extracted from coregistered intraoperative images are employed to guide a computational model based on consolidation theory. Computed whole-brain deformation is then used to generate a model-updated MR image set for neurosurgical guidance. In this paper, we present the complete modular components of our integrated, model-based, neurosurgical guidance system and demonstrate its typical clinical work-flow in the OR.

7625-116, Poster Session

Augmented reality guidance system for peripheral nerve blocks

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Peripheral nerve block treatments are ubiquitous in hospitals and pain clinics worldwide. State of the art techniques use ultrasound (US) guidance and/or electrical stimulation to verify needle tip location. However, problems such as needle-US beam alignment, poor echogenicity of block needles and US beam thickness can make it difficult for the anaesthetist to know the exact needle tip location. Inaccurate therapy delivery raises obvious safety and efficacy issues. We have developed and evaluated a needle guidance system that makes use of a magnetic tracking system (MTS) to provide anaesthetists with a virtual reality enhanced guidance platform to accurately localize the needle tip as well as its projected trajectory. In initial studies subjects performed simulated nerve block deliveries in a polyvinyl alcohol (PVA) phantom to compare needle guidance under US alone compared to US placed in our augmented reality (AR) environment. Our phantom study has shown an increase in targeting accuracy of 0.86 mm compared to 1.54 mm in US guidance alone.

Currently, the MTS uses 18 and 21 gauge hypodermic needles with a 5 degree of freedom (DOF) sensor located at the needle tip. These needles can only be sterilized using an ethylene oxide process. In the interest of providing clinicians with a simple and efficient guidance system, we also evaluated the possibility of attaching the sensor at the needle hub as a simple clip-on device. To do this, we simultaneously performed a needle bending study to assess the reliability of a hub-based sensor.

7625-117, Poster Session

Ultrasound guided spine needle insertion

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An ultrasound (US) guided, CT augmented, spine needle insertion system

is introduced. The system consists of an electromagnetic (EM)

tracker, a US transducer, and a preoperative CT volume. The core of the system is a GPU-accelerated, biomechanically constrained group-wise CT to US volume registration algorithm that registers each vertebra independently of each other. The preoperative CT is manually divided into subvolumes each containing a single vertebra. Intraoperatively, a US volume is reconstructed from a set of 2D freehand US images. During each registration iteration, each CT subvolume is subjected to registration parameters and used to constructed a "simulated" US volume. An intensity-based similarity metric is used to compare the simulated and the intraoperative US volume. The similarity metric is further argumented by a biomechanical spring-model that represented the intervertebral structure. The registration algorithm is implemented in GPU, allowing real-time performance in a clinical setting.

The spine needle navigational system combines the specificity and accuracy of the CT with the ease of use, speed, and safe operation of the ultrasound. The tracked pose of the calibrated US transducer is used to define a texture plane and texture coordinate that "slice" through the registered CT volume. This produces a 2D CT image that corresponds to the live-US image. The graphical user interface is composed of the Digitally Reconstructed Radiograph (DRR) of the CT volume, surface rendering of the bony anatomy, 2D CT and live US images, and realtime graphical representation of the surgical instruments.

7625-118, Poster Session

Statistical atlas based extrapolation of CT data

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We present a framework to estimate the missing anatomical details from a partial CT scan with the help of statistical shape models. The motivating application is periacetabular osteotomy (PAO), a technique for treating developmental hip dysplasia, an abnormal condition of the hip socket that, if untreated, may lead to osteoarthritis. The common goals of PAO are to reduce pain, joint subluxation and improve contact pressure distribution by increasing the coverage of the femoral head by the hip socket. While current diagnosis and planning is based on radiological measurements, because of signicant structural variations in dysplastic hips, a computer-assisted geometrical and biomechanical planning based on CT data is desirable to help the surgeon achieve optimal joint realignments. Most of the patients undergoing PAO are young females, hence it is usually desirable to minimize the radiation dose by scanning only the joint portion of the hip anatomy.

These partial scans, however, do not provide enough information for biomechanical analysis due to missing iliac region. A statistical shape model of full pelvis anatomy is constructed from a database of CT scans. The partial volume is first aligned with the mean shape using an affine registration, followed by a deformable registration step. Partial CT scans are created from the full scans and osteotomy cuts are simulated. Results from these simulation experiments are presented using both the male and female atlases.

7625-119, Poster Session

Mastoid fiducial markers for enhancement of navigation accuracy in lateral skull base surgery based on oral splint registration

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Purpose: Patient to image registration using fiducial markers on a maxillary splint is an established and proven non-invasive registration method. However, the accuracy for image guided temporal bone surgery is not sufficient. It was the purpose of this study to evaluate if maxillary splint registration could be improved using additional mastoid markers. Methods: In a phantom study Target registration error in lateral skull base and temporal bone was compared using 3 registration methods: 1.) Registration with markers on a maxillary splint only. 2.) Markers on a maxillary splint plus one fiducial marker on the ipsilateral mastoid. 3.) Markers on a maxillary splint plus mastoid fiducial markers, one on each side. Results: Average target registration error with method 1 (splint only) was 3.31 mm (SD=1.26 mm). With method 2 (1 additional mastoid marker) TRE improved significantly to 1.42 mm (SD=0.55 mm). Method 3 (2 additional mastoid markers) resulted in further improvement of TRE to 1.16mm (SD=0.39 mm). Conclusion: The addition of 1 ipsilateral mastoid registration marker adds considerably to the navigation accuracy in the lateral skull base. Implantation of a single marker on the mastoid adds little distress to the patient. Even more accuracy is possible with bilateral additional markers. However, compared to measurements in literature, gold standard is still fiducial marker registration with at least 4 fiducial markers implanted locally.

7625-120, Poster Session

A new method of morphological comparison for bony reconstructive surgery: maxillary reconstruction using scapular tip bone

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An esthetic appearance is one of the most important factors for reconstructive surgery. The current practice of maxillary reconstruction chooses radial forearm, fibula or iliac rest osteocutaneous to recreate three-dimensional complex structure of palate and maxilla. However, these bone flaps lack of shape similarity to the palate and are less esthetically satisfactory. Considering similarity factors and vasculature advantages, reconstructive surgeons recently explored the use of a scapular tip myo-osseous free flaps to restore the excised site. We have developed a new method that quantitatively evaluates the morphological similarity of the scapula tip bone and palate based on a diagnostic volumetric computed tomography (CT) image. This quantitative result was further interpreted as a color map that rendered on the surface of a three-dimensional visual model. For the surgical planning, this color interpretation could potentially assist the surgeon to maximize the orientation of the bone flaps for best fit of the reconstruction site. With an approval from the Research Ethics Board (REB) of the University Health Network, Toronto, we conducted the retrospective analysis of radiographs obtained from 10 patients. Each patient had a CT scan through the maxilla and of the chest on the same day. Based on this image set, we simulated total, subtotal and hemi palate reconstruction. The first processing step was the segmentation of bone tissue, which was achieved semi-automatically. The segmented volumes were then converted into a Stereo Lithography (STL) model for manual registration that simulates the surgical procedure. The final result was expressed in terms of color coded geometric distances and surface curvature between two STL models.

7625-121, Poster Session

Measurement of complex joint trajectories using slice-to-volume 2D/3D registration and cine MR

C. Bloch, C. Gendrin, M. Figl, C. Weber, E. Unger, S. M. Aldrian, W. Birkfellner, Medizinische Univ. Wien (Austria)

A method for studying the in vivo kinematics of complex joints is presented.

It is based on automatic fusion of single slice cine MR images capturing the dynamics and a static MR volume. With the joint at rest the 3D scan is taken. In the data the anatomical compartments are identified and segmented resulting in a 3D volume of each individual part. In each of the cine MR images the joint parts are segmented and their pose and position are derived using a 2D/3D slice-to-volume registration to the volumes.

The method is tested on the carpal joint because of its complexity and the small but complex motion of its compartments.

For a first study a human cadaver hand was scanned and the method was evaluated with artificially generated slice images. Starting from random initial positions of about 5 mm translational and 12 degrees rotational deviation, 70 to 90 % of the registrations converged successfully to a deviation better than 0.5 mm and 5 degrees.

First evaluations using real data from a cine MR were promising.

The feasibility of the method was demonstrated. However we experienced difficulties with the segmentation of the cine MR images. We therefore plan to examine different parameters for the image acquisition in future studies.

7625-122, Poster Session

Diagnostic radiograph-based 3D femoral bone reconstruction and pose estimation

P. Gamage, S. Q. Xie, P. Delmas, The Univ. of Auckland (New Zealand)

Three dimensional (3D) visualization of anatomy plays an important role in image guided orthopedic surgery and ultimately motivates minimally invasive procedures. However, direct 3D imaging modalities such as Computed Tomography (CT) are restricted to a minority of complex orthopedic procedures. Thus the diagnostics and planning of many interventions still rely on two dimensional (2D) radiographic images, where the surgeon has to mentally visualize the anatomy of interest. This research aims to augment the current 2D images with 3D models to provide better image guidance to femur fracture surgery. The paper will discuss a bi-planar 3D reconstruction methodology driven by prominent femoral anatomy edges and contours identified on orthogonal 2D radiographs.

The 3D reconstruction process can be separated into three distinct components: shape customization, fracture incorporation and pose estimation. The shape customization utilizes a generic 3D bone surface model, which is deformed to the shape of the patient's anatomy through a non rigid registration process. In the proceeding fracture incorporation, the fracture surface is modeled and a 2D-3D registration performed to separate the bone into the proximal and distal fragments. The final pose estimation step attempts identify the pose of each fragment. This pose estimation is performed through a feature based 2D-3D registration between the pair of 2D x-ray images with the 3D customized anatomical model.

The results obtained through the proposed methodology convey a reconstruction accuracy of 1-2mm (in comparison to 3D CT scan data), which is deemed clinically acceptable for diagnostic and preoperative planning purposes.

7625-123, Poster Session

Splint deformation measurement: a contribution to quality control in computer assisted surgery

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Setting up a reliable and accurate reference coordinate system is a crucial part in computer assisted navigated surgery. As the use of splints is a well established technique for this purpose and any change in its geometry directly influences the accuracy of the navigation, a regular monitoring of such deformations should occur as a means of quality control.

This work presents a method to quantify such deformations based on computed tomography images of a splint equipped with fiducial markers.

Point-to-point registration is used to match the two data sets and some markers near to the navigation field are used to estimate the registration error. The Hausdorff Distance, describing the maximum of all minimal distances between two point sets in general, is applied to the surfaces of the models, being a measure for the overall change in geometry.

Finally this method for quantification is demonstrated using a computed tomography data set of such a splint together with an artificially modified one, being an initial step to a study examining the influence of the Sterrad sterilisation system on acrylic splints.

7625-124, Poster Session

A three-dimensional finite element analysis of the osseointegration progression in the human mandible

Y. M. Kadah, N. D. Hassan, E. Esmail, Cairo Univ. (Egypt)

In this study, three-dimensional (3D) finite element analysis was used to model the effect of the peri-implant bone geometry and thickness on the biomechanical behavior of a dental implant/supporting bone system. The 3D finite element model of the jaw bone, trabecular and cortical, was developed based on computerized tomography (CT) scan technology while the dental implant model was created based on a commercially available implant design. Two models, cylindrical and threaded, representing the peri-implant bone region were simulated. In addition, various thicknesses (0.1 mm, 0.3 mm, 0.5 mm) of the peri-implant bone region were modeled to account for the misalignment during the drilling process. Different biomechanical properties of the peri-implant bone region were used to simulate the progression of the osseointegration process with time. Four stages of osseointegration were modeled to mimic different phases of tissue healing of the peri-implant region starting with soft connective tissue and ending with complete bone maturation.

For the realistic threaded model of the peri-implant bone region, von Mises stress and displacement in the dental implant and jaw bone (cortical, trabecular) were higher than those computed for the simple cylindrical peri-implant bone region model.

On the other hand, maximum von Mises stress and displacement in the dental implant decreased as the oseeointegration progressed with time for realistic thicknesses of the peri-implant bone region. However, von Mises stress in jaw bone decreased with the progression of the osseointegration process with time at higher peri-implant bone region thicknesses and showed a complicated response at lower thicknesses.

7625-125, Poster Session

Visualization of 3D kinematics using reconstructed bony surfaces of the elbow obtained using x-ray computed tomography

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An approach for direct visualization of continuous three-dimensional elbow joint kinematics using reconstructed surfaces obtained from x-ray computed tomography has been developed. Simulation of elbow motion was achieved in cadaveric specimens (n=6) using an upper arm simulator previously developed in the laboratory. Direct visualization of the motion of the ulna and humerus were obtained using a contact based registration technique employing fiducial markers. Using fiducial markers, the rendered humerus and ulna were positioned according to the simulated motion. The specific aim of this study was to investigate the effect of radial head arthroplasty on restoring elbow joint kinematics and stability. The position of the ulna with respect to the humerus was visualized for the intact elbow, the radial head resected elbow and the radial head replaced elbow. Additionally, this study employed a graphic approach to assess the change in ulnar position in a single plane of motion. Direct visualization of the registered humerus/ulna was achieved and showed an increase in valgus angulation of the ulna with respect to the humerus after radial head excision. However, this increase in valgus angulation was restored to that of the intact native radial head following radial head arthroplasty. These findings were consistent with previous studies investigating elbow joint stability following radial head arthroplasty. Using this approach, the coupled motion of ulna undergoing motion in all 6 DoF can be directly visualized. Visualizing joint kinematics and stability will provide clinicians' insight into the bony interactions which occur following surgical and medical interventions.

7625-35, Session 8

Toward image-based global registration for bronchoscopy guidance

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Virtual image-based bronchoscopic systems have been found to be useful for carrying out accurate and skill-independent bronchoscopies. A crucial step to the success of these systems during a live procedure is the local registration of the current real bronchoscope position to the virtual bronchoscope of the guidance system. The synchronization between the live and the virtual bronchoscope is generally lost during adverse events such as patient coughing with guidance often adversely disrupted. Manual intervention by an assisting technician often helps in recovering from such a disruption, but this results in extra procedure time and some potential uncertainty in the locally registered position. To rectify this difficulty, we present for the first time a global-registration algorithm that identifies the bronchoscope position without the need for significant bronchoscope maneuvers or technician intervention. The method involves a fast local-registration search over all the branches in a global airway-bifurcation search space, with the normalized correlation metric used for finding the best match. We have achieved a global registration accuracy near 90% in tests over a set of three different virtual bronchoscopic cases and with live guidance in an airway phantom. The method shows considerable potential for enabling global technician-independent guidance of bronchoscopy, without the need of any external device such as an electromagnetic sensor.

7625-36, Session 8

Rapid block matching based nonlinear registration on GPU for image-guided radiation therapy

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To compensate for non-uniform deformation due to patient motion within fractions and between fractions in image guided radiation therapy, a block matching technique was adapted and implemented on the GPU to determine the displacement vector field that maps the displacement between successive CT images. Normalized cross correlation (NCC) was chosen as the similarity metric for the matching step, with regularization of the displacement vector field being performed by mean filtering. A multi-scale multi-resolution framework was adopted to further improve the performance of the algorithm. The nonlinear registration algorithm was first applied to estimate the intra-fractional motion from 4D lung CT images. It was also used to calculate the inter-fractional organ motion between planning CT (PCT) and Daily Cone Beam CT (CBCT) images of thorax. For both experiments, manual landmark-based evaluation was performed to quantify the registration performance. In 4D dynamic CT registration, the RMS TRE was 0.63mm. In PCT-CBCT registration, the RMS TRE was 3.26mm. Compared to the CPU based AtamaiWarp program, our GPU implementation achieves comparable registration accuracy and is ~30 times faster. The results highlight the potential utility of our algorithm for online adaptive radiation treatment.

7625-37, Session 8

Towards real-time 2D/3D registration for organ motion monitoring in image-guided radiation therapy

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Nowadays, radiation therapy systems incorporate kilo voltage imaging units which allows the real-time acquisition of intra-fractional X-ray images of the patient with high details and contrast. An application of this technology is tumor motion monitoring during irradiation. For tumor tracking implanted markers or passive and active position sensors are used but require an intervention. 2D/3D intensity based registration is an alternative non-invasive method but the procedure must be sped up to the update rate of the device, which lies in the range of 5 Hz.

In this paper we investigate fast CT to kilo voltage X-ray 2D/3D image registration using a new porcine reference phantom. Fast registration became possible using two procedures previously developed by our group: wobbled splatting implemented on the GPU for the DRR computation and rank correlation. The mean projection distance (mPD) is used to assess the accuracy of the registrations. The mean and standard deviation of the mPD of 150 registrations are 4.75 +- 2.76. Currently, the mean registration time is of 9.1 seconds which is by a magnitude faster than computation time reported in the literature.

7625-38, Session 8

User-driven 3D mesh region targeting

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We present a method for the fast selection of a region on a 3D mesh using geometric information. This is done using a weighted arc length minimization with a conformal factor based on the mean curvature of the 3D surface. A careful analysis of the geometric estimation process enables our geometric curve shortening to use a reliable smooth estimate of curvature and its gradient. The result is a robust way for a user to easily interact with particular regions of a 3D mesh construced from medical imaging. We describe the applicability of the method for real-time clinician use.

In this study, we focus on building a robust and semi-automatic method for extracting selected folds on the cortical surface, specifically for isolating gyri by drawing a curve along the surrounding sulci. It is desirable to make this process semi-automatic because manually drawing a curve through the complex 3D mesh is extremely tedious, while automatic methods cannot realistically be expected to select the exact closed contour a user desires for a given dataset. In the technique described here, a user places a handful of seed points surrounding the gyri of interest; an initial curve is made from these points which then evolves to capture the region.

7625-39, Session 8

Segmenting TRUS video sequences using local shape statistics

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Automatic segmentation of the prostate in transrectal ultrasound (TRUS) may improve the fusion of TRUS with magnetic resonance imaging (MRI) for TRUS/MRI-guided prostate biopsy and local therapy. It is very challenging to segment the prostate in TRUS images, especially for the base and apex of the prostate due to the large shape variation and low signal-to-noise ratio. To successfully segment the whole prostate from 2D TRUS video sequences, this paper presents a new model based algorithm using both global population-based and adaptive local shape statistics to guide segmentation. By adaptively learning shape statistics in a local neighborhood during the segmentation process, the algorithm can effectively capture the patient-specific shape statistics and the large shape variations in the base and apex areas. After incorporating the learned shape statistics into a deformable model, the proposed method can accurately segment the entire gland of the prostate with significantly improved performance in the base and apex. The proposed method segments TRUS video in a fully automatic fashion. In our experiments, 19 video sequences with 3064 frames in total grabbed from 19 different patients for prostate cancer biopsy were used for validation. It took about 200ms for segmenting one frame on a Core2 1.86 GHz PC. The average mean absolute distance (MAD) error was 1.65±0.47mm for the proposed method, compared to 2.50±0.81mm and 2.01±0.63mm for independent frame segmentation and frame segmentation result propagation, respectively. Furthermore, the proposed method reduced the MAD errors by 49.4% and 18.9% in the base and by 55.6% and 17.7% in the apex, respectively.

7625-40, Session 9

Development and validation of a real-time reduced field of view imaging driven by automated needle detection for MRI-guided interventions

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Automatic tracking and scan plane control in MRI-guided therapy is an active area of research. However, there has been little research on tracking needles without the use of external markers. Current methods also do not account for possible needle bending, because the tip does not get tracked explicitly. In this paper, we present a preliminary method to track a biopsy needle in real-time MR-images based on its visible susceptibility artifact and automatically adjust the next scan plane in a closed loop to keep the needle's tip in the field of view. The images were acquired with a Single Shot Fast Spin Echo sequence combined with a reduced FOV techniques using 2D RF pulses, which allows a reduction in scan time without compromising spatial resolution. The software was implemented as a plug-in module for open-source medical image visualization software 3D Slicer to display the current scan plane with the highlighted needle. Tests using a gel phantom and an ex vivo tissue sample are reported and evaluated in respect to performance and accuracy. The preliminary results proved that the method allows an image update rate of one frame per second with a root mean square error within 4 mm. The proposed method may therefore be feasible in MRI-guided targeted therapy, such as prostate biopsies.

7625-41, Session 9

Assessment of registration accuracy in three-dimensional transrectal ultrasound images of prostates

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In order to obtain a definitive diagnosis of prostate cancer, over one million men undergo prostate biopsies every year. Currently, biopsies are performed under two-dimensional (2D) transrectal ultrasound (TRUS) guidance with manual stabilization of a hand-held end- or side-firing transducer probe. With this method, it challenging to precisely guide a needle to its target due to a potentially unstable ultrasound probe and limited anatomic information, and it is impossible to obtain a 3D record of biopsy locations. We have developed a mechanically-

stabilized, 3-dimensional (3D) TRUS-guided prostate biopsy system, which provides additional anatomic information and permits a 3D record of biopsies. A critical step in this system's performance is the registration of 3D-TRUS images obtained during the procedure, which compensates for intra-session motion and deformation of the prostate. We evaluated the accuracy and variability of surface-based 3D-TRUS to 3D-TRUS rigid and non-rigid registration by measuring the target registration (TRE) error as the post-registration misalignment of manually marked, corresponding, intrinsic fiducials. We also measured the fiducial localization error (FLE), to measure its contribution to the TRE. Our preliminary results yielded mean TRE values of 2.13 mm and 2.09 mm for rigid and non-rigid techniques, respectively. Our FLE of 0.21 mm did not dominate the overall TRE. These results compare favorably with a clinical need for a TRE of less than 2.5 mm.

7625-42, Session 9

Accuracy validation for MRI guided robotic prostate biopsy

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We report a quantitative evaluation of the clinical accuracy of a MRI guided robotic prostate biopsy system that has been in use for over five years at the US National Cancer Institute. A two-step rigid volume registration using mutual information between the pre and post needle insertion images was performed. Contour overlays of the prostate before and after registration were used to validate the registration. A total of 20 biopsies from 5 patients were evaluated. The maximum registration error was 2mm. The mean biopsy target displacement, robot needle placement error, and biopsy error was 5.4mm, 2.2mm, and 5.1mm respectively. The results show that the pre-planned biopsy target did dislocate during the procedure and therefore causing biopsy errors.

7625-43, Session 9

Registration of ultrasound to CT angiography of kidneys: a porcine phantom study

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3D ultrasound (US) to computed tomography (CT) registration is a topic of significant interest because it can potentially improve many minimally invasive procedures such as laparoscopic partial nephrectomy. Partial nephrectomy patients often receive preoperative CT angiography, which helps define the important structures of the kidney such as the vasculature. Intraoperatively, dynamic real-time imaging information can be captured using ultrasound and compared with the preoperative data. Providing accurate registration between the two modalities would enhance navigation and guidance for the surgeon. However, one of the major problems of developing and evaluating registration techniques is obtaining sufficiently accurate and realistic phantom data especially for soft tissue. We present a detailed procedure for constructing tissue phantoms using porcine kidneys, which incorporates contrast agent into the tissue such that the kidneys appear representative of human CT angiography. These phantoms are also imaged with US and resemble US images from human patients. We then perform registration on corresponding CT and US datasets using a simulation-based algorithm. The method simulates an US image from the CT, generating an intermediate modality that resembles ultrasound. This simulated US is then registered to the original US dataset. Being able to test our registration method on realistic datasets facilitates the development of novel CT to US registration techniques such that we can generate an effective method for human studies.

7625-44, Session 9

Localization of brachytherapy seeds in ultrasound by registration to fluoroscopy

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Motivation: In prostate brachytherapy, transrectal ultrasound (TRUS) is used to visualize the anatomy, while implanted seeds can be seen in C-arm fluoroscopy or CT. Intra-operative dosimetry optimization requires localization of the implants in TRUS relative to the anatomy. This could be achieved by registration of TRUS images and the implants reconstructed from fluoroscopy or CT. Methods: TRUS images are filtered, compounded, and registered on the reconstructed implants by using an intensity-based metric based on a 3D point cloud to volume registration scheme. A phantom was implanted with 48 seeds, imaged with TRUS and CT/X-ray. Ground-truth registration was established between the two. Seeds were reconstructed from CT/X-ray. Seven TRUS filtering techniques and two image similarity metrics were analyzed as well. Results: The noise reduction filter coupled with a beam width filter produced best results when applying the normalized correlation metric (NC) yielding a Target Registration Error (TRE) value of 0.54 ± 1.36 mm. When applying the mean squares (MS) metric, a combination of noise reduction, phase congruency and beam width filters yielded a TRE of 0.03 ± 0.44 mm. A false positive analysis using both metrics was performed with final results being 0.72 ± 0.28 mm for NC metric and 0.24 ± 0.12 mm for the MS metric. Finally, the more precise MS metric yielded an average error of 3.27 ± 1.42 mm in clinical data. Conclusion: Fully automated seed localization in TRUS performed excellently on ground-truth phantom, adequate in clinical data and was time efficient having an average runtime of 90 seconds.

7625-45, Session 9

Design of a predictive targeting error simulator for MRI-guided prostate biopsy

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Multi-parametric MRI is a new imaging modality superior in quality to Ultrasound which is currently used in standard prostate biopsy procedures. Surface-based registration of the pre-operative and intra-operative prostate volumes is a simple alternative to side-step the challenges involved with deformable registration. However, segmentation errors inevitably introduced during prostate contouring spoil the registration and biopsy targeting accuracies. For the crucial purpose of validating this procedure, we introduce a fully automated and customizable simulator which determines the resulting targeting errors of simulated registrations between prostate volumes given user-provided parameters for organ deformation, segmentation, and targeting. We present the workflow executed by the simulator in detail and discuss the parameters involved. We also present a segmentation error introduction algorithm, based on polar curves and natural cubic spline interpolation, which realistically mimics contouring errors introduced by a physician. One simulation, including all I/O and preparation for rendering, takes approximately 1 minute and 40 seconds to complete on a system with 3 GB of RAM and four Intel Core 2 Quad CPUs each with a speed of 2.40 GHz. Preliminary results of our simulation suggest the maximum tolerable segmentation error given the presence of a 5.0 mm wide small tumor is between 4-5 mm. We intend to validate these results via clinical trials as part of our ongoing work.

7625-46, Session 10

Towards hybrid bronchoscope tracking under respiratory motion: evaluation on a dynamic motion phantom

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This paper presents a hybrid camera tracking method using electromagnetic (EM) tracking and image-based registration and its evaluation on a dynamic motion phantom. As respiratory motion can significantly affect rigid registration ofthe EM tracking and CT coordinate systems, a standard tracking approach that initializes imagebased registration with absolute pose data acquired by EM tracking will fail as soon as the initial camera pose is too far away from the actual pose. We here propose two new schemes to approach this problem, which intelligently combine absolute pose data from EM tracking with relative motion data combined from EM tracking and imagebased registration. They both significantly improve the overall camera tracking performance. We constructed a dynamic phantom simulating the respiratory motion ofthe airways to evaluate our proposed method. Although the maximum simulated respiratory motion is up to about 24 mm, our experimental results demonstrate that the proposed method can track a bronchoscope more accurately and robustly than our previously proposed method.

7625-47, Session 10

CT image reconstruction of a totally deflated lung using extrapolated deformable registration

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A novel technique is proposed to reconstruct CT image of a totally deflated lung using the breath-hold lung's CT images acquired during respiration. Such reconstructed CT image would be very useful in performing tumor ablative procedures such as lung brachytherapy, which can aid in targeting the tumor for lung cancer treatment. To minimize target motion within the lung, tumor ablative procedures are frequently performed while the lung is totally deflated. Deflating the lung during such procedures renders pre-operative images acquired using breath-hold or sequential CT protocols ineffective for targeting the tumor, because those images correspond to the lung while it is partially inflated. Furthermore, the problem cannot be solved using intra-operative Ultrasound (US) images. This is because US images are very sensitive to residual air in a deflated lung, thus it is not an effective intra-operative imaging modality by itself. One possible approach for image guided lung brachytherapy is to register high quality preoperative CT images of the deflated lung with their corresponding low quality intra-operative US images. To obtain the CT images of deflated lung we present a novel image reconstruction technique. The proposed technique was implemented using two deformable registration methods: multi-resolution b-spline and multi-resolution demons. The technique was applied to an ex-vivo porcine lung where the preliminary results were found to be very encouraging.

7625-48, Session 10

Representing flexible endoscope shapes with hermite splines

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Navigation of a flexible endoscope is a challenging surgical task: the shape of the end-effector of the endoscope, interacting with surrounding tissues, determine the surgical path along which the endoscope is pushed. We present a navigational system that visualized the shape of the flexible endoscope tube to assist gastrointestinal surgeons in performing Natural Orifice Translumenal Endoscopic Surgery (NOTES). The system used an electromagnetic positional tracker, a catheter embedded with multiple electromagnetic sensors, and graphical user interface for visualization. Hermite splines were used to interpret the position and direction outputs of the endoscope sensors. We conducted NOTES experiments on live swine involving 6 gastrointestinal and 6 general surgeons. Participants who used the device first were 14.2 +- 74.5% slower the second time (when not using the device). Participants who used the device second were 33.6 +- 32.1% faster than the first session (p=0.179). The trend suggests that spline-based visualization is a promising adjunct during NOTES procedures.

7625-49, Session 10

Airway shape assessment with visual feed-back in asthma and obstructive diseases

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Airway remodeling in asthma patients has been studied in vivo by means of endobronchial biopsies allowing to assess structural and inflammatory changes. However, this technique remains relatively invasive and difficult to use in longitudinal trials. The development of alternative non-invasive tests, namely exploiting high-resolution imaging modalities such as MSCT, is gaining interest in the medical community. This paper develops a fully-automated airway shape assessment approach based on the 3D segmentation of the airway lumen from MSCT data. The objective is to easily notify the radiologist on bronchus shape variations (stenoses, bronchiectasis) along the airway tree during a simple visual investigation. The visual feed-back is provided by means of a volume-rendered color coding of the airway calibers which are robustly defined and computed, based on a specific 3D discrete distance function able to deal with small size structures. The color volume rendering (CVR) information is further on reinforced by the definition and computation of a shape variation index along the airway medial axis enabling to detect specific configurations of stenoses. Such cases often occur near bifurcations (bronchial spurs) and they are either missed in the CVR or difficult to spot due to occlusions by other segments. Consequently, all detected shape variations (stenoses, dilations and thickened spurs) can by additionally displayed on the medial axis and investigated together with the CVR information. The proposed approach was evaluated on a MSCT database including twelve patients with severe or moderate persistent asthma, or severe COPD, by analyzing segmental and subsegmental bronchi of the right lung. The only CVR information provided for a limited number of views allowed to detect 78% of stenoses and bronchial spurs in these patients, whereas the inclusion of the shape variation index enabled to complement the missing information.

7625-50, Session 10

Anatomical modeling of the bronchial tree

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The bronchial tree is of direct clinical importance in the context of respective diseases, such as chronic obstructive pulmonary disease (COPD). It furthermore constitutes a reference structure for object localization in the lungs and it finally provides access to lung tissue in e.g. bronchoscope-based procedures for diagnosis and therapy. This paper presents a comprehensive anatomical model for the bronchial tree, including statistics of position, relative and absolute orientation, length, and radius of 34 bronchial segments, going beyond previously published results. The model has been built from 16 manually annotated CT scans, covering several branching variants. The model is represented as a centerline/tree structure but can also be converted in a surface representation. Possible model applications are either to anatomically label extracted bronchial trees or to improve the tree extraction itself by identifying missing segments or sub-trees, e.g. if located beyond a bronchial stenosis. Bronchial tree labeling is achieved using a naïve Bayesian classifier based on the segment properties contained in the model in combination with tree matching. The tree matching step makes use of branching variations covered by the model. An evaluation of the model has been performed in a leave-one-out manner. In total, 87% of the branches resulting from preceding airway tree segmentation could be correctly labeled. The individualized model enables the detection of missing branches, allowing a targeted search, e.g. a local re-run of the tree-segmentation segmentation.

7625-51, Session 11

The MITK image-guided therapy toolkit and its application for augmented reality in laparoscopic prostate surgery

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Image Guided Therapy (IGT) faces researchers with high demands and efforts in system design, prototype implementation, and evaluation. The lack of standardized software tools, like algorithm implementations, tracking device and tool setups, and data processing methods escalate the labor for system development and sustainable system evaluation.

In this paper, a new toolkit component of the Medical Im-aging and Interaction Toolkit (MITK), the MITK-IGT, and its exemplary application for computer-assisted prostate surgery are presented. MITK-IGT aims at integrating soft-ware tools, algorithms and tracking device interfaces into the MITK toolkit to provide a comprehensive software frame-work for computer aided diagnosis support, therapy plan-ning, treatment support, and radiological follow-up.

An exemplary application of the MITK-IGT framework is introduced with a surgical navigation system for laparos-copic prostate surgery. It illustrates the broad range of ap-plication possibilities provided by the framework, as well as its simple extensibility with custom algorithms and other software modules.

7625-52, Session 11

Model-updated image-guided liver surgery: preliminary results using intra-operative surface characterization

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Compensating for intraoperative deformations using computational models has shown promising results. Since computational time is an important factor during surgeries, a priori knowledge of the possible sources of deformation can increase the accuracy and efficiency of model-updated image-guided systems. Recently, we proposed approaches utilizing a template of pre-operatively computed model solutions in the context of partial hepatectomies. Similar to our previous work, we will use an iterative approach that updates the point correspondences between the measured intra-operative data and the model solutions and then combine the model solutions in

a linear fashion to match the measured sparse intra-operative data. Two different approaches to obtaining the point correspondences will be explored in this work. Intra-operative liver surface descriptions for patients undergoing partial hepatectomies obtained using an optically tracked laser range scanner will be used and semi-quantitative and qualitative validations will be presented. Preliminary results presented here are encouraging and indicate that the method should provide a more realistic and viable method to compensate for soft tissue deformation within the time constraints of hepatic resections.

7625-53, Session 11

A 3D-elastography-guided system for laparoscopic partial nephrectomies

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We propose a tracked laparoscopic system for ultrasound-based 3D elasticity imaging (EI) to provide a novel modality for registration with pre-operative CT. Such a system is suited for interventions like laparoscopic partial nephrectomies, where this new use of EI makes exact execution of pre-operative planning possible.

Quick acquisition and registration of 3D-EI volume data allows intra-operative registration with CT and thus with pre-defined target and critical regions (e.g. tumors and vasculature). This real-time location information is then overlaid onto a tracked endoscopic video stream to help the surgeon avoid vessel damage and still completely resect tumors including safety boundaries.

The proposed system promises to increase the success rate for partial nephrectomies and potentially for a wide range of other laparoscopic soft tissue interventions. This is enabled by the two components of robust real-time elastography and fast 3D-EI/CT registration. With high quality, robust strain imaging (through a combination of dynamic programming 2D-EI, optimal frame pair selection, and optimized palpation motions), kidney tumors that were previously unregistrable or even invisible with conventional B-mode ultrasound can now be imaged reliably in interventional settings. Furthermore, this allows the transformation of planning CT data of kidney ROIs to the intra-operative setting with a markerless mutual-information-based registration, using EM sensors for intra-operative motion tracking.

7625-54, Session 11

Fast automatic path proposal computation for hepatic needle placement

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Radiofrequency ablation (RFA) has become an established treatment option for early hepatocellular carcinoma and for metastatic liver tumors that are not suited for surgical resections. This minimally invasive therapy employs a radiofrequency applicator in the form of a straight needle or a multitined needle which induces electrical energy into the tumor tissue and destroys it due to induced heat. Precise planning and execution of the needle placement are necessary to increase the safety and the efficacy of the RFA. Multiple criteria affect the appropriateness of a needle path and have to be taken into account during needle path determination. Since double oblique paths are quite common, path determination in 2D slices demands considerable experience. Other techniques that utilize needle shaped instruments

such as biopsy, seed implantation for brachytherapy, microwave ablation and cryoablation face similar challenges. Therefore we propose a method that automatically computes optimal path proposals for a given target point inside the liver to support the planning process for RFA and for hepatic needle placement in general. Prerequisites are segmentation results of the liver and all relevant risk structures as well as the tumor in the case of tumor ablation therapies. In addition, a preprocessing step with a duration of few seconds has to be carried out once per patient. The method utilizes the graphics hardware of the workstation to compute path proposals within computation times that allow for interactive updates upon changes of the target point and other relevant input parameters.

7625-55, Session 11

The application of collision detection to assess implant insertion in elbow replacement surgery

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An important aspect of artificial replacements of the human joint is the fit achieved between the implant and bone canal. This study investigated the kinematics and dynamics of the insertion procedure for the humeral implant of the elbow in an attempt to determine its final posture within the canal. A specially developed algorithm employed CT-derived models of bone and collision-detection. By measuring the misalignment between the natural FE axis of the humeral bone and the one materialized by the analyzed prosthesis, a prediction can be made regarding the fit between the canal and the implant. Using an in-vitro validation on cadaver specimens, this technique was shown to accurately predict canal stem misalignment.

7625-56, Session 11

A novel technique for analysis of accuracy of magnetic tracking systems used in image guided surgery

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The expanding application and availability of image-guided intervention techniques require accurate and precise methods of locating tools placed within the body. The application of image-guidance to percutaneous procedures requires tracking technologies which do not depend on line of sight (as do optical trackers). This is often accomplished using magnetic tracking systems. However, magnetic tracking systems are subject to errors from both intrinsic system sources and the tracking environment (e.g. the procedure room, the region of the body, etc.). Previous studies have developed various metrics for determination of tracker accuracy; however, such evaluations are often limited to a single tracker. In our work, we describe a new method for assessment of tracking systems using a novel universal "phantom system". Within this framework, we describe a special protocol for the acquisition of a dense sampling of the specified work volume of any tracking system. We propose several methods of analysis of the data produced by this special type of acquisition. These methods have then been applied to commonly used commercial tracking systems and the tracking accuracies of these systems are compared and discussed.

Conference 7626: Biomedical Applications in Molecular, Structural, and Functional Imaging

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7626-01, Session 1

Strain correction in interleaved strain-encoded (SENC) cardiac MR

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Strain Encoded (SENC) CMR is a technique that directly encodes the regional strain into the acquired images. By acquiring two images with different tunings (low and high tunings), a dense estimate of longitudinal strain on the short-axis view or circumferential strain on the long-axis view can be measured. Non-Interleaving acquisition was used to capture the two sets of images which lead to doubling the acquisition time. Recently, interleaving acquisition is used to reduce the acquisition time by 50%; however, errors in the strain calculations due to inter-tunings motion of the heart arise. The goal of this work is to propose a method for correcting these errors, so that fast acquisition with accurate strain measurements is achieved. For interleaved acquisition, with low temporal resolution, the low and high tuning images will correspond to different points in time in the cardiac cycle. The proposed technique is used to correct for this misalignment in time by trying to estimate the shift in the frequency (which depends on the strain rate) to adjust the signal intensities, so that the exact strain values are computed. Test data were acquired using Philips Achievea scanner. The proposed method was able to correct the strain curves, and it becomes nearly identical to the ideal strain curves. Also simulated data was generated to validate the proposed method. It is noticed that the correction algorithm is more tolerant for lower temporal resolution, and it relaxes the imaging constraints that will improve the SNR of the image.

