MEMS programmable spectral imaging for remote sensing

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A scalable, large format, data and power efficient imaging spectrometer with a high speed, digitally tunable optical filter enables rapid selection of spectral bands of interest.

A key issue in remote sensing is the selective capture of images from specific wavelength bands. We have recently demonstrated a highly-efficient system for performing this task that uses grating electromechanical system (GEMS) light modulation: technology that was originally conceived and developed at Eastman Kodak Company for use in the high-end commercial display market.1, 2 Our new system enables the rapid selection of high-quality user-defined wavelength bands across a large format TDI (time-delay-and-integration) scanning or area-array staring sensor.

Our microelectromechanical-system- (MEMS-) programmable spectral imaging (MPSI) brassboard system was designed with a custom, 50-channel GEMS modulator for linear-scan imaging (see Figure 1). GEMS is a diffractive-MEMS spatial light modulator that contains a linear array of actuators capable of high-speed operation, high optical contrast, and good efficiency. The system is configured as a double-pass (disperse/de-disperse) imaging spectrometer and targets a pushbroom scanning architecture (sequential capture of linear images) with a TDI image sensor. Compatibility with TDI scanning provides a >20× scan-rate advantage over conventional hyperspectral imagers. The optical system includes three lens groups that are arranged in a one-to-one-to-one imaging configuration, with a patterned mirror and transmission volume phase grating placed near the common focus of all three lenses. In a remote sensing system, the fore optics (not shown) would collect light to form an image at the entrance slit.

The band-pass characteristics of the MPSI system are shown in Figure 2(a). As currently configured, the 32-channel system has a range of approximately 450-700nm with 14 narrow 5nm bands near the center of the spectral range and 18 wider 10nm bands near the edges. The bandwidth of each band is determined by the diffraction optics (grating pitch and lens focal length), the

![Figure 1. The MPSI system design is shown along side a view of the patterned mirror that acts as a selective optical stop to pass only the bands chosen by the GEMS device.](image)

![Figure 2. Spectral measurements of (a) MPSI band-pass characteristics and (b) the illumination lamp.](image)

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Figure 3. Measured spectra showing the ability to (a) select bandwidth and (b) generate more complex filter shapes.

width of each GEMS modulator channel, and the number of modulator channels being driven at the same time. It should be noted that a significant portion of the roll off towards blue and red wavelengths is due to the illumination light source itself, as evident from Figure 2(b).

As an example of the system’s spectral selection and imaging, a fundamental feature of the dispersive / de-dispersive system architecture is its ability to produce more-complex spectral transmission functions. The Figure 3 images labeled “All Bands” and “Red & Blue Bands” illustrate advanced band-pass capabilities for panchromatic or dual-band capture. The MPSI system also provides variable bandwidth selection by turning on adjacent modulator channels. Figure 3 shows bandwidths from 5nm to 40nm wide in 5nm increments. It should be noticed that, even when the bandwidth is changed, the top of the band pass remains nearly free of ripple and the band edges retain constant slope. More complex filter shapes, such as a filter with dual pass bands, are also possible: see Figure 3(b).

Figure 4 shows sample spectral separation images for a studio scene obtained by scanning a color slide at the input of the system. To produce a TDI-like hardware simulation, separate slices of the scene were captured using the color digital camera and stitched together to generate these images.

Conclusion
The MEMS programmable spectral imaging system enables high-performance imaging of arbitrary, narrow or wide spectral bands of interest across the visible spectrum without any moving mechanical parts. The architecture combines the scan-rate advantage of a TDI multispectral system with the spectral capability of a hyperspectral system. Image simulations validate the utility of target detection using a limited number of visible spectral bands selected using a priori knowledge of the target and

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background spectra. Future generations of MPSI systems will be designed to support the short-, mid-, and long-wavelength infrared bands.

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References