7626-02, Session 1

Multimodal image registration: matching MRI with histology

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Spatial correspondence between histology and multi sequence MRI can provide information about the capabilities of non-invasive imaging to characterize cancerous tissue. However, the correlation of MR images with histological tumor tissue sections is complicated by shrinkage and deformation of the tissue which occurs during the excision of the tumor and the histological processing. The aim of this work is to propose a methodology to establish a 3D relation between in vivo MRI tumor data and 3D histology of tumor sections. The key features of the methodology are a very dense histologic sampling, up to 120 histology slices per tumor are acquired, the utilization of the whole 3D data sets, mutual information based non rigid B-spline registration and the exploitation of an intermediate ex vivo MRI. Prior to ex vivo MRI a thin section of the tumor is sliced off to define the imaging plane for ex vivo MRI and the plane for cutting histological sections. This reference plane limits the degrees of freedom for elastic registration.

Whereas between ex-vivo MRI and in-vivo MRI the computed elastic deformations represent significant shape changes, the elastic deformations resulting from registering histology and ex-vivo MRI consist primarily of shrinkage of the specimen (up to 25%) due to the process of dehydration. Using this methodology, it is possible to account for changes caused by the excision of the tumor, the process of fixation and dehydration and the histological slicing. As a result, histological annotation can be directly related to the corresponding in vivo MRI.

7626-03, Session 1

Quantitative evaluation of liver function using gadoxetate disodium (Gd-EOB-DTPA) enhanced MR imaging

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Purpose: Gadoxetate disodium (Gd-EOB-DTPA) is a novel targeted MR contrast agent that combines two features for extracellular and hepatocyte-specific, and has been used in clinical applications for evaluating liver function. Indocyanine green (ICG), a tricarbocyanine dye, is widely used for its clearance test in the evaluation of liver function because it is removed from circulation exclusively by the liver. The objective of this study was to evaluate the liver function based on ICG elimination rate constant (ICG K) by use of feature values derived from Gd-EOB-DTPA enhanced MR imaging (EOB-MRI).

Methods: We evaluated eighteen patients who had EOB-MRI and ICG clearance test within 4 weeks. Gd-EOB-DTPA (0.1 mL/kg body weight) was intravenously administered, and 2D-GRE T1 weighted images using a 3.0 T MRI scanner were obtained including the liver and spleen at 20 min after the administration. The feature values for liver volume (V), mean pixel value of the liver (L20) and spleen (S20) were measured based on the contours of the lesion which was provided manually by radiologists. The liver function was evaluated by use of many parameters including V×(L20 - S20)/S20.

Results: The correlation coefficient between many parameters and ICG K was evaluated, and a high correlation (r = 0.92) was observed for determining quantitative evaluation of liver function by use of V×(L20 - S20)/S20, whereas the correlation between L20 and ICG K was low (r = 0.33).

Conclusions: The parameters derived from EOB-MRI may correlate well with ICG K, thus suggesting a possibility to estimate segmental liver function using EOB-MRI, which would be useful for preoperative evaluation of the liver reserve.

7626-04, Session 1

Development of image processing methods to quantify spatial and temporal ventilation dynamics using hyperpolarized 3He magnetic resonance imaging in chronic obstructive pulmonary disease

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Hyperpolarized helium-3 (3He) magnetic resonance imaging (MRI) has emerged as a radiological research method for imaging both structural and functional changes within the airways and airspaces of the lung. Here we endeavor to use hyperpolarized 3He MRI to develop novel methods for quantifying ventilation dynamics in response to salbutamol in a small group of subjects with Chronic Obstructive Pulmonary Disease (COPD). Whole body 3.0 Tesla Excite 12.0 MRS system was used with broadband imaging capability to obtain multi-slice coronal images using fast gradient-echo method with centric k-space sampling acquired immediately after subjects inhaled 3He gas administered from 1L Tedlar bag. Static ventilation images for three COPD ex-smokers were acquired before and after 400 µg salbutamol administration, and pixels receiving ventilation were quantified. Post-salbutamol

ventilation images mean pixel count was higher than pre-salbutamol mean pixel count. Co-registration of pre- and post-salbutamol ventilation images was also performed following signal normalization, thresholding, and two-dimensional rigid image registration based on three to seven fiducial markers for visualization and quantification of regional ventilation changes. Co-registration tools quantified regions of ventilation change, and there were more pixels corresponding to newly ventilated regions from the post-salbutamol image. Evaluating ventilation dynamics post-salbutamol using co-registration tools provides regional information to identify functional ventilation improvements post-bronchodilator.

7626-05, Session 1

The improvement of ICA with projection technique in multitask fMRI data analysis

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The existence of the potential non-independency between task-related components in multi-task functional magnetic resonance imaging (fMRI) studies limits the general application of Independent Component Analysis (ICA) method. The ICA with projection (ICAp) method proposed by Long (2009, HBM) demonstrated its capacity to solve the interaction among task-related components of multi-task fMRI data. The basic idea of projection is to remove the influence of the uninteresting tasks through projection in order to extract one interesting task-related component. However, both the stimulus paradigm of each task and the homodynamic response function (HRF) are essential for the projection. Due to the noises in the data and the variability of the HRF across the voxels and subjects, the ideal time course of each task for projection would be deviant from the true value, which might worsen the ICAp results. In order to make the time courses for projection closer to the true value, the iterative ICAp is proposed in this study. The iterative ICAp is based on the assumption that the task-related time courses extracted from the fMRI data by ICAp is more approximate to the true value than the ideal reference function. Simulated experiment proved that both the spatial detection power and the temporal accuracy of time course were increased for each task-related component. Moreover, the results of the real two-task fMRI data were also improved by the iterative ICAp method.

7626-06, Session 2

Bayesian network analysis applied to grey matter volumes of cortical regions

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Analysis of structural networks in the brain can be useful for understanding development, disease and functional orchestration of various brain regions. Such an analysis based on correlation coefficent has shown a remarkable similarity in structural and functional networks. While such network reveal information about interdependence of brain regions, the do not provide information about directional causality between them. Since time seris for structural data is not available, causality is difficult to determine. We hypothesize that directed graph based on Baysian networks can provide some insight into structural interdependence. In this paper we employ a structure learning algorithm for Bayesian network to get connectivity in grey matter volume and cortical surface area. The Bayesian network of cortical structures revealed a striking connectivity pattern with higher level functional areas connected to many different lower level functional areas in a hierarchial manner.

7626-07, Session 2

Magnetic resonance imaging for white matter degradation in fornix following mild traumatic brain injury

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Fornix is the primary white matter (WM) pathway interconnecting the hippocampus and the rest of limbic system via mammillary bodies. It might be susceptible to traumatic brain injury (TBI) and result in various post-concussive symptoms of cognitive, executive and memory dysfunctions. However, rare neuroimaging studies have been conducted in exploring the fornix WM degradation in TBI especially for mild cases (mTBI), and no longitudinal measurements have been performed to elaborate the fornix alteration in TBI. We believe that this inactivity can be partially attributed to the smaller size of fornix as well as the inability of traditional techniques like structural MRI in assessing the diffuse axonal injury (DAI) resulted from the stretching and shearing of WM fibers. In the present study, both structural MRI and DTI techniques were used to evaluate the WM degradations of fornix in 24 patients imaged in an actuate stage within 7 weeks after the injury. Longitudinal analysis was obtained for 12 patients with an additional 6-month follow up scan. Our DTI data indicated that the fraction anisotropy (FA) values of fornix WM are significantly lower in the mild TBI than those of matched healthy controls, and that the fornix degradation tends to continue with further slightly lower FA values. Structural analysis with fornix-to-brain-ratio (FBR) confirmed the DTI findings by evidence that the mild TBI patients have a significant FBR reduction in the acute stage and this fornix atrophy continues with slightly lower FBR after 6 months of recovery.

7626-08, Session 2

Statistical shape analysis of gender differences in the lateral ventricles

Q. He, D. Karpman, Y. Duan, Univ. of Missouri-Columbia (United States)

This paper aims at analyzing gender differences in the 3D shapes of lateral ventricles, which will provide reference for the analysis of brain abnormalities related to neurological disorders. Previous studies mostly focused on volume analysis, and the main challenge in shape analysis is the required step of establishing shape correspondence among individual shapes. We developed a simple and efficient method based on anatomical landmarks. 14 females and 10 males with matching ages participated in this study. 3D ventricle models were segmented from MR images by a semiautomatic method. Six anatomically meaningful landmarks were identified by detecting the maximum curvature point in a small neighborhood of a manually clicked point on the 3D model. Thin-plate spline was used to transform a randomly selected template shape to each of the rest shape instances, and the point correspondence was established according to Euclidean distance and surface normal. All shapes were spatially aligned by Generalized Procrustes Analysis. Hotelling T2 two-sample metric was used to compare the ventricle shapes between males and females, and False Discovery Rate estimation was used to correct for the multiple comparison. The results revealed significant differences in the anterior horn of the right ventricle.

7626-09, Session 2

Shape analysis of corpus callosum in phenylketonuria using a new 3D correspondence algorithm

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Statistical shape analysis of brain structures has gained increasing

interest from neuroimaging community because it can precisely locate shape differences between healthy and pathological structures. The most difficult and crucial problem is establishing shape correspondence among individual 3D shapes. This paper proposes a new algorithm for 3D shape correspondence. A set of landmarks are sampled on a template shape, and initial correspondence is established between the template and the target shape based on the similarity of locations and normal directions. The landmarks on the target are then refined by iterative thin plate spline transformation. The algorithm is simple and fast, and no spherical mapping is needed. We apply our method to the statistical shape analysis of the corpus callosum in phenylketonuria, and significant local shape differences between the patients and the controls are found in the anterior most and posterior most of the corpus callosum.

7626-10, Session 2

Mapping gray matter volume and cortical thickness in Alzheimer's disease

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Gray matter voxel-based volume and cortical thickness are the two important indices widely used to detect neuropathological changes in brain structural magnetic resonance imaging. Using optimized VBM protocol and surface-based cortical thickness measure, this study comprehensively investigated the regional changes of cerebral cortex in AD, and compared the statistical mapping between gray matter voxel-based volume and cortical thickness as well. Thirteen patients with AD and fourteen matched healthy controls were included in this study. Results showed that gray matter voxel-based volume and cortical thickness reductions were highly correlated in temporal lobe and its medial structure. Especially, parahippocampal gyrus and posterior cingulate gyrus were statistical consistency regions in left and right hemisphere using these two indices. Moreover cortical significant reduced regions of gray matter volume were obviously more than that of cortical thickness. These findings suggest that gray matter volume and cortical thickness are effective indices for understanding the neuropathology in AD.

7626-11, Session 2

The posterior cingulate cortex consistently plays the pivotal role in the default mode network across different healthy subjects under different fMRI scan parameters

R. Li, J. Li, X. Miao, L. Yao, X. Wu, Beijing Normal Univ. (China)

Resting-state functional MRI (fMRI) studies have suggested the posterior cingulate cortex (PCC) plays a pivotal role in the default mode network (DMN), a set of coactivated brain regions characterizing the resting-state brain. Concerning this finding we propose the following questions in this study: Does PCC consistently play the equally crucial role in the DMN across different subjects, such as healthy young and healthy old subjects? Whether the fMRI scan environments or parameters would affect the results? To address these questions, we collected resting-state fMRI data on four groups of subjects: two healthy young groups scanned under 3-T and 1.5-T MRI systems respectively, and two healthy old groups both scanned under 3-T MRI system but with different scan parameters. Then group independent component analysis was used to isolate the DMN, and partial correlation analysis was employed to reveal the direct interactions between core brain regions from the DMN. Last, the number of directly and significantly correlated brain regions for each region in the DMN within each group was calculated. We found that PCC was the region consistently having the largest number of directly interacted brain regions in the four groups, suggesting the pivotal role of PCC in the DMN was stable and consistent across different healthy subjects. The

results also suggested the function of PCC would be more critical in healthy old groups compared with healthy young groups. And the factors of scan environments and parameters did not show any obvious impact on the above conclusions in this investigation.

7626-12, Session 3

A review of multivariate methods in brain imaging data fusion

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There is great potential benefit in group analysis based on the joint information from multiple task brain imaging data. On joint analysis of functional MRI datasets, a variety of multivariate methods have shown their strengths and been applied to achieve different purposes based on their respective assumptions. In this paper, we provide a comprehensive review on both the advantages and limitations of six data fusion models, including 1) four blind methods: joint independent component analysis (ICA), multimodal canonical correlation analysis (mCCA), CCA on blind source separation (CCA_S) and partial least squares (PLS); 2) two semi-blind methods: parallel ICA and coefficent constrained ICA (CC-ICA). We also propose a novel model for joint blind source separation (BSS) of two datasets using a combination of CCA and ICA, i.e., 'CCA+ICA', which, compared with other joint BSS methods, can achieve higher decomposition accuracy as well as the correct automatic source link. Applications of the proposed CCA+ICA to real multi-task fMRI data further showed its advantages on data fusion and interpretation of group differences (schizophrenia patients versus controls) in contrast with joint ICA and mCCA, promising wide applicability in the medical imaging community.

7626-13, Session 3

Improving visualization of intracranial arteries at the skull base for CT angiography with calcified plaques

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Computed tomographic angiography (CTA) is the most frequently used noninvasive imaging modality for the detection of vascular anomalies in the acute setting. A precise, computerized three-dimension representation of the vascular structures can provide invaluable insights for making the real-time operating room decision. In the past, bony structures at the skull base were the main studied obstacle to detection and estimation of arterial stenoses and aneurysms. Today, direct subtraction and the matched mask bone elimination (MMBE) have become standard methods for removing bony structures. However, clinicians regularly find that calcified plaques at or near the carotid canal cannot be removed satisfactorily by existing methods. The blood-plaque boundary tends to be blurred by subtraction operation while plaque size is constantly overestimated by the bone mask dilation operation in the MMBE approach. In this study, we propose using the level of enhancement to adjust the MMBE bone mask more intelligently on the artery- and tissue-bone/calcified plaque boundaries. In our new approach, the original MMBE method will only apply to the tissue-bone/plaque boundary voxels. The artery-bone/plaque boundary voxels, identified by a higher enhancement level, are processed by direct subtraction instead. A dataset of 6 patients (3 scanned with a regular radiation dose and 3 scanned with a reduced dose) with calcified plaques at or near the skull base is used to examine our new method. Preliminary results indicate that the visualization of intracranial arteries with calcified plaques at the skull base can be improved effectively and efficiently.

7626-14, Session 3

Intraoperative prediction of tumor cell concentration from mass spectrometry imaging

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This work is motivated by the problem of accurately locating tumor boundaries during brain tumor surgery. Currently, such boundary is typically localized using preoperative images and neuronavigation tools. While improved prognosis is associated with minimal residual tumor, an added challenge arises in surgical-decision making to completely excise the tumor and preserve eloquent cortex. An objective assessment of patterns of tumor cell concentration could help in performing this boundary location by identification of local minima of the tumor cell concentration which can be associated with tumor boundaries. In this work, we aim to correlate the mass spectrometry data - acquired from tissue sections by the Desorption Electrospray Ionization (DESI) approach - with histopathological scores of cellular density (as evaluated by the neuropathology expert), towards demonstrating that a system can be trained apriori on available tissue samples with known scores, and can be used intraoperatively as an integrated DESI probe to predict the score of the tissue under analysis. As a first step towards this, we analyze the data from a training set of subjects with different histopathological scores towards learning a "model" that best distinguishes between the samples of different scores. We then apply this model to predicting the scores for the tissue samples from a new unseen subject. We also explore approaches to normalize the data from each subject so as to minimize the impact of intersubject variance on the applicability of the learned model to previously unseen data.

7626-15, Session 3

Retrospective analysis of application of compressive sensing to 1H MR metabolic imaging

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Purpose: To demonstrate application of compressed sensing on phantom models of 1H MR metabolic imaging. Methods: Reconstruction of data, simulated to be acquired through compressed sensing is implemented on a computer generated phantom simulating two metabolites of the human brain. The effect of Gaussian noise on this phantom is evaluated for values of SNR in the range of 2 db to 14 db. A retrospective analysis of the application of such a reconstruction method for 1H Chemical Shift Imaging (CSI) of previously acquired in-vitro brain phantom is done for the first time. The results are compared with the reconstruction done from complete k-space. Results: The computer generated phantom reconstruction was evaluated for varying values of undersampling factor from 0.2 to 0.9 by obtaining the corresponding Normalized Root Mean Square Error (NRMSE) values. An undersampling factor of 0.5 was chosen as an optimal value for undersampling with a mean NRMSE of 0.005 over 10 trials and NRMSE was 0.008 with the addition of Gaussian noise. In the case of the in-vitro phantom, the reconstruction showed a mean NRMSE was less than 1%.(all slices).Conclusion: It has been shown that a L1-norm based reconstruction method can be successfully applied on 1H CSI in-vitro and computer generated phantom data sets for the first time. Further work would involve implementation and validation of the one implemented and other L1-norm reconstruction algorithms on various other anatomical CSI data sets thus enabling CSI to have shorter acquisition times and serve as a viable tool in the clinic.

7626-16, Session 3

Improved estimation of parametric images of cerebral glucose metabolic rate from dynamic FDG-PET using volume-wise principle component analysis

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Dynamic positron emission tomography (PET) is a promising diagnostic tool to predict biological and physiological changes in vivo through quantitatively estimation of parametric images on voxel level. However, the process usually suffers from high sensitivity to image noise. To address this problem, a volume-wise principal component analysis (PCA) based kinetics method is proposed. In this method, firstly dynamic PET data are properly transformed to standardize noise variance as PCA is a data driven technique and can not itself separate signals from noise. Secondly, the volume-wise PCA is applied on PET data. The signals can be mostly represented by the first few principle components (PC) and the noise is left in the subsequent PCs. Then the first few PCs are mapped back to the original data space as noise-reduced data using 'inverse PCA'. It should also be transformed back according to the transform method used in the first step to maintain the scale of the original data set. Finally, the obtained new data set is used to generate parametric images using the non-linear least squares (NLS) estimation. Compared with conventional NLS method, the proposed method can achieve high statistical reliability in the generated parametric images. The effectiveness of the method is demonstrated both with computer simulation and with clinical dynamic FDG PET study.

7626-17, Session 4

Assessment of contrast flow modification in aneurysms treated with closed-cell, self-expanding asymmetric vascular stents (SAVS)

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The Asymmetric Vascular Stent (AVS) is an experimental device, specially designed for intracranial aneurysm (IA) treatment through intra-aneurysmal blood flow diversion and thrombosis promotion. The stent has a low-porosity patch to cover only the aneurysm neck while the rest of the stent is very porous to avoid blockage of adjacent vessel branches. The AVS design in this study is similar to state-of-the-art, closed-cell, self-expanding, neurovascular stents, with the addition of a PTFE patch. The stents were used to treat ten elastase-induced aneurysm models in rabbits. The treatment effect was analyzed using normalized time-density curves (NTDC) measured on angiograms by pixel-value integration over a region-of-interest containing the aneurysm. These curves were normalized to the total bolus injection. Pre- and post- stented NTDC peak ratios were used as the main treatment outcome indicator. Pre-stented NTDC peaks were between 30% and 5% depending on the aneurysm-vasculature geometry and location of the contrast bolus injection. All post-treatment NTDC peaks were under 2% of the total measured bolus injection. Two aneurysms showed a pre-/post- peak ratio of only 0.5 after treatment, but displayed partial thrombosis and very little flow at the 4-week follow-up. The other aneurysms showed a peak ratio smaller than 0.02 after treatment and were fully thrombosed at the 4-week follow-up. We demonstrate aneurysmal blood flow diversion using a new low-porosity, patch-containing, self-expanding asymmetric vascular stent (SAVS) in an elastase side-wall aneurysm model. Treatment outcome results and angiographic analysis indicate that the new self-deploying stent design has great potential for clinical implementation.

7626-18, Session 4

A new image-based process for quantifying hemodynamic contributions to long-term morbidity in a rabbit model of aortic coarctation

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Coarctation of the aorta (CoA) is associated with reduced life expectancy despite treatment. Interestingly, much of the related long-term morbidity can be explained by abnormal hemodynamics, vascular biomechanics and cardiac function. MRI has played an important role in assessing coarctation severity, but the heterogeneity and small number of patients at each center presents an obstacle for determining causality. This work describes optimized imaging parameters to create computational fluid dynamics (CFD) models revealing changes in hemodynamics and vascular biomechanics from a rabbit model. CoA was induced surgically at 10 weeks using silk or dissolvable ligatures to replicate native and end-to-end treatment cases, respectively. Cardiac function was evaluated at 32 weeks using a fastcard SPGR sequence in 6-8 two-chamber short-axis views. Left ventricular (LV) volume, ejection fraction, and mass were quantified and compared to control rabbits. Phase contrast (PC) and angiographic MRI were used to create CFD models using cvSim software. Ascending aortic PCMRI data were mapped to the model inflow and outflow boundary conditions replicated measured pressure (BP) and flow. CFD simulations were performed using a stabilized finite element method to calculate indices including velocity, BP and wall shear stress (WSS). CoA models displayed higher velocity through the coarctation region and decreased velocity elsewhere, leading to decreased WSS above and below the stenosis. Pronounced wall displacement was associated with CoA-induced changes in BP. CoA caused reversible LV hypertrophy. Cardiac function was maintained, but caused a persistent hyperdynamic state. This model may now be used to investigate potential mechanisms of long-term morbidity.

7626-19, Session 4

Computational blood flow and vessel wall modeling in a CT-based thoracic aorta after stent-graft implantation

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Abnormal blood flow conditions and structural fatigue within stented vessels may lead to undesired failure causing death to the patient. Image-based computational modeling provides a realistic insight into the patient-specific biomechanics and enables accurate predictive simulations of development, growth and failure of cardiovascular diseases as well as associated risks. Controlling the efficiency of an endovascular treatment is necessary for the evaluation of potential complications and predictions on the assessment of the pathological state.

In this paper we investigate the effects of stent-graft implantation on the biomechanics in a patient-specific thoracic aortic model. The patient geometry and the implanted stent-graft are obtained from morphological data based on a CT scan performed during a controlling routine. Computational fluid dynamics (CFD) and computational structure mechanics (CSM) simulations are conducted based on the finite volume method (FVM) and on the finite element method (FEM) to compute the hemodynamics and the elastomechanics within the aortic model, respectively. Physiological data based on transient pressure and velocity profiles are used to set the necessary boundary conditions. Further, the effects of various physical conditions on the biomechanics are also investigated. Thereby, the interaction of the aorta with the stent

and the stent-graft is simulated using various constraint conditions. The quantification of the hemodynamics and the elastomechanics post endovascular intervention provides a realistic controlling of the state of the stented vessel and of the efficiency of the therapy. Consequently, computational modeling would help in evaluating individual therapies and optimal treatment strategies in the field of minimally invasive endovascular surgery.

7626-20, Session 4

Optical imaging of steady flow in a phantom model of iliac stenosis: comparison of CFD simulations with PIV measurements

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Experimental and numerical simulations of steady flow through a severe stenosed tube have been performed in order to model the biofluid dynamics of an actual vascular stenosis. A Particle Image Velocimetry (PIV) apparatus was set up and used to measure the flow fields across a Gaussian-shaped 87% area stenotic phantom. The flow parameters were adjusted to the phantom geometry in order to mimic the blood flow through the femoral artery. Computational Fluid Dynamics (CFD) simulation of the same flow was also performed and the results were compared with those of PIV measurements.

7626-21, Session 4

Accurate 2D cardiac motion tracking using scattered data fitting incorporating phase information from MRI

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Magnetic resonance imaging has been widely used in measuring cardiac motion due to its ability to non-invasively and selectively alter tissue magnetization and produce tags on the deforming tissue. B-splines have been used to fit the tag lines due to their ability to conform to local deformations while enforcing continuity. In this paper, we describe a new approach to analysis of tagged MR images using multilevel B-splines fitting incorporating phase information. By considering the tag line intersections as scattered data, multilevel B-splines can result in accurate and fast approximation without specifying the control point locations explicitly. Dense virtual tag intersections based on Harmonic Phase are created and incorporated into the multilevel B-spline fitting process. The accuracy and the effectiveness of the proposed method have been validated by using simulated data from the 13-parameter kinematic model of Arts and by using in vivo canine data.

7626-22, Session 4

Comparison of myocardial motion estimation methods based on simulated echocardiographic B-mode and RF data

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Heart disease is one of the major causes of mortality and morbidity in the United States. Echocardiography plays an important role in the diagnosis of cardiovascular diseases. In this paper, we combine a ventricular kinematic model and an ultrasound simulation model in order to simulate the echocardiographic imaging process. The result achieves more realistic B-Mode images in addition to the raw RF data when compared to previous echocardiography simulation models. The improvements are due to the use of a shift-variant PSF and more accurate cardiac motion assumptions. One attribute of the simulator is also that it provides the ground-truth vector field of ``ventricular deformations'' which may be used to strictly validate motion estimation

and elastography algorithms. Several echocardiography parameters were taken into account including central frequency, apodization, number of elements in the array, speed of sound, and number of scatterers.

Different motion estimation techniques such as Lucas-Kanade, Horn-Schunck, Brox et al, Black and Anandan, and Block Matching (BM) were applied to the simulated B-mode images and RF data. The results were validated with the ground-truth motion fields from the actual deformations. This paper shows the first application of optical flow on echocardiography RF data using normalized data in piece-wise segments of RF images.

The validations show that Brox et al method performs better than other motion estimation techniques when applied to B-Mode and RF data. Also, as intuitively expected, use of RF data results in more accurate displacement fields than when B-mode images are used.

7626-23, Session 5

A numerical study of the inverse problem of breast infrared thermography modeling

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Infrared thermography has been shown to be a useful adjunctive tool for breast cancer detection. Previous thermography modeling techniques generally dealt with the "forward problem", i.e., to estimate the breast thermogram from known properties of breast tissues. The present study aims to deal with the so-called "inverse problem", namely to estimate the thermal properties of the breast tissues from the observed surface temperature distribution. By comparison, the inverse problem is a more direct way of interpreting a breast thermogram for specific physiological and/or pathological information. In tumor detection, for example, it is particularly important to estimate the tumor-induced thermal contrast, even though the corresponding non-tumor thermal background usually is unknown due to the difficulty of measuring the individual thermal properties. Inverse problem solving is technically challenging due to its ill-posed nature, which is evident primarily by its sensitivity to imaging noise. Taking advantage of our previously developed forward-problem-solving techniques with comprehensive thermal-elastic modeling, we examine here the feasibility of solving the inverse problem of the breast thermography. The approach is based on a presumed spatial constraint applied to three major thermal properties, i.e., thermal conductivity, blood perfusion, and metabolic heat generation, for each breast tissue type. Our results indicate that the proposed inverse-problem-solving scheme can be numerically stable under imaging noise of SNR ranging 32 ~ 40 dB, and that the proposed techniques can be effectively used to improve the estimation to the tumor-induced thermal contrast, especially for smaller and deeper tumors.

7626-24, Session 5

Microwave imaging of the breast with incorporated structural information

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Microwave imaging for biomedical applications, especially for early detection of breast cancer and effective treatment monitoring, has attracted increasing interest in last several decades. This fact is due to the high contrast between the dielectric properties of the normal and malignant breast tissues at microwave frequencies ranging from high megahertz to low gigahertz. The available range of dielectric properties for different soft tissue can provide considerable functional information about tissue health. Nonetheless, one of the limiting weaknesses of microwave imaging is, unlike that for conventional modalities such as X-ray CT or MRI, it inherently cannot provide high resolution images. The conventional modalities can produce highly resolved anatomical information but often cannot provide the functional information required

for diagnoses. We have developed a soft prior regularization strategy that can incorporate the prior anatomical information from either x-ray, MR or other sources and use it in a way to refine the resolution of the microwave images while also retaining the functional nature of the images. The anatomical information is first used to create an imaging zone mesh which delineates separate internal substructures and an associated weighting matrix that numerically groups the values of closely related nodes within the mesh. This information is subsequently used as a regularizing term for the Gauss-Newton reconstruction algorithm. This approach exploits existing technology in a systematic way without making potentially biased assumptions about the properties of visible structures. We present a series of breast-shaped simulation and phantom image reconstructions along with those for initial clinical patient data.

7626-25, Session 5

Reconstruction and visualization of 3D multimodality image-guided near infrared spectroscopy estimates for breast cancer applications

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Multi-modality image-guided near infrared spectroscopy (IG-NIRS) has been used to recover 3D estimates of tissue types composing the breast in-vivo such as adipose and fibroglandular tissues using boundary element method (BEM). This was extended to tumor tissue in subjects with cancer and/or undergoing neoadjuvant treatment. Results from a subject undergoing neoadjuvant chemotherapy, show a decrease in concentration of total hemoglobin during treatment both in adipose and in tumor tissue. Tools for multi-modality optical visualization have been developed using VTK/ITK and the entire procedure in between data acquisition and visualization is being automated for clinical use.

7626-26, Session 5

A novel and fast method for cluster analysis of DCE-MR image series for segmentation of breast tumors

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A novel approach is introduced for clustering tumor regions with similar signal-time series measured by dynamic contrast-enhanced (DCE) MRI to segment the tumor area in breast cancer. Each voxel of the DCE-MRI data set is characterized by a signal-time curve. The clustering process uses two describer values for each pixel. The first value is L2-norm of each time series. The second value r is calculated as sum of differences between each pair of $S(n-i)$ and $S(i)$ for $i = \{0...n/2\}$ where S is the intensity and n the number of values in a time series. We call r reverse value of a time series. Each time series is considered as a vector in an n-dimensional space and the L2-norm and reverse value of a vector are used as similarity measures. The curves with similar L2-norms and similar reverse values are clustered together. The method is tested on breast cancer DCE-MRI data sets with N = 256 x 256 spatial resolution and n = 128 temporal resolution. The quality of each cluster is described through the variance of Euclidean distances of the vectors to the mean vector of the corresponding cluster. The combination of both similarity measures improves the segmentation compared to using each measure alone.

7626-27, Session 5

Modeling bioluminescent photon transport in tissue based on radiosity-diffusion model

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Bioluminescence tomography (BLT) is a non-invasive optical molecular imaging modality that aims to monitor biological processes at cell and molecular level in vivo. The model for the bioluminescent photon propagation plays an important role in the BLT study. Due to the high computational efficiency, diffusion approximation (DA) is generally applied in the BLT. But DA is valid only in highly scattering and weakly absorbing regions, and fails in non-scattering or low-scattering tissues, such as a cyst in the breast, the cerebrospinal fluid (CSF) layer of the brain and synovial fluid layer in the joints. A Radiosity-Diffusion method is proposed for dealing with the non-scattering regions within diffusing domains in this paper. This hybrid method incorporates a priori information of the geometry of non-scattering regions, which can be acquired by magnetic resonance imaging (MRI) or x-ray computed tomography (CT). Then the implementation uses a finite element method (FEM) to ensure the high computational efficiency. Finally, we demonstrate the method to be comparable to Mont Carlo (MC) method which is regarded as a 'gold standard' for photon transportation simulation.

7626-28, Session 6

Microvascular blood flow mapping from wide-field optical fluctuations measurements

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We report recent results in angiographic mapping from endogenous blood flow contrast in vivo with an interferometric technique. Our approach consists in recording fluctuation patterns of near infrared laser light with an array detector. Imaging of the Doppler spectrum from the phase fluctuations of the light backscattered by the sample under investigation is made from wide-field interference measurements between the scattered optical field and a reference field. This allows a precise determination of the scattered field spatial phase retardation in the detector plane and enable image reconstruction by holographic algorithms. Radiofrequency-selective optical fluctuations measurements between 0 and 100 kHz are enabled by detuning the reference beam with respect to the illumination beam. A high detection sensitivity is crucial to assess optical spectrum dispersion from momentum transfer between scattered light and biological tissues in the low radiofrequencies range. Our approach has the strong advantage of enabling imaging of the optical Doppler spectrum in vivo in low-light conditions. Sensitive light fluctuations probing with a charge-coupled device (CCD) or complementary metal-oxide semiconductor (CMOS) camera is enabled by a highly efficient noise cancelation scheme involving a double modulation of the signal. Images of exposed cerebral cortex in mice exhibit local motion contrasts from blood flow down to the smallest capillaries. Because it is based on low power near infrared optical radiation, this approach has the potential to pave the way to the development of innovative non-ionizing tools for functional biopsy of hemodynamic components.

7626-29, Session 6

Automated 3D segmentation of intraretinal layers from optic nerve head optical coherence tomography images

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Optical coherence tomography (OCT), being a noninvasive imaging modality, has begun to find vast use in the diagnosis and management of retinal diseases. In glaucoma,for instance, the retinal nerve fiber layer (RNFL) has been known to reduce in thickness. The availability of the considerably larger volumetric data further increased the need for new processing techniques. In this paper, we present an automated 3-D graph-theoretic approach for the segmentation of 8 surfaces (7 layers) of the retina from 3-D spectral-domain OCT images centered on the optic nerve head (ONH). The multiple surfaces are detected simultaneously through the computation of a minimum-cost closed set in a vertex-weighted graph constructed using edge/regional information, subject to a priori determined varying surface interaction and smoothness constraints. The method incorporates the location of the large blood vessels and the optic disc to address the challenges presented by these structures. The overall mean unsigned positioning error was found to be 13.4 +/- 5.2µm when comparing the algorithm to the manual tracings of an observer on 10 volumetric datasets of glaucomatous eyes. The resulting RNFL thickness maps show a thickness of 74.5 +/- 34.9µm in the normals eyes and 60.7 +/- 26.8µm in the glaucomatous eyes (p < 0.01).

7626-30, Session 6

3D segmentation of retinal blood vessels in spectral-domain OCT volumes of the optic nerve head

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Segmentation of retinal blood vessels can provide important information for detecting and tracking retinal vascular diseases including diabetic retinopathy. Many studies about 2-D segmentation of retinal blood vessels in various imaging modalities have been performed. However, 3-D segmentation of retinal blood vessels in spectral-domain optical coherence tomography (OCT) volumes capable of providing geometrically accurate vessel models, to the best of our knowledge, has not been previously studied. The purpose of this study is to develop and evaluate an automated method that can detect 3-D retinal blood vessels from spectral-domain OCT scans centered on the optic nerve head (ONH). The proposed method utilized a fast multiscale 3-D graph search to segment retinal surfaces and a triangular mesh-based 3-D graph search to detect retinal blood vessels. An experiment on 30 ONH-centered OCT scans (15 right eye scans and 15 left eye scans) was performed, and the mean unsigned error was 3.375 ± 2.457 voxels (0.101 ± 0.074 mm).

7626-31, Session 6

Cryo-imaging of stem cells in cardiovascular therapeutics

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We developed a cryo-imaging system which provides single-cell detection of fluorescently labeled stem cells throughout a mouse and applied it to cardiovascular regenerative medicine. Alternating between sec¬tioning and imaging, the system collects tiled color brightfield

and fluorescence block face images, creating >60 GB data volumes at 10micron-scale. Stem cells (MSCs) labeled with quantum dots were injected via tail vein in mice with or without myocardial infarction (MI). Cryo-imaging and interactive visualization allowed us to examine cell biodistribution at scales from whole mouse to organ to tissue to single cell. Dividing numbers of cells in heart to lung gave a delivery ratio (RD), which normalized for injection variation. Stem cell homing was evident. At Day1-Day4, RD (with,without MI) was (0.17+/-0.02,0.02), (0.15+/-0.02,0.04), (0.21+/-0.03,0.03), and (0.28+/-0.03,0.05), respectively. Over time, cells near the infarct remained whereas other cells disappeared. From Day1-Day5, the percent of cells in the heart, in and near the infarct were 1%, 17%, 18%, 30%, and 44%, respectively. At Day1, histograms of cells per cluster (heart,lung) were remarkably consistent: (73%,75%), (15%,16%), (6%,6%) for 1's, 2's, and 3's, respectively, providing intriguing hypotheses for investigation. There were some few (4%) large clusters (>4 cells) in the lung not in the heart, probably indicating filtered cell "clumps." Over time, clusters had more cells giving us a unique way to quantify cell division in vivo. Remarkably, with only about 800 cells in the heart with a mean minimum distance of 130micron, there is significant cardiac recovery, arguing for a very strong paracrine effect from each cell. Cryo-imaging promises to be an important tool for the study of stem cell biology, delivery, homing factors, differentiation, etc.

7626-32, Session 6

Cryo-imaging in a toxicological study on mouse fetuses

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We applied our cryo-imaging system to detect signals of developmental toxicity in transgenic mouse fetuses resulting from maternal exposure to a developmental environmental toxicant (2,3,7,8-tetrachlorodibenzo-p-dioxin, TCDD). We utilized a fluorescent transgenic mouse model that expresses Green Fluorescent Protein (GFP) exclusively in smooth muscle under the control of the smooth muscle gamma actin (SMGA) promoter (SMGA/EGFP mice kindly provided by J. Lessard, U. Cincinnati). Analysis of cryo-image data volumes comprised of very high-resolution anatomical brightfield and molecular fluorescence block face images, revealed qualitative and quantitative morphological differences in control versus exposed fetuses. Fetuses randomly chosen from pregnant females euthanized on gestation day (GD) 18 were either manually examined or cryo-imaged. For cryo-imaging, fetuses were embedded, frozen and cryo-sectioned at 20 μm thickness and brightfield color and fluorescent block-face images were acquired with an in-plane resolution of ≈15 μm. Automated 3D volume visualization schemes segmented out the black embedding medium and blended fluorescence and brightfield data to produce 3D reconstructions of all fetuses. Comparison of Treatment groups TCDD GD13, TCDD GD14 and control through automated analysis tools highlighted differences not observable by prosectors performing traditional fresh dissection. For example, severe hydronephrosis, suggestive of irreversible kidney damage, was detected by cryoimaging in fetuses exposed to TCDD. Automated quantification of total fluorescence in smooth muscles revealed suppressed fluorescence in TCDD-exposed fetuses. This application demonstrated that cryo-imaging can be utilized as a routine high-throughput screening tool to assess the effects of potential toxins on the developmental biology of small animals.

7626-33, Session 6

Adhesive improvement in optical coherence tomography combined with confocal microscopy for class V cavities investigations

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The purpose of this study is to present a non invasive method for the marginal adaptation evaluation in class V composite restorations. Standardized class V cavities, prepared in human extracted teeth, were filled with Premise (Kerr) composite. The specimens were thermo cycled. The interfaces were examined by Optical Coherence Tomography method (OCT) combined with the confocal microscopy and fluorescence. The optical configuration uses two single mode directional couplers with a superluminiscent diode as the source at 1300 nm. The scanning procedure is similar to that used in any confocal microscope, where the fast scanning is en-face (line rate) and the depth scanning is much slower (at the frame rate). Gaps at the interfaces as well as inside the composite resin materials were identified. OCT has numerous advantages which justify its use in vivo as well as in vitro in comparison with conventional techniques. The main problems were observed at the adhesive layers where it is very hard to observe the adhesive in compare with the materials defects. For this reason the adhesive was improved in order to be more scattered and in this way to observe better the difference between the adhesive layer and the materials defects that could lead to micro leakage.

7626-34, Session 7

Quantitative evaluation of bronchial enhancement: preliminary observations

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It has been known for several years that airflow limitations in the small airways may be an important contributor to Chronic Obstructive Pulmonary Disease (COPD). Quantification of wall thickness has lately gained attention thanks to the use of high resolution CT, with novel approaches focusing on automated methods that can substitute for visual assessment. While increased thickening of the wall is considered evidence of inflammatory disease, we hypothesize that there may be additional ways to detect and quantify inflammation, specifically the uptake of contrast material. In this preliminary investigation, we selected patients with documented chronic airway inflammation, and for whom pre and post contrast datasets were available. On targeted reconstruction of right upper and lower lobes, we selected airways with no connections to surrounding structures, and used a modified Full-Width-Half-Max method for quantification of lumen diameter, wall thickness, and wall density. Matching airway locations on the pre- and post-contrast cases were compared. Airways from patients without airway disease served as a control. Results for the airway disease cases showed an average enhancement of 72 HU within the airway walls, with a standard deviation of 59 HU. In the control group the average enhancement was 16 HU with standard deviation of 22 HU. While this study is limited in number of cases, we hypothesize that quantification of contrast uptake is an additional factor to consider in assessing airway inflammation. At the same time we are currently investigating whether enhancement can be measured via a "contrast" map created with dual energy scanning, where a 3-value decomposition algorithm differentiates iodine from other materials. This technique would eliminate both the need for a pre-contrast scan, and the task of matching airway locations on pre- and post- scans.

7626-35, Session 7

Microstructural analysis of secondary pulmonary lobule imaged by synchrotron radiation micro CT using offset scan mode

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The lung consists of numerous anatomic units smaller than a lobe or segment. The secondary pulmonary lobule and lung acinus are widely considered to be fundamental units of these subsegmental lung units. Airways, pulmonary arteries, veins, lymphatics, and lung interstitium are represented at the level of the secondary lobule. The recognition of abnormalities relative to the lobular anatomy has become increasingly important in the diagnosis and differential diagnosis of lung abnormalities at clinical routines of CT examinations. This paper aims at three-dimensional (3-D) microstructural analysis of the lobular anatomy with isotropic spatial resolution in the range of several micrometers to quantitatively describe relation between the architectures and abnormalities. Recent commercial micro CT scanners play a vital role to imaging the lung micro-architectures. However, only a limit number of attempts have been conducted because of difficulties to image the secondary pulmonary lobule beyond the scan field of view and the limited contrast lung parenchyma. A main focus of this paper is to demonstrate the ability of synchrotron radiation micro CT (SRμCT) using offset scan mode in microstructural analysis of the secondary pulmonary lobule. The inflated and fixed lung specimen was imaged with resolution of 5.87x5.87x5.87 μm3 by using offset scan mode of the SRμCT (15 keV) at the synchrotron radiation facility (SPring-8). The 3-D SRμCT image which was stacked 2624 slices (each slice:7287x7287 voxels) covered the secondary pulmonary lobule being included in the lung specimen. A proper threshold value for appropriate segmentation was interactively determined to the volume of interest representing the secondary pulmonary lobule. Following transformation of the segmented binary image to a skeletonized surface representation, each voxel was classified as a curve, surface, or junction. Each component such as lobular airway, pulmonary artery, and vein were extracted interactively by using the voxel classification result which offered geometrical information. The resulting volumetric image from the SRμCT is ready to be used for 3-D microstructural analysis of the lobular anatomy.

7626-36, Session 7

Human airway tree structure query atlas

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A queryable electronic atlas was developed to quantitatively characterize the normal human lung airway tree and to provide a better understanding of the lung for diagnosing diseases and evaluating treatments. The atlas consists of airway measurements taken from CT images using the Pulmonary Workstation II (PW2) software package. The PW2 software generates more than 3000 measurements of the airway tree for each scan. These measurements include airway cross-sectional area at midpoint between branch points; maximum and minimum diameter of a particular airway cross section at segment midpoint; average, maximum, and minimum wall thickness per branch and as a function of generation; wall thickness uniformity within a branch and across a given generation; ratio of average wall thickness to airway cross-sectional area; and volume of air and wall tissue along individual airway branches. The atlas provides user friendly interfaces for interrogating population statistics, comparing populations, comparing individuals to populations, and comparing individuals to other individuals. Populations can be selected based on age, gender, race, ethnicity, and normalcy/disease. The atlas database consists of measurements from 129 image scans and consists of data from 59 males and 70 females; 68 non-smokers and 61 smokers; and 2 American Indians, 2 Asians, 15 Black/African Americans, and 110 White/Caucasians of which 4 are Hispanic/Latino. 12 of the atlas subjects are designated as having abnormal pulmonary functional tests of which 10 are smokers and 2 are non-smokers. The atlas mainly consists of measurements from individuals in the age ranges 20-30 and 40-50 years old.

7626-38, Session 7

Development of spatial ventilation heterogeneity and temporal ventilation probability image analysis tools and application to asthma hyperpolarized 3He magnetic resonance imaging

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Asthma is a chronic inflammatory disorder of the lung and recent imaging studies have demonstrated a heterogeneous distribution of ventilation and of ventilation abnormalities in asthma. Our objective was to develop and contrast clinically relevant hyperpolarized 3He magnetic resonance imaging analysis tools in order to quantitatively and qualitatively represent the day to day variations of ventilation patterns in asthma subjects. Mean signal coefficient of variation (CoV), previously developed by Albert et al., and mean signal ventilation gradient (VG) with varying regional dimensions were used as a measure of spatial ventilation heterogeneity in the lung. Temporal probability maps were computed to visualize the distribution of ventilation over three visits in a single map. Seven subjects with a history of mild to moderate exercise induced asthma were included in the analysis. Regional VG measurements recorded greater variations at the three visits than did the regional CoV measurements. However, none of the variations between subjects for any measurement were significantly different. There were no apparent differences between the three local dimensions used for each measurement. Temporal probability maps were also developed to provide a way to visualize regional ventilation patterns over three visits in a single map. Future work will aim to develop more robust quantitative statistics from our tools and apply them to an exercise induced asthma treatment study.

7626-39, Session 7

The effect of ACE inhibition on the pulmonary vasculature in a combined model of chronic hypoxia and pulmonary arterial banding in Sprague Dawley rats

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Angiotensin II has been identified as a mediator of pulmonary hypertension (PH). It has been shown to promote vascular smooth muscle cell hypertrophy and hyperplasia as well as stimulate synthesis of extracellular matrix proteins. Inhibition of angiotensin converting enzyme (ACE-I) has been shown, in rat models of PH, to attenuate vascular remodeling and decrease pulmonary vascular resistance. In this study we used rat models of chronic hypoxia as well as partial left pulmonary artery occlusion (PLPAO) to evaluate effects of ACE-I. Sprague Dawley rats were placed in hypoxia (FiO2 0.1) with one group in chronic hypoxia and the second group undergoing PLPAO three days prior to placement in hypoxia. The rats were in hypoxia for twenty-one days to establish pulmonary hypertension, after which treatment was started with captopril (20 mg/kg/day) for twenty-one days. After forty-two days endpoint studies were done looking at lung hemodynamics specifically; pulmonary vascular resistance, hematocrit, RV/LV+septum ratio, and ACE activity, as well as pulmonary vessel morphology and biomechanics using microfocal CT. Microfocal CT was used to image the pulmonary artery tree at twelve different pressures (40, 35, 30, 25, 20, 15, 12, 10, 7, 5, 3, and 0 mmHg). Images were then reconstructed to measure the segment length, diameter, and distensibility of the vascular tree. Preliminary data suggests that the chronic hypoxia group has a lower pulmonary vascular resistance compared to the hypoxia + PLPAO group as well as longer segment lengths and a larger diameter of the pulmonary vessels.

7626-40, Session 7

Arterial morphology responds differently to Captopril then N-acetylcysteine in a monocrotaline rat model of pulmonary hypertension

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Pulmonary hypertension (PH) is an incurable condition inevitably resulting in death as a result of increased right heart work load and eventual failure. PH causes pulmonary vascular remodeling, including muscularization of the arteries, and a reduction in the typically large vascular compliance of the pulmonary circulation. We used a rat model of monocrotaline (MCT) induced PH to evaluated and compared Captopril (an angiotensin converting enzyme inhibitor with antioxidant capacity) and N-acetylcysteine (NAC, a mucolytic with a large antioxidant capacity) as possible treatments. Twenty-eight days after MCT injection, the rats were sacrificed and heart, blood, and lungs were studied to measure indices such as right ventricular hypertrophy, hematocrit, pulmonary vascular resistance (PVR), vessel morphology and biomechanics. We implemented microfocal X-ray computed tomography to image the pulmonary arterial tree at intravascular pressures of 30, 21, 12, and 6 mmHg and then used automated vessel detection and measurement algorithms to perform morphological analysis and estimate the distensibility of the arterial tree. The vessel detection and measurement algorithms quickly and effectively mapped and measured the vascular trees at each intravascular pressure. Monocrotaline treatment, and the ensuing PH, resulted in a significantly decreased arterial distensibility, increased PVR, and tended to decrease the length of the main pulmonary trunk. In rats with PH induced by monocrotaline, Captopril treatment significantly increased arterial distensibility and decrease PVR. NAC treatment did not result in an improvement, providing no increase in distensibility and causing a further increase in PVR. Interestingly, NAC tended to increase pulmonary trunk length more than Captopril.

7626-78, Session 7

Two-dimensional airway analysis using probabilistic neural networks

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Although 3-D airway tree segmentation permits analysis of airway paths of practical lengths and facilitates visual inspection, 2-D single image-based airway analysis removes the dependence of following the airway path to what may appear as a lone airway section lung periphery. One disadvantage of 2D schemes is the lack of the ability to identify the airway generation (Gb). We applied a 2D based scheme to detect airway sections depicted on individual CT images. We computed airway lumen area (Ai), airway cross-sectional area (Aw), the ratio (Ra) of Ai to Aw, and the thickness (Tw) using our 2-D based airway analysis algorithm. We developed and tested two probabilistic neural networks (PNN) based on differently computed airway features. The PNN were trained and tested on 12 lung CT examinations. The overall accuracy for the PNN that utilized Ai and Ra for identifying an airway section's generation to within +/-one generation was 76.7%. The PNN that included wall thickness did not improve identification accuracy. This preliminary study demonstrates the feasibility of automated identification of the generation of the airway detected on a single CT images without information from neighboring images.

7626-61, Poster Session

A microfabricated phantom for diffusion tensor imaging

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A microfabricated phantom with application in diffusion tensor imaging (DTI) is presented. Using lithography technique, we have the capability of creating microchannels in the same scale as actual neural fibers (few to tens of microns in diameter). The method is flexible in generating different geometrical patterns. Neural bundles were simulated by designing a large number of microchannels, running parallel to each other.

PDMS, the casting material, is not diffusible to water. This applies the restriction to the diffusion of water molecules in different directions. The dimensions of the channels can be calculated based on the desired fractional anisotropy (FA) ratios.

Many unresolved issues in studying and improving diffusion tensor imaging can be carefully investigated by implementing an artificial model of neural bundles with well-known geometrical parameters. Problems affiliated with the crossing fibers in 'tractography' are among these issues. Since the topology of the tracts is known, whenever the full characterization of water motion is desired, the elements of the diffusion tensor can be calculated to be compared to the measured values. Optimization of the pulse sequences and calibration of the gradients in DTI are among other applications of such phantom.

The phantom is made of PDMS, a silicon based, MRI compatible material. Once the mold is generated, creating new phantoms is easy, quick and inexpensive and requires no special equipments.

7626-62, Poster Session

Extension of dVCA model and its application in estimating fMRI components

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Differentially variable component analysis (dVCA) is a Bayesian inference framework for single-trial event-related potentials (ERP) analysis. In this paper, we extend the dVCA model and apply it to functional magnetic resonance imaging (fMRI) data, where fMRI images are modeled as the linear combination of ongoing activity and multiple fMRI components that are relatively location-locked to certain tasks. The extended dVCA algorithm estimates each component's time-invariant spatial patterns, and its time-variant amplitude scaling factors and location shifts. Our algorithm works well on simulated image data and experimental fMRI images acquired with simple finger tapping task.

7626-63, Poster Session

Inferring visual system connectivity using dynamic causal modeling of functional magnetic resonance imaging data

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We propose algorithm model, dynamic causal modeling (DCM) that describes the interaction of several Brain Regions based on functional magnetic resonance imaging time series to make inferences about functional integration and segregation within the human brain. The method is to demonstrate using real data to show how such models are able to characterize interregional dependence. We extend estimating and reviewing designed model to characterize the interactions between regions and then to estimate the effective connectivity between these regions. All designs, estimates, reviews are implemented using SPM, one of the free best software packages used for design models and analysis for inferring about FMRI functional magnetic resonance imaging time series.

7626-64, Poster Session

fMRI and EEG brain activation patterns in an analytic reasoning task

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Functional magnetic resonance imaging (fMRI) is used to model brain activation patterns associated with various perceptual and cognitive processes as reflected by the hemodynamic (BOLD) response. And, while many sensory and motor tasks are associated with relatively simple activation patterns in a given localized region, higher-order cognitive tasks produce activity in many different brain areas, often involving a complex neural circuit. An fMRI study was conducted to identify the regions of the brain that are activated during the performance of an analytic reasoning task in contrast to a simple counting (control) task (i.e., simply enumerating the number of elements comprising the reasoning problems). A general linear model analysis (GLM) and a hybrid PICA/GLM (probabilistic independent component analysis [1]) were conducted to statistically identify regions of activation during analytic reasoning in a group of five subjects. The GLM model identified activation in expected locations, primarily the left inferior frontal and middle frontal gyri (Brodmann Areas 47 and 6), the cingulate gyri (Brodmann Areas 32 and 31), the right inferior frontal gyrus (Brodmann Area 47), and the right inferior parietal lobe (Brodmann Area 40). The hybrid PICA/GLM analysis also identified these regions of activation, and it also found several additional regions including Brodmann Areas 8 and 9 and additional regions of activation in the cingulate cortex (Brodmann Areas 24 and 41). The results suggest that a hybrid PICA/GLM may be better suited than GLM to capturing the true activation patterns associated with a complex cognitive task like analytic reasoning.

7626-65, Poster Session

Simultaneous measures of kinematics and fMRI: relation between movement parameters and activation maps in healthy subjects

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When facing neurological diseases, hemiparesis is not a static phenomenon and some recovery is foreseen depending on the severity of the damage and the choice of the rehabilitation treatment. So far, it is still reduced the capability to evaluate with accurate, quantitative and repeatable measures the outcomes of rehabilitation therapies and consequently the optimization of the treatment on each patient. To evaluate a rehabilitation protocol, it is needed a preliminary study in healthy subjects. This study aimed at identifying on healthy subjects the correlation among motor performances and brain activation maps, by the contemporary use of functional magnetic resonance imaging (fMRI) and optoelectronic motion analysis. The first goal was to individuate how movement parameters such as amplitude, frequency and velocity affect the related cerebral flow maps in active, passive and electrical stimulated movements. We identified different protocols so as to optimize the measured cerebral maps and the repeatability of the results. Selected protocols were tested with the collaboration of a significant number of healthy subjects after a training session. fMRI images and kinematics data were acquired for each protocol. Images analysis followed, using kinematics data as regressors. The work is preliminary to the following exploitation of the combined system in the evaluation of neurological patients where the definition of the motor tasks could be only partially accomplished and/or differently executed depending on the patient residual functionality.

7626-66, Poster Session

Regional homogeneity changes in prelingually deafened patients: a resting-state fMRI study

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Abstract: Resting-state functional magnetic resonance imaging (fMRI) is a technique that measures the intrinsic function of brain and has some advantages over task-induced fMRI. Regional homogeneity (ReHo) assesses the similarity of the time series of a given voxel with its nearest neighbors on a voxel-by-voxel basis, which reflects the temporal homogeneity of the regional BOLD signal. In the present study, we used the resting-state fMRI data to investigate the ReHo changes of the whole brain in the prelingually deafened patients compared with the normal controls. 18 deaf patients and 22 healthy subjects were scanned in the rest condition. For ReHo analysis, Kendall's coefficient of concordance (KCC) was calculated to measure the degree of regional coherence of fMRI time courses, and compared between patients and controls. Using general linear model (GLM), significant changes were found in the deaf patients (corrected by false discovery rate (FDR), $p < 0.05$). We found regional coherence decreased significantly in the left frontal lobe, bilateral temporal lobe and thalamus in the prelingually deafened patients when compared with the normal controls. Meanwhile, significantly increased regions were detected in the right corpus callosum and postcentral gyrus, cerebellum and left cingulate gyrus in deaf persons. These results show that the prelingually deafened patients have higher degree of regional coherence in the paleocortex, and lower degree in neocortex. Since neocortex plays an important role in the development of auditory, these evidences may suggest that the deaf persons active the paleocortex to offset the loss of auditory.

7626-67, Poster Session

Topologic analysis and comparison of brain activation in normal people versus epilepsy patients: an fMRI study

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This paper describes the development of novel computer-aided analysis algorithms to identify the language activation patterns at certain Regions of Interest (ROI) in Functional Magnetic Resonance Imaging (fMRI). Previous analysis techniques have been used to compare normal and pathologic activation patterns in fMRI images resulting from identical tasks but have been unable to segregate one from the other. This paper presents new analysis techniques and algorithms capable of identifying a pattern of language activation associated with localization related epilepsy. fMRI images of 64 normal individuals and 31 patients with localization related epilepsy have been studied and analyzed on an ROI basis. All subjects are right handed with normal MRI scans and have been classified into three age groups (4-6, 7-9, 10-12). Our initial efforts have focused on investigating activation in the Left Inferior Frontal Gyrus (LIFG). A number of volumetric features have been extracted from the data. The LIFG has been also cut into slices; the activation has been investigated topographically on a slice by slice basis. Overall, a total of 809 features have been extracted, and correlation analysis was applied to eliminate highly correlated features. Principal Component analysis was then applied to account only for major components in the data and One-Way Analysis of Variance (ANOVA) has been applied to test for significantly different features between normal and patient groups. Twenty Nine features has been found where their means for the normal group are significantly ($p < 0.05$) different than the patient group.

7626-68, Poster Session

Dealing with difficult deformations: construction of a knowledge-based atlas

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Cleft Lip and/or Palate (CLP) is the most common congenital craniofacial malformation and is caused by lack of fusion of facial processes in the young fetus leading to clefting that may be either uni- or bilateral. CLP is treated by surgical closure of the lip and palate soon after birth. However, a major problem in habilitation is still asymmetry of the constructed nose and upper lip [1].

The material consisted of 3-dimensional CT scans of 23 Taiwanese infants with UCLP. The infants were scanned before lip repair at the age of 3 months, and again after lip repair at the age of 12 months. Using atlases it was possible to achieve point correspondences from the patient before surgery to the patient after surgery.

The method used, combine non-rigid registration based on B-splines with thin-plate splines to deal with the change in morphology; in this case for closing the cleft.

The results are convincing and a first move towards an automatic registration method for dealing with changes due to surgery and growth.

7626-69, Poster Session

Dynamic CT head phantom for perfusion and angiography studies

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Contrast imaging is a compelling enhancement for the portable, flat panel-based brain CT scanner currently under development at Xoran. Due to the relative low temporal resolution of flat panel detectors, enabling tomographic imaging on such platform requires optimizing the imaging and injection protocols. A dynamic CT head phantom was designed to facilitate this task. The Dynamic Perfusion and Angiography Model (PAM), mimics tissue attenuation in CT images, provides physiological timing for angiography and perfusion studies, and moves fluid with properties similar to those of blood. The design consists of an arterial system, which contains bifurcating vessels that feed into perfusion chambers, mimicking blood flow through capillaries and smaller vessels, and a venous system, which is symmetrical to the arterial side and drains the perfusion chambers. The variation of geometry and flow rate in the phantom provides the physiological total time that fluid spends in the head, and the difference in material densities correlates to CT numbers for biological tissues. This paper discusses the design of Dynamic PAM and shows experimental results demonstrating its ability to realistically simulate blood flow. Results of dynamic imaging studies of the phantom are also presented

7626-70, Poster Session

International standards for pandemic screening using infrared thermography

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The threat of a virulent strain of influenza, severe acute respiratory syndrome (SARS), tuberculosis, recent outbreak of H1N1/A virus (swine flu) and possible mutations are a constant threat to global health. Implementation of pandemic infrared thermographic screening is based on the detection of febrile temperatures (inner canthus of the eyes) that are correlated with an infectious disease. Previous attempts at pandemic thermal screening have experienced problems (e.g. SARS outbreak , Singapore 2003) associated with the deployment plan, implementation and operation of the screening thermograph. Since this outbreak, the International Electrotechnical Commission has developed (IEC 80601 Medical electrical equipment - Part 2-59: Particular requirements for the basic safety and essential performance of screening thermographs for human febrile temperature screening and International Organization for Standardization ISO/TR 13154:2009 describes the deployment, implementation and operational guidelines. These international standards set minimum requirements for thermographic system fever screening and procedures that insure reliable and reproducible measurements. This includes camera calibrations, use of black body radiators, view field, focus, pixels within measurement site, image positioning, and deployment locations. Many current installations in airports are not taking into account critical issues addressed in the new standard, and are operating below the necessary efficiency. These documents, related thermal research, implications for epidemiology screening, and the future impact on medical thermography will be discussed.

7626-71, Poster Session

Erode/dilate analysis of micro-CT images of myocardial microcirculation

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Analysis of 3D images of vascular trees presents a major logistic and multi-scale imaging challenge. One approach that greatly reduces the image analysis difficulty is to use a sequential "erode/dilate" approach which progressively eliminates branches of increasing diameter. Although this provides useful data for detecting changes in branching geometry, this eliminates information about the "mother"-to-"daughter" branch relationships. In addition, if the analysis is performed on a biopsy, which includes intact and arbritarily cut vascular trees, then the analysis may be misrepresenting the branching geometry due to disproportionate sampling of the different branch generations. To quantify the impact of this loss of branching hierarchy information we analyzed 3D micro-CT images (4µm and 20µm isotropic voxels) of porcine myocardial biopsies obtained in control animals and in animals after 100µm diameter microspheres were injected into the coronary artery perfusing the site of subsequent biopsy. After the in vivo embolization the vascular tree was injected with radiopaque Microfil^© and the biopsies harvested. The analysis of the micro-CT images of the biopsies involved erode/dilate analysis of the opacified vessels in the entire biopsy and of just one vascular tree (segmented via a "connect" function) in that biopsy. This isolated tree was also analyzed by dimensional measurement of all the branches/ segmental volumes. The results show that all three methods provide the same relationships. In the embolized specimens the volumes loss estimated with the erode/dilate method applied to vessels below 60µm diameter closely matched for all three analyses methods.

7626-72, Poster Session

Evaluation of the effect of atorvastatin on carotid atherosclerosis using 3D ultrasound-based texture analysis

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Carotid atherosclerosis is the major cause of ischemic stroke, a leading cause of death and disability in the developed world. This is driving the development of image analysis methods to quantitatively evaluate local arterial effects of new potential treatments of carotid disease.

Here we investigate the use of novel texture analysis tools in the search for a sensitive method to detect changes in the carotid arteries due to statin therapy. 3D carotid ultrasound images were acquired from the left and right carotid arteries of 35 subjects (16 treated with 80 mg atorvastatin and 19 treated with placebo) at baseline and after 3 months of treatment. Two-hundred and seventy texture features from 7 texture techniques, i.e., first order statistics, spatial gray level dependence matrix, gray level run length statistics, gray level difference statistics, neighborhood gray tone difference matrix, laws texture energy measures, and Fourier power spectrum were extracted from 3D ultrasound carotid artery images. These images previously had their vessel walls (VW) manually segmented. Top ranked individual texture features were selected and compared to the VW volume (VWV) change using 3 measures: distance between classes, Wilcoxon rank sum test, and accuracy of the classifiers. Six classifiers were used: LDC, QDC, PARZENC, LOGLC, NMC, and NAIVEBC. Using laws texture energy measure (L7R7) increases the average accuracy and area under the ROC curve to 74.4% and 0.72 respectively compared to 57.2% and 0.61 using VWV change. Thus, the results demonstrate that texture features are more sensitive in detecting drug effects on the carotid vessel wall than VWV change.

7626-73, Poster Session

A temporally constrained ICA (TCICA) technique for artery-vein separation of cerebral microvasculature

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A fully automatic data driven technique which incorporates additional a priori information from physiological modeling is developed for the separation of arteries and veins in contrast-enhanced studies of the cerebral microvascular. A dynamic data set of 50 images taken by two-photon microscopy technique which records the bolus passage through artery and vein is used here. A constrained ICA technique is developed to extract the vessel specific dynamics of artery and vein by adding two constraints to classical ICA algorithm. One of the constraints guarantees that the extracted curves follow the pharmacokinetic model of blood passage through vessels by fitting the curves to a gamma variate function. Positivity as the second constraint indicates that none of the extracted factor images that correspond to the artery, vein or other clutters in the imaging field of view has negative impact on the acquired images.

Experimental results show improved performance of the proposed constrained ICA over classical ICA techniques in generating physiologically meaningful curves, they are also closer to that of pixel by pixel model fitting algorithms and perform better in handling noise. This technique is also fully automatic and does not require specifying regions of interest which is critical in model based techniques

7626-74, Poster Session

Tracking planar lung motion in 4D CT with optical flow: validations and comparison of global, local and local-global methods

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While different optical flow techniques continue to appear, there has been a lack of quantitative and objective evaluation of them on lung images. For a common set of 4D CT lung images, we report the results of a number of regularly cited optical flow techniques, including global, local and combined local-global methods used for tracking planar lung motion. Our comparisons are primarily empirical, and concentrate on the accuracy, that is magnitude and direction at a discrete set of landmark points with known motions, and reliability, that is objective lung boundary deformation tracking; our results show that performance can differ significantly among the techniques.

7626-75, Poster Session

Influence of imaging quality on magnetic resonance-based pressure gradient measurements

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In cardiovascular diagnostics, the knowledge of blood pressure can be very helpful for the physician. Nowadays, blood pressure values are usually obtained by non-invasive sphygmomanometric methods or invasive catheter measurements. Magnetic resonance imaging (MRI) offers a promising approach to establish a non-invasive method for blood pressure measurements. In MRI, phase-contrast sequences are used to acquire velocity-encoded data. Fluid pressure gradients can be derived from the measured velocities using Navier-Stokes equations. Unfortunately, this technique is known to suffer from a strong sensitivity to imaging quality. Especially the low signal-to-noise ratios (SNR) of phase contrast MRI data combined with the limited spatial and temporal resolution could severely reduce the reliability of computed pressure gradient values. In this paper we present computations of blood pressure gradients using phase contrast MRI measurements of a phantom, which mimics blood flow using a computer-driven pump. The influence of image quality of the velocity-encoded data as well as of different segmentation techniques are evaluated for constant and pulsatile flows. In case of constant flow, the pressure gradient values computed via Navier-Stokes equations show good agreement with theoretical values if physical a-priori knowledge is incorporated. If a pulsatile aortic flow profile is applied, the computed pressure gradients generally match catheter measurements well. Nevertheless, an underestimation of pressure gradient peaks is observed. Different segmentation techniques influence the amount of root mean squared errors between computation and measurement as well as their reduction by using higher SNRs.

7626-76, Poster Session

Hardware and software system for automatic microemulsion evaluation by analysis of optical properties

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The development of a new hardware device, called Microemulsion Analyser (MEA), which facilitates the preparation and evaluation of microemulsions is introduced. Microemulsions, consisting of three phases (oil, surfactant and water), prepared on deep well plates according to the PDMPD method can be automatically evaluated by means of the optical properties. The ratio of ingredients to form a microemulsion strongly depends on the properties and the amounts of the used ingredients. A microemulsion assay is set up on deep well plates to find those ratios. The optical properties of the ingredients change from turbid to transparent as soon as a microemulsion is formed. For measuring the turbidity the MEA contains a frame and an image-processing and analysis algorithm. The frame itself consists of aluminum, an electro luminescent foil (ELF) and a camera. As the frame keeps the well plate at the correct position and angle the ELF provides constant illumination of the plate from below. The camera provides an image which is processed by the algorithm to automatically evaluate the wells turbidity. Afterwards, a phase diagram is created to visualize the information. This build-up can be used to analyze microemulsion assays and to archive results in a standardized way. Further on it is possible to do stability tests of the assay by creating special differential stability diagrams after a period of time.

7626-77, Poster Session

Fibre reinforced prostheses investigated with opto-electronic non invasive method: optical coherence tomography

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The all denture prostheses are currently made using different technologies. The classical technology implies obtaining the acrylate resin which is then placed in a special mold in order to induce by heating the polymerization reaction. Unfortunately this procedure leads to a denture with many pores with or without surface opening. Increasing the biomechanical comportment of the all dentures bases implies fiber reinforcing. The different fibers reinforcing products made very difficult the evaluation of their performances and biomechanical properties analysis. For these structural investigations of reinforcing fibers on the all dentures bases the optical coherence tomography was used as a noninvasive method. The incident beams used for this experiment were 670 nm and 1300 nm. The 1300 nm system has a confocal microscope that allow to evaluate in a real time comparative way the firsts slices. The obtained results point out the structural defects between the fibers and the acrylic material in the all dentures bases. As a conclusion of this study, the optical coherence tomography could be considered as a noninvasive structural defects investigation method.

7626-79, Poster Session

The effect of viscosity on the phase of the nanoparticle magnetization induced by a harmonic applied field

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It has been shown that the temperature of magnetic nanoparticles can be estimated with excellent accuracy using the ratio of the harmonics of the magnetization induced by a harmonic magnetic field. An important property of the harmonics is that they can be measured in vivo from very small numbers of nanoparticles. The idea has been generalized to show that the ratio of the harmonics reflects the Brownian motion of the nanoparticles so any physical property influencing the Brownian motion can also be estimated. Those physical properties include temperature, viscosity and bound state. We present theory and preliminary data suggesting that the phase of the harmonics can also be used to estimate Brownian motion, in this case the viscosity. The use of the phase should increase the stability enabling measurements at lower concentrations of nanoparticles. The use of the phase also suggests methods of separating dynamic effects such as viscosity from static effects such as the rigidity of the matrix surrounding the nanoparticles that do not restrict the frequencies of applied field employed.

7626-80, Poster Session

Preliminary optical coherence tomography investigation of early non-carious cervical lesions

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Aim and objectives: Non-carious cervical lesions (NCL) are defined as the loss of tooth substance at the cemento-enamel jonction. They are attributed to abrasion (excessive horizontal toothbrushing), erosion (chemical action not involving bacteria) and/or occlusal overload

(abfractions). Abfractions are wedge-shaped cervical lesions which appear due to flexure of enamel and/or dentin at some location distant from the actual point of loading. The present study proposes the microstructural characterization of early NCL by optical coherence tomography (OCT).

Materials and methods: 33 extracted teeth were investigated using OCT. 28 teeth were derived from patients with active bruxism and laterotruzive/mediotruzive interferences; they presented early NCL and various degrees of occlusal pathological attrition. The other 5 teeth, with a normal morphology of the dental crowns, were not exposed to occlusal overload in the past.

The dental samples were investigated using a OCT device operating at 1300 nm (B-scan and C-scan mode). The OCT images were further compared with micro - computer tomography images and with histological sections.

Results: Teeth with a normal crown morphology had a homogeneous structure of the cervical enamel on OCT images. The OCT investigation of the occlusal overloaded teeth revealed damage in the microstructure of the cervical hard tissues. The high occlusal forces produced a characteristic pattern of large cracks, which did not reach the tooth surface The cervical microstructural pattern can be easily identified both on OCT C- scan and OCT B-scan images.

Conclusions: OCT is a promising imaging method for early NCL, which can confirm the presence of occlusal overload in their etiology.

7626-81, Poster Session

Advantage of topological texture measures derived from Minkowski functionals (MF) and scaling index method (SIM) in comparison with biomechanical finite elements method (FEM) for the prediction of osteoporosis

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The assessment of trabecular bone microarchitecture by numerical analysis of high resolution magnetic resonance images provides global and local structural characteristics, which improve understanding of the progression of osteoporosis and its diagnosis. In the present work we applied the finite elements method, which models biomechanical behaviour of the bone, the scaling index method, which describes the topology of the structure on a local level, and Minkowski Functionals, which are global topological characteristics, for analysing 3D HRMR images of 48 distal radius specimens in vitro. Diagnostic performance of texture measures derived from the numerical methods was compared with regard to the prevalence of vertebral fractures. Both topological methods showed significantly better results than those obtained using BMD and the failure load estimated by FEM. The receiver operating characteristic analysis for differentiating fractured and non-fractured subjects revealed area under the curve of 0.63 for BMD, 0.66 for maximum compressive strength as determined in a biomechanical test, 0.72 for critical load estimated by FEM, 0.79 for MF4 and 0.86 for SIM. The combination of FEM and SIM on tissue level showed that in both weak and strong bones the plate-like substructure of the trabecular network was the main load bearing part of the inner bone and that the relative amount of plates to rods was the most important characteristic for the prediction of bone strength. The present study also showed, that local topological measures derived from SIM were the most skeletal site independent characteristics and can be successfully applied for diagnosis of osteoporosis.

7626-82, Poster Session

Optical coherence tomography implied in implant bone interface investigation: numerical simulation and tensional stamps as complementary non invasive methods

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The prosthetic restoration of the mandible edentulous represents one of the most challenging tasks for a dentist. The reduced surface of the prosthetic area (7 - 12 cm2), the perpendicular insertion of many muscles, and the mobility of the tongue and the obstruction of the alveolar artery which leads to quicker atrophy of the mandible alveolar crest represent major obstacles in a normal prosthetic treatment. The quality of the evaluation of implant insertion could be investigated by implant bone interface analysis. In this study the numerical simulation, tensional stamps and optical coherence tomography as a noninvasive method were used in order to evaluate these interfaces. The system contains two interferometers and one scanner. For each incident analysis a stuck made of 61 slices was obtain. These slices were used in order to obtain a 3D model of the implant bone interface. The results obtained point out the existence of gaps between the implant and the bone. In conclusion the optical coherence tomography could be used for implant bone interface investigation. The results from simulations were verified by the micro measurement method. The OCT investigations were focused towards those areas in order to investigate the probability of non contact zones presence in implant mandible bone interfaces.

7626-83, Poster Session

Microscopic resolution imaging and proteomics correlation at histogeographically identical location: point by point correlation between ex vivo tissue imaging with high field MRI and multiplex tissue immunoblotting for proteomics profiling

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In the era of high-tech medicine, where an increasing variety of non-invasive, radiological imaging modalities are available, it is extremely important to validate new imaging technologies with histopathologic correlation. Frequently there are discrepancy as to size or extent of abnormalities in "Radiology-Pathology correlation" involving in vivo radiographic findings and surgical pathology specimens. As it poses many challenges to conduct point by point correlation between in vivo imaging and histopathology in histogeographically identical manner, we investigated the feasibility of ex vivo tissue imaging to bridge the gap between in vivo imaging and histopathology. Recent advances in high field MRI have achieved the resolution at microscopic level. At the present time, higher field systems, such as 14Tesla (14T), is available, which can offer 25 m in-plane resolution. With microscopic resolution, the findings obtained by ex vivo imaging are readily to correlate with histopathology after the identical plane is obtained. We further determined to explore the feasibility of even imaging correlation with proteomics profile using a novel technology for proteomics profiling in multiplex manner, which is called 'multiplex tissue immunoblotting" (MTIB). This technology is capable of demonstrating expression pattern

of multiple proteins in a single histology tissue section, which can be reliably correlated with histopathology. Thus, it is feasible to correlate ex vivo imaging with protein expression pattern between tissue imaging and MTIB.

7626-41, Session 8

3D geometry-based quantification of colocalizations in three-channel 3D microscopy images of soft tissue tumors

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We introduce a new model-based approach for automatic quantification of colocalizations in multi-channel 3D microscopy images. The approach is based on different 3D parametric intensity models in conjunction with a model fitting scheme to localize and quantify subcellular structures with high accuracy. The central idea is to determine colocalizations between different channels based on the estimated geometry of subcellular structures as well as to differentiate between different types of colocalizations. Furthermore, we perform a statistical analysis to assess the significance of the determined colocalizations. We have successfully applied our approach to about 400 three-channel 3D microscopy images of human soft-tissue tumors.

7626-42, Session 8

Hierarchical patch generation for multilevel statistical shape analysis by principal factor analysis decomposition

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We present a framework for multi-level statistical shape analysis, applied to the study of anatomical variability of abdominal organs. Statistical models were built hierarchically, allowing the representation of different levels of detail. Principal factor analysis was used for decomposition of deformation fields obtained from non-rigid registration at different levels, and provided a compact model to study shape variability within the abdomen. To assess and ease the interpretability of the resulting deformation modes, a clustering technique of the deformation vectors was proposed. The analysis of deformation fields showed a strong correlation with anatomical landmarks and known mechanical deformations in the abdomen. Clusters of modes of deformation from fine-to-coarse levels explain tissue properties, and inter-organ relationships. Our method further presents the automated hierarchical partitioning of organs into anatomically significant components that represent potentially important constraints for abdominal diagnosis and modeling, and that may be used as a complement to multi-level statistical shape models.

7626-43, Session 8

A multithread based new sparse matrix method in bioluminescence tomography

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Among many molecular imaging modalities, bioluminescence

tomography (BLT) stands out as an effective approach for in vivo imaging because of its noninvasive molecular and cellular level detection ability, high sensitivity and low cost in comparison with other imaging technologies. However, there exists the case that large scale problem with large number of points and elements in the structure of mesh standing for the small animal or phantom. And the large scale problem's system matrix generated by the diffuse approximation (DA) model using finite element method (FEM) is large. So there wouldn't be enough memory (RAM) for the program and the related inverse problem couldn't be solved. Considering the sparse property of the BLT system matrix, we've developed a new sparse matrix (ZSM) to overcome the problem. And the related algorithms have all been speeded up by multi-thread technologies. Then the inverse problem is solved by Tikhonov regularization method in adaptive finite element method (AFEM) framework. Finally, the performance of this method is tested on a heterogeneous phantom and the boundary data is obtained through Monte Carlo simulation. During the process of solving the forward model, the ZSM can save more processing time and memory space than the usual way, such as those not using sparse matrix and those using Triples or Cross-Linked sparse matrix. Numerical experiments have shown when more CPU cores are used, the processing speed is increased. By incorporating ZSM, BLT can be applied to large scale problems with large system matrix.

7626-44, Session 8

Limited-memory-BFGS-based iterative algorithm for multispectral bioluminescence tomography with Huber regularization

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Multispectral bioluminescence tomography is becoming a promising tool because it can resolve the biodistibution of bioluminescent reporters associated with cellular and subcellular function through several millimeters with to centimeters of tissues in vivo. Generally, to recover the bioluminescent sources, the source reconstruction problem is formulated as a nonlinear least-squares-type bounds constrained optimization problem. However, bioluminescence tomography (BLT) is an ill-posed problem. For the sake of stability and uniqueness of BLT, many algorithms have been proposed to regularize the problem, such as L2 norm and L1 norm. Here, we proposed a new regularization method with Huber function to regularize BLT problem to obtain robustness like L1 and rapid convergence of L2. Furthermore, the computational burden is largely increased with the use of spectral data. Therefore, there is a critical need to develop a fast reconstruction algorithm for solving multispectral bioluminescence tomography. In the paper, a limited memory quasi-Newton algorithm for solving the large-scale optimization problem is proposed to fast localize the bioluminescent source. In the numerical simulation, a heterogeneous phantom is used to evaluate the performance of the proposed algorithm with the Monte Carlo based synthetic data. The results demonstrate the potential and merits of the proposed algorithm.

7626-45, Session 8

Performance evaluation of the non-linear and linear estimation methods for determining kinetic parameters in dynamic FDG-PET study

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Dynamic positron emission tomography (PET) is a promising diagnostic tool to quantitatively predict biological and physiological changes in vivo through estimation of kinetic parameters. In this work, several popular linear and non-linear estimation methods for determining kinetic parameters using PET imaging with FDG are compared and evaluated. The simulation studies are presented. The linear estimation methods include linear least squares (LLS), generalized linear least squares (GLLS) and total least squares (TLS), while the non-linear

estimation methods include non-linear least squares (NLS), weighted non-linear least squares using noisy tissue time activity data (WNLS1), weighted non-linear least squares using noise-free tissue time activity data (WNLS2) and iteratively re-weighted non-linear least squares (IRWNLS). There are several findings: 1. The choice of weights plays an important role in non-linear estimation methods. Weighting using noisy data should be avoided. NLS is most recommended. 2. Non-linear estimation methods are prone to produce lower-biased, higher-precision parameter estimates while linear estimation methods are much more computational efficient. 3. Compared with non-linear estimation methods, GLLS performs well when noise level is low, but worse especially in determining k3 and k4 when noise level is high. What's more, GLLS does not show obvious advantage in running time. This finding contradicts previous reports.

7626-46, Session 9

Image analysis and computational physiology of the heart

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Multi-scale models of the heart and other organs are being developed under the umbrella of the Physiome Project of the International Union of Physiological Sciences (IUPS) and the Virtual Physiological Human (VPH) project funded by the European Commission. These computational physiology models deal with multiple physical processes (coupled tissue mechanics, electrical activity, fluid flow, etc) and multiple spatial and temporal scales. They are intended both to help understand physiological function and to provide a basis for diagnosing and treating pathologies in a clinical setting. A long term goal of the project is to use computational modeling to analyze integrative biological function in terms of underlying structure and molecular mechanisms. It is also establishing web-accessible physiological databases dealing with model-related data at the cell, tissue, organ and organ system levels [1-4].

Two major developments in current medicine are, on the one hand, the revolution in genomics and proteomics and, on the other, the revolution in medical imaging in which the physiological function of the human body can be studied with a plethora of imaging devices such as MRI, CT, PET, ultrasound, electrical mapping, etc. The challenge for the VPH/Physiome Project is to link these two developments for an individual - to use complementary genomic and medical imaging data, together with computational modelling tailored to the anatomy, physiology and genetics of that individual, for patient-specific diagnosis and treatment. To support these goals the VPH/Physiome project is developing XML markup languages (CellML & FieldML) for encoding models, together with model repositories and software tools for creating, visualizing and executing these models [5].

The talk will describe current progress in the development of the VPH/Physiome project, particularly in its application to the heart.

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7626-47, Session 9

Left-ventricle segmentation in real-time 3D echocardiography using a hybrid active shape model and optimal graph search approach

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Quantitative analysis of the left ventricular shape and motion patterns associated with left ventricular mechanical dyssynchrony (LVMD) is essential for diagnosis and treatment planning in congestive heart failure. Real-time 3D echocardiography (RT3DE) used for LVMD analysis frequently has heavy speckle noise or partially incomplete data, thus a segmentation method utilizing learned global shape knowledge is beneficial. In this study, the endocardial surface of the left ventricle (LV) is segmented using a hybrid approach combining active shape model (ASM) with optimal graph search. The latter is used to achieve landmark refinement in the ASM framework. Optimal graph search translates the 3D segmentation into the detection of a minimum-cost closed set problem in graph theory and can produce globally optimal result. Various information -- gradient, scan line model, intensity distributions, and regional-property terms -- are used to define the costs for the graph search. The developed method was tested on 36 RT3DE datasets acquired from 20 LVMD patients. The segmentation accuracy was assessed by surface positioning error and volume overlap measured for the whole LV as well as 16 standard LV regions. The segmentation produced very good results that were not achievable using ASM or graph search alone.

7626-48, Session 9

Image- and model-based analysis of constitutive properties of cellular structures

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Determination of constitutive properties of cells is essential to quantitative description of mechanical phenotype of normal and pathological cells. Existing cell micromanipulation techniques are based on complex experimental procedures that have one of the following drawbacks: they do not allow unsupervised analysis of large number of cells and/or probing of intracellular structures that are not directly exposed to external loads. Alternatively, mechanical behavior of cellular matter can be studied in time series of microscopic images that depict successive cellular deformation under the impact of applied forces. Experimentally observed changes of cellular contours or texture can be used for estimation of material parameters of the entire cell or a partial region of the cellular interior. In this work, we present a general framework for determination of constitutive properties of living cells which is based on reformulation of parameter estimation problem as an image registration problem, i.e., material constants are determined as modeling parameters that minimize dissimilarity between computationally predicted and experimentally observed images. Our experimental studies demonstrate application of this approach for determination of canonical material properties of single cells and intracellular structures (i.e., cell nucleus) on the basis of image data assessed by different contacting as well as fully non-contacting experimental techniques.

7626-49, Session 9

Compartmental model of 18F-choline

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The MADEIRA Project (Minimizing Activity and Dose with Enhanced Image quality by Radiopharmaceutical Administrations), cofunded by the European Commission through EURATOM Seventh Framework Programme, aims to improve the efficacy and safety of 3D functional imaging by optimizing, among others, the knowledge of the temporal variation of the radiopharmaceuticals' uptake in and clearance from tumor and healthy tissues. With the help of compartmental modeling it is intended to optimize the time schedule for data collection, thus contributing to reduce the radiation exposures of the patients. The model will also be adopted to evaluate the organ doses to the patients.

Administration of 18F-choline to screen for recurrence or metastasis in prostate cancer patients is one of the diagnostic applications under consideration in the frame of the project. PET and CT images have been acquired up to four hours after injection of 18F-choline. Additionally blood and urine samples have been collected and measured in a gamma counter.

The radioactivity concentration in different organs and data of plasma and urine clearance were used to set-up a compartmental model of the biokinetics of the radiopharmaceutical. It features a central compartment (blood) exchanging with organs. The structure describes explicitly liver, kidneys, spleen, plasma and bladder as separate units with a forcing function approach. The model is presented together with an evaluation of the individual and population kinetic parameters, and a revised time schedule for data collection is proposed.

This optimized time schedule will be validated in a further set of patient studies.

7626-50, Session 10

Limitations of measurement-based system functions in magnetic particle imaging

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Magnetic particle imaging (MPI) is a new tomographic imaging technique capable of determining the spatial distribution of superparamagnetic iron oxide particles at high temporal and spatial resolution. Reconstruction of the particle distribution requires the system function to be known. In almost all other tomographic imaging techniques, a basic mathematical model of the system function exists, so that for reconstruction of an image, only measured data from the object under examination have to be provided. Due to the complex behavior of the particle dynamics, this is more complicated in MPI. Therefore, to date, the system function is measured in a tedious calibration procedure. To this end, a small delta sample is moved to each position inside the measuring field, while the magnetization response is acquired consecutively. However, although this measurement-based approach provides a good estimate of the system function, it has several drawbacks. Most important, the measured system function contains noise, which limits the size of the delta sample and in turn the resolution of the sampling grid. In this work, the noise induced limitations of the measurement-based system function are investigated in a simulation study. More precisely, the influence of the system function noise and the size of the delta sample on the resulting image quality after reconstruction are analyzed.

7626-51, Session 10

Arterial double-contrast dual-energy MDCT: in-vivo rabbit atherosclerosis with iodinated nanoparticles and gadolinium agents

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An in-vivo feasibility study of potentially improved atherosclerosis CT imaging is presented. By administration of two different contrast agents to rabbits with induced atherosclerotic plaques we aim at identifying both soft plaque and vessel lumen simultaneously. Initial injection of iodinated-nanoparticle (INP) contrast agent (N1177 - Nanoscan Imaging), two to four hours before scan, leads to its later accumulation in macrophage-rich soft plaque, while a second gadolinium contrast agent (Magnevist) injected immediately prior to the scan blends with the aortic blood. The distinction between the two agents in a single scan is achieved with a double-layer dual-energy MDCT (Philips Healthcare) following material separation analysis using the reconstructed images of the different x-ray spectra. A single contrast agent injection scan, where only INP was injected two hours prior to the scan, was compared to a double-contrast scan taken four hours after INP injection and immediately after gadolinium injection. On the single contrast agent scan we observed along the aorta walls, localized iodine accumulation which can point on INP uptake by atherosclerotic plaque. In the double-contrast scan the gadolinium contributes a clearer depiction of the vessel lumen in addition to the lasting INP presence. The material separation shows a good correlation to the pathologies inferred from the conventional CT images of the two different scans while performing only a single scan prevents miss-registration problems and reduces radiation dose. These results suggest that a double-contrast dual-energy CT may be used for advanced clinical diagnostic applications.

7626-52, Session 10

Quantification of fluorescent spots in time series of 3D confocal microscopy images of endoplasmic reticulum exit sites based on the HMAX transform

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We present an approach for the quantification of fluorescent spots in time series of 3D confocal microscopy images of endoplasmic reticulum exit sites of dividing cells. Fluorescent spots are detected based on extracted image regions of highest response using the HMAX transform and prior convolution of the 3D images with a Gaussian kernel. The sensitivity of the involved parameters was studied and a quantitative evaluation using both 3D synthetic and 3D real data was performed. The approach was successfully applied to more than one thousand 3D confocal microscopy images.

7626-53, Session 10

Photoreceptor cell counting in adaptive optics retinal images using content-adaptive filtering

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Automated counting of photoreceptor cells in high-resolution retinal images generated by adaptive optics (AO) imaging systems is important due to its potential for screening and diagnosis of diseases that affect human vision. A drawback in recently reported photoreceptor cell counting methods is that they require user input of cell structure parameters. This paper introduces a method that overcomes this shortcoming by using a content-adaptive filtering (CAF) algorithm. In this method, image frequency content is initially analyzed to design a customized filter using the McClellan transformation, with passband chosen to emphasize cell structures suitable for subsequent processing. The McClellan transform is used to design a circularly symmetric bandpass filter as retinal cells have no preferred

orientation. The automated filter design eliminates the need for manual determination of cell structure parameters, such as cell spacing. Following the preprocessing step, cell count estimation is performed on the binarized filtered image by finding regional points of high intensity. Photoreceptor cell count estimates using this automated procedure were found to be comparable to manual count (gold standard). The results of application of the new method to test images showed overall improved performance compared with previously reported methods requiring user-supplied input. The performance of the method was also examined by application to images with variable cell spacing.

7626-54, Session 10

Micro-rheology: evaluating the rigidity of the microenvironment surrounding antibody binding sites

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The microscopic rigidity of structural elements of the cell and of the extracellular matrix control the genetic expression of factors that control critical aspects of malignancy including metastasis and neoangiogenesis. Methods of measuring the rigidity in vitro are being developed and exploited to explore the mechanisms involved. But no methods that function in vivo are available. We demonstrate proof of concept that the stiffness of the microenvironment surrounding bound magnetic nanoparticles can be measured using the shape of the spectra of the magnetization induced by a harmonic applied field. The microscopic region where the stiffness is measured can be selected by selecting the antibody binding sites for which the nanoparticles are targeted. In other applications, the same signal from the nanoparticles has been measured in vivo at very low concentrations so the methods demonstrated here should be capable of measuring low concentrations in vivo as well. The ability to measure the rigidity in vivo will enable the links between genetic control and rigidity to be explored in the complex in vivo environment for the first time.

7626-55, Session 11

Quantifying mechanical properties in a murine fracture healing system using inverse modeling: preliminary work

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Understanding bone remodeling and mechanical property characteristics is important for assessing treatments to accelerate healing or in developing diagnostics to evaluate successful return to function. The murine system whereby mid-diaphaseal tibia fractures are imparted on the subject and fracture healing is assessed at different time points and under different therapeutic conditions is a particularly useful model to study. In this work, a novel inverse geometric nonlinear elasticity modeling framework is proposed that can reconstruct multiple mechanical properties from uniaxial testing data. This is investigated within the context of a murine cohort (n=3) that are 14 days post fracture. This work is the first to report mechanical properties of a callus using an inverse problem methodology whereby 2758.4 ± 682.5 kPa, 0.467 ± 0.009 were found to be the Young's modulus and Poisson's ratio, respectively. In addition better consistency of the reconstructed metrics over more traditional metrics is demonstrated.

7626-56, Session 11

Scaling relations between bone volume and bone structure as found using 3D µCT images of the trabecular bone taken from different skeletal sites

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According to Wolff's law bone remodels in response to the mechanical stresses it experiences so as to produce a minimal-weight structure that is adapted to its applied stresses. Here, we investigate the relations between bone volume and structure for the trabecular bone using 3D µCT images taken from different skeletal sites in vitro, namely from the distal radii (96 specimens), thoracic (73 specimen) and lumbar vertebrae (78 specimens). We determine the local structure of the trabecular network by calculating (an-)isotropic scaling indices (α, α_z). These measures have been proven to be able to discriminate rod- from sheet-like structures and to quantify the alignment of structures with respect to a preferential direction as given by the direction of the external force. Comparing global structure measures derived from the scaling indices (mean, variance) with the bone mass (BV/TV) we find that all correlations obey very accurately power laws with scaling exponents of 1.09, 1.05, 1.07 ($<\alpha>$), 1.12, 1.04, 1.10 (var(α)), 1.14, 1.12, 1.15 ($<\alpha_z>$) and 1.12, 1.04 ,1.10 (var(α_z)); distal radius, thoracic vertebra and lumbar vertebra respectively). Thus, these relations turn out to be site-independent, albeit the mechanical stresses to which the bones of the forearm and the spine are exposed, are quite different. The similar alignment might not be in agreement with a universal validity of Wolff's law. On the other hand, such universal power law relations may allow to develop additional diagnostic means to better assess healthy and osteoporotic bone.

7626-57, Session 11

Evaluation of trabecular bone patterns on dental radiographic images: influence of cortical bone

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For some authors trabecular bone is highly visible in intraoral radiographs. For other authors, the observed intrabony trabecular pattern is a representation of only the endosteal surface of cortical bone, not of intermedullary striae. The purpose of this preliminary study was to investigate the true anatomical structures that are visible in routine dental radiographs and classically denoted trabecular bone. The ultimate goal is then to characterize the correlation between the radiograph and the CT scan data to label each pixel or voxel either as trabecular or cortical bone. Computed radiography (CR) images of dog mandible section in molar regions were compared with simulations calculated from high-resolution micro-CT volumes. Calculated simulations were obtained using the Mojette Transform. By digitally editing the CT volume, the simulations were separated into trabecular and cortical components into a region of interest. Different images were compared and correlated, some bone texture parameters calculated using Mazda software. A high correlation was found between computed radiographs and calculated simulations from micro-CT, as well as between calculated simulations with and without cortical bone. Texture parameters calculated on simulations with and without cortical bone gave similar results.

The Mojette transform was successful to obtain high quality images. Cortical bone did not contribute to change in a major way simulated images and texture analysis results. These first results imply that:

- intrabony trabecular pattern observed on radiographs can not only be a representation of the cortical bone endosteal surface;

- trabecular bone is highly visible in intraoral radiographs.

7626-58, Session 11

A non-rigid registration approach for mouse whole body skeleton registration

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Micro-CT/PET imaging scanner provides a powerful tool to study tumor in small rodents in response to therapy and characterize newly PET radiotracers in small animal models. Accurate image registration is a necessary step to quantify the characteristics of images acquired with time beings. Small animal registration is challenging because of its joint structure and posture and position difference in each acquisition. In this paper, we propose a non-rigid registration approach for the automatic registration of mouse whole body skeletons. A series of pre-processing steps are proposed to extract and obtain a clean and usable skeleton from a mouse micro-CT image. A source skeleton or a template, which consists of major skeleton and fore body skeleton and hind body skeleton, is processed by the pre-processing method. A mouse whole body approach is proposed by a coarse-to-fine process based on our improved 3D shape context non-rigid registration method. The robustness of the approach has been validated on mouse hind limb skeletons. The results of the tests demonstrated there were no significant differences for the convergence of the registration process and the mean registration errors between inter- and intra-subject groups of the mice. The whole body skeleton registration approach has been tested on 21 pairs of mouse CT images with variations of individuals and time-instances. The experimental results demonstrated the stability and accuracy of the proposed method for automatic mouse whole body skeleton registration.

7626-59, Session 11

Prediction of biomechanical trabecular bone properties with geometric features using MR imaging

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Trabecular bone parameters extracted from magnetic resonance (MR) images are compared in their ability to predict biomechanical properties determined through mechanical testing. Trabecular bone density and structure changes throughout the proximal tibia are indicative of several musculoskeletal disorders of the knee joint that involve changes in the bone quality and the surrounding soft tissue. Recent studies have shown that MR imaging, most frequently applied for soft tissue imaging, also allows non-invasive 3-dimensional characterization of bone microstructure. Sophisticated MR image features that estimate local structural and geometric properties of the trabecular bone may improve MR imaging's ability to determine local bone quality in vivo. The purpose of the current study is to use whole joint MR images to compare the performance of trabecular bone features extracted from the images in predicting biomechanical strength properties measured

on the corresponding ex vivo specimens. The regional apparent bone volume fraction (appBVF) and scaling index method (SIM) derived features were calculated; a Multilayer Radial Basis Functions Network was then optimized to calculate the prediction accuracy as measured by the root mean square error (RSME) for each bone feature. The best prediction result was obtained with a SIM feature with the lowest prediction error (RSME=0.246) and the highest coefficient of determination (R2 = 0.769). The current study demonstrates that the combination of sophisticated bone structure features and supervised learning techniques can improve MR imaging as an in vivo imaging tool in determining local trabecular bone quality.

7626-60, Session 11

Morphological characterization of dental prostheses interfaces using optical coherence tomography

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Fixed partial prostheses as integral polymers or metal-polymers bridges are mainly used in the frontal part of the dental arch (especially the integral bridges). They have to satisfy high stress as well as esthetic requirements. The masticatory stress may induce fractures of the bridges. These may be triggered by initial materials defects or by alterations of the technological process. The fractures of these bridges lead to functional, esthetic and phonetic disturbances which finally render the prosthetic treatment inefficient. Dental interfaces represent one of the most significant aspects in the strength of the dental prostheses under the masticatory load. The purpose of this study is to evaluate the capability of optical coherence tomography (OCT) to characterize the dental prostheses interfaces. The materials used were several fixed partial prostheses integral polymers and metal-polymers bridges. As a conclusion, it is important to have a non invasive method to investigate dental prostheses interfaces before their insertion in the oral cavity. The purpose of this study is to evaluate the capability of OCT to detect and analyze the possible fractures in several integral fixed partial dentures. The materials used were several fixed partial prostheses integral polymers and metal-polymers bridges. In order to discover the defects, scanning was performed from incisal, vestibular, oral and cervical directions. Material defects such as fractures and pores are investigated using OCT. As a conclusion, it is important to have a non invasive method to investigate fixed partial prostheses before their insertion in the oral cavity .

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7627-01, Session 1

Maintaining quality in the UK breast screening program

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Breast screening in the UK has been implemented for over 20 years and annually nearly two million women are screened with an estimated 1,400 lives saved. Nationally, some 700 individuals interpret mammograms in 110 screening centres. Currently, women aged 50 to 70 are invited for screening every three years and by 2012 this age range will increase to 47 - 73 years. There is a rapid ongoing transition from using film mammograms to full field digital mammography such that in 2010 every screening centre will be partly digital. An early, and long running, concern has been how to ensure the highest quality of imaging interpretation across the UK given the use of a three year screening interval. To partly address this question a self assessment scheme was developed in 1988 and subsequently implemented nationally in the UK as a mandatory activity. The scheme will be detailed from its wholly accidental beginnings, through its various developments to current incarnation and future plans. This encompasses both radiological (single view screening, two view screening, mammographic film and full field digital mammography) as well as design changes (cases reported by means of: form filling; PDA; tablet PC; iphone, and the internet). The scheme gives rise to a rich data source which is regularly plundered to examine different aspects of radiological performance. Overall it represents the real world trials and tribulations of conducting medical imaging investigations in an everyday clinical screening situation.

7627-02, Session 1

Rating scales for observer performance studies

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We compared the measured performance of radiologists reading a set of screening mammograms with and without CADe as measured by the BI-RADS assessment scale or a 9-point rating scale.

Eight MQSA radiologists read 300 screening mammograms (66 contained at least one cancer and 234 were normal based on two-year follow-up). Both without and then with CADe, the radiologists gave their BI-RADS assessment for each case and, for each suspicious lesion in the image, reported their confidence on a 9-point scale (1=no evidence for recall; 5=equivocal; 9=overwhelming evidence for recall) that the lesion needed to be worked up. The radiologists were instructed to read the case as they would clinically. We used MRMC ROC analysis employing PROPROC curve fitting to analyze the data, once for the BI-RADS data and again for that collected on the 9-point scale.

Because radiologists were reading screening mammograms, not all radiologists used the full BI-RADS scale. Two used only BI-RADS 0,1 and 2, two used the full scale, and four used categories 3, 4, and 5 sparingly. This inconsistent use of the BI-RADS scale is consistent with clinical practice (as evidence by the published literature).. The difference in AUC between the with- and without-CADe reading conditions was -0.0064 using BI-RADS and 0.0002 for the 9-point scale. However, the standard error in the difference of 0.0073 for BI-RADS was larger than 0.0043 for the 9-point scale.

The BI-RADS and the 9-point scales appear to give similar results in terms of AUC.. However, the 95% CIs of the individual estimates of AUC were substantially smaller for the 9-point scale.

7627-03, Session 1

Evaluating the realism of synthetically generated mammographic lesions: an observer study

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A method has been developed for generating synthetic masses that exhibit the appearance of real breast cancers in mammograms. To be clinically useful, the synthetic masses must appear sufficiently realistic, even to expert mammography readers. We present the results of an observer study in which 10 expert mammography readers at the Nightingale Breast Centre, Manchester attempted to distinguish between real and synthetically generated masses.

Each reader rated a set of 30 real and 30 synthetics masses on a scale ranging from "definitely real" to "definitely synthetic". ROC curves were fitted to their responses and the area-under-curve (AUC) used to quantify the ability of a reader to identify synthetic masses. An AUC of 0.5 implies a no better than chance ability to distinguish between real and synthetic masses, whilst an area of 1 implies perfect identification. The mean AUC was 0.70±0.09, showing the readers were able to identify synthetic masses at a rate statistically better than chance. This suggests further improvements must be made to the mass synthesis method.

The 10 readers were comprised of 4 radiologists and 6 breast physicians/radiographers. The mean AUC for the two groups were 0.70±0.16 and 0.71±0.03 respectively, showing no statistical advantage for either group. Data were collected on the experience of each reader, in order to assess whether this was correlated with ability to identify synthetic masses. No significant correlation was found. Both findings imply the participants in the study were all of sufficient expert standard and would be suitable candidates for further repeat studies.

7627-04, Session 2

Use of a visual discrimination model to detect compression artifacts in virtual pathology images

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A major issue in telepathology is the extremely large and growing size of digitized "virtual" slides, which can require several gigabytes of storage and cause significant delays in data transmission for remote image interpretation and interactive visualization by pathologists. Compression can reduce this massive amount of virtual slide data, but reversible (lossless) methods limit data reduction to less than 50%, while lossy compression can degrade image quality and diagnostic accuracy. "Visually lossless" compression offers the potential for using higher compression levels without noticeable artifacts, but requires careful selection of bit rates, which can vary significantly with image content. We investigated the utility of a visual discrimination model (VDM) for predicting JPEG 2000 bit rates corresponding to visually lossless compression of virtual slides for breast biopsy specimens. Threshold bit rates were determined experimentally with human observers for a variety of tissue regions cropped from virtual slides. VDM distortion-visibility metrics for images compressed to their visually lossless bit rates were nearly constant and significantly less variable than peak signal-to-noise ratio (PSNR) and Structural Similarity (SSIM)

metrics. Our results suggest that VDMs could be used to guide the lossy compression of virtual slides to achieve consistent visual quality in terms of artifact visibility while providing 4 to 5 times the data compression of reversible methods.

7627-05, Session 2

Spatial noise suppression for LCD displays: noise contrast

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LCD monitors used for radiologic diagnosis exhibit a random spatial gain-fluctuation pattern that can be characterized as multiplicative fixed-pattern noise. Our goal is to characterized the noise pattern as an image we call a noise map. The map is of an individual monitor. We then use this noise map to pre-process mammograms in such a way as to compensate for the degradation that the noise will cause when the image is displayed. This paper concentrates on extraction of noise maps for individual monitors and on the path that they follow through the processing procedure. The maps are extracted from over-sampled digital camera captures. The digital levels of the captured images are converted to luminance then the images are Fourier filtered to remove the grid pattern and sub-pixel structure. The conversion to luminance is necessary because the processing we have proposed involves spread; the spread is linear in luminance. We have found that use of an appropriate super-Gaussian filter obviates the need for warping the input image; the spatial distortions are mild compared to the tolerance of the filter. We then convert the values to the digital driving levels used for the LCD display. At this stage, we compare the processed mammogram to the original mammogram. Finally, we display the processed mammogram and uniform image and capture again. This final step is necessary to provide the material input to observer-performance prediction programs. Additionally, we use this final step to provide a feedback loop tuning of for our image pre-processing.

7627-06, Session 2

High-fidelity color video reproduction of open surgery by six-band camera

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The video capture of surgery is valuable for the case archive, conference, education, and telesurgery including the support by a remote expert surgeon. However, the colors reproduced by conventional RGB-based video systems differ from the original, which causes difficulty for the observers in understanding the details of the operation. For high-fidelity color reproduction, the application of multispectral imaging is promising. In this paper, the technology of multispectral video capture and spectrum-based color reproduction was applied to the open surgery and medical doctors visually evaluated the reproduced image quality. Seven cases of hand operations were captured by a 6-band high-definition video camera, and following experiments were conducted;

1) The image qualities of videos captured by 6-band and conventional RGB cameras were evaluated based on Scheffe's paired comparison test. Three doctors scored 8 items for evaluation into 6 levels. Among the items for evaluation, the 6-band system was rated significantly higher in "color reproducibility," "fidelity," and "material appearance" at 95% confidence level.

2) The reproduced videos from 6-band, 3-band and RGB cameras were compared, where four medical doctors scored the color difference into 5 levels. The perceived color differences between 6-band/RGB and 6-band/3-band were significant at 95% confidence level, if small number of samples that shows different tendency were excluded.

The color difference of skin was especially apparent, according to the doctors' comments.

3) The high-fidelity color videos were generated from 6-band data by a color converter and transmitted via local network, with using the H.264/AVC encoder. Through informal evaluation, 15Mbps was rated approximately good for the video reproduction.

In conclusion, the application of multispectral color technology is promising for the quality improvement of surgery videos.

7627-07, Session 2

DICOM GSPS affects on contrast detection threshold

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While previous research has been done to determine the contrast detection threshold in medical images, we have found it difficult to translate the results into settings that can be used for the optimization of image quality. Since many of these papers were done before the widespread use of DICOM GSPS calibrated monitors, how the GSPS affects the detection threshold and whether the median background intensity shift has been minimized by GSPS remain unknown. We set out to determine if the median background affected the detection of a low-contrast object in a clustered lumpy background, which simulated a mammography image. Our results show that shifts in the median background intensity did not affect the detection performance. The contrast detection threshold appears close to +3 gray levels above the background, but our high false positive rate may have impacted our results.

7627-08, Session 2

Comprehensive quantitative image quality evaluation of compressed sensing MRI reconstructions using a weighted perceptual difference model (Case-PDM): selective evaluation, disturbance calibration and aggregative evaluation of noise, blur, aliasing and oil-painting artifacts

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The perceptual difference model (Case-PDM) is being used to quantify image quality of fast MR acquisitions and sparse reconstruction algorithms as compared to slower, full k-space, high quality reference images. To date, most perceptual difference models average image quality over a wide range of image degradations and assume that the observer has no bias towards any of them. Here, we create metrics weighted to different types of artifacts, calibrated to a human observer's preference, and then aggregate them to produce a comprehensive evaluation. The selective PDM is tuned using test images from an input reference image degraded by noise, blur, aliasing, or "oil-painting." To each artifact, responses of cortex channels in the PDM are normalized to be weights used for selective evaluation. A pair comparison experiment based on functional measurement theory was used to calibrate selective PDM score of each artifact to its measured disturbance. Test images of varying quality were from identical reference image degraded by one type of artifact. We found that human observers rated aliasing > blur > oil-painting > noise. In order to validate the new evaluation approach, PDM scores were compared to human ratings across a large set of compressed sensing MR reconstruction test images of varying quality. Human ratings (i.e. overall, noise, blur, aliasing, and oil-painting ratings) were obtained

from a modified Double Stimulus Continuous Quality Scale experiment. For 3 brain images (transverse, sagittal, and coronal planes), averaged r values [comprehensive-PDM, noise-PDM, blur-PDM, aliasing-PDM, oil-painting-PDM] were [0.947±0.010, 0.827±0.028, 0.913±0.005, 0.941±0.016, 0.884±0.025]. We conclude the weighted Case-PDM is useful for selectively evaluating MR reconstruction artifacts and the proposed comprehensive PDM score can faithfully represent human evaluation, especially when demonstrating artifact bias, of compressed sensing reconstructed MR images.

7627-09, Session 2

A gaze-contingent high-dynamic range display for medical imaging applications

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Due to the nature of liquid crystal material properties, the current liquid crystal display technology hinders its applications in medical imaging, where wide dynamic range and dense grayscales are demanded. This paper proposes a solution by employing properties of the human visual system. The dynamic range of human eye is in the order of 10, which is achieved by light adaptation. At any given time, the visual system has a limited output dynamic range between 100 and 1000. Furthermore, because of uneven distributions of rod- and cone-photoreceotors on human retina, the sensitivity to spatial frequency between fovea and parafovea varies greatly. The proposed approach is to dynamically optimize the display image for the gazed area only such that the observer can perceive the full dynamic range. A gaze-contingent interactive display system based on an 8-bit LCD and a video-based eye-tracker was implemented to emulate a 12-bit display.

7627-10, Session 3

The assessment of stroke multidimensional CT and MR imaging using eye movement analysis: does modality preference enhance observer performance?

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Purpose: Medical imaging provides information about a patients' health status, to inform and reduce diagnostic uncertainty. As 3D and 4D imagery becomes commonplace, research must examine how multidimensionality and multimodality affects image interpretation and accuracy. Few studies have examined observer performance using multidimensional images and to the authors' knowledge, no studies have compared CT and MR observer performance using eye movement analysis in Stroke. This study aims to explore eye-movements and confidence/ location responses for CT and MRI imaging to uncover visual search and performance differences by level of experience.

Methods: An eye movement study was designed to assess 48 predetermined CT and MRI matched cases as read by 27 observers: Novices; Specialist Registrars, and Consultant Radiologists. Abnormality presence or absence was rated on a four-point Likert scale and location task. Half of the clinical cases were accompanied by clinical information; half were not, to assess the impact of clinical information on performance.

Results: Data analysis is underway to compare confidence ratings and location data using JAFROC analysis within the MRMC framework (2). Figure of Merit analysis is being applied to compare observer performance between modalities.

Conclusion: Results highlight differences in visual search behaviour amongst novice, trainee and expert observers in both CT and MR images. Eye movement differences between modalities will be subtle and altered by level of experience. Clinical information is expected

to alter performance within modalities, but not between them. This research has important implications for comparing observer performance between CT and MRI modalities within neuroradiology.

7627-11, Session 3

Breast Screening: visual search as an aid for digital mammographic interpretation training

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Digital mammography is gradually being introduced across all breast screening centres in the UK during 2010. This provides increased training opportunities using lower resolution, lower cost and more widely available, devices in addition to the clinical digital mammography workstations. This study examined how experienced breast screening personnel performed when they examined sets of difficult DICOM two-view screening cases in three conditions: on GE digital mammography workstations, LCD monitor (using a DICOM viewer) and an iphone (running Osirix software). In each condition they either viewed the full images unaided or were permitted to use the post-processing manipulations of pan, zoom and window level/ width adjustments. For each case they had to report the feature type, rate their confidence on the presence of abnormality, classify the case and specify case density. Their visual search behaviour was recorded throughout using a head mounted eye tracker. Additionally aspects of their real life screening performance and performance on a national self assessment scheme were examined. Data indicate that screening experience plays a major role in doing well on the self assessment scheme. Task performance was best on the clinical workstation. Further detailed data analysis is in progress, early results indicate that abnormal cases could be identified with both the monitor and iphone. The latter is not ideal for examining full images due to the amount of scrolling and zooming required. Overall, results indicate that low cost devices could be used to provide additional tailored training as long as device resolution and HCI aspects are carefully considered.

7627-12, Session 3

Visual search characteristics in mammogram reading: SFM vs. FFDM

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Purpose: Most previous studies comparing radiologists' behavior when reading mammograms (1) that have been 'digitized' from screen-film mammography (SFM) films and (2) 'digital' mammograms obtained through the use of Full-Field Digital Mammography (FFDM) systems have shown no difference in performance between the two modalities. One large multi-center study has found an advantage for FFDM when searching for breast cancer: (i) in women younger than 50 years of age; (ii) in women with dense breast tissue; and (iii) in pre- and peri-menopausal women. Another difference that is often mentioned is that reading times tend to be different, but a common trend has not been determined yet; in other words, some find that the reading of FFDM is faster than the reading of SFM, whereas others find that it is slower. In addition, while the visual search characteristics used by radiologists in the reading of 'digitized' mammograms have been previously studied and are moderately understood, few perceptual studies have been carried out which characterize the radiologists' search behavior when reading 'digital' mammograms. In this paper we will characterize such a behavior and relate it to the previously published findings in reading of 'digitized' mammograms. Moreover, we will use spatial frequency analysis to determine the characteristics of the radiologists' search, and we will compare such characteristics to those obtained in the analysis of search in 'digitized' mammograms.

Results: Preliminary analysis of the two parts (SFM and FFDM) of the

study indicates that reading characteristics are widely different between 'digitized' and 'digital' mammograms. For example, as shown by several previously published studies, median 'time to hit' the location of a true malignant mass that has been correctly identified and reported by the radiologists (i.e., a True Positive - TP - finding) is below 1 second for 'digitized' mammograms, but for 'digital' mammograms, median 'time to hit' the location of a TP decision is 8.4 seconds. Dwell times in the location of decision outcomes is also significantly increased for 'digital' mammograms. Preliminary results show that, while for 'digitized' mammograms median dwell times in the locations of True Positives, False Positives and False Negatives are 1.067 sec, 0.925 sec and 0.550 seconds, respectively, for 'digital' mammograms the same times are 2.3 sec, 3.0 sec and 1.2 sec, respectively. Previous analysis of the 'digitized' mammograms showed that radiologists perceived the cancers that they correctly reported (True Positives) at image onset, and that this percept biased their sampling of the case from the start. Similar results were not found for areas that yielded False Positives or False Negative decisions. Currently we are conducting a similar analysis for the reading of the 'digital' mammograms.

7627-13, Session 3

Eye-position recording during brain MRI examination to identify and characterize steps of glioma diagnosis

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MRI is an essential appliance for brain glioma diagnosis thanks to its ability to produce images in any layout plan and to its numerous sequences adapted to both anatomic and functional imaging. In this paper, we investigate the use of an eye-tracking system to explore relationships between visual scanning patterns and the glioma diagnostic process during brain MRI analysis.

We divide the analyzed screen in ROIs, each ROI corresponding to one sequence. Analyzing temporal organization of fixation location intra ROI and between ROI enables to split up the diagnostic process into different steps. The analysis of saccadic amplitudes reveals clear delimitation of three sequentially steps. During the first step (characterized by large saccades), radiologist has a short review on all sequences and on patient report. In the second step (characterized by short saccades), radiologist scans sequentially and systematically all the slices of each sequence. The fixation duration in one ROI depends on the number of slices, on lesion subtlety and on lesion contrast in the sequence to be analyzed. In order to improve the detection, localization and characterization of the glioma, the radiologist compares sequences one to each others during the third step (characterized by large saccades).

Eye-position recording enables to define each elementary task implemented during diagnostic process of glioma detection and characterization on brain MRI. Total dwell time associated with one MRI sequence (one ROI) and contrast in primary lesion area enable to estimate the amount and subtleties of diagnosis criteria provided by the sequence. From this information, one could establish some rules to optimize brain MRI compression (depending on the sequence to be compressed).

7627-14, Session 3

Reading a radiologist's mind: monitoring rising and falling interest levels while scanning chest x-rays

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Radiological images constitute a special class of images that are captured (or computed) specifically for the purpose of diagnosing patients. However, because these are not "natural" images,

radiologists must be trained to interpret them through a process called "perceptual learning". However, because perceptual learning is implicit, experienced radiologists often find it difficult to explicitly (i.e. verbally) train less experienced colleagues. Current methods of training can take years before a new radiologist is fully competent to independently interpret medical images. We hypothesize that eye tracking technology (coupled with multimedia technology) can be used to accelerate the process of perceptual learning through a Hebbian learning process. This would be accomplished by providing a radiologist-in-training with real-time feedback as he/she is fixating on an important region of an image. Of course this would require that the training system have information about what regions of an image are important - information that could presumably be solicited from experienced radiologists. However, our previous work has suggested that experienced radiologists are not always aware of those regions of an image that attract their attention, but are not clinically significant - information that is very important to a radiologist in training. This paper discusses a study in which local entropy computations were done on scan path data, and were found to provide a quantitative measure of the moment-by-moment interest level of radiologists as they scanned chest x-rays. The results also showed a striking contrast between the moment-by-moment deployment of attention between experienced radiologists and radiologists in training.

7627-15, Session 4

Effects of fixed-rate CT projection data compression on perceived and measured CT image quality

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Compression of raw CT data can significantly reduce CT scanner bandwidth and bandwidth-related cost. Since it guarantees predictable bandwidth, fixed-rate CT data compression is preferable to lossless compression, but fixed-rate compression can introduce image artifact. In this research, we use several automated image quality metrics commonly used in image processing, including peak signal-to-noise (PSNR) and structural similarity (SSIM), to quantify the magnitude and location of image artifacts caused by fixed-rate compression of CT projection data. Using four artifact reduction masks applied to the image's periphery, iso-center, air pixels, and bone pixels, we observed a significant reduction in the number and density of visible artifacts as measured by Hounsfield Unit (HU) differences and SSIM metrics. Artifact pixels that remain after applying the four artifact reduction masks are typically isolated and widely dispersed. Even before artifact reduction masks are applied, the SSIM metrics often exceed 0.98, which is considered visually indistinguishable. The excellent correlation of automated image quality metrics and the success with artifact reduction masks explains why radiologists are unlikely to notice the effects of fixed-rate projection data compression in CT images. The automated metrics used here can also be used to prioritize CT volume images, which significantly reduces the number of images used in subjective image quality studies by not including images that radiologists will perceive as indistinguishable.

7627-16, Session 4

Flexible endoscope shape visualization and NOTES application

E. C. S. Chen, L. C. Hookey, R. E. Ellis, Queen's Univ. (Canada)

Navigation of a flexible endoscope is a challenging surgical task: the shape of the end-effector of the endoscope, interacting with surrounding tissues, determine the surgical path of which the endoscope is being pushed along. We present a navigational system that visualizes the shape of the flexible endoscope tube to assist gastrointestinal (GI) surgeons to perform Natural Orifice Translumenal Endoscopic Surgery (NOTES). The system is composed

of an electromagnetic (EM) tracker, an EM-tracked catheter, and graphical user interface for visualization. The catheter is embedded with 8 5DOF magnetic coils that are strategically placed along the length of the catheter. During the surgery, the catheter is inserted into a working channel of the endoscope. The positional and the tangential information of the tracked catheter are used to construct a mathematical spline that approximates the shape of the endoscope tube.

We conducted NOTES experiments on swine animals involving 6 GI and 6 general surgeons. The NOTES procedure involves the visual identification and physical touching of 4 internal targets by the endoscope tip. Participants who used the system first were 14.21 +- 74.53% slower the second time (when not using the device). Participants who used the system second were 33.60 +- 32.07% faster than the first session (p=0.179).

7627-17, Session 4

Image fade in computed radiography is exacerbated by increased kVp

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Processing of Computed radiography image plates involves a time delay between the image acquisition and processing. This delay can vary from 1 to 30 minutes depending on the clinical situation. This study aims to examine the effects latent image fade upon the low contrast resolution of computed radiography images over time and establish whether kVp has an influence on image fade. Three observers assessed the images. Image quality figures were calculated as a measure of contrast detail resolution.

Significant reductions in low contrast resolution was seen to occur as the delay between exposure and processing increased. The image quality decreased by 2.8% at 5mins; 6% at 10mins and 8.8% at 20mins. Deterioration then continued at a steady rate until the plateau of 20.7% was reached at 3 hours finally at 15hrs the deterioration was 40.49% compared to the reference image.

The rate of this deterioration increased with kVp. At 20mins for 75kVp the low contrast resolution had decreased by 8.8%; at 80kVp it was 9.6%; 10.15% at 85kVp and at 95kVp 16.8%.

A substantial decrease in low contrast resolution of CR images result from long delays between exposure time and processing, this is exacerbated by higher kVps. Radiographers will lose at least 8.8% in low contrast resolution of an image with a processing delay of 20 minutes.

7627-18, Session 4

Optimal processing of isotropic 3D black-blood MRI for accurate estimation of carotid wall thickness

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Quantification of carotid wall thickness is important in cross-sectional stroke risk analysis and longitudinal monitoring of atherosclerosis. Black blood MRI has been shown to be an useful tool in measuring carotid wall thickness. Previous studies measured wall thickness by segmenting the arterial wall and lumen on an acquisition plane and matching these two contours. If the acquisition plane is oblique to the artery, measurement made based on matching 2D contours would overestimate the wall thickness by a factor of sec alpha, where alpha denotes the obliqueness angle. This problem can be understood as a 3D surface mismatch problem, and we proposed to use a 3D surface correspondence algorithm in measuring wall thickness. We evaluated the effect of this problem by comparing the thickness measurements obtained using 2D correspondence methods with that obtained using the 3D correspondence method. In addition to the surface mismatch problem, many other factors contribute to the inaccuracy of wall

thickness measurement. Thus, we also measured the wall thickness based on images resliced perpendicular to the centerline of the vessel. Since obliqueness artifact is minimized in this set of images, the wall thickness measurement obtained based on this set of images is used as the surrogate gold standard. Our comparison between the wall thickness measurement based on parallel image slices and this surrogate gold standard showed that the difference between thickness measurements obtained using the two methods is within ±0.3mm at more than 90% of vertices. Therefore, we recommend the conventional parallel reslicing method because it is a more convenient thickness measurement method.

7627-19, Session 4

Color calibration and color-managed medical displays: does the calibration method matter

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Our laboratory has implemented a suite of color calibration and monitor profiling packages which employ a variety of colorimeters. Each of the methods computes gamma correction tables for the red, green and blue color channels of a monitor that attempt a) to match a desired luminance range and response curve and b) to maintain a target color temperature across the range of grey values.

All of the methods examined here produce ICC (International Color Consortium) profiles that describe the color rendering capabilities of the monitor after calibration. Color profiles incorporate a transfer matrix that establishes the relationship between RGB driving levels and XYZ (tristimulus) coordinates of the resulting on-screen color; the matrix is developed by displaying color patches on the monitor and reading the luminance and chromaticity with a sensor. The number and chromatic distribution of color patches varies across methods and is usually not under user control.

In this work we examine the effect of employing differing calibration and profiling methods on rendition of color images. A series of color patches encoded in sRGB color space were presented on the monitor using color-management software that utilized the ICC profile produced by each method. The patches were displayed on the calibrated monitor and measured with a CS200 colorimeter. Differences in intended and achieved luminance and chromaticity were computed using the CIELAB 2000 deltaE metric (deltaE = 1 is one just noticeable difference in color). We observed two-to three JND's in achieved color when comparing calibration methods.

7627-20, Session 4

Evaluating segmentation algorithms for diffusion-weighted MR images: a task-based approach

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Apparent Diffusion Coefficient (ADC) obtained from Diffusion Weighted Magnetic Resonance Imaging (DWMRI) has emerged as a novel biomarker for evaluating anti-cancer therapy response. An increase in the ADC of the lesion during treatment indicates that the patient is responding well to the therapy. As the first step in computing ADC of the lesion, accurate lesion segmentation should be performed. There is ongoing research as well as published literature on methods to perform accurate lesion segmentation in these images. To quantitatively evaluate these segmentation algorithms, the same standard approaches are taken as for evaluating segmentation algorithms in normal images. However, the end task of these images is to estimate ADCs correctly, and these standard approaches do not evaluate the

segmentation algorithms on this task-based measure. Moreover, most standard methods rely on there being perfect manual segmentation of the lesion.

However, because of low SNR in DWMRI images and fuzzy lesion boundaries, many a times the manual segmentations are themselves error prone. In this paper, we deal with both of the above issues. We present two methods for evaluating segmentation algorithms on the task-based measure of ADC estimation. The first method compares segmentation algorithms given approximately good manual segmentation results from a radiologist. The second method compares the automated segmentation algorithms, even if we do not have good manual segmentation results.

7627-43, Poster Session

Assessment of automated detection of analyzable metaphase chromosome cells depicted on scanned digital microscopic images

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Visually searching for analyzable metaphase chromosome cells under microscopes is a time-consuming and difficult. To improve detection efficiency, consistency and accuracy, we developed an automated microscopic image scanning system to acquire images that has sufficient spatial resolution allowing clinicians to do diagnosis. However, in the large volume of scanned images from one specimen, only a few regions of interest (ROI) contain analyzable cells. A computer-aided detection (CAD) scheme was developed to detect analyzable cells. Thus, clinicians only need to observe and interpret the limited number of ROIs. In this study, we evaluated CAD performance using nine sets of images scanned from either bone marrow (3) or blood (6) specimens for diagnosis of leukemia. The automated selected results were compared with the visual selection. In the experiment, clinicians visually searched for the analyzable cells from specimens under microscopes. The specimens were then automated scanned followed by applying CAD to detect and save ROIs containing analyzable cells while deleting others. The selected ROIs were examined by three clinicians. From the scanned images, CAD selected more analyzable cells than initial visual examination in both blood and bone marrow specimens. In general, CAD had higher performance in analyzing blood specimens. Even in three bone marrow specimens, CAD selected 54, 23, 60 ROIs, respectively. Except matching with the initially visually selected 4, 3, and 5 analyzable cells, clinicians also selected 4 and 1 new analyzable cells in two specimens, which were missed in initially visual searching. This experiment showed the feasibility of applying this CAD-guided high-resolution image scanning system to prescreen and select ROIs that contain analyzable cells. The success and the further improvement of this CAD-guided automated system will have great impact on the future clinical practice in genetic laboratories to detect and diagnose diseases.

7627-44, Poster Session

Does a spatial frequency pathway lead to the first overt decision in the pulmonary nodule search task?

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Aim: To investigate the relationship between the image properties of regions fixated before the first decision and the fidelity of the first decision.

Background: Recent studies in mammography show that the first overt decision (TP or FP) has a great impact on further image reading including the correctness of the following decisions. The correlation between the spatial frequency properties of the local background

following decision sites and the first decision correctness has been reported.

Methods: Subjects were selected with different radiological experience in detection of pulmonary nodules from PA chest radiographs. The performance differences between subjects' groups were analysed through JAFROC methodology. The number of TP and FP made as a first decision were analysed in terms of the JAFROC score individually per subject. The number of decisions were analysed in terms of the first and preceding decisions. A spatial frequency (SF) properties analysis was carried out on foveal locations of selected regions: the first three the longest dwelled before first overt decision and the first decision sites. ANOVA was used to compare the logarithm values of energy carried by wavelet coefficient obtained from stationary packet decompositions up to 3rd level framed by Daubechies function. The SF features were selected to neglect the redundancy of the wavelet representations reducing 84 to 29 SF bands.

Results: A strong correlation was found between the number of TP as a first decision and the outcome JAFROC score ($r = 0.74$). The number of FP as a first decision was found negatively correlated with JAFROC ($r = -0.75$). No significant differences ($p < 0.05$) were found between SF properties of early dwelled regions and the decision sites. The work is still in progress.

7627-45, Poster Session

Effect of background detail on CD curve slope in CT head images

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The purpose of this work was to analyze the influence of background structure on the slopes of contrast-detail (CD) curves in CT images acquired in uniform phantoms, anthropomorphic head phantoms, and in clinical head CT images. Alternative forced-choice (AFC) studies were performed using CT images acquired in uniform (water) phantoms, anthropomorphic (RANDO and ATOM) phantoms, and clinical head scans. The AFC experiments measure the lesion contrast (I92%) that corresponds to 92% detection efficiency. The AFC experimental results were plotted as a function of lesion size to produce CD curves, and the slopes of the curves determined when plotted on log-log axes. The Rose model of detection predicts a slope of -1.0 for disk lesions in uniform backgrounds and white noise. CD curve slopes showed a progression that depends on the complexity of the background structure in the CT images. For uniform water phantom images, the slope averaged -0.9, which is close to that predicted by the Rose model. For the anthropomorphic phantoms, the slope averaged -0.57, and for the patient scans the average slope was -0.29. The slope of CD curves depends strongly on the background structure of the images in which the lesions are embedded, with increased background structure leading to decreased CD curve slopes. The Rose model reasonably predicts the slopes for CD curves acquired in uniform phantoms, but is a poor predictor of slopes in clinical head images.

7627-46, Poster Session

A support vector machine designed to identify breasts at high risk using multi-probe generated REIS signals: a preliminary assessment

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A new resonance-frequency based electronic impedance spectroscopy (REIS) system with multi-probes including one central and six that are designed to contact breast skin in circle with a radius of 60 millimeter distance to the central ("nipple") probe, has been assembled and installed in our breast imaging facility. We are conducting a prospective

clinical study to test the performance of this REIS system in identifying younger women (< 50 years old) at higher risk for having or developing breast cancer. In this preliminary study, we selected a subset of 100 examinations. Among these, 50 are positive cases recommended for a biopsy due to detection of a highly suspicious breast lesion and 50 are negative as determined during mammography screening. REIS output signal sweeps, we used to compute an initial feature that included both amplitude and phase information representing differences between corresponding (matched) EIS signal values acquired from the left and right breasts. A genetic algorithm was applied to reduce the feature set and optimize a support vector machine (SVM) to classify the REIS examinations. Using the leave-one-case-out testing method, the classification performance as measured by the area under receiver operating characteristic (ROC) curve was 0.816 ± 0.042. This pilot analysis suggests that the new multi-probe-based REIS system could potentially be used as a risk stratification tool to identify pre-screened young women who are at higher risk of having or developing breast cancer.

7627-47, Poster Session

Comparison of algorithms for ultrasound image segmentation without ground truth

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Image segmentation is a pre-requisite to medical image analysis. A variety of segmentation algorithms have been proposed, and most are evaluated on a small dataset or based on classification of a single feature. The lack of a gold standard (ground truth) further adds to the discrepancy in these comparisons. This work proposes a new methodology for comparing image segmentation algorithms without ground truth by building a matrix called region-correlation matrix. Subsequently, suitable distance measures are proposed for quantitative assessment of similarity. The first measure takes into account the degree of region overlap or identical match. The second considers the degree of splitting or mis-classification by using an appropriate penalty term. These measures are shown to satisfy the axioms of a quasi-metric. They are applied for a comparative analysis of synthetic segmentation maps to show their direct correlation with human intuition of similar segmentation. Since ultrasound images are difficult to segment and usually lack a ground truth, the measures are further used to compare the recently proposed spectral clustering algorithm (encoding spatial and edge information) with standard k-means over abdominal ultrasound images. Improving the parameterization and enlarging the feature space for k-means steadily increased similarity to spectral clustering.

7627-48, Poster Session

Optimization of detector thickness for single slice helical CT with ROC study

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Normally, the speed of bed movement per rotation (pitch) is fixed with the requirement of CT scanning speed. To reduce system cost, single slice helical CT (SSHCT) is chosen in many applications. It is interesting and useful in real life to answer the question that how to design the detector to obtain optimal performance of a SSHCT in a detection task. In this work, we applied ROC study for the optimization of detector thickness along the direction of rotation axis for our SSHCT. In our study, compound Gaussian noises are modeled in numerical simulations for both with and without defect objects. An analytical reconstruction method with rebinning is used for noisy data reconstruction. It can be seen that thin detectors lead to artifacts, and that thick detectors lead to defect blurring and lower contrast. They both have impacts on defects detecting in the case of noisy data. With ROC tests done on images from five choices of detector thickness, optimal performance is obtained when choosing detector thickness being around a quarter of pitch. We also studied the relationship between detectability and noise level. We found that, for a certain

signal, thin detector SSHCT is more sensitive to noise. This agrees with the fact that more photons are accumulated on thick detectors.

7627-49, Poster Session

Evaluation of deformable registration on preclinical datasets using mass conservation

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Quantitative evaluation of multi modality non-rigid registration is a very important, open and application specific problem. Several atlas based evaluation methods have already been proposed [1]. In this work non-rigid registration algorithm for full body CT-PET scans of small animals using mass conservation of labeled organs as a metric are evaluated. The deformation field obtained from each algorithm is applied on to an atlas designed from the same images. Organ labels are used to estimate the mass conservation and the quantitative analysis of the registration with B-spline, demons and level set method is presented.

7627-50, Poster Session

Quantification of diagnostic radiography image quality based on patient anatomical contrast-to-noise ratio: a preliminary study with chest images

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The quality of a digital radiograph for diagnostic imaging depends on many factors, such as the capture system DQE and MTF, the exposure technique factors, the patient anatomy, and the particular image processing method and processing parameters used. Therefore, the overall image quality as perceived by the radiologists is, in large part, subjective. This work explores objective image quality matrices directly from display-ready patient images.

A preliminary study was conducted based on a multi-frequency analysis of anatomy contrast and noise magnitude from 75 computed radiography (CR) chest radiographs (25 PA, 25 AP captured with anti-scatter grids, and 25 AP without grids). In particular, each chest image was decomposed, using the Laplacian Pyramid method, into five digressive frequency sub-bands. In the first two highest frequency bands, noise dominates most of the space except for some edge information that remains. Sub-sampling and statistical test methods were used to exclude edge information and produce a smooth noise map. In the several lower frequency bands, edge information dominates the whole space, which was extracted for contrast assessment. Five "anatomical anchor" or pathological invariant region-of-interests (ROIs) were manually selected from each image for noise assessment, together with the manubrium sterni region for contrast assessment. By combining noise and contrast in different sub-bands, the contrast-to-noise ratio (CNR) was calculated as a function of the spatial frequency of the anatomy. The contrast and noise values were then compared to the subjective ratings of the same ROIs established by human observers.

The calculated contrast and noise values correlated well with the human observers' overall ratings. The discrepancy can be explained by the fact that the human psycho-visual response was not factored into the noise calculation. The CNR value in the manubrium sterni region is a good representation of the overall image quality.

7627-51, Poster Session

Efficacy of fractal analysis in identifying glaucomatous damage

P. Y. J. Kim, K. M. Iftekharuddin, The Univ. of Memphis (United States); P. Gunvant, Southern College of Optometry (United States)

In this work, we propose a novel fractal-based technique to analyze 2D pseudo representation of 1D retinal nerve fiber layer (RNFL) thickness dataset for early detection of glaucoma. In our proposed technique, we first convert the 1D RNFL thickness data into pseudo 2D image and then exploit 2D fractal analysis (FA) technique to obtain representative features. These 2D features are further reduced with principal component analysis (PCA) and for the final classification between normal and glaucomatous eyes is obtained using Fischer's linear discriminant analysis (LDA). An independent dataset is used for training and testing the classifier. The technique is used on randomly selected GDx variable corneal compensator (VCC) eye data from the 227 study participants (116 patients with glaucoma and 111 patients with healthy eyes). We compute sensitivity, specificity and area under receiver operating characteristic (AUROC) for statistical performance comparison with other known techniques. Our classification performance shows that fractal-based analysis technique is superior to the standard machine classifier Nerve Fiber Indicator (NFI).

7627-21, Session 5

Does reader visual fatigue impact interpretation accuracy?

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Rationale: To measure the impact of reader of reader visual fatigue by assessing symptoms, the ability to keep the eye focused on the display and diagnostic accuracy.

Methods: Twenty radiology residents and 20 radiologists were given a diagnostic performance test containing 60 skeletal radiographic studies, half with fractures, before and after a day of clinical reading. Diagnostic accuracy was measured using area under the proper binormal curve (AUC). Error in visual accommodation was measured before and after each test session and subjects completed the Swedish Occupational Fatigue Inventory (SOFI) and the oculomotor strain subscale of the Simulator Sickness Questionnaire (SSQ) before each session.

Results: Average AUC was 0.89 for before work test and 0.85 for the after work test, ($F(1,36) = 4.15$, $p = 0.049 < 0.05$). There was significantly greater error in accommodation after the clinical workday ($F(1,14829) = 7.81$, $p = 0.005 < 0.01$), and after the reading test ($F(1,14829) = 839.33$, $p < 0.0001$). SOFI measures of lack of energy, physical discomfort and sleepiness were higher after a day of clinical reading ($p < 0.05$). The SSQ measure of oculomotor symptoms (i.e., difficulty focusing, blurred vision) was significantly higher after a day of clinical reading ($F(1,75) = 20.38$, $p < 0.0001$).

Conclusion: Radiologists are visually fatigued by their clinical reading workday. This reduces their ability to focus on diagnostic images and to accurately interpret them.

7627-22, Session 5

The varying effects of ambient lighting on low contrast detection tasks

M. F. McEntee, B. Martin, Univ. College Dublin (Ireland)

Monitors with lower spatial and contrast resolution such as off-the-shelf 1 megapixel LCDs are used in a variety of lighting setting for the assessment of NG and central lines. To determine whether ambient light settings effect the detection of low contrast objects on 1MP and 3MP LCD monitors a 1MP (NEC-Multisync 1980SXi) and 3MP (Barco-

Corinis MFGD3420) LCD were tested using a CDRAD test tool and an anthropomorphic phantom with nasogastric (NG) tube and central line were used.

Light settings of 35 and 100Lux were used. All images of the CDRAD and phantom were assessed on both monitors by three observers. A four alternative forced choice technique was used to rate low contrast detail. The observers then rated the visualisation of anatomical and inserted line structures on the chest radiographs in comparison to reference images. Visual grading scores were calculated. Statistical differences between CDRAD scores were assessed using ANOVA. The Kappa statistic was used for observer agreement. To analyse observer performance at high or low ambient light settings the Student's paired t-test was conducted.

At 100 Lux (the ambient lighting commonly found in wards) there was no significant advantage in using a 3MP over a 1MP for either the CDRAD ($p</=0.17$) or NG tube identification ($p</=0.31$). The highest performance was achieved when using a 3MP monitor at 35 Lux ($p</=0.01$).

At all light levels there was adequate visualisation of the NG tube and central line on the 1 MP monitors these are therefore acceptable for these visualisation tasks.

7627-23, Session 5

Nuisance levels of noise effects radiologists performance

M. F. McEntee, A. Coffey, J. T. Ryan, A. O Beirne, Univ. College Dublin (Ireland); M. G. Evanoff, The American Board of Radiology (United States); D. J. Manning, Univ. of Cumbria (United Kingdom); P. C. Brennan, The Univ. of Sydney (Australia)

PURPOSE: The radiology reporting room can have many distractions. The sound of dictation is often accompanied by computer hard drives, air-conditioning units, telecommunications devices and the general noise of the imaging department. This work aimed to assess the effect of noise on the diagnostic performance of radiologists.

MATERIALS/METHODS: Noise levels commonly experienced in the imaging department were initially measured and recorded. The level of Noise was recorded 10 times in 14 areas within a radiology department. Eleven of which were radiology reporting rooms. Recordings were then edited into one 15 minute soundtrack of clinically relevant noise. Consultant Radiologists (n=26) assessed 30 posteroanterior chest x-ray images for the presence or absence of nodular lesions in the absence and presence of clinically relevant noise. Jackknife free-response receiver-operating characteristic analysis was performed.

RESULTS: The noise measured in the clinical departments, rarely exceeded that encountered within normal conversation. The maximum mean value for a radiology reporting room being 56.1dBA. Radiologists' performance in the presence of noise did not differ significantly from that without noise. The difference in the figure of merits of +0.03, +0.01, and 0.0 with noise in comparison to without noise for cardiopulmonary radiologists, non-cardiopulmonary radiologists and all radiologists, respectively. No differences were seen for false-positive and false-negative scores or the time assessing the images.

CONCLUSION: This work demonstrated that the level of noise normally found within the Diagnostic Imaging Department is not a major distractor during this radiological task.

7627-24, Session 5

Impact of adaptation time on contrast sensitivity

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For softcopy reading of mammograms, a room illuminance of 10 lx is recommended in standard procedures. Room illuminance affects the

maximal monitor contrast and the global luminance adaptation of the visual system. A radiologist observer has to adapt to low luminance levels, when entering the reading room. Since the observer's sensitivity to low-contrast patterns depends on adaptation state and processes, it can be expected that the contrast sensitivity is lower at the beginning of a reading session. We investigated the effect of an initial time of dark adaptation on the contrast sensitivity. A study with eight observers was conducted in the context of mammographic softcopy reading. Using Gabor patterns with varying spatial frequencies, orientations, and contrast levels as stimuli in an orientation discrimination task, the intra-observer contrast sensitivity was determined for foveal vision. Before performing the discrimination task, the observers adapted for two minutes to an average illuminance of 450 lx. Thereafter, contrast thresholds were repeatedly measured at 10 lx room illuminance over a course of 15 minutes. The results show no significant variations in contrast sensitivity during the 15 minute period. Thus, it can be concluded that taking an initial adaptation time does not affect the perception of low-contrast objects in mammographic images presented in the typical softcopy reading environment. Therefore, the reading performance should not be negatively influenced when the observer starts immediately with reading of mammograms. The results can be used to optimize the workflow in the radiology reading room.

7627-25, Session 5

Spatial resolution and chest nodule detection: an interesting incidental finding

R. J. Toomey, M. F. McEntee, J. T. Ryan, A. Hayes, Univ. College Dublin (Ireland); P. C. Brennan, The Univ. of Sydney (Australia)

This study reports an incidental finding from a larger work. It examines the relationship between spatial resolution and nodule detection for chest radiographs. Twelve examining radiologists with the American Board of Radiology read thirty chest radiographs in two conditions - full (1500 × 1500 pixel) resolution, and 300 × 300 pixel resolution linearly interpolated to 1500 × 1500 pixels. All images were surrounded by a 10-pixel sharp grey border to aid in focussing the observer's eye when viewing the comparatively unsharp interpolated images. Fifteen of the images contained a single simulated pulmonary nodule. Observers were asked to rate their confidence that a nodule was present on each radiograph on a scale of 1 (least confidence, certain no lesion is present) to 6 (most confidence, certain a lesion was present). All other abnormalities were to be ignored. No windowing, levelling or magnification of the images was permitted and viewing distance was constrained to approximately 70cm. Images were displayed on a 3 megapixel greyscale monitor. Receiver operating characteristic (ROC) analysis was applied to the results of the readings using the Dorfman-Berbaum-Metz multiple-reader, multiple-case method. No statistically significant differences were found with either readers and cases treated as random or with cases treated as fixed. Low spatial frequency information appears to be sufficient for the detection of chest lesion of the type used in this study.

7627-26, Session 6

Validation of the NPWE model observer to predict the CDMAM performance

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The evaluation of image quality in mammography is performed with the CDMAM phantom at different dose levels and spectrum qualities, in order to set the mammographic unit with the optimal parameters. The CDMAM is a very time-consuming procedure, due to the 16 images needed to be exposed for every dose level, and to the time needed to read the images. To overcome this last problem an automatic software (CDCOM) can be used and the results are then corrected in order to obtain human-like results, but the time needed to acquire the image remains large.

In this paper a NPWE model observer to predict the CDMAM performances, based on MTF and NPS measurements, is proposed.

This model has been developed by other groups and here has been optimized in order to predict the CDMAM results for different systems.

15 mammographic systems (11 DR and 4 CR systems) have been evaluated, acquiring the CDMAM at different dose levels. The results have been analyzed in order to obtain the threshold gold thickness for each diameter of the phantom and then compared with the values calculated with the observer model.

The agreement is good enough to propose further investigation in order to validate the NPWE observer model as evaluation method of the image quality during the QC. This method requires only 2 MTF images and 5 flat images (to calculate the response curve and the NPS) and allows the prediction of the CDMAM performance for different spectra and dose levels.

7627-27, Session 6

The use of steerable channels for detecting asymmetrical signals with random orientations

B. Goossens, L. Platiša, E. Vansteenkiste, W. R. Philips, Univ. Gent (Belgium)

In the optimization of medical imaging systems, there is a stringent need to shift from human observer studies to numerical observer studies, because of both cost and time limitations. Numerical models give an objective measure for the quality of displayed images for a given task and can be designed to predict the performance of medical specialists performing the same task. For the task of signal detection, the channelized Hotelling observer (CHO) has been successfully used, although several studies indicate an overefficiency of the CHO compared to human observers. One of the main causes of this overefficiency is attributed to the intrinsic uncertainty about the signal that a human observer is dealing with. However, deeper knowledge of the discrepancies of the CHO and the human observer may provide extra insight in the processing of the human visual system and this knowledge can be utilized to better fine-tune medical imaging systems.

In this paper, we investigate the optimal detection of asymmetrical signals with statistically known random orientation, based on joint detection and estimation theory. We derive the optimal channelized observer for this task and we show that the optimal detection in channel space requires the use of steerable channels, which are used in steerable pyramid transforms in image processing. Even though the use of CHOs for SKS tasks has not been studied so far, our findings indicate that CHO models can be further extended to incorporate intrinsic uncertainty about the signal to behave closer to humans. Experimental results are provided to illustrate these findings.

7627-28, Session 6

Personalized numerical observer

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It is widely accepted that medical image quality should be assessed using task-based criteria, such as human-observer (HO) performance in a lesion-detection (scoring) task. HO studies are time consuming and cost prohibitive to be used for image quality assessment during development of either reconstruction methods or imaging systems. Therefore, a numerical observer (NO), a HO surrogate, is highly desirable. In the past, we have proposed and successfully tested a NO based on a supervised-learning approach (namely a support vector machine) for cardiac gated SPECT image quality assessment. In the supervised-learning approach, the goal is to identify the relationship between measured image features and HO myocardium defect likelihood scores.

Thus far we have treated multiple HO readers by simply averaging or pooling their respective scores. Due to observer variability, this may be suboptimal and less accurate. Therefore, in this work, we are setting our goal to predict individual observer scores independently in the

hope to better capture some relevant lesion-detection mechanism of the human observers. This is even more important as there are many ways to get equivalent observer performance (measured by area under receiver operating curve), and simply predicting some joint (average or pooled) score alone is not likely to succeed.

7627-29, Session 6

Using channelized Hotelling observers to quantify temporal effects of medical liquid crystal displays on detection performance

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Current clinical practice is rapidly moving in the direction of volumetric imaging. Often, radiologists interpret these images in stack-mode medical liquid crystal displays at browsing rates of 30 frames per second or higher. However, recent studies suggest that the slow temporal response of the display can compromise the image quality. In order to quantify the temporal effect of medical displays on detection performance, we investigate two designs of a multi-slice channelized Hotelling observer (msCHO) model in the task of detecting a single-slice signal in multi-slice simulated images. The design of msCHO models is inspired by simplifying assumptions about how humans observe while viewing in the stack-browsing mode. For comparison, we consider a standard CHO applied only on the slice where the signal is located, recently used in a similar study. We refer to it as a single-slice CHO (ssCHO). Overall, our results confirm previous findings that the slow temporal response of medical displays degrades the detection performance of the observers. More specifically, the performance range of msCHO designs is higher compared to the ssCHO suggesting that the extent and rate of degradation may be less than previously estimated by the ssCHO. Especially, the difference between msCHO and ssCHO is more significant for higher browsing speeds than for slow image sequences or static images. This, together with their design criteria which is driven by the assumptions about humans, makes the msCHO models promising candidates for further studies aimed at building anthropomorphic observer models for the stack-mode image presentation.

7627-30, Session 6

Rapid performance evaluation for ideal FROC and AFROC observers

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FROC and AFROC analyses are useful in medical imaging to characterize detection performance for the case of multiple lesions. We had previously developed (SPIE09) ideal FROC and AFROC observers. Their performance is ideal in that they maximize the area or any partial area under the FROC or AFROC curve. Such observers could be useful in imaging system optimization or in assessing human observer efficiency. However, the performance evaluation of these ideal observers is impractically computationally complex. We propose three reasonable assumptions under which the ideal observers reduce approximately to a particular form of a scan-statistic observer. Performance for the "scan-statistic-reduced ideal observer" can be evaluated far more rapidly albeit with slight error than that of the originally proposed ideal observer. Through simulations, we confirm the accuracy of our approximate ideal observers. We also compare the performance of our approximate ideal observer with that of a conventional scan-statistic observer and show that the performance of our approximate ideal observer is significantly greater.

7627-31, Session 6

Model observers for complex discrimination tasks: assessment of multiple coronary stent placements

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The evaluation of multiple stent placements in interventional cardiology is an important clinical task based on visual information extracted from a cineangiogram. The placement of multiple coronary stents requires fine judgments of distance between deployed stents. Ideally, multiple stents form a continuous region of support for the vessel, however gaps between stents are associated with restenosis. Making these judgments is difficult because of limited system resolution, noise, low contrast of the deployed stent, and stent motion during the cardiac cycle. We use performance in this task as a figure of merit for optimizing image display. Our approach involves simulating pairs of stents with predefined gaps along with a guidewire that are embedded in a patient angiogram selected from a previously acquired database. The stent/guidewire assembly is anchored to tracked points on the coronary vasculature to give the simulated stents realistic translational motion. The varied magnification, orientation, and motion of the simulated stents make this a complex discrimination task.

In previous work [Abbey et al., SPIE 2008; Zhang et al., SPIE 2009], we described our simulation procedure in detail, and we also reported results of human observers for a task involving discrimination of 4 gap sizes under various frame rates and number of frames. Here, we report the results of three model observers (i.e. NPW, NPWE, and PWMF) in the same task. Under signal known exactly conditions, model observers substantially outperform human observers in terms of discrimination accuracy. Integrating responses across multiple frames also improves the performance of model observers.

7627-32, Session 7

Influencing clinicians and healthcare managers: can ROC be more persuasive?

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Receiver Operating Characteristic analysis provides a reliable and cost effective performance measurement tool, without using full clinical trials. However, when ROC analysis shows that performance is statistically superior in one condition than another it is difficult to relate this result to effects in practice, or even to determine whether it is clinically significant. In this paper we present two concurrent analyses: using ROC methods alongside single threshold recall rate data, and suggest that reporting both provides complimentary data. Eight mammographers (average 8 years experience reading mammograms) read 160 difficult cases (41%malignant) twice, with and without prior mammograms. Lesion location and probability of malignancy was reported for each case and analyzed using JAFROC. Concurrently each participant chose recall or return to screen for each case. JAFROC analysis showed that the presence of prior mammograms improved performance (p=.006). Single threshold data showed that the number of false positive recalls was 26% higher without prior mammograms (p<.05). This would correspond to an increase in recall rate from 3.7% to 4.6% at the study hospital. Whilst ROC methods account for all possible thresholds of recall and have higher power, providing a single threshold example of false positive, false negative, and recall rates when reporting results can be more influential for clinicians.

7627-33, Session 7

Behavior of the decision variables of the three-class ideal observer for univariate trinormal data

D. C. Edwards, C. E. Metz, The Univ. of Chicago (United States)

We are attempting to extend receiver operating characteristic (ROC) analysis to tasks with more than two classes. This is difficult because of the rapid increase in complexity, in general, of both observer behavior and evaluation of its performance, as the number of classes involved increases. Many researchers have proposed addressing this complexity by imposing simplifications on the model; for example, by using univariate data rather than the bivariate data employed by the general three-class ideal observer. We have investigated a univariate trinormal model for the underlying data of a three-class ideal observer. Although a reasonably complete description of the ideal observer's behavior in this case is attainable, this behavior is more complicated than might intuitively be expected.

7627-34, Session 7

Therapy operating characteristic (TOC) curves and their application to the evaluation of segmentation algorithms

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It is now generally accepted, at least in the SPIE Medical Imaging community, that image quality must be assessed on the basis of the ability of a user to perform a medically relevant tasks with the image data. For diagnostic tasks, a wide variety of evaluation methods related to receiver operating characteristic (ROC) curves have been developed and used to assess imaging systems and reconstruction algorithms. Much less has been done with the estimation tasks that arise in the context of radiotherapy.

This paper presents a general framework for assessing imaging systems and image-analysis methods on the basis of therapeutic rather than diagnostic efficacy. By analogy to ROC, it introduces the Therapy Operating Characteristic or TOC curve, which is a plot of the probability of tumor control vs. the probability of normal tissue complications as the overall level of the treatment beam is varied.

The proposed figure of merit is the area under the TOC, denoted AUTOC. If the treatment planning algorithm is held constant, AUTOC is a metric for the imaging and image-analysis components, and in particular for segmentation algorithms that are used to delineate tumors and normal tissues. On the other hand, for a given set of segmented images, AUTOC can also be used as a metric for the treatment plan itself.

Mathematical and statistical properties of the TOC and AUTOC are discussed, and practical approaches to its implementation are presented. The approach is illustrated with a simulation study of segmentation methods for lung cancer.

7627-35, Session 7

Comparisons of binary ROC curve, three-class 2D ROC surface and three-class 5D ROC hypersurface

X. He, E. C. Frey, The Johns Hopkins Univ. (United States)

Recently we have shown that the 2-D three-class ROC sensitivity surface fully describes optimal three-class task performance in the sense that there is a one-to-one correspondence between the 2-D sensitivity surface and the triplet of likelihood ratio distributions, assuming such a triplet exists. This finding apparently contradicts some

of the tenets of the general three-class theory. This paper compares binary ROC curve with three-class 5-D hypersurface and 2 D ROC surface. We found that the 2-D three-class ROC surface shares many decision theoretic properties of the binary ROC curve, except that it does not directly predict task performance for general utilities. For example, the ROC curve (or surface) uniquely corresponds to one pair (or triplet) of likelihood ratio distributions, assuming such a pair (or triplet) exists and the ROC curve (or surface) is concave. On the other hand, we found the 5-D hypersurface does not behave comparable as the binary ROC curve in many of these aspects. Based on these results, we conclude that the 2-D ROC surface may be preferable as a starting point for comparing systems used to perform 3-class diagnostic tasks.

7627-36, Session 7

Modality ordering consistency between ROC and JAFROC

D. P. Chakraborty, Univ. of Pittsburgh (United States); F. Zanca, Univ. Hospital Gasthuisberg (Belgium)

Purpose: Jackknife alternative free-response receiver operating characteristic (JAFROC) analysis is being increasingly used to assess performance in tasks involving lesion localization. ROC methodology, the current standard, is widely accepted, but the ROC paradigm cannot accommodate localization information. Strong justification is needed to use an alternative paradigm over a long (~1945) established standard. So far the justification for the newer (2004) JAFROC method has come from the resemblance of the free-response paradigm to clinical tasks requiring lesion localization and improved statistical power of JAFROC over ROC analysis. However, questions have been raised whether JAFROC yields the same modality ordering as ROC. Inconsistent modality-ordering between ROC and JAFROC would seriously challenge the validity of JAFROC. The aim of this work was to examine this issue.

Methods: A dataset of 200 images, two modalities, interpreted by 4 mammographers in FROC mode, was analyzed by JAFROC. After 18 months independent ROC data obtained using the same dataset and readers was analyzed by DBM-MRMC. One thousand simultaneous reader-case bootstraps were used to quantify agreement. For each bootstrap JAFROC and DBM-MRMC yielded inter-modality figures-of-merit (FOMs) differences and p-values. Bootstraps where either method (generally ROC) yielded p > 5% were discarded, as this implies that one or both methods could not reject the NH and therefore could not determine the modality ordering. There remained 154 instances, for each of which both methods found significant differences between the modalities on the same bootstrapped dataset. Conditions under which modality-ordering consistency may not be as good were also examined.

Results: Only one of the 154 JAFROC and ROC inter-modality FOM differences had different signs. The odds-ratio (OR) was greater than 152 and the p-value that OR was greater than 1 was less than 0.006. Conditions under which modality-ordering consistency may not be as good are (i) the FOM differences are small so that there will be few instances where both JAFROC and ROC yield significant differences; (ii) if ROC or AFROC curves cross and TPF at specified FPF is used as the FOM, then modality-ordering is not unique and (iii) if different FOMs are chosen, e.g., partial area under FROC vs. area under ROC, modality-ordering may not be unique.

Conclusions: In this study modality-ordering consistency was almost perfect. To our knowledge no one has conducted independent FROC and ROC studies on the same readers and cases, the most direct way to examine the modality-ordering-consistency issue.

7627-37, Session 8

The effect of image interpretation training on the fracture recognition performance of radiographers

M. F. McEntee, N. Bergin, Univ. College Dublin (Ireland)

The aim of this study is to measure the effect of medical image interpretation training for radiographers. The study examines the performance of radiographers without image interpretation training and radiographers who are undergoing image interpretation training. In the course of the study, effects of previous experience are evaluated, in regard to number of years of radiographic experience and also previous interpretative experience.

A Free-response Receiver Operator Characteristic (FROC) study was performed to assess nine radiographers undergoing medical image interpretation training and to compare their performance with nineteen radiographers, without similar training. The radiographers evaluated 30 postero-anterior wrist images, in carefully controlled conditions, which included normal and abnormal distal radii. The results were evaluated with FROC analysis. the AUC, was the figure of merit. Specificity, sensitivity and average times were statistically compared using a one-way ANOVA and an independent t-test.

The study showed there was no statistical difference between the groups of radiographers' AUC values ($p \leq 0.98$). There was no statistical difference in sensitivity ($p \leq 0.31$), while there was an improved performance noted in specificity ($p \leq 0.06$). The study found there was little correlation between increasing years of radiographic experience and improved performance ($p \leq 0.52$), but it was noted there was an improvement when radiographers' previous image interpretation experience was considered ($p \leq 0.04$). It was seen there was weak correlation of increasing time spent on interpretation and improved performance ($p \leq 0.70$). Radiographers will be followed to the completion of their training and further results will be reported. Previous interpretative experience was an important factor in fracture detection performance.

7627-38, Session 8

User modeling for improved computer-aided training in radiology: concepts and preliminary experiments

M. A. Mazurowski, J. Y. Lo, G. D. Tourassi, Duke Univ. (United States)

Mammography is an efficient screening modality for breast cancer. However, interpretation of mammographic images is a difficult task and notable variability between radiologists' performance has been documented. A significant factor impacting radiologists' diagnostic performance is adequate training. In this study we propose a new paradigm for computer-assisted training in radiology based on constructing user models for radiologists-in-training that capture individual error making patterns. Such user models are developed and trained to use image features for prediction of the extent of error made by a particular radiologist for variety of cases and therefore estimate difficulty of different types of cases for that radiologist. The constructed user model can be used to develop a personalized training protocol for the radiologist-in-training that concentrates on cases that may pose a particular difficulty to the trainee. We initially demonstrate the concept of building individual user models for the task of breast mass diagnosis. Data collected from three resident observers at Duke University was used for the experiments. The result indicate that the proposed models are capable of learning to distinguish difficult and easy cases for each observer with moderate accuracy which shows promise for the proposed concept.

7627-39, Session 8

A novel methodology for display 2D MTF evaluation: the pixel spread function (PxSF)

A. Vetsuypens, C. Marchessoux, T. R. Kimpe, Barco N.V. (Belgium)

MTF (Modular Transfer Function) is used as a metric for the sharpness of the images displayed on a monitor. However, MTF is often only measured in one dimension (usually horizontally or vertically). The goal of this work is to provide a methodology that allows measuring the MTF of a display correctly in 2D. Existing methodologies are analyzed to determine if they are satisfactory. We concluded that all of the currently used methodologies have shortcomings. To overcome the limitations of the existing technologies, a new methodology is introduced, the Pixel Spread Function. In this methodology, an impulse to the display is approximated by a single lit pixel, on a uniform background. The measurements are performed at a very close distance, to limit the degradations introduced by the measurement system. By applying signal processing, the 2D MTF has been obtained for this methodology. After averaging the results for multiple images and pixel positions and removing the camera degradation, the methodology proved to be reproducible and easy to perform. To validate the proposed methodology, a mathematical model has been created to that allows simulating the MTF. Since the geometrical structure of the pixel has the largest impact on the obtained result, the model is based on it. Other degradations in the system (aberrations, diffraction,...) are approximated by an additional blurring step. The theoretical and experimental results were compared, and it was concluded that the methodology is valid.

7627-40, Session 8

Mammographic feature type and reader variability by occupation: an ROC study

H. J. Scott, A. G. Gale, Loughborough Univ. (United Kingdom)

Previous work has outlined that certain mammographic appearances feature more prominently in reader's false negative responses on a self-assessment scheme. Bi-annually 600 breast-screening film-readers complete at least one round of the Personal Performance in Mammographic Screening (PERFORMS) self-assessment scheme in the UK. The main occupational groups in UK Breast Screening can be categorised thus, Radiologist, Technologists and Symptomatics. Previous work has shown that these groups can vary in their reading 'style' and accuracy on self-assessed cases. These groups could be said to contain individuals each with (arguably) pronounced differences in their real life reading experience, symptomatic readers routinely read a large number of cases with abnormal appearances and Technologists (specially trained to read films) do not have the same medical background as breast-screening Radiologists. We aimed to examine overall (national) and group (occupational) differences in terms of ROC analysis on those mammographic cases with different mammographic appearance (feature type). Several main feature types were identified namely; Well Defined Mass (WDM), Ill Defined Mass (IDM), Spiculate Mass (SPIC), Architectural Distortions (AD), Asymmetry (ASYM) and Calcification (CALC) and in addition, where possible, cases were fractionated by classification type (malignant, benign and normal cases). Results will be discussed in light of differences in real-life practice for each of the occupational groups and how this may impact on accuracy over certain mammographic appearances.

7627-41, Session 8

Towards validation of a 3D structured background model for breast imaging

I. S. Reiser, K. Little, R. M. Nishikawa, The Univ. of Chicago (United States)

DESCRIPTION OF PURPOSE: Breast tomosynthesis is a novel modality for breast imaging that aims to provide partial depth resolution of the tissue structure. In order to optimize tomosynthesis acquisition and reconstruction parameters, it is necessary to model the structured breast background. The purpose of this work was to investigate whether filtered noise could be used as a structure surrogate.

METHODS: Human performance in a SKE detection task was determined through 2-AFC experiments using tomosynthesis backgrounds extracted from 55 normal breasts. Mathematically defined lesions were projected and reconstructed using the same acquisition and reconstruction parameters as the clinical data. Signal radii were 0.025, 0.1 and 0.4 cm. Performance in the center projection as well as a reconstructed slice through the signal center was determined. The gray-scale volume was binarized and attenuation coefficients of adipose or fibroglandular tissue were assigned to the voxels. This volume was then projected and reconstructed and performance of a prewhitening observer was computed for the lice and center projections.

RESULTS: For both observers and backgrounds, threshold amplitude was lower in the reconstructed slice than in the center projection. For the smallest/largest signal, the average decrease was 4/1.8 (human observer, clinical background) and 3.5/2 (model observer, filtered noise background).

CONCLUSIONS: For a detection task, similar trends in performance reduction between reconstructed slice and center projection were found for clinical and simulated structured backgrounds. This indicates that detection performance based on the filtered noise background model may be used to predict performance in actual breast backgrounds.

7627-42, Session 8

Fuzzy description of skin lesions

N. Laskaris, L. Ballerini, R. B. Fisher, B. Aldridge, J. Rees, The Univ. of Edinburgh (United Kingdom)

We propose a system for describing skin lesions images based on a human perception model.

Pigmented skin lesions including melanoma and other types of skin cancer as well as non-malignant lesions are used.

Works on classification of skin lesions already exist but they mainly concentrate on melanoma.

The novelty of our work is that our system gives to skin lesion images a semantic label in a manner similar to humans.

This work consists of two parts: first we capture they way users perceive each lesion, second we train a machine learning system that simulates how people describe images.

For the first part, we choose 5 attributes: colour (light to dark), colour uniformity (uniform to non-uniform), symmetry (symmetric to non-symmetric), border (regular to irregular), texture (smooth to rough). Using a web based form we asked people to pick a value of each attribute for each lesion.

In the second part, we extract 94 features from each lesions and we trained a machine learning algorithm using such features as input and the values of the human attributes as output.

Results are quite promising, especially for the colour related attributes, where our system classifies over 80% of the lesions into the same semantic classes as humans.

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7628-01, Session 1

Imaging informatics in the era of healthcare reform

K. M. Siddiqui, Microsoft Corp. (United States)

No abstract available

7628-02, Session 1

Database schema models of integrated relational databases for biomedical information systems

D. Kim, A. Alaoui, B. A. Levine, K. R. Cleary, Georgetown Univ. Medical Ctr. (United States)

Biomedical Informatics depends on the accessibility of large heterogeneous databases of clinical, imaging and biological data from disparate sources. The integration of these databases must take into account the diverse and flexible schemas used to store and manage the information contained within. Relational databases are often the preferred method for storing integrated biomedical data, however, traditional relational databases cannot efficiently support integrated biomedical information. Therefore, the creation of new database models to manage diverse and flexible schemas is required. This paper proposes several schemas to integrate biomedical information from disparate sources, and an experimental evaluation of their efficiency.

7628-03, Session 1

Managing and querying image annotation and markup in XML

F. Wang, T. C. Pan, Emory Univ. (United States); J. Permar, The Ohio State Univ. (United States); A. Sharma, J. Saltz, Emory Univ. (United States)

Proprietary approaches for representing annotations and image markup are serious barriers for researchers to share image data and knowledge. The Annotation and Image Markup (AIM) project is developing a standard based information model for image annotation and markup in health care and clinical trial environments. The complex hierarchical structures of AIM data model pose new challenges for managing such data in terms of performance and support of complex queries. In this paper, we present our work on managing AIM data through a native XML approach, and supporting complex image and annotation queries through native extension of XQuery language. Through integration with xService, AIM databases can now be conveniently shared through caGrid.

7628-38, Session 1

An automatic system to detect and extract texts of medical images for de-identification

Y. Zhu, Syracuse Univ. (United States); P. Singh, K. M. Siddiqui, M. Gillam, Microsoft Corp. (United States)

Recently, there is an increasing need to share medical images for research purpose. In order to respect and preserve patient privacy, most of the medical images are de-identified with protected health information (PHI) before research sharing. Since manual de-identification is time-consuming and tedious, so an automatic de-identification system is necessary and helpful for the doctors to remove text from medical images. A lot of papers have been written about text detection and extraction algorithms, however, little has been applied to de-identification of medical images. Since the de-identification system is designed for end-users, it should be effective, accurate and fast. This paper proposes an automatic system to detect and extract text from medical images for de-identification purposes, while keeping the medical objects intact. First, considering the texts have a remarkable contrast with the background, a region variance based algorithm is used to detect the text regions. In post processing, geometric constraints are applied to the detected text regions to eliminate over-segmentation, e.g., lines and medical objects. After that, a region based level set method is used to extract texts from the detected text regions. A demo of the text detection and extraction system is implemented, which shows that our method can detect most of the texts in the images. Preliminary results validate that our method can detect and extract texts in medical images with a 99% recall rate. Future research of this system includes algorithm improvement, performance evaluation, and computation optimization.

7628-04, Session 2

Evaluation of an open source tool for indexing and searching enterprise radiology and pathology reports

W. Kim, W. W. Boonn, Hospital of the Univ. of Pennsylvania (United States)

Data mining of existing radiology and pathology reports within an enterprise health system can be used for clinical decision support, research, education, as well as operational analyses. In our health system, the database of radiology and pathology reports exceeds 12 million entries. We are building an web based tool to allow search and data analysis of these combined databases using freely available and open source tools. The native open source database has built-in full text indexing capabilities, however the performance is poor when indexing a very large database. To improve performance, we have incorporated a open source full-text SQL indexing tool. Prior to implementation, a nightly full reindex would take over 6 hours. This has now been reduced to 20 minutes. Previously, search and analysis strings were limited to very simple queries due to performance constraints. After implemention, it is now possible to perform realtime complex boolean queries, on-the-fly negation search, and operational queries such as turn-around-time analysis.

7628-05, Session 2

Minimizing the semantic gap in biomedical content-based image retrieval

H. Guan, S. K. Antani, L. R. Long, G. R. Thoma, National Library of Medicine (United States)

A primary challenge for biomedical Content-Based Image Retrieval (CBIR) is to achieve meaningful mappings to bridge the semantic gap between the high-level biomedical semantic concepts and the low-level visual features in images. This paper presents a comprehensive learning-based scheme for this challenge to improve retrieval quality. The proposed scheme mainly contains two algorithms: a learning-based feature selection and fusion algorithm and the Ranking Support Vector Machine (Ranking SVM) algorithm. The feature selection algorithm aims at select 'good' features and fusion them by different similarity measurements to provide the better representation of the high-level concepts with the low-level image features. The Ranking

SVM is applied to learn the retrieval rank function and associate the selected low-level features with query concepts given the ground-truth ranks of the training samples. Briefly, the proposed scheme addressed four major issues in CBIR to improve the retrieval accuracy: image feature extraction, selection and fusion, similarity measurements, the association of the low-level features with high-level concepts, and the generation of rank function to support high-level semantic image retrieval. It models the relationship between semantic concepts and image features, and performs retrieval at the semantic level. We apply it to the problem of vertebra shape retrieval on a digitized spine x-ray image collection from the second National Health and Nutrition Examination Survey (NHANES II). The experimental results show that the mean average precision (MAP) of proposed scheme is improved by up to 41.92% over the conventional similarity measurements.

7628-06, Session 2

Semantic annotation of medical images

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Diagnosis and treatment planning for patients can be significantly improved by comparing with clinical images of other patients with similar anatomical and pathological characteristics. This requires the images to be annotated using common vocabulary from clinical ontologies. Current approaches to such annotation are typically manual, consuming extensive clinician time, and cannot be scaled to large amounts of imaging data in hospitals. On the other hand, automated image analysis while being very scalable do not leverage standardized semantics and thus cannot be used across specific applications. In our work, we describe an automated and context-sensitive workflow based on an image parsing system complemented by an ontology-based context-sensitive annotation tool. An unique characteristic of our framework is that it brings together the diverse paradigms of machine learning based image analysis and ontology based modeling for accurate and scalable semantic image annotation.

7628-07, Session 2

A hierarchical SVG image abstraction layer for medical imaging

E. Kim, X. Huang, G. Tan, Lehigh Univ. (United States); L. R. Long, S. K. Antani, National Library of Medicine (United States)

As medical imaging rapidly expands, there is an increasing need to structure and organize image data for efficient analysis, storage and retrieval. In response, a large fraction of research in the areas of content-based image retrieval (CBIR) and picture archiving and communication systems (PACS) has focused on structuring information to bridge the "semantic gap", a disparity between machine and human image understanding. An additional consideration in medical images is the organization and integration of clinical diagnostic information. As a step towards bridging the semantic gap, we design and implement a hierarchical image abstraction layer using a XML based language, SVG (scalable vector graphics). Our method encodes features from the raw image and clinical data standards into an extensible "layer" that can be efficiently searched and stored. Any feature extracted from the raw image including, color, texture, orientation, size, neighbor information, etc., can be combined in our abstraction with high level descriptions or classifications. Also, being a W3C (world wide web consortium) standard, SVG is able to be displayed by most web browsers, interacted with by ECMAScript (standardized scripting language, e.g. JavaScript, JScript), and indexed and retrieved by XML databases and XQuery. Using these open source technologies enables straightforward integration into existing systems. Furthermore, our representation can natively characterize an image in a hierarchical tree structure to support multiple levels of segmentation. From our results, we show the

flexibility and extensibility of our abstraction facilitates effective storage and retrieval of medical images.

7628-08, Session 2

CBIR for mammograms using medical image similarity

D. Tahmoush, Univ. of Maryland, College Park (United States)

One fundamental problem remains in the area of medical image analysis and retrieval: how to measure radiologist's perception of similarity between two images. This paper develops a similarity function that is learned from medical annotations and built upon extracted medical features in order to capture the perception of similarity between images with cancer. The technique first extracts high-level medical features from the images to determine a local contextual similarity, but these are unordered and unregistered from one image to the next. Second, the feature sets of the images are fed into the learned similarity function to determine the overall similarity for retrieval. This technique avoids arbitrary spatial constraints and is robust in the presence of noise, outliers, and imaging artifacts. We demonstrate that utilizing unordered and noisy higher-level cancer detection features is both possible and productive in measuring image similarity and developing CBIR techniques.

7628-09, Session 2

Exemplary design of a DICOM structured report template for CBIR integration into radiological routine

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The large and continuously growing amount of medical image data demands access methods with regards to content rather than simple text-based queries. The potential benefits of content-based image retrieval (CBIR) systems for computer-aided diagnosis (CADx) are evident and have been approved. Still, CBIR is not a well-established part of daily routine of radiologists. We have already presented a concept of CBIR integration for the radiology workflow in accordance with the Integrating the Healthcare Enterprise (IHE) framework. The retrieval result is composed as a Digital Imaging and Communication in Medicine (DICOM) Structured Report (SR). The use of DICOM SR provides interchange with PACS archive and image viewer. It offers the possibility of further data mining and automatic interpretation of CBIR results. However, existing standard templates do not address the domain of CBIR. We present a design of a SR template customized for CBIR. Our approach is based on the DICOM standard templates and makes use of the mammography and chest CAD SR templates. Reuse of approved SR sub-trees promises a reliable design which is further adopted to the CBIR domain. We analyze the special CBIR requirements and integrate the new concept of similar images into our template. Our approach also includes the new concept of a set of selected images for defining the processed images for CBIR. A commonly accepted pre-defined template for the presentation and exchange of results in a standardized format promotes the widespread application of CBIR in radiological routine.

7628-22, Poster Session

DICOMGrid: a middleware to integrate PACS and EELA-2 grid infrastructure

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Medical images provide lots of information for physicians, but the huge amount of data produced by medical image equipments in a modern

Health Institution is not completely explored in its full potential yet. Nowadays medical images are used in hospitals mostly as part of routine activities while its intrinsic value for research is underestimated. Medical images can be used for the development of new visualization techniques, new algorithms for patient care and new image processing techniques. These research areas usually require the use of huge volumes of data to obtain significant results, along with enormous computing capabilities. Such qualities are characteristics of grid computing systems such as EELA-2 infrastructure (http://www.eu-eela.eu/). The grid technologies allow the sharing of data in large scale in a safe and integrated environment and offer high computing capabilities.

In this paper we describe a DicomGrid middleware to store and retrieve medical images, properly anonymized, that can be used by researchers to test new processing techniques, using the computational power offered by grid technology. The idea is also to be able to rely on collaborative data provided by different institutions, gathering a vast amount of data that can offer a significant statistical distribution of a particular disease, so the results obtained are reliable. A prototype of DicomGrid middleware is under evaluation and permits to submit jobs to the EELA-2 grid infrastructure while offering to the user a simple interface that requires a minimal understanding of the grid operation.

7628-32, Poster Session

Content-based numerical report searching for image enabled case retrieval

L. Xue, T. Ling, Z. He, J. Zhang, Shanghai Institute of Technical Physics (China)

In this presentation, we described a new approach to search and retrieve numerical reports based on the contents of parameters from large database of numerical reports. We adopted high-dimension-index method to solve the problem of content-based numerical report searching and retrieval, developed two kinds of indexing and querying modal such as modal index and query, and non-modal index and query, for different numerical report retrieval applications. Also, we discussed how to integrate this new content-based numerical report retrieval method into a USIS and EMR system for image-enabled case retrieval application.

7628-33, Poster Session

Web-accessible cervigram automatic segmentation tool

Z. Xue, S. K. Antani, L. R. Long, G. R. Thoma, National Library of Medicine (United States)

Uterine cervix image analysis is of great importance to the study of uterine cervix cancer which is among the leading cancers affecting women worldwide. In this paper, we describe our proof-of-concept Web-accessible system for automated segmentation of significant tissue regions in uterine cervix images. It demonstrates our research efforts toward promoting collaboration between engineers and physicians which is crucial to many medical image analysis projects developed by universities and engineers. We report on the design and implementation of a system that unifies the merits of two commonly used languages, MATLAB and Java. It circumvents the heavy workload of recoding the sophisticated segmentation algorithms originally developed in MATLAB into Java while allowing remote users who are not experienced programmers and algorithms developers to apply those processing methods to their own cervicographic images and evaluate the algorithms. Several other practical issues of the systems are also discussed, like the compression of images and the format of the segmentation results.

7628-34, Poster Session

Image consistency rendering for portable chest radiography

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Image quality and appearance may vary substantially due to the variations in image acquisition techniques, patient and apparatus positioning, and image processing techniques. These differences may in turn affect the ability of clinicians to interpret images effectively and efficiently in areas where diagnoses require comparison of images acquired at different times from different modalities, for example, mammography and portable chest radiography. Image rendering to improve the consistency in quality and appearance across time and modality will improve both the efficiency and effectiveness of image interpretation. This paper presents a technique for improving the consistency of portable chest radiographic images. The technique automatically determines the regions-of-interest (ROIs) as anchor points for tone-scale rendering. The consistency rendering is dictated by the predetermined anchor points.

7628-35, Poster Session

Displaying Dicom-SR reports on non-SR aware radiology workstations

G. Carlsson, Sahlgrenska Univ. Hospital (Sweden); L. Lindsköld, M. Wintell, Västra Götalandsregionen (Sweden)

In the Vastra Gotaland region (VGR) we use an Information Infrastructure containing all radiological information produced within the region. All information is stored as Dicom-objects. This means that request and report information is stored as Structured Reports (SR)-objects together with the images if they exist.

At Sahlgrenska University Hospital (SU) in Gothenburg, Sweden we have radiological workstations that can't display the contents in the SR-objects and have a working RIS-integration at the same time.

We have developed some software in conjunction with the dcmtk-software package developed by the Oldenburg University to make it possible to display information from SR-objects on the radiological workstations.

The workstations have the ability to use Web-functionality so the solution is based on web-technology.

The following happens when a request is made to display the SR-information:

Workstation calls a cgi-script that checks if the archive has any SR-reports for the given study.

A c-move request is sent to the archive to send the SR-objects (reports) to a Dicom-receiver on the web-server.

The dicom-receiver (storescp) creates html-files with help of a modified version of dsr2html.

The cgi-script reads the names of the created html-files and returns the names in a javascript-array.

The report is displayed on the workstation.

By writing software combined with the usage of open source software we have developed a well functional solution to display SR-reports stored in a Information Infrastructure on workstations that initially can't show SR-information by themselves.

7628-36, Poster Session

Data migration and persistence management in a medical imaging informatics data grid

J. Lee IV, The Univ. of Southern California (United States)

The Medical Imaging Informatics Data Grid project is an enterprise infrastructure solution developed at USC for archiving digital medical images and structured reports. Migration methodology and policies are needed to maintain data persistence and fault-tolerance as the volume of data being replicated amongst multi-side storage nodes of a data grid start to fill up. The methodology should accommodate varying file system storage capacities at each site, and also have the intelligence to migrate studies with high probabilities of activity out of storage locations with lower priority and under-performing storage nodes. The database and file migration processes involved must not disrupt the existing workflow in the data grid model, specifically the query and retrieval functions. This paper discusses the challenges, policies, and protocols required to provide data persistence through data migration in a medical imaging informatics data grid.

7628-37, Poster Session

Computer-aided diagnosis workstation and teleradiology network system for chest diagnosis using the web medical image conference system with a new information security solution

H. Satoh, Tokyo Health Care Univ. (Japan)

Mass screening based on multi-helical CT images requires a considerable number of images to be read. It is this time-consuming step that makes the use of helical CT for mass screening impractical at present. Moreover, the doctor who diagnoses a medical image is insufficient in Japan. To overcome these problems, we have provided diagnostic assistance methods to medical screening specialists by developing a lung cancer screening algorithm that automatically detects suspected lung cancers in helical CT images, a coronary artery calcification screening algorithm that automatically detects suspected coronary artery calcification. We also have developed the teleradiology network system by using Web medical image conference system. In the teleradiology network system, the security of information network is very important subjects. Our Tele Radiology network system can perform Web medical image conference in the medical institutions of a remote place using the web medical image conference system with information security solution called "GFI E-Tally". Our Privacy and information security technology of information security solution ensures compliance with Japanese regulations. GFI was also certified to ISO/IEC 27001. Biometric face authentication used on site of Tele Radiology makes "Encryption of file" and "Success in login" effective. As a result, patients' private information is protected. We can share the screen of Web medical image conference system from two or more web conference terminals at the same time. An opinion can be exchanged mutually by using a camera and a microphone that are connected with workstation. Based on these diagnostic assistance methods, we have developed a newly computer-aided workstation and a newly teleradiology network that can display suspected lesions three-dimensionally in a short time. The results of this study indicate that our radiological information system without film by using computer-aided diagnosis workstation and our teleradiology network system can increase diagnostic speed, diagnostic accuracy and security improvement of medical information.

7628-10, Session 3

Support of surgical process modeling by using adaptable software user interfaces

T. Neumuth, B. Kaschek, M. Czygan, Univ. Leipzig (Germany); D. Goldstein, Univ. of Leipzig (Germany); G. Strauss, J. Meixensberger, O. Burgert, Univ. Leipzig (Germany)

Surgical Process Modeling (SPM) is a useful method for acquiring data about the evolution of surgical procedures. The resulting models might be used for a variety of use cases including evaluation studies, procedure optimization, education, or workflow management scheme design. This work proposes the use of adaptable situation-aware user

interfaces for observation support software for SPM. We developed a method to support the modeling of the observer by using a knowledge base. This is used to drive the graphical user interface for the observer to restrict the search space of terminology depending on the current situation. In the evaluation study it is shown, that the workload of the observer was decreased significantly by using adaptable user interfaces. 54 observer recordings were analyzed by using the NASA Task Load Index. It was found that for the observer was disburdened significantly in recording effort, mental demand and temporal demand by using the adaptable user interface.

7628-11, Session 3

Storing data generated by optical surface scanners using DICOM: a white paper

O. Burgert, T. Treichel, M. Gessat, Univ. Leipzig (Germany)

There are many applications in computer assisted surgery and related disciplines which involve the usage of directly measured surfaces. Those surfaces are usually measured using so called "Surface Scanners" which are using structured light (pattern projection or laser) to measure the surface. From an integration standpoint, it would be beneficial for many applications to have all patient data in one common repository and since in many cases radiology images are involved as well, a PACS is a natural option for storage of this data. DICOM - the major standard used for storage and transmission of data within a PACS - recently introduced the option to store surface meshes natively. This new Surface Mesh IOD (Information Object Definition) can serve as a basis for storage of data generated by an optical surface scanner. Nonetheless, a new Information Object Definition for this kind of data has to be introduced to reflect the specific needs: Device specific parameters have to be stored and, in addition to the Surface Mesh IOD, there must be the possibility to store textures as well. This paper gives an overview about the specific requirements and an outline of a Work Item leading to a Scanned Surface IOD.

7628-12, Session 3

Migration from a prototype ePR for IA-MISS system to alpha version

J. R. Documet, B. J. Liu, A. H. Le, The Univ. of Southern California (United States)

Last year we presented a paper that describes the design and clinical implementation of an ePR (Electronic Patient Record) system for Image-Assisted Minimally Invasive Spinal Surgery (IA-MISS). The goal of the ePR is to improve the workflow efficiency by providing all the necessary data of a surgical procedure from the preparation stage until the recovery stage. The mentioned ePR has been already implemented and it has been in use for the last 6 months. In this paper, we will describe the migration process from a prototype version of the system to a more stable and easily-to-replicate beta version.

7628-13, Session 3

Decision support tools for proton therapy ePR: intelligent treatment planning navigator and radiation toxicity tool for evaluating of prostate cancer treatment

A. H. Le, R. R. Deshpande, B. J. Liu, The Univ. of Southern California (United States)

The electronic patient record (ePR) has been developed for prostate cancer patients treated with proton therapy. The ePR has functionality to accept digital input from patient data, perform outcome analysis and patient and physician profiling, provide clinical decision support and suggest courses of treatment, and distribute information across different platforms and health information systems. In previous years,

we have presented the infrastructure of a medical imaging informatics based ePR for PT with functionality to accept digital patient information and distribute this information across geographical location using Internet protocol. In this paper, we present the ePR decision support tools which utilize the imaging processing tools and data collected in the ePR. The two decision support tools including the treatment plan navigator and radiation toxicity tool are presented to evaluate prostate cancer treatment to improve proton therapy operation and improve treatment outcomes.

7628-14, Session 3

The development of a disease oriented eFolder for multiple sclerosis decision support

K. C. Ma, P. Moin, J. R. F. Fernandez, C. Jacobs, L. Amezcua, B. J. Liu, The Univ. of Southern California (United States)

Multiple sclerosis (MS) is a demyelinating disease of the central nervous system. The chronic nature of MS necessitates multiple MRI studies to track disease progression. Currently, MRI assessment of multiple sclerosis requires manual lesion measurement and yields an estimate of lesion volume and change that is highly variable and user-dependent. In the setting of a longitudinal study, disease trends and changes become difficult to extrapolate from the lesions. In addition, it is difficult to establish a correlation between these imaged lesions and clinical factors such as treatment course. To address these clinical needs, an MS specific e-Folder for decision support in the evaluation and assessment of MS has been developed. An e-Folder is a disease-centric electronic medical record in contrast to a patient-centric electronic health record. Along with an MS lesion computer aided detection (CAD) package for lesion load, location, and volume, clinical parameters such as patient demographics, disease history, clinical course, and treatment history are incorporated to make the e-Folder comprehensive. With the integration of MRI studies together with related clinical data and informatics tools designed for monitoring multiple sclerosis, it provides a platform to improve the detection of treatment response in patients with MS. The design and deployment of MS e-Folder aims to standardize MS lesion data and disease progression to aid in decision making and MS-related research.

7628-15, Session 4

Multi-site evaluation of a computer aided detection (CAD) algorithm for small acute intra-cranial hemorrhage and development of a stand-alone CAD system ready for deployment in a clinical environment

R. R. Deshpande, K. C. Ma, J. Lee, T. Chan, B. J. Liu, H. K. Huang, The Univ. of Southern California (United States)

Timely detection of Acute Intra-cranial Hemorrhage (AIH) in an emergency environment is essential for the triage of patients suffering from Traumatic Brain Injury. Moreover, the small size of lesions and lack of experience on the reader's part could lead to difficulties in the detection of AIH. A CT based CAD algorithm for the detection of AIH has been developed in order to improve upon the current standard of identification and treatment of AIH. A retrospective analysis of the algorithm has already been carried out with 135 AIH CT studies from the Los Angeles County General Hospital/ University of Southern California Hospital System (LAC/USC). AIH studies have also been collected from Walter Reed Army Medical Center, and are currently being processed using the AIH CAD system as part of implementing a multi-site assessment and evaluation of the performance of the algorithm. The sensitivity and specificity numbers from the Walter Reed study will be compared with the numbers from the LAC/USC study. Simultaneously, a separate system with a user friendly GUI has been developed to supplant the MATLAB coded version and facilitate implementation in a clinical setting.

7628-16, Session 4

Computer-aided bone age assessment for ethnically diverse older children using integrated fuzzy logic system

K. C. Ma, P. Moin, B. J. Liu, The Univ. of Southern California (United States)

Bone Age Assessment (BAA) of children is a clinical procedure frequently performed in pediatric radiology to evaluate the stage of skeletal maturation based on the left hand x-ray radiograph. The current BAA standard in the US is using the Greulich & Pyle (G&P) Hand Atlas, which was developed fifty years ago and was only based on Caucasian population from the Midwest US. To bring the BAA procedure up-to-date with today's population, a Digital Hand Atlas (DHA) consisting of 1400 hand images of normal children of different ethnicities, age, and gender. Based on the DHA and to solve inter- and intra-observer reading discrepancies, an automatic computer-aided bone age assessment system has been developed and tested in clinical environments. The algorithm utilizes features extracted from three regions of interests: phalanges, carpal, and radius. The features are aggregated into a fuzzy logic system, which outputs the calculated bone age. The previous BAA system only uses features from phalanges and carpal, thus BAA result for children over age of 15 is less accurate. In this project, the new radius features are incorporated into the overall BAA system. The bone age results, calculated from the new fuzzy logic system, are compared against radiologists' readings based on G&P atlas, and exhibits an improvement in reading accuracy for older children.

7628-17, Session 4

Quality control of diffusion weighted images

Z. Liu, Y. Wang, The Univ. of North Carolina at Chapel Hill (United States); G. Gerig, S. Gouttard, R. Tao, T. Fletcher, The Univ. of Utah (United States); M. A. Styner, The Univ. of North Carolina at Chapel Hill (United States)

Diffusion Tensor Imaging (DTI) has become an important MRI procedure to investigate the integrity of white matter in brain in vivo. DTI itself is estimated from a series of acquired MR Diffusion Weighted Imaging (DWI). DWI data suffer from inherent low SNR, overall long scanning time of multiple directional encoding with correspondingly large risk to encounter motion artifacts, as well as susceptibility artifacts in several regions close to the brain. These artifacts can be too severe for a correct and stable estimation of the diffusion tensor. Thus, a quality control (QC) procedure is absolutely necessary for DTI studies.

Currently, routine DTI QC procedures are conducted manually by visually checking the DWI data set in a gradient by gradient and slice by slice way. The results often suffer from low consistence across different data sets, lack of agreement of different experts, and difficulty to judge motion artifacts by qualitative inspection. Additionally considerable manpower is needed for this step due to the large number of images to QC, which is common for group comparison and longitudinal studies, especially with increasing number of diffusion gradient directions.

We present a framework for automatic DWI quality control. We developed a tool called DTIPrep that pipelines information checking, image cropping/padding, artifacts checking, and correction and DTI computation functionalities with a detailed protocoling and reporting facility. DTIPrep is fully open source and available as part of the UNC NeuroLib software repository.

This framework/tool has been successfully applied to several DTI studies with several hundred DWIs in our lab as well as collaborating labs in Utah and Iowa. In our studies, the tool provides a crucial piece for robust DTI analysis in brain white matter study.

7628-18, Session 4

An automatic quantification system for MS lesions with integrated DICOM structured reporting (DICOM-SR) for implementation within a clinical environment

C. Jacobs, K. C. Ma, P. Moin, B. J. Liu, The Univ. of Southern California (United States)

Multiple Sclerosis (MS) is a common neurological disease affecting the central nervous system characterized by pathologic changes including demyelination and axonal injury. MR imaging has become the most important tool to evaluate the disease progression of MS characterized by the occurrence of white matter lesions. Currently, radiologists evaluate and assess MS lesions manually by estimating the lesion volume and amount of lesions. This process can be time-consuming and sensitive to intra- and inter-observer variability. Therefore, there is a need for automatic segmentation of the MS lesions followed by lesion quantification. A fully automatic segmentation algorithm to identify the MS lesions has been developed. The algorithm is accelerated by parallel computing using Graphics Processing Units (GPU) for practical implementation into a clinical environment. Characterized quantification of the lesions is performed and the results, including lesion volume and amount of lesions, are stored in a structured report together with the lesion location in the brain. The development of this structured report in collaboration with radiologists aims to facilitate outcome analysis and treatment assessment of the disease and is standardized based on DICOM-SR. The results can be distributed to other DICOM-compliant clinical systems that support DICOM-SR such as PACS. The implementation of a fully automatic segmentation and quantification system together with a method for storing, distributing, and visualizing key imaging and informatics data in DICOM-SR for MS lesions improves the clinical workflow of radiologists and visualizations of the lesion segmentations and can provide 3-D insight into the distribution of lesions in the brain.

7628-19, Session 4

A proxy of DICOM services

L. S. Ribeiro, C. M. Azevedo Costa, J. L. Oliveira, Univ. de Aveiro (Portugal)

The production of digital medical images is increasing and is nowadays an essential aid to medical decisions. During the last decade, the production and storage of digital medical images has been increasing and these diagnostic tools have increasingly become an essential aid to medical decisions.However, despite the growing importance, Picture Archiving and Communication Systems (PACS) are typically oriented to supporting a single healthcare institution, and the sharing of medical data across institutions is still a difficult process. This paper describes a proposal to publish and control Digital Imaging Communications in Medicine (DICOM) services in a wide domain composed of several healthcare institutions. The system creates virtual bridges between intranets enabling the exchange, search and store of the medical data within the wide domain. The service provider publishes the DICOM services following a token-based strategy. The token advertisements are public and known to all system users. However, access to the DICOM service is controlled through a role association between an access key and the service. Furthermore, in medical diagnoses, time is a crucial factor. Therefore, our system is a turnkey solution, capable of exchanging medical data across firewalls and Network Address Translation (NAT), avoiding bureaucratic issues with local network security. Security is also an important cover issue - in any transmission across different domains, data is encrypted by Transport Layer Security (TLS) cryptographic protocol.

7628-20, Session 4

A practical fast method for medical imaging transmission based on the DICOM protocol

R. Maani, S. Camorlinga, N. Arnason, R. Eskicioglu, Univ. of Manitoba (Canada)

The standard format for medical imaging storage and transmission is Digital Imaging and Communications in Medicine (DICOM). Nowadays, and specifically with large amounts of medical images acquired by modern modalities the need for a fast data transmission between DICOM application entities is tangible. In some applications (particularly those aiming to provide real-time services), this demand is critical. This paper introduces a method which aims to provide a fast and simple way of image transmission by utilizing the DICOM protocol. The current implementations of DICOM protocol usually care about connecting DICOM application entities and a fast method for data transmission is not noted decently. In the process of connecting two DICOM application entities, the format of the transmission is agreed upon. The two entities choose an encoding that is supported by both. For instance, if one entity does not support compression the other one cannot use that option. In the proposed method we use a pair of Interfaces to deal with this issue and provide a fast way of medical data transmission between any two DICOM application entities. These Interfaces use both compression and multi-threading techniques to transfer the images in a fast way. The Interfaces can be used without any change to the current DICOM application entities. In fact, the Interfaces listen to the incoming messages from the DICOM application entities, intercept the messages and carry out the data transmission fast.

7628-21, Session 5

Framework design and development of an informatics architecture for a systems biology approach to traumatic brain injury

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Traumatic Brain Injury (TBI) is estimated to affect 1.4 million Americans every year, of which 50,000 die and 275,000 suffer major consequences. Although TBI is a problem of major medical and socioeconomic significance, its pathogenesis is not completely understood and it is often difficult to assess its pathological progression. As part of a large, multi-center project to study mild and moderate TBI, we are developing a database and informatics system to integrate a wide range of clinical, biological, and imaging data. This database is a cornerstone of our systems-based approach to TBI with the goals of developing and validating biomarker panels that might be used to diagnose brain injury, predict clinical outcome, and eventually develop improved therapeutics and clinical interventions into the standard care. This paper will present the architecture for an informatics system that stores the disparate data types and permits easy access to the data for analysis.

7628-23, Session 5

An investigator-centric data model for organizing multimodality images and structured reports within small animal imaging facilities

J. Lee, A. Gurbuz, B. J. Liu, The Univ. of Southern California (United States)

The images and reports generated in many small animal imaging facilities are often archived onto large hard-drives or a myriad of DVD's, without so much as directory and file names to remind users of its content and format type. An investigator-centric database and reporting protocol is the first step towards organizing metadata and

interoperability of these multimodality data files. This paper will address two important data archiving objectives in small animal imaging facilities today. First, a relational database model to organize metadata of raw images, post-processed images and findings around an investigator is designed. The benefits of this database are a removed dependency on staff paper records for experimental information and a streamlined data workflow for systems integration infrastructure. The investigator-centric data model will include experimental metadata, imaging modality parameters, study dates, study status, file locations or URL's, and findings when structured reports are available, whereby covering the entire small animal imaging workflow. Second, an XML reporting protocol will be presented as a means to normalize these database fields into a single file format that can be transmitted and utilized to populate the investigator-centric database.

7628-24, Session 5

ePR for data grid breast imaging: design and specifications

J. R. Documet, B. J. Liu, The Univ. of Southern California (United States)

The utilization of breast MRI is increasing in the diagnostic evaluation of suspicious breast findings. As more imaging centers implement dedicated breast MR, the need for managing data on a large scale, nationally and even some times internationally, has become more apparent. Our design proposal is to utilize the data grid for managing the storage of the medical images and an ePR that provides the interface to manage the health data of Breast Cancer Patients. The ePR for Data Grid Breast Imaging provides a large-scale database infrastructure for future data mining and research.

7628-25, Session 5

Pitfalls in radiology informatics when deploying a enterprise solution

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In the VGR, Sweden. Sharing of data from 4 PACS system have been done through the Radiology Information Infrastructure that where deployed in 2007, and during 2008 and 2009 also including the information obtained from 3 different RIS systems installed in the region.

Interoperability was developed according to the IHE mission, i.e. applying standards such as digital imaging and communication in medicine (DICOM) and Health Level 7 (HL7) to address spe¬cific clinical communication needs and support optimal patient care. [4,5,6]

However using standards and information models are good for interoperability, but not enough for collaboration i.e. first and second opinion. The need for interaction leads to a common negotiated interface and in contrary with interoperability the approach will be a common defined semantic model.

Radiology informatics is the glue between the standards, information models and semantics used within radiology and their customers to share information.

The pitfalls in Radiology Informatics: SYNTAX, HARMONIZATION OF THE SYNTAX, LACK OF STANDARD SUPPORT.

This study concludes that to avoid pitfalls in the deployment of the Radiology Information infrastructure there is a need for information harmonization on top of using information models and standards, this harmonization within the semantic area is hard to complete before deployment, it must be seen as a harmonization over time, that will be user driven. The role for the Radiology Information Infrastructure is merely to display the lack of consistency that will occur when different systems and culture are sharing the same Information Infrastructure.

7628-26, Session 6

Transforming the radiological interpretation process: TRIP TM, Where are we now?

J. C. Honeyman-Buck, Society for Imaging Informatics in Medicine (United States)

Transforming the Radiological Interpretation Process - TRIP TM has been an active initiative of the Society for Imaging Informatics in Medicine - SIIM for seven years. Initially defined to encourage research, education, and discovery of innovative solutions for the problem of information and image overload, much work has been accomplished. The focus of the initiative was to find ways to improve the efficiency of handling large data sets, to improve communication of results and to reduce medical errors. This presentation is a review of the goals of the initiative, what has been accomplished, and what work is still needed. The author reviewed peer reviewed literature as well as commercial solutions to evaluate progress and adoption of available solutions. A gap analysis was performed between the requirements and solutions which suggests needed directions for researchers, developers, and manufacturers to meet the needs of radiologists who are faced with ever increasing numbers of images, increasing work loads, and often difficult communication paths for reporting results to the appropriate caregiver.

7628-27, Session 6

Analyzing how radiologists recommend follow-up: towards development of an automated tracking and feedback system for clinical, laboratory and radiologic studies

T. S. Cook, J. N. Itri, W. Boon, The Univ. of Pennsylvania Health System (United States); W. Kim, Hosptial of the Univ. of Pennsylvania (United States)

Radiologists often recommend further imaging, laboratory or clinical follow-up as part of a study interpretation, but rarely receive feedback as to the results of these additional tests. In most cases, the radiologist has to actively seek this information by searching through the multiple electronic medical records at our institution. In this work, we seek to determine if it would be possible to automate the feedback process by analyzing how radiologists phrase recommendations for clinical, laboratory or radiologic follow-up. We surveyed a dozen attending radiologists to create a set of phrases conventionally used to indicate the need for follow-up. Next, we mined dictated reports over a 1-year period to quantify the appearance of each of these phrases. We are able to isolate 5 phrases that appear in over 21,000 studies performed during the 1-year period, and classify them by modality. By automatically mining imaging reports for these key phrases and tracking these patients' electronic medical records for additional imaging or pathology, we can begin to provide radiologists with automated feedback regarding studies they have interpreted. Furthermore, we can analyze how often these recommendations lead to a definitive diagnosis and enable radiologists to adjust their practice and decision-making accordingly and ultimately improve patient care.

7628-28, Session 6

Minerva: using a software program to improve resident performance during independent call

J. N. Itri, R. O. Redfern, T. S. Cook, M. H. Scanlon, The Univ. of Pennsylvania Health System (United States)

We have developed an application called Minerva that allows tracking of resident discrepancy rates and missed cases. Minerva mines the radiology information system (RIS) for preliminary interpretations provided by residents during independent call and copies both the

preliminary and final interpretations to a database. Both versions are displayed for direct comparison by Minerva and classified as 'in agreement', 'minor discrepancy' or 'major discrepancy' by the resident program director. Minerva compiles statistics comparing minor, major and total discrepancy rates for individual residents relative to the overall group. Discrepant cases are categorized according to date, modality and body part and reviewed for trends in missed cases.

The rate of minor, major and total discrepancies for residents on-call at our institution was similar to rates previously published, including a 2.4% major discrepancy rate for second year radiology residents in the DePICTORS study and a 2.6% major discrepancy rate for resident at a community hospital. Trend analysis of missed cases was used to generate a topic-specific resident missed case conference on acromioclavicular (AC) joint separation injuries, which resulted in a 75% decrease in the number of missed cases related to AC separation subsequent to the conference.

Using a software program to track of minor and major discrepancy rates for residents taking independent call using modified RadPeer scoring guidelines provides a competency-based metric to determine resident performance. Topic-specific conferences using the cases identified by Minerva can result in a decrease in missed cases.

7628-29, Session 6

A zero-footprint 3D visualization system utilizing mobile display technology for timely evaluation of stroke patients

B. J. Liu, M. Law, K. Wang, J. Lee, G. Whang, The Univ. of Southern California (United States)

When a patient is accepted in the emergency room suspected of stroke, time is of the utmost importance. The infarct brain area suffers irreparable damage as soon as three hours after the onset of stroke symptoms. A CT scan is one of the standard first line of investigation with imaging and is crucial to identify and properly triage stroke cases. The availability of an expert Radiologist in the emergency environment to diagnose the stroke patient in a timely manner only increases the challenges within the clinical workflow. Therefore, a truly zero-footprint web-based system with powerful advanced visualization tools for volumetric imaging including 2D. MIP/MPR, 3D display can greatly facilitate this dynamic clinical workflow for stroke patients. Together with mobile technology, the proper visualization tools can be delivered at the point of decision anywhere and anytime. We will present a small pilot project to evaluate the use of mobile technologies using devices such as iPhones in evaluating stroke patients. The results of the evaluation as well as any challenges in setting up the system will also be discussed.

7628-30, Session 6

Parallel image registration with a thin-client interface

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Despite its high significance, the clinical utilization of image registration remains limited because of its lengthy execution time and a lack of easy access. The focus of this work is twofold. First, we accelerate our course-to-fine, volume subdivision-based image registration algorithm by a novel parallel implementation that maintains the accuracy of our uniprocessor implementation. Second, we develop a thin-client computing model with a user-friendly interface to perform rigid and nonrigid image registration. Our novel parallel computing model uses Message Passing Interface (MPI) on a 32-core cluster. The results show that, compared with the uniprocessor implementation, the parallel implementation of our image registration algorithm is 18 times faster for rigid image registration and 13 times faster for nonrigid registration for the images used. To test the viability of such systems for clinical use, we developed a thin-client in the form of a plug-in in OsiriX, a well known open source PACS workstation and DICOM viewer, and used

it for two applications. The first application registered the baseline and follow-up MR brain images, whose subtraction was used to track progression of multiple sclerosis. The second application registered preprocedural PET and intraprocedural CT of radiofrequency ablation patients to demonstrate a new capability of multimodality imaging guidance. The registration acceleration coupled with the remote implementation using a thin-client should ultimately increase accuracy, speed and access of image registration-based interpretations in a number of diagnostic and interventional applications.

7628-31, Session 6

Performance evaluation for volumetric segmentation of multiple sclerosis lesions using MATLAB and computing engine in the graphical processing unit (GPU)

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Multiple Sclerosis (MS) is a progressive neurological disease affecting myelin pathways in the brain. Multiple lesions in the white matter can cause paralysis and severe motor disabilities of the affected patient. Currently, MRI assessment of multiple sclerosis requires manual lesion measurement and yields an estimate of lesion volume and change that is highly variable and user-dependent. Moreover, the quantitative reproducibility through human observers is poor. Augmenting computer aided detection (CAD) with imaging informatics methods, a 3-D CAD MS package would facilitate the physician's timely diagnosis, improve accuracy, and assess quantitatively the progress of drug therapy treatment. Despite the highly optimized algorithm of imaging processing that is used in CAD development, MS CAD integration and evaluation in clinical workflow is technically challenging due to the requirement of high computation rates and memory bandwidth. In this paper, we present the development and evaluation of using a computing engine in the graphical processing unit with MATLAB for segmentation of MS lesions. The success of this study allows MS CAD to rapidly integrate in an electronic patient record or any disease-centric health care system.

7629-01, Session 1

Automated 3D whole-breast ultrasound imaging, a novel technology using 3D spatial compounding of ultrasound volumes: results of a clinical pilot study

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We present first clinical results of a novel, fully automated 3D breast ultrasound system. The objective of this study was to investigate (1) the clinical feasibility of automated (operator-independent) whole-breast ultrasound and (2) the added value of combining ultrasound imaging with diffuse optical tomography (DOT). Co-registration of structural information from ultrasound can help the reconstruction and interpretation of functional images such as DOT.

A prototype ultrasound scanner has been developed with three 3D transducers in a cup. The shape of the cup matches the Philips Diffuse Optical Mammography system to enable straightforward co-registration of optical and ultrasound images. During a measurement each transducer scans the breast at 4 different views. The resulting 12 volumes are registered into a single volume using spatial compounding.

A pilot study with 23 patients was performed at Leiden University Medical Center. For comparison, breasts of patients were imaged with both conventional ultrasound and automated 3D ultrasound. Lesion visibility was assessed for both imaging modalities in collaboration with an ultrasound radiologist. Also, 4 volunteers were scanned with both the ultrasound prototype and the Philips Diffuse Optical Mammography system.

Automated 3D whole-breast ultrasound images have been obtained. Breast shape could be visualized in these images, suggesting that ultrasound could support the reconstruction and interpretation of DOT images. Individual benign and malignant masses could be identified from the 3D images, however lesion visibility is less compared to conventional breast ultrasound.

7629-02, Session 1

Reconstruction error in 3D ultrasound imaging with mechanical probes

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Three-dimensional (3D) ultrasound data are acquired mostly using a dedicated 3D mechanical probe that houses a 1D convex array transducer and swivels it back and forth in the elevation direction (continuous scanning) for faster acquisition. When 3D ultrasound data are acquired via continuous scanning but the continuous motion of a transducer is not taken into account during reconstruction, the reconstructed volume contains error. This reconstruction error has not been systematically analyzed before, and it is often overlooked. In this paper, we have carefully analyzed this error. This error is a complex function of many scan parameters. Also, it varies depending on the location in an acquired volume. Once the volume is defined, the error at each voxel location increases when the transducer angular speed increases. The mean error is calculated by averaging the errors for all voxel locations. With the volume angle of 60 degrees, the sector angle of 60 degrees, the scan depth (D) of 12 cm and the number of scanlines per slice of 96, for example, the mean error is 18.4 mm when the transducer angular speed of 0.6 degrees/ms is used for a volume rate of 10 volumes/s. When we lower the transducer angular speed to 0.06 degrees/ms for a volume rate of 1 volume/s while maintaining all other scan parameters, the mean error decreases to 1.4 mm. Also, we have assessed the impact of this error on reconstructed images via Field II simulations of a 3D phantom. We have found that the amount of this error could be significant and the resulting image quality can be degraded, especially at high volume rates.

7629-03, Session 1

3D motion and strain estimation of the heart: initial clinical findings

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Introduction: The quantitative assessment of regional myocardial function remains an important goal in clinical cardiology. As such, Doppler Myocardial Imaging and derived techniques such as strain rate imaging have been introduced. In order to solve some of the pitfalls of this Doppler-based strain imaging technique, speckle tracking imaging has more recently become commercially available allowing measuring myocardial motion and deformation within the image plane. Recently, volumetric ultrasound has become more readily available. Our lab has previously presented a method based on spatio-temporal elastic registration of ultrasound volumes to estimate myocardial motion and deformation in 3D. This method was optimized on simulated data sets.

Aim: The aim of the study was to test this methodology in a clinical setting by comparing its findings to those of a reference method.

Methods: 30 subjects were enrolled in this study: 10 normal volunteers (mean age 30y ±9.7), 10 patients with previous myocardial infarction (mean age 60y ±11.6) and 10 patients with arterial hypertension and moderate LVH (mean age 58y±14.0). Standard echocardiography was performed and gray scale (frame rate- 65±7 frames/s) and Myocardial Velocity Imaging (MVI, frame rate 190±10frames/s) data were acquired in the apical 4-chamber, 2 chamber and long axis view and in the parasternal short axis view at basal, middle and apical level. Moreover, full- volume data sets were recorded from the apical 4-chamber view, at frame rates of 20±4 Hz, by ECG gating over 5 to 7 cardiac cycles during a single breath-hold. From the MVI data longitudinal strain (LL) was extracted using custom- made software (SPEQLE, KU Leuven) and a commercial speckle tracking tool (EchoPac, GE VingMed, Horten, Norway) was used to extract LL, CC, RR from the B-mode images. Finally, LL, CC, RR were also estimated from the volumetric data using the new 3D strain methodology. For all methods, strain curves were extracted in an 18 segments model of the left ventricle and expressed as percentage. For all strain components differences between the groups were tested using one- way ANOVA.

Results: For the global 3D strain values in the normal group we found: LL=-16.33±1.65; CC=-16.62±1.52; RR = 47.02 ±13.36. Significant differences were found using the 3D strain methodology between the normals and the infarct patients for all strain components. Moreover, intermediate values were found for LL and RR using this methodology. Although the absolute values between the methods did not match, the relative LL differences between the three groups were similar to the 1D reference method. Also, the 2D strain methodology showed a similar pattern although differences between groups did not always reach statistical significance.

Conclusion: Although the absolute values of the 3D strain components as assessed by this new methodology were not identical to the reference methods, the relationship between different patient groups was similar. A single volumetric acquisition could however be used to extract all strain components.

7629-04, Session 1

Registration of x-ray mammograms and three-dimensional speed of sound images of the female breast

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Breast cancer is the most common type of cancer for women in Europe and North America. The established screening method to detect breast cancer in an early stage is X-ray mammography, though X-ray has often low contrast for tumors located within glandular tissue. A new imaging approach is Ultrasound Tomography generating three-dimensional speed of sound images.

This paper describes a method to evaluate the clinical applicability of three-dimensional speed of sound images by automatically registering the images with the corresponding X-ray mammograms. The challenge is that X-ray mammograms show two-dimensional projections of a deformed breast whereas speed of sound images render a three-dimensional undeformed breast in prone position. This conflict requires estimating the relation between deformed and undeformed breast and applying the deformation to the three-dimensional speed of sound image. The deformation is simulated based on a biomechanical model using the finite element method. After simulation of the compression, the contours of the X-ray mammogram and the projected speed of sound image overlap congruently.

The quality of the matching process was evaluated by measuring the overlap of a lesion marked in both modalities. Using four test datasets, the evaluation of the registration resulted in an average tumor overlap of 97%. The developed registration provides a basis for systematic evaluation of the new modality of three-dimensional speed of sound images, e.g. allows a greater understanding of tumor depiction in these new images.

7629-05, Session 1

Breast imaging with ultrasound tomography: a comparative study with MRI

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Magnetic resonance imaging (MRI) is now recognized as the most accurate means for determining tumor involvement in breast tissue. However, this imaging modality is extremely expensive to operate, requires a specialized staff, and can be uncomfortable for the patient. A method that provides similar imaging performance but at lower cost would therefore be an attractive alternative for breast imaging.

A novel method, based on the principles of ultrasound tomography (UST), was used to generate in-vivo patient data and reconstruct images of the breast. This paper reports on a study that compares images taken with the UST method and MRI.

The data were collected at the Karmanos Cancer Institute in Detroit MI from patients recruited at our breast center. Tomographic sets of images were constructed from the data and used to form 3-D image stacks corresponding to the volume of the breast. From qualitative and quantitative assessments of both sets of images, we show that UST and MRI images show strikingly similar representations of a patient's breast anatomy. Our preliminary study shows a generally high degree of correlation between the MR images and those obtained with UST. Small differences in visualization of breast anatomy can be accounted for by differences in voxel characteristics and the fact that the breast positioning differs slightly between the UST and MRI exams.

7629-06, Session 2

A 1D wavelet filtering for ultrasound images despeckling

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Ultrasound images appearance is characterized by speckle, shadows, signal dropout and low contrast which make them really difficult to process and leads to a very poor signal to noise ratio. Therefore, for main imaging applications, a denoising step is necessary to apply successfully medical imaging algorithms on such images.

However, due to speckle statistics, denoising and enhancing edges on these images without inducing additional blurring is a real challenging problem on which usual filters often fail. To deal with such problems, a large number of papers are working on B mode images considering that the noise is purely multiplicative. Making such an assertion could be misleading, because of internal pre-processing such as log compression which are done in the ultrasound device. To address those questions, we designed a novel filtering method based on 1D Radiofrequency signal. Indeed, since B mode images are initially composed of 1D signals and since the log compression made by ultrasound devices modifies noise statistics, we decided to filter directly the 1D Radiofrequency signal envelope before log compression and image reconstitution, in order to conserve as much information as possible. A bi-orthogonal wavelet transform is applied to the log transform of each signal and an adaptative 1D split and merge like algorithm is used to denoise wavelet coefficients. Experiments were carried out on synthetic data sets simulated with Field II simulator and results show that our filter outperforms classical speckle filtering methods like Lee, non-linear means or SRAD filters.

7629-07, Session 2

Advanced noise reduction in placental ultrasound imaging using CPU and GPU: a comparative study

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This paper presents our results on comparing different implementations of the 3D anisotropic diffusion speckle noise reduction technique on ultrasound images. In our project we are developing a novel volumetric calcification assessment metric for the placenta, and providing a software tool for this purpose including automatic segmentation and 3D visualization. As a basis of these processing steps we need a fast and efficient way to eliminate speckle noise from our data sets.

Previous works on this topic by Duan, Q (Duan, Angelini et al. 2004) and Sun, Q. (Sun, Hossack et al. 2004) are proved that the 3D anisotropic noise reduction (3D SRAD) method shows exceptional performance in enhancing ultrasound images for object segmentation. Therefore we implemented this method in our software application and did a comparative study on the different variants in terms of performance and computation time. In order to increase processing speed we needed to utilize the full potential of today's cutting edge GPUs.

Our 3D data sets are represented in a spherical volume format. In the aim of 2D slice visualization and segmentation it is needed to do a "scan conversion" or "slice-reconstruction" step, which includes coordinate transformation from spherical to Cartesian, re-sampling of the volume and an interpolation.

Combining the noise filtering and slice reconstruction in one process on the GPU, we have achieved close to real-time operation on high quality data sets without the need of down-sampling or reducing image quality. For the GPU programming we used OpenGL shading language so our solution is fully portable.

7629-08, Session 2

Automatic detection and measurement of femur length from fetal ultrasonography

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Femur bone length is used in the clinical assessment of fetal growth, development and in the prediction of gestational age (GA). In this paper, we present a completely automated two-step method for identifying femur and measuring fetal femur length from 2-D ultrasound images. The detection algorithm is premised on the distribution of anatomical shape and presentation of the femur bone in typical fetal femur scans and their sizes across the gestational trimesters. The femur is automatically detected from a 2-D ultrasound image using a normalized score that accounts for the cumulative sum of all these factors. Once the femur is localized, the measurement process utilizes a polynomial curve fitting technique to determine the end-points of the bone from a 1-D profile that is most distal from the transducer surface. The method has been tested with manual measurements made on 35 third trimester femur images by two clinical experts. The measurements made by the experts are strongly correlated (Pearson's coefficient = 0.96). Likewise, the algorithm estimate is strongly correlated with expert measurements (Pearson's coefficient = 0.96 and 0.93). Based on fetal age estimates and their bounds specified in Standard OB Tables, the GA predictions from automated measurements are found to be within ±1SD of GA estimates from both manual measurements in 30/35 cases, within ±2SD in 34/35 cases and within ±3SD in all 35 cases. The method presented in this paper can be adapted to perform automatic measurement of other fetal limbs.

7629-09, Session 2

Trajectory-based deformation correction in ultrasound images

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In ultrasound imaging, tissue deformation due to contact between skin surface and the probe is a unique feature and poses a challenge to the development of many image reconstruction techniques, such as multimodal image fusion and registration, quantitative anatomy, multi-angle compound image, and image-guided surgery. Although deformation correction methods are often desired to provide undeformed images of tissue structure, they have not been well-studied. In this paper, a novel trajectory-based method to correct deformation in ultrasound images was described. In order to characterize the deformation of tissue under different contact forces, a force sensor was installed in a novel robotic ultrasound imaging system to provide contact force measurement. Optical flow methods were used for displacement estimation between B-mode images under different contact forces. Combining these sets of information, a trajectory field was built for the specific subject under an ultrasound scan, where pixel coordinates in the scan plane were plotted against each value of applied force. Extrapolation algorithms were then applied on each trajectory to relocate the corresponding pixels to where they would have been had there been no contact, thereby correcting the deformed appearance of tissue in the B-mode images. This method was verified by using finite-element analysis (FEA) and ultrasound simulation, and it was shown that this method can improve compound image quality. Contrast of the compound B-mode image was improved, and the boundaries between different materials were more discernible. More simulation and in vitro experiments are to be performed and are expected to provide further verification for this method.

7629-10, Session 2

Real-time ultrasound simulation for low cost training simulators

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Medical ultrasound is widely used for diagnostic purposes, navigation in minimally invasive procedures and for other therapeutic procedures. Extensive and repeated training is needed for efficient use of the technology. Simulator training has been proposed as a complement to other training methods. Advantages of simulator training include access to a large number of normal and rare cases without the need for suitable volunteers and available ultrasound equipment. Real-time ultrasound simulators which use computed tomography (CT) recordings to model the patient anatomy have been developed. The image simulation for real-time simulators generally lacks the accuracy of the relatively slow ultrasound simulators based on physical principles. A way to include physical accuracy for the real-time simulator is to pre-simulate a three-dimensional (3D) volume off-line for real-time cross-sectioning. This approach, however, does not take into account the direction dependent resolution of ultrasound imaging. We propose a method for real-time simulation of medical ultrasound imaging for use in CT-based ultrasound simulators on low cost platforms. The method consists in multiplying a pre-simulated speckle image by an any-plane cross section of a reconstructed CT image volume in real time. The proposed method requires less computer memory and better reproduces the difference between lateral and radial resolution than does cross-sectioning a 3D ultrasound volume. We show that the method is satisfactory for still images, and well applicable to ultrasound simulators for which the correlation of the speckle pattern between views is not important.

7629-11, Session 2

Ultrasound image quality assessment: a framework for evaluation of clinical image quality

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Improvement of ultrasound imaging should be guided by their diagnostic value. Evaluations of clinical image quality is generally performed subjectively, because objective criteria have not yet been fully developed and accepted for the evaluation of clinical image quality. Based on recommendation 500 from (ITU-R) for such subjective quality assessment, this work presents equipment and a methodology for clinical image quality evaluation for guiding the development of new and improved imaging. The system is based on a BK-Medical 2202 ProFocus scanner equipped with a UA2227 research interface, connected to a PC through X64-CL Express camera link. Data acquisition features subject data recording, loading / saving of exact scanner settings for later experiment reproducibility, free access to all system parameters for beamformation and is certified for clinical use, enabling the ability to perform assessment on a large data set, regardless of recording site. The free access to all system parameters enables the ability to capture standardized images as found in the clinic and experimental data from new processing or beamformation methods. The length of the data sequences is only restricted by the memory of the external PC. Data may be captured interleaved, switching between multiple setups, to maintain identical transducer, scanner, region of interest and recording time on both the experimental- and standardized images. Data storage is approximately 15.1 seconds pr. 3 sec sequence including complete scanner settings and patient information, which is fast enough to get sufficient number of scans under realistic operating conditions, so statistical evaluation is valid and reliable.

7629-12, Session 3

Accurate step-FMCW ultrasound ranging and comparison with pulse-echo signaling methods

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This paper presents a method and experimental setup for high-frequency ultrasound ranging based on stepped frequency-modulated continuous waves (FMCW), capable of producing a higher signal-to-noise ratio (SNR) compared to traditional pulse-echo signaling. In current ultrasound systems, the use of higher frequencies (10-20 MHz) to enhance resolution lowers SNR due to frequency-dependent attenuation. The proposed ultrasound signaling format, step-FMCW, is well-known in the radar community, and features lower peak power, wider dynamic range, lower noise figure and simpler electronics in comparison to pulse-echo systems.

In pulse-echo ultrasound ranging, distances are calculated using the transit times between a pulse and its subsequent echoes. In step-FMCW ultrasonic ranging, the phase and magnitude differences at stepped frequencies are used to sample the frequency domain. Thus, by taking the inverse Fourier transform, a comprehensive range profile is recovered that has increased immunity to noise over conventional ranging methods. This results in a higher received signal-to-noise ratio, and thus an increase in accuracy.

Step-FMCW and pulse-echo waveforms were created using custom-built hardware consisting of an arbitrary waveform generator and dual-channel super heterodyne receiver, providing high resolution in signal quality and high accuracy in detection. The measurement setup included single-element ultrasound transducers and soft-tissue phantoms. The custom ultrasound transceiver was designed and built due to the system requirements of high frequency-of-operation, flexibility of signaling methods, low-cost, portability, and adaptability to different transducers with varying characteristics.

7629-13, Session 3

Optoacoustic spectroscopic imaging of radiolucent foreign bodies

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One of the leading causes of medical malpractice claims in emergency medicine is the misdiagnosis of the presence of foreign bodies. Radiolucent foreign bodies are especially difficult to differentiate from surrounding soft tissue, gas, and bone. Current imaging modalities employed for the detection of foreign bodies include: X-ray computed tomography, magnetic resonance, and ultrasound; however, there is no consensus as to which modality is optimal for diagnosis. Because many radiolucent foreign bodies have sufficient contrast for imaging in the optical domain, we are exploring the use of laser-induced optoacoustic imaging for the detection of foreign bodies, especially in craniofacial injuries, in which the foreign bodies are likely to lie within the penetration depth of visible and near infrared wavelengths. Tissue-simulating phantoms containing various common foreign bodies have been constructed. Images of these phantoms have been successfully generated using two laser-based optoacoustic imaging methods with different detection modalities. In order to enhance the image contrast, common foreign bodies are being scanned over a wide range of wavelengths to obtain the spectroscopic properties of the materials commonly associated with these foreign bodies. This spectroscopic characterization will help select specific wavelengths to be used for imaging specific objects and provide useful diagnostic data about the material properties of the object.

7629-14, Session 3

Tomographic reconstruction of the pulse-echo spatial impulse response

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Virtually every area of ultrasonic imaging research requires accurate estimation of the spatiotemporal impulse response function. The impulse response is difficult to predict accurately using numerical techniques because small unknown perturbations in array properties generate significant changes in the pulse-echo field pattern. Experimental estimation employs echoes recorded from a line scatterer oriented perpendicular to the scan plane. The echo time series from line scatterers positioned throughout the field of view describe shift variance of the line response. We propose a technique that reconstructs point spread functions from line-scatterer echoes treated as projections. At range z0 along the beam axis, a line scatterer is rotated in the xy-plane to record echo time series g(t, x',Θ) along the array axis (x') and at line-scatterer angle (Θ). For each echo time t, x' axis is rescaled as a function of Θ and the echoes are back-projected and filtered. Reconstructing data in this manner gives the impulse response at range z0. By fixing x,y we obtain the point spread function for the spatial location, and by fixing t we obtain the spatial sensitivity function, which maps the spatial distribution of the pulse-echo field at time t. The paper shows how to make these measurements and gives examples from two commercial systems (Siemens Antares and Ultrasonix Sonix-RP). Using Field II predictions to model experiments, we found reconstruction accuracy within 5% rms error for 30 dB echo SNR. Impulse response measurement accuracy is greatly improved using filtered back-projection methods.

7629-15, Session 3

Assessment of harmonic source correction for ultrasound medical imaging

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We hypothesize that the first harmonic can be used as an operator specifiable active point source for wavefront correction to improve ultrasound image quality. Ultrasound medical images consist of a mixture of point targets, specular targets, and speckle targets; the feasibility of a wavefront correction scheme based on the first harmonic is demonstrated for these three target types. Electronic aberrators were applied to transmit and receive apertures with focusing errors following uniform random distributions ranging in magnitude from 0 to $2\pi/3$, π, $4\pi/3$, $5\pi/3$, and 2π radians at 4.17 MHz. The peak amplitude of beamplots measured in a water tank showed a decrease of 4, 7, 13, 23, and 43 dB respectively from the unaberrated beam. A physical aberrator molded from RTV with RMS error of 0.22π rad at 4.17 MHz was also studied. A 2.08 MHz fundamental beam which generated harmonics was focused at three types of targets: a point reflector (hydrophone tip), a specular reflector (sheet of Lucite), and a speckle target (phantom with large number of sub-resolution scatterers). A bandpass filter extracted the 4.16 MHz 1st harmonic from the received signal. A multi-lag least-means-squares cross-correlation method determined the corrective delays for each aberrator. Corrections were applied in transmit and receive to the desired 4.17 MHz imaging beam. Peak levels of the electronically aberrated imaging beam with correction applied improved by at least 85% for the point target, 70% for the specular target, 20% for the speckle target, and 47% for the RTV aberrator.

7629-16, Session 3

Detection of multiple electrical sources in tissue using ultrasound current source density imaging

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Three dimensional mapping of bioelectric sources in the body with high spatial resolution is important for diagnosing and treating a variety of cardiac and neurological disorders. Ultrasound current source density imaging (UCSDI) is a new technique that maps electrical current flow in tissue. UCSDI is based on the acoustoelectric (AE) effect, an interaction between electrical current and acoustic pressure waves propagating through a conducting material and has distinct advantages over conventional electrophysiology (i.e., without ultrasound).

In this study, UCSDI was used to simultaneously image current flow induced in two nerve phantoms positioned at different depths. Simulation software based on the AE effect was developed in Matlab to complement the experimental model and further characterize the relationship between the ultrasound beam and electrical properties of the tissue. Both experimental and simulated images depended on the magnitude and direction of the current, as well as the geometry (shape and thickness) and location of the current sources in the ultrasound field. The AE signal was proportional to pressure and current with detection levels on the order of 1 mA/cm2 at 258 kPa.

We have detected simultaneously two separate current sources in nerve phantoms using UCSDI. These results are consistent with simulations consisting of multiple current sources. Real-time 3-D UCSD images of current flow co-registered with anatomical (pulse echo) ultrasound potentially facilitates corrective procedures for cardiac and neural abnormalities.

7629-17, Session 4

On sound speed estimation using wave-based ultrasound tomography

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We present results obtained using a time domain wave-based reconstruction algorithm for an ultrasound transmission tomography scanner with a circular geometry. A comprehensive description of this type of algorithm has been given elsewhere. The focus of this work is on the practical issues related to the wave-based approach. A wave-based approach models more accurately the propagation of ultrasound in an inhomogeneous medium. It thus allows to improve the spatial resolution of the image compared to a ray-based method. However, it suffers from two major drawbacks which limit its application in a practical setting: convergence is difficult to obtain and the method is computationally prohibitive.

We address the first problem by appropriate initialization using a ray-based reconstruction. Then, the complexity of the method is reduced by means of an efficient parallel implementation using graphical processing units. The details of the implementation are briefly outlined. This manuscript is reproducible, meaning that all the results presented here can be reproduced using the code and data that will be made available online.

7629-18, Session 4

Robust ultrasound travel-time tomography using the bent-ray model

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We present a bent ray reconstruction algorithm for an ultrasound tomography (UT) scanner designed for breast screening. The scanner consists of a circular array of transmitters and receivers which encloses the object to be imaged. By solving a non-linear system of equations, the reconstruction algorithm estimates the sound speed of the object using the set of travel time measurements. The main difficulty in this inverse problem is to ensure the convergence and robustness to noise. In this paper, we propose a gradient method to find a solution for which the corresponding travel times are closest to the measured travel times in the least squares sense. To this end, first the gradient of the cost function is derived using the Fermat's Principle. Then, the iterative non-linear conjugate gradient algorithm solves the minimization problem. This is combined with the backtracking line search method to efficiently find the step size in each iteration. This approach is guaranteed to converge to a local minimum of the cost function where the convergence point depends on the initial guess. Moreover, the method has the potential to easily incorporate regularity constraints such as sparsity as a priori information on the model. The method is tested both numerically and using in vivo data obtained from the UT scanner. The results confirm the stability and robustness of our approach for the breast screening application.

7629-19, Session 4

Inverse scattering and refraction corrected reflection for breast cancer imaging

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Reflection ultrasound has been utilized as an adjunct imaging modality for over 30 years. TechniScan, Inc. has developed unique, transmission and concomitant reflection algorithms which are used to reconstruct images from data gathered during a breast scanning process called Warm Bath Ultrasound (WBU). The transmission algorithm yields high resolution, 3-D, attenuation and speed of sound (SOS) images. The reflection algorithm is based on canonical ray tracing utilizing refraction correction via the SOS and attenuation reconstructions. The refraction correction reflection algorithm allows 360 degree compounding resulting in the reflection image. The requisite data are collected when scanning the entire breast in a 33o C water bath on average in 8 minutes. This presentation explains how the data are collected and processed by the 3-D transmission and reflection imaging mode algorithms. The processing is carried out using two NVIDIA® Tesla GPU processors and an Intel® Quad processor, accessing data on a 4-TeraByte RAID. The WBU images are displayed in a DICOM viewer that allows registration of all three modalities. Several representative cases are presented to demonstrate potential diagnostic capability including: a cyst, fibroadenoma, carcinoma, and a dense, normal breast. WBU images (SOS, attenuation, and reflection modalities) are shown along with their respective mammograms and standard ultrasound images. In addition, anatomical studies are shown comparing WBU images and MRI images of a cadaver breast. This innovative technology is designed to provide additional tools in the armamentarium for diagnosis of breast disease.

7629-20, Session 4

The different structural scales of the breast and their impact on time-of-flight and diffraction tomography

P. Huthwaite, F. Simonetti, Imperial College London (United Kingdom); L. Huang, Los Alamos National Lab. (United States)

Ultrasound tomography (UST) has been considered for the early detection of breast cancer since the 1970s. Central to its effectiveness

are the algorithms used to display maps of material properties such as the speed of sound. Most studies have been based on Time-of-Flight Tomography (TFT) that employs the ray approximation of X-ray CT, which is satisfactory when the size of the characteristics to be reconstructed is much larger than the wavelength, l, of the probing wave. However, to achieve full breast penetration, UST prototypes employ low frequencies in the region of 2 MHz (l=0.75 mm). Therefore, TFT is not suitable for reliably imaging features that are less than 5 l as image artifacts may arise from diffraction effects. The resolution of TFT is dependent on both l and the distance between sensors, D, which for a typical UST setup lead to a minimum resolvable distance, sqrt(lD), that is not sufficient to detect small masses. In contrast, Diffraction Tomography (DT), is suitable for imaging features that are in the order of l and can achieve a resolution of l /2 but fails to reconstruct larger objects. While TFT can image the global anatomy, DT can be adapted to look at the finer structures leading to the concept of Multiscale Diffraction Tomography (MSDT). This paper explores MSDT by studying the interplay between different geometrical scales and material contrast. The aim is to assess the range of validity of TFT and MSDT as well as exploring the possibility of integrating MSDT with TFT.

7629-21, Session 4

In-vivo imaging results with ultrasound tomography: report on an ongoing study at the Karmanos Cancer Institute

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Our laboratory has focused on the development of UST for breast imaging. To that end we have been developing and testing a clinical prototype in the Karmanos Cancer Institute's (KCI) breast center. The development of our prototype has been guided by clinical feedback from data accumulated from over 300 patients recruited over the last 4 years. Our techniques generate whole breast reflection images as well as images of the acoustic parameters of sound speed and attenuation. The combination of these images reveals major breast anatomy, including fat, parenchyma, fibrous stroma and masses. Fusion imaging, utilizing thresholding, is shown to visualize mass characterization and facilitates separation of cancer from benign masses. These initial results indicate that operator-independent whole-breast imaging and the detection and characterization of cancerous breast masses are feasible using acoustic tomography techniques.

Analyses of the prototype images suggests that we can detect the variety of mass attributes noted by cur¬rent ultrasound-BIRADS criteria, such as mass shape, acoustic mass properties and architecture of the tumor environment. These attributes help quantify current BIRADS criteria (e.g. "shadowing" or high attenuation) and provide greater possibilities for defining a unique signature of cancer. The potential for UST to detect and characterize breast masses was quantified using an ROC analysis of UST measurements from the most recent cohort of patients imaged with the latest version of our prototype. Our preliminary results suggest that the development of a formal predictive model, in support of larger future trials, is warranted.

7629-22, Session 4

Volumetric, quantitative ultrasound measurements of the breast: the role of sound speed in assessing breast cancer risk

L. Myc, N. Duric, P. J. Littrup, Karmanos Cancer Institute (United States)

It has now been firmly established, through a number of studies, that variations among women in breast tissue composition, as reflected in the radiological appearance of the breast, are strongly associated with differences in breast cancer risk. Mammographic density (MD), in particular, has been shown to be associated with breast cancer risk. However, the performance of MD in individual prediction is modest. Improved risk prediction would positively influence risk assessment

and approaches to breast cancer prevention.

We report on studies carried out at the Karmanos Cancer Institute, Michigan, with an experimental prototype capable of quantitative ultrasound measurements of the entire breast volume. In contrast to mammography, this method is quantitative, volumetric, free of radiation, is not operator dependant, involves no compression of the breast, and the examination time is short (1 minute per subject). Initial studies have shown a strong but non-linear correlation between measured sound speed in breast tissue and MD. We present updated results based on measurements of 200 patients.

In a separate study we have compared the average sound speed of the breast with percent parenchyma, as measured by MRI. In a sample of 20 patients we found a very strong linear correlation (R > 0.9), consistent with the hypothesis that volumetric measurements of breast density have the potential to be more accurate compared to 2-D approaches for assessing breast cancer risk. An increase in accuracy is expected to have an impact on both clinical and research applications. Risk prediction in individuals would likely improve substantially.

7629-23, Session 5

Fabrication and characterization of an indium tin oxide acoustoelectric hydrophone

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Clinical ultrasound (US) techniques for imaging and therapy require a precise knowledge of the intensity distribution of the ultrasound field. Piezoelectric hydrophones are currently the instrument of choice for mapping the US field, but these devices are both expensive and fragile. We have developed a new type of hydrophone based on the acoustoelectric (AE) effect. By Ohms law, this pressure induced change in electric resistivity produces a voltage proportional to electric current density. In this study a number of different hydrophone designs were created out of indium tin oxide (ITO) on either glass or Mylar substrates using photolithographic techniques. A constriction in the current path within the hydrophone is engineered to create a sensitivity zone of high current density where the AE voltage is greatest. In our devices this zone is 100 nm thick and 75 micron, 100 micron, or 100 microns square in the center of a 20 mm x 30 mm dumbbell or bow-tie design. To evaluate the designs we measured the pressure field of a 2.25 MHz single element transducer (focal length = 2.7 inches, f/# = 1.8) The performance was compared to a commercial needle hydrophone (Onda Inc.). The -6 dB focal spot sizes were 1.875 mm and 1.75 mm for the bow-tie and dumbbell hydrophones, respectively. This compares well with the commercial hydrophone measurement of 1.5 mm. The sensitivity was 2 nV/Pa.

Acoustoelectric hydrophones are potentially cheaper and more robust than the piezoelectric models currently in clinical use, while offering comparable performance.

7629-24, Session 5

Novel interconnection and fabrication method for high-frequency ultrasound arrays

E. A. Simpson, H. S. Lay, G. R. Lockwood, Queen's Univ. (Canada)

A 50 MHz, 32-element linear array has been developed that employs a newly-proposed interconnection scheme that simplifies the fabrication process. The fabricated array is a hybrid transducer structure incorporating both a piezoelectric substrate and a silicon substrate in the same device. The interconnection scheme consists of a set of 32 linear, Cr/Au electrodes with a width of 15 um and a pitch of 30 um (lambda-spacing at 50 MHz) patterned on the surface of the silicon

substrate using photolithography. Another set of Cr/Au electrodes was patterned on the surface of the piezoelectric layer, and the two layers were connected using an anisotropic conductive adhesive (ACA). The ACA used in this process was developed in-house and consists of spherical silver particles (0.5 to 1 um in diameter) uniformly distributed throughout an epoxy matrix. To avoid the several alignment restrictions that would result if the two electrode patterns were identical, a grid-pattern of square electrodes was substituted on the piezoelectric layer with a smaller diagonal dimension than the spaces between the silicon electrodes. In the fabricated linear array, the shorting of adjacent grid elements was avoided by using a piezoelectric grid electrode width of 8 um. A tungsten-loaded epoxy backing layer was added to the acoustic stack and an impedance plot was measured for a single array element. The impedance plot showed the expected resonance at 51 MHz.

7629-25, Session 5

Simulation-based optimization of the acoustoelectric hydrophone for mapping an ultrasound beam

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Most single element hydrophones depend on a piezoelectric material that converts pressure changes to electricity. These devices, however, are expensive, susceptible to damage at high pressure, and/or have limited bandwidth and sensitivity. The acoustoelectric (AE) hydrophone is based on the AE effect, an interaction between electrical current and acoustic pressure generated when acoustic waves travel through a conducting material. As we have demonstrated previously, an AE hydrophone requires only a conductive material and can be constructed out of common laboratory supplies to generate images of an ultrasound beam pattern consistent with more expensive hydrophones.

In this report we describe simulations aimed at optimizing the design of the AE hydrophone with experimental validation using new devices composed of a semi-conducting element of indium tin oxide. Several shapes (e.g., bowtie and dumbbell) and resistivities were considered. The AE hydrophone with a dumbbell configuration achieved the best beam pattern of a 2.25MHz ultrasound transducer with lateral and axial resolutions consistent with images generated from a commercial hydrophone (Onda Inc.). We hope that design optimization will lead to new devices for monitoring ultrasonic fields for biomedical applications, including lithotripsy and focused ultrasound surgery.

7629-26, Session 5

fabrication of a conformal, ring-annular ultrasound array

A. E. Dann, D. B. Bennett, Univ. of California, Los Angeles (United States); R. S. Singh, Univ. of California, Santa Barbara (United States); W. S. Grundfest, M. O. Culjat, Univ. of California, Los Angeles (United States)

This paper presents the fabrication of a conformal, ring-annular ultrasound imaging array. Two-dimensional (2-D) ultrasound scanning is possible with ring-annular array transducers in which a number of piezoelectric elements are arranged in a circle. The 2-D scanning technique can be realized through time delays, potentially allowing for 3-D imaging. Ring-annular array transducers have previously been shown to have increased bandwidth, better signal-to-noise, and uniform scanning in space in contrast to 2-D matrix arrays of an equal number elements and aperture size. Conformal, ring-annular transducers have the ability to match the curvature of body surfaces, and have the additional advantage that the flexible array elements can be mechanically focused to provide enhanced focusing capabilities relative to rigid ring-annular arrays.

The process developed for the fabrication of conformal, ring-annular ultrasound array is presented. A microfabrication approach is used

to produce ring-annular arrays featuring flexible joints with high durability, and capable of scaling in size and element architectures. The fabrication process yields a ring of piezoelectric transducer elements held together with polyimide, which is the basis of the flexible joints that enable conformal ultrasonography. The described fabrication process is used to produce a ring-annular array with a single ring containing piezoelectric elements, but the process can be extended to form arrays with multiple annular-rings of varying sizes. The transducer had a fundamental thickness-mode resonant frequency of 12 MHz, a 6 dB bandwidth of 30%, and an acoustic pulse width of 1.8 µs in water.

7629-27, Session 5

Method of testing multistatic image reconstruction algorithms using finite-element analysis software

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This paper presents the description and validation technique of a 2D image reconstruction algorithm designed for a multistatic ultrasound imaging system. New ultrasound imaging systems require comprehensive investigation of interplay between transducer configurations, data acquisition, and image formation techniques. Advancements in ultrasonic simulation software now permit accurate and detailed modeling of complex transducer designs, which reduce the cost, time, and uncertainty associated with the development process.

A multistatic pulse-echo algorithm has been designed to process multiple time-voltage profiles from various transducer array setups. However, further analysis of algorithm capability must address a wide range of transducer and wave propagation properties. This has been achieved using the finite-element time-domain piezoelectric simulation software suite, PZFlex (Weidlinger Associates, Los Altos, CA). Transducer arrays were constructed in the software environment to illuminate 2D regions, typically on the scale of several millimeters. These regions generally consisted of bony targets embedded in soft tissue. Linear, as well as circumferential arrays were examined to demonstrate the algorithm's potential for handling a wide range of transducer configurations.

Following transmission of a short pulse into the region by a single element, all elements were set to receive mode. In a complete multistatic signaling cycle, each element transmits exactly once. The time-domain voltage plots generated from each transmit-receive element pair were overlaid onto an image range bin matrix in MATLAB, forming the reconstructed image. Description of this imaging technique is included along with PZFlex simulation models and their associated reconstructions.

7629-28, Session 6

Validation platform for ultrasound-based monitoring of thermal ablation

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PURPOSE: A ground-truth validation platform was developed to provide spatial correlation between US, temperature measurements and histopathology images to validate US based thermal ablation monitoring methods. METHOD: The apparatus consists of a container box with integrated fiducial lines. The box is filled with gel, with the suspended tissue sample inside. Following US imaging, the gel block is sliced and pathology images are acquired. Interactive software segments the fiducials and structures of interest in the pathology and US images. The software reconstructs the regions in 3D space and performs analysis and comparison of the features identified from

pathology and ultrasound. RESULTS: The apparatus and software were constructed to meet technical requirements. Shapes were contoured, reconstructed and registered in the common coordinate system of fiducials. There was agreement between the shapes, but systematic shift of several millimeters was found between histopathology and US. This indicates that during pathology slicing shear forces tend to dislocate the fiducial lines. Softer fiducial lines and harder gel material can eliminate this problem. CONCLUSION: Viability of concept was presented. Despite our straightforward approach, further experimental work is required to optimize all materials and customize software.

7629-28, Session 6

The potential of focused ultrasound for brain treatments

K. H. Hynynen, Sunnybrook Health Sciences Ctr. (Canada)

Focused Ultrasound is a noninvasive method to deliver highly concentrated mechanical energy deep in the body and it has been explored for tissue ablation for over half a century. Safe clinical use requires that the focus is guided by an imaging method. Magnetic Resonance Imaging (MRI) provides such features as excellent soft tissue contrast, which make it well suited for the guidance of focused energy delivery.

Animal experiments have shown that focused ultrasound exposures can induce transient and local increase in the cell membrane or blood vessel wall permeability. This may allow localization of the treatment based on imaging information. This potential for delivering large molecules into an image defined location has especially high potential in the brain where the Blood-Brain barrier (BBB) prevents the diffusion of most therapeutic and imaging agents into the brain from the blood vessels. Focused ultrasound has now been explored by several research groups for the disruption the blood-brain barrier for targeted delivery of therapy agents. This method coupled with the development of phased array methods for focusing ultrasound exposures through intact skull may have significant potential in future clinical patient care.

In this talk the basic concepts of ultrasound induced BBB disruption will be reviewed. The animal experiments conducted so far for the utilization of the method for the treatment of brain will be summarized.

7629-29, Session 6

Development of an MRI-compatible focused-ultrasound system for the investigation of novel therapeutic applications in preclinical animal models

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MRI-guided focused-ultrasound therapy is being investigated as a non-invasive method to improve the delivery of therapeutic agents in the body. The goal of this work was to develop a focused-ultrasound system, for preclinical investigations, that is capable of operating within a closed-bore MRI. The system uses piezoelectric actuators and optical encoders to position a focused-ultrasound transducer to targeted tissues under MRI guidance. The actuator and encoder signals are transmitted through low-pass-filtered connectors on a grounded RF-penetration panel to prevent signals from the drive electronics from corrupting image acquisition. The transducer is attached to the positioning system by a rigid beam and is submerged within a closed water tank. The beam passes into the tank through flexible bellows to ensure that the system remains sealed. An RF coil acquires high-resolution images in the vicinity of the target tissue. An aperture on the water tank, centered about the RF coil, provides an access point for target sonication. Registration between ultrasound and MRI coordinates involves sonicating a temperature-sensitive phantom

and measuring the centroid of the thermal focal zone in 3D. A 5 cm linear travel with a positioning resolution of 0.05 mm was achieved for each axis. The entire system was constructed with non-magnetic components and operation of the system within the bore of clinical MRI scanners of different manufacturers was feasible. Simultaneous motion during imaging did not result in any mutual interference or image artifacts. This system can be used for high-throughput small-animal experiments to study the efficacy of ultrasound-enhanced drug delivery.

7629-29, Session 6

Calibration of temperature measurements with CT for ablation of liver tissue

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Purpose: It was the aim of this study to calculate the relationships between the CT value and temperature for the range of ablation therapy.

Materials and Methods: Bovine liver was heated by different methods concerning only steady heat growth on the sample. Image acquisition was performed with a clinical multi-slice CT scanner before and during ablation. Real time temperature was measured and stored using calibrated thermal sensors. Images were analyzed at CT workstation.

Results: It was feasible to validate the spatial and temporal temperature growth during heating by means of declining CT values in the performed images. The change of CT value with respect to temperature rise was found to be linear. The thermal sensitivity for liver tissue was -0.54±0.10 HU/ oC.

Conclusion: It is shown that CT can be calibrated to predict temperature distribution during heating.

7629-30, Session 6

The ACUSITT ultrasonic ablator: the first steerable needle with an integrated interventional tool

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Steerability in percutaneous medical devices is highly desirable, enabling the needle to avoid sensitive structures (e.g. nerves or blood vessels), access obstructed anatomical targets, and compensate for the inevitable errors induced by registration accuracy thresholds and tissue deformation during insertion. Thus, mechanisms for needle steering have been of great interest to the engineering community in the past few years, and several have been proposed. While many interventional applications have been hypothesized for steerable needles (essentially anything deliverable via a regular needle), none have yet been demonstrated as far as the authors are aware. Instead, prior papers focus on model validation and accuracy assessment. In this paper, we present the first integrated steerable needle-interventional device. The ACUSITT integrates a multi-tube steerable Active Cannula (AC) with an Ultrasonic Interstitial Thermal Therapy ablator (USITT) to create a steerable percutaneous device that can deliver a spatially and temporally controllable (both mechanically and electronically) thermal dose profile. We present our initial experiments toward applying the ACUSITT to treat large liver tumors through a

single insertion. This involves repositioning the ablator tip to several different locations, without withdrawing it from the liver capsule, under 3D Ultrasound image guidance. In our experiments, the ACUSITT was deployed to three positions, each 2cm apart in a conical pattern to demonstrate the capability of ablating large liver tumors 7cm in diameter through a single entry point into the liver capsule.

7629-31, Session 7

Quantification of turbulence intensity in patients with symptomatic carotid artery disease: a pilot study

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The most widely performed test for patients suspected of having carotid atherosclerosis is Doppler ultrasound (DUS). Unfortunately, limitations in sensitivity and specificity prevent DUS from being the sole diagnostic tool. Novel DUS velocity-derived parameters, such as turbulence intensity (TI), may provide enhanced hemodynamic information within the carotid artery, increasing diagnostic accuracy. In this study, we evaluate a new technique for recording, storing and analyzing DUS in a clinical environment, and determine the correlation between TI and conventional DUS measurements. We have recruited 21 patients with a mean age of 70±11 yrs. An MP3 recorder was used to digitally record Doppler audio signals three times at three sites: the common carotid artery, peak stenosis and region of maximum turbulence. Each dataset was analyzed off-line to produce a mean velocity waveform. A Fourier-based technique was used to calculate TI, facilitating clinical application without additional ECG-gating data. A FFT was applied to the mean velocity waveform, and a high-pass filter was used to remove frequencies below 12Hz, which are due to the underlying pulsatile carotid waveform. TI was calculated as the standard deviation of this Fourier-filtered mean velocity data. We found that TI and clinical PSV were linearly dependent (P<0.001) within the region of maximum turbulence and the precision of all TI measurements was found to be 13% (CI 11-16%). We have demonstrated the ability to record Doppler waveform data during a conventional carotid exam, and apply off-line custom analysis to Doppler velocity data to produce measurements of TI.

7629-32, Session 7

Global optimization for motion estimation with applications to ultrasound videos of carotid artery plaques

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Motion estimation from digital video is an ill-posed problem that requires a regularization approach. Regularization introduces a smoothness criterion that also reduces the resolution of the estimates. The problem is further complicated for ultrasound videos (US), where speckle noise levels can be significant. Accurate motion estimation requires the modification of several parameters so as to control the level of smoothness and thus the resolution of the estimates. Moreover, accurate pixel velocity estimation is problematic when the true motion of a video sequence is required. The problem is that often there is no ground truth to use for comparison. This problem is present in all real video sequences that are used as input to any motion estimation algorithm and is an open problem in biomedical applications like motion analysis of US of carotid artery (CA) plaques which can provide important information for diagnosis of atherosclerotic plaques; but since there is no ground truth, there will always be uncertainty as to the accuracy of the calculated motion.

The values of the regularization weights and motion parameters have a direct impact on the accuracy of the estimation, and the most

common approach to set them is a heuristic selection that can lead to an estimation error. Thus, a global optimization framework for motion parameter optimization is presented. This framework uses realistic, carotid artery motions to provide optimal parameter values for a variety of motions and is tested on ten different US videos using two different motion estimation techniques.

7629-33, Session 7

IVUS-based histology of atherosclerotic plaques: improving longitudinal resolution

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Although Virtual Histology (VH) is the in-vivo gold standard for atherosclerosis plaque characterization in IVUS images, it suffers from a poor longitudinal resolution due to ECG-gating. In this paper, we propose an image-based approach to overcome this limitation. Since each tissue has different echogenic characteristics, they show in IVUS images different local frequency components. By using Redundant Wavelet Packet Transform (RWPT), IVUS images are decomposed in multiple sub-band images. To encode the textural statistics of each resulting image, run-length features are extracted from the neighborhood centered on each pixel. To provide the best discrimination power according to these features, relevant sub-bands are selected by using Local Discriminant Bases (LDB) algorithm in combination with Fisher's criterion. A structure of weighted multi-class SVM permits the classification of the extracted feature vectors into three tissue classes, namely fibrofatty, necrotic core and calcified tissues. Results shows the superiority of our approach with an overall accuracy of 72% in comparison to methods based on Local Binary Pattern and Co-occurrence, which respectively give accuracy rates of 71% and 70%.

7629-34, Session 7

Ultrasound-directed robotic system for thermal ablation of liver tumors: a preliminary report

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Thermal ablation has been proved safe and effective for treatment of liver cancer. Currently, manually performed thermal ablation is greatly dependent on the surgeon's acupuncture manipulation against

hand tremor. Besides that, inaccurate or inappropriate acupuncture position and pose will also decrease the final treatment effect. In order to lighten the burden of surgeon as well as to improve the treatment effect, we develop an ultrasound-directed robotic system for thermal ablation of liver tumors. In this paper, a brief introduction of our system is given and then two innovative techniques are proposed to solve the two critical problems in the system: ultrasound calibration and accurate 2D-3D ultrasound image registration. The image noise and artifact caused reduction in accuracy of point or line extraction is the main limitation of accurate ultrasound calibration. To reduce the error of point extraction, we propose a novel point extraction method: we define a points extraction error function based on the geometric property of our N-fiducial phantom, then points which minimize the error function will be selected as accurate points. Accurate 2D-3D ultrasound image registration is another difficult problem. It is hard to define a sound similarity metric between ultrasound images for their low image quality, which prevents from an accurate registration result. According to the property of ultrasound image, we proposed a new similarity metric based on Euclidean distance transform (EDT) to finish accurate 2D-3D ultrasound image registration. The effectiveness of the two techniques is demonstrated in our phantom experiments.

7629-35, Session 7

Liver fibrosis grading using multiresolution histogram information in real time ultrasound elastography

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Despite many limitations, liver biopsy remains the gold standard method for grading and staging liver biopsy. Several modalities have been developed for a non invasive assessment of liver diseases. Real-time ultrasound elastography may constitute a true alternative to liver biopsy by providing an image of tissular elasticity distribution correlated to the fibrosis grade.

In this paper, we investigate a new approach for the assessment of liver fibrosis in patients with a chronic viral hepatitis by the classification of fibrosis morphometry to interpret images as fibrosis scores (1 to F1, 2 for F2, etc....). Multiresolution histogram, based on a combination of intensity and texture features, has been tested as feature space. Thus, the ability of such multiresolution histograms to discriminate fibrosis grade has been proven. The results have been tested on 30 patients (17 men and 13 women), aged 45 to 70 with a chronic viral hepatitis, that underwent a real time elastography and FibroScan examination.

7629-36, Session 7

Replace-approximation method for ambiguous solutions in factor analysis of ultrasonic hepatic perfusion

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Factor analysis is an efficient technique to the analysis of dynamic structures in medical image sequences and recently used in contrast-enhanced ultrasound (CEUS) of hepatic perfusion. Time-intensity curves (TICs) extracted by factor analysis can provide much more diagnostic information for doctors and improve diagnostic rate of focal liver lesions (FLLs). However, one of the major drawbacks of factor analysis of dynamic structures (FADS) is non-uniqueness of the result when only non-negativity criterion is used. In this paper, we propose a new method of replace-approximation based on apex-seeking for ambiguous FADS solutions. Due to a partial overlap of different structures, factor curves are assumed to be approximately replaced by the curves existing in medical image sequences. Therefore, how to find optimal curves is the key point of the technique. No matter how many structures are assumed, our method always starts to seek apices from one-dimensional space where the original high-dimensional data is mapped. By finding two stable apices from one dimensional space, the method can ascertain the third one. This technique and two variants of apex-seeking method were tested on two phantoms of blood perfusion. The results showed that the technique works better than two variants in comparison of region of interest measurements from phantom data. This method can be applied to the estimation of TICs derived from CEUS images and separate different physiological regions in hepatic perfusion.

7629-37, Session 7

SMURF imaging of thermally ablated liver lesions

S. A. McAleavey, Univ. of Rochester (United States)

No abstract available

7629-38, Poster Session

Liver ablation guidance with real-time elastography

H. Rivaz, I. N. Fleming, M. A. Choti, G. D. Hager, E. M. Boctor, The Johns Hopkins Univ. (United States)

Monitoring the ablation process in order to document adequacy of margins during treatment is of significant importance. In this paper we propose a regularized ultrasound elastography technique for visualizing the ablation lesion and the cancerous lesion in Hepatocellular carcinoma (HCC). The main focus of this work is on devising techniques to generate elasticity images which distinguish the cancerous tumor and the ablation lesion. Regularized ultrasound elastography combines image data with the tissue displacement continuity prior to solve for the displacement field. The parameters of the elastography techniques are varied inside the ablation lesion to increase the visibility of the harder cancerous tumor inside the ablation lesion. We use finite element and Field II simulation to obtain how the elastography parameters should be varied.

7629-39, Poster Session

Improved 3D reconstruction algorithm for ultrasound B-scan image with freehand tracker

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EM algorithm for the reconstruction of freehand B-Scan ultrasound image was developed by Joao M. Sanches et al. The reconstruction has a parameter which can be adjusted so that the results can be smoother or sharper depending to the value of . In order to make the image smoother inside the organs but sharper in their boundaries simultaneously, we introduced a improved EM algorithm: EM algorithm with a diffusion filer or is referred as EMD algorithm. There was a cubic average filter inside the loop of the iteration of the EM algorithm. This average filter is replaced by a diffusion filter in the EMD algorithm. The diffusion filter offers an additional parameter which can be used to adjust the reconstructed image with better optimization in both smoothness insider the human organ and sharpness in its boundary.

Two above mentioned reconstruction algorithms for the freehand B-scan ultrasound image are compared through the simulation and the phantom measurements. In the simulation, the parameters of two algorithms are optimized to get smallest errors. The errors are compared between two algorithms with optimized parameters.

For the phantom measurement, the Eigen's tracker System is used to continuously measure the coordinates of the ultrasound probe. The ultrasound B-Scan frame is synchronously recorded with the probe coordinates. Zonare ultrasound machine is used to acquire the 2D frame images. The segmentation of the reconstruction results is done. The segmentation volumes of the prostate phantoms are compared.

The results shows that EMD algorithm is better at reducing the noises and keeping the image edge comparing to EM algorithm. Eigen's tracker is cacaple to acquire freehand ultrasound data for a 3D image reconstruction with high quality.

7629-40, Poster Session

Coronary 3D reconstruction using IVUS images only: a numeric phantom framework

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Intravascular ultrasound (IVUS) examination offers a tomographic view of the vessel, having the catheter tip as reference. During

examination, the catheter is pulled back with a constant speed (0.5 or 1.0 mm/s) and the ultrasound transducer captures cross-sections of the coronary. Currently, 3D IVUS reconstruction is based on single-plane or biplane angiography together with IVUS images. In this work, we present a preliminary approach to reconstruct tridimensionally the catheter and coronary path, based only on IVUS sequence. We have developed numerical phantoms of tridimensional coronary, modeling it as a curved tube. Inside the lumen borders, we have simulated the catheter path dynamically. The optimal path for each given catheter length was obtained using graph theory. Moreover, we have simulated IVUS acquisition and we have used this set of images to reconstruct tridimensional information. This framework is limited by assumptions such as the smoothness of the catheter curvature and borders. Further improvements and investigations on robustness of this approach are in progress.

7629-41, Poster Session

Image enhancement for sonograms acquired by high frame rate mode

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Sonography performed in high frame rate aims to achieve high temporal resolution so that recording every movement of soft tissue in any moment can be achieved. Echocardiography and fetal echocardiography are typical examinations performed in high frame rate. In general, image quality of sonograms acquired by high frame rate mode is comparatively poorer than that acquired by low frame rate mode. It results from the duration between two successive frames is too short to produce a sonogram with high quality. Advanced processing for improving image quality of the sonograms is beneficial to increase accuracy of diagnosis if the acquired sonograms are selected or stored for clinical uses. Poor definition and rich noises are drawbacks usually found in the sonograms acquired by high frame rate mode. To improve image quality of the sonograms, we propose an approach which can remove noises and enhance the textures in the sonograms. Two techniques are involved in the approach: addition of spatial information and image averaged by cycle-spinning. The former intends to generate extra spatial information from the original image so that the image can be further enhanced. The latter aims to remove noises by averaging images which have been undergone frame shifting and coefficient addition. Our experimental results show that randomly scatter noises, not speckles, are effectively removed and the definition of texture is further reinforced. Consequently, the processed sonograms are improved not only in image quality but also in visual perception.

7629-42, Poster Session

Simulation and training of ultrasound supported anaesthesia: a low-cost approach

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The daily challenge for the anaesthesiologists is the 3D angle-depending handling of the needle and the transducer while watching the 2D ultrasound image on the monitor. This approach describes how a simulation and training set for ultrasound supported anaesthesia could be built based on wireless low-cost devices and an interactive computer simulation of a 2D ultrasound image. For training purposes the injection needle and the transducer are replaced by wireless Bluetooth-connected 3D tracked devices, which are embedded in WII-Mote controllers (Nintendo-Brand). In correlation to the tracked 3D positions of the needle and transducer models the visibility and position of the needle should be simulated in the 2D generated ultrasound image. In future, this tracking and visualization software module could be integrated in a more complex training set, where complex injection paths could be trained based on a 3D segmented model and the training results could be part of a curricular e-learning module.

7629-43, Poster Session

A feasibility study of epicardial coronary angiography from microbubble-contrasted tridimensional echocardiography: segmentation approaches

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Conventional coronary angiography has been the current gold standard for evaluation of coronary stenosis severity. However, this is an invasive procedure, based on ionizing radiation (X-Ray) and dependent of nephrotoxic contrast agents. Although alternative techniques already exist, they require high-costs technology, as magnetic resonance and computerized tomography.

Recently, echocardiography has emerged as an important medical image modality in Cardiology. Due to its ease of use and multiple attractive features, this technology sparked significant interest in the research community. In addiction, with the advent of microbubble-based contrast agents and array transducers, 3D-echocardiography now presents itself as a relative low-cost, non invasive and non ionizing alternative method to visualize arteries and their dynamics.

This paper investigates some segmentation techniques to emphasize and isolate epicardial coronaries in 3D-echocardiographic images. We tested 4 different image segmentation algorithms based on fuzzy-connectedness theory that seems to be a suited approach for the problem. Three are literature methods and one original contribution. Basically, the proposed approach delimits the object from a seed and a guide-seed voxels, both defined by the user. These selections provide enough data to improve the fuzzy-connectedness attributes and parameters computation, since they optimize all, weights estimation, fuzzy-affinity and shortest-path algorithm.

For a training set with 240 simulated images, literature methods reached 85,5% to 92,0% accuracy, while the proposed method reached 95,2% accuracy. This is a very good rate and an incentive to future work on the area. Next step is to assess these algorithms using real images. Preliminary tests in real images showed good perspective to our aims.

7629-44, Poster Session

Detecting breast microcalcifications using super-resolution ultrasound imaging: a numerical phantom study

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Microcalcifications are the first sign of breast cancer in more than half of all cases. X-ray mammography is the only imaging modality routinely used for detecting breast microcalcifications. However, it is relatively ineffective in women with dense breasts. Ultrasound imaging could be an attractive alternative, but it lacks of the capability for microcalcification detection because of its poor image quality. Super-resolution imaging has recently been developed as a promising tool to break through the resolution limit of conventional imaging. We explore the capability of a novel super-resolution ultrasound imaging method for breast microcalcification detection using numerical phantoms. Super-resolution imaging is based on singular value decomposition of the so-called multistatic matrix that is obtained by measuring all the possible transmit-receive pairs across the aperture of a linear ultrasound array. Only the singular values above the noise threshold are used for image reconstruction, leading to partial noise suppression and high-resolution images with fewer speckles. The method makes use of the full waveform of ultrasound data including multiple scattering, as well as a factorization scheme to achieve an image resolution that is not possible by conventional ultrasound imaging. We generate numerical data for breast phantoms containing inclusions that mimic microcalcifications. Typical distributions of microcalcifications found on mammograms are used to construct numerical phantoms. We

demonstrate that microcalcifications can be detected at full spatial resolution using the super-resolution ultrasound imaging method.

7629-45, Poster Session

Fetal biometry of abdominal circumference (AC) for Malaysian pregnant women

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The purpose of this study is to build the fetal abdominal circumference (AC) biometry values for Malaysian population. Retrospective study was done at Hospital Pulau Pinang, Malaysia with 7204 pregnant women were involved. Besides retrieved the AC mean values of this study (ACmean), the AC data were also categorized according to maternal and infant characteristics. Comparisons of ACmean with other AC studies were performed. The SPSS software version 15 was used for data analysis. There are 14356 AC data were recorded. Greater ACmean growth rate was noticed for GA <26 weeks (11.02 mm/week) than GA $\geq$26 weeks (7.01 mm/week), suggested that rapidly AC growth in second than third trimester. Statistically, the fetus gender shows significant difference (SD) results with male have higher AC values than female. Infants with greater birth weight (BW), length and head circumference (HC) of birth were noticed to have higher AC values. Diseases of heart and renal seem to effect the AC values of fetus. The ACmean has SD with 13 studies but inversely results were shown for the other 6, and closest similarity with Hadlock et al. (1984) study (t = -0.129). Overall, more than 80% of the comparisons resulted as SD (158) with only 32 were not. Therefore, each country should have their own standard AC of fetus biometry for their own population.

7629-46, Poster Session

Application of external tracking in ultrasound elasticity imaging

P. Foroughi, G. D. Hager, E. M. Boctor, The Johns Hopkins Univ. (United States)

Despite the success of strain imaging in medical applications such as diagnosis and screening of breast lesions and prostate cancer, strain imaging has not been widely adopted in clinical procedures. Some of the limiting factors seem to be the difficulty in acquiring reliable images and interpreting them, the lack of consistency over time, and the dependency of image quality to the level of expertise of the user. We previously demonstrated the potential of exploiting an external tracker to partially alleviate these issues and enhance the quality of ultrasound strain imaging. The tracking data enabled fast and automatic selection of pairs of RF frames to be used in strain calculation. Here, we investigate the sensitivity of this method to inaccuracies in tracking information. Based on the results, we devise a method that can compensate for the limited resolution of the tracker for small motions using image content. Lastly, we propose a method to combine the strain images to improve the quality of the final image. For this purpose, we use the tracking data to normalize the images and to determine which images and more specifically which parts of each image should be combined. We have acquired RF frames synchronized with tracking data from livers of pig containing an ablated region and a breast phantom using two different tracking devices; an optical tracker and a less accurate electromagnetic tracker. The preliminary results are promising and a thorough analysis of the obtained data is underway.

7629-47, Poster Session

Monitoring breast masses with ultrasound tomography in patients undergoing neoadjuvant chemotherapy

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Ten patients undergoing neoadjuvant chemotherapy for breast cancer were monitored with a prototype based on the concept of ultrasound tomography. Patients were scanned on multiple occasions over the course of their chemotherapy. Images of reflection, sound speed and attenuation, representing the entire volume of the breast, were reconstructed from the exam data and analyzed for time-dependent changes during the treatment period. It was found that changes in acoustic properties of the tumors could be measured directly from the images. The measured properties include reflectivity, sound speed and attenuation, leading to measurable changes in the volume, shape and internal attributes of the tumors.

These measurements were used to monitor the response of the tumors to the therapy with the goal of correlating results with pathological and clinical outcomes. Comparisons with tumor size changes based on traditional US and MRI indicates potential for accurate, quantifiable tracking of tumor volume. Furthermore, our results also show declines in internal properties of the tumors, relating to biomechanical changes in the tumor properties. Future work includes an expansion of the study to a larger cohort of patients for determining the statistical significance of our findings.

7629-48, Poster Session

Novel reconstruction and feature exploitation techniques for sensorless freehand 3D ultrasound

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Out-of-plane motion in freehand 3D ultrasound can be estimated using the correlation of corresponding patches, leading to sensorless freehand 3D ultrasound systems. The correlation between two images is related to their distance by calibrating the ultrasound probe: the probe is moved with an accurate stage and images of a phantom are collected, such that the position of each image is known. Since parts of the calibration curve with higher derivative gives lower displacement estimation error, previous work limits displacement estimation to parts with maximum derivative. In this paper, we first propose a novel method for exploiting the whole calibration curve by weighting the expected accuracy with the derivative of the calibration curve. We then propose for the first time using constrains inside the image to enhance the accuracy of out-of-plane motion estimation. Simulation data is presented for validation, and real tissue experiments are underway.

7629-49, Poster Session

Prostate brachytherapy seed localization using combined photoacoustic and ultrasound imaging

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Brachytherapy is mostly performed with transrectal ultrasound (TRUS) guidance. TRUS has been popular thanks to its real-time nature, low cost, and apparent ease of use. While TRUS provides adequate imaging of the soft tissue anatomy, it does not allow for reliable localization of the implanted brachytherapy seeds. Unfortunately, there are a number of mechanical factors that cause the seeds to deviate from their original plan. In this paper, we propose a novel, cost-effective, and feasible approach that provides precise intra-operative localization of the implanted seeds in relation to the prostate; thereby provides Intra-operative dosimetry and conformal brachytherapy, without modifying the established standards of care or the safety of the procedure. The essence of our idea is based on the ability to localize the seeds in relation to the prostate imaging simultaneously, by utilizing PhotoAcoustic (PA) and UltraSound (US) imaging using standard linear array probe. We showed that conventional brachytherapy seeds can be identified using PA imaging. Initial studies were conducted using phantom-based experiments, and promising results strongly support our novel system.

7629-50, Poster Session

Ultrasound images using a PE-CMOS sensor with multi-transducers: a preliminary investigation on blood vessel plaques and bone fractures

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In this paper, we present some preliminary studies in ultrasound medical images (in vitro) using a laboratory prototype featuring a 6th generation PE-CMOS ultrasound sensing array, an acoustic compound lens, and multiple plane-wave transducers. With the integration of multiple transducers, the prototype is capable of generating ultrasound images in transmission and/ or reflection geometrical configurations.

In this study, we used 6th generation PE-CMOS ultrasound sensing array with multi-transducers to investigate its potential to evaluate early signs of plaque in carotid artery and to detect small bone fractures. We found that the 6th generation PE-CMOS ultrasound sensor with and without multiple plane-wave transducers has advantages of greater sensitivity and good contrast performance.