RELATIVE MTF CHARACTERIZATION AND CORRECTION OF LANDSAT 4

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INTRODUCTION

Landsat 4 TM, band 2, detectors 2 and 4 are currently turned off in the normal Landsat production system, since they display low Modulation Transfer Function (MTF) behavior compared to other Landsat 4 detectors. This low MTF behavior causes a substantial blur in data from these detectors [1]. This blur can be seen in Figure 1 which shows two calibration pulses in the forward scan direction of band 2, taken from a Landsat 4 calibration file. The detectors of Landsat 4 are numbered from bottom to top, so the bottom line of data represents the response of detector one. The responses of detectors two and four can be seen to be substantially broader than and shifted from those of the other detectors.

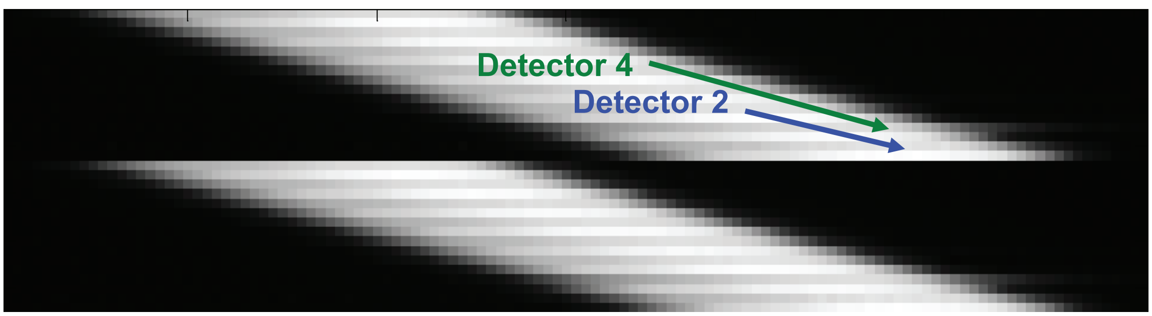

Figure 1: Landsat 4 Band 2 Forward Scan Calibration File Data.

PROCEDURE

It is desired to adjust the responses of detectors 2 and 4 to better match the responses of the other detectors. Detector 6 is used as a reference because of its close physical location to the detectors, and it passes through the same electronics (odd and even detectors pass through different sets of electronics). A comparison between detectors 2 and 4 and the reference provides an estimation of the amount of blur inherent in these two detectors relative to the reference. Using this relative blur estimation, the detectors can be corrected.

A line of data in an image as it comes from the instrument, *g(x)*, is composed of the actual image, *f(x)*, blurring, *h(x)*, and noise, *n(x)* according to

$$g(x) = f(x) * h(x) + n(x)\,. \tag{1}$$

If this equation is moved to the frequency domain via the Fourier Transform, it takes the form of Equation 2.

$$G(u) = F(u) \cdot H(u) + N(u) \tag{2}$$

$G(u)$, $F(u)$, $H(u)$, and $N(u)$ are the frequency domain representations of the received image degraded by the instrument, the true image, the blurring function, and noise, respectively. From Equation 2, it is easy to find an estimate of the image without blurring.

$$\hat{F}(u) = \frac{G(u)}{H(u)} \tag{3}$$

$\hat{F}(u)$ is the estimation of the non-blurred image in the frequency domain. By taking the inverse Fourier Transform, an estimate of the non-blurred image is obtained.

$$\hat{f}(x) = \Im^{-1}\left\{\hat{F}(u)\right\} = \Im^{-1}\left\{\frac{G(u)}{H(u)}\right\} \tag{4}$$

$H(u)$ is the estimate of the amount of blurring in the image, and by removing it, the actual non-blurred image can be found [2]. This paper uses a comparative approach to find $H(u)$, so the MTF is only a relative and not an absolute estimate.

The first step in estimating the relative MTF is to calculate an "average" calibration pulse for each detector [3]. The "average" calibration pulse is an oversampled, smoothed, moving window filter fit to the combination of each forward scan line of data for a detector from the calibration file. A single calibration file contains nearly 200 forward scan lines of data from each detector. A Fast Fourier Transform (FFT) is calculated for each detector, and the FFTs of detectors 2 and 4 are divided by the FFT of detector 6. This quotient is the relative MTF.

To correct the blurring in an image, the FFT of the image must simply be divided by the relative MTF and transformed back into the spatial domain [2]. However, the FFTs used to calculate the relative MTF contain numerous zero, or near zero, crossings. Zero crossings cause the estimate to be unreliable at those frequencies, so the relative MTF needs to be adjusted at these locations. Each FFT also approaches zero at high frequency; thus, the estimate becomes unreliable at high frequencies. Most scenes do not contain a significant amount of data at higher frequencies, though, so a pseudo-inverse filter can be used as the correction filter where the relative MTF covers the frequency range from DC to a certain cutoff, and unity gain is used for higher frequencies.

RESULTS AND ANALYSIS

Figures 2 and 3 show the magnitude and phase of the estimated zero-crossing adjusted relative MTFs with the high frequency cutoffs. It can be seen in Figure 2 that the magnitude of both relative MTFs are below 1. This represents a detector whose response is less sensitive to changes in scene content than normal which would cause a blur in the imagery, with respect to the other detectors. In Figure 3, the phase is less than zero; this represents a delay in the response of a detector.

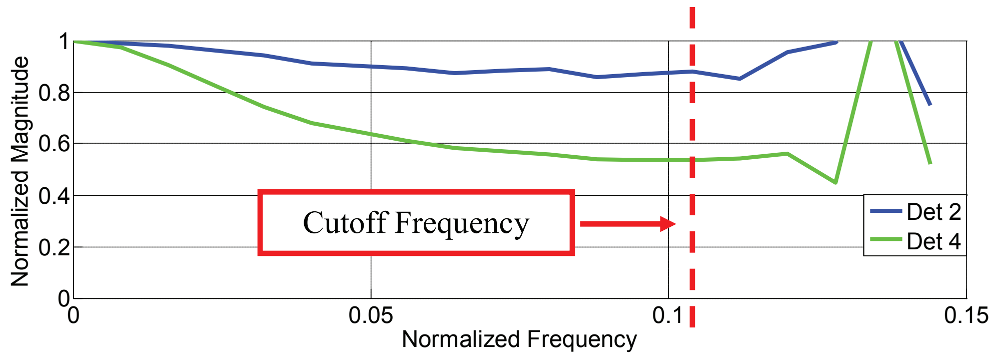

Figure 2: Detector 2 and 4 Relative MTF (Magnitude).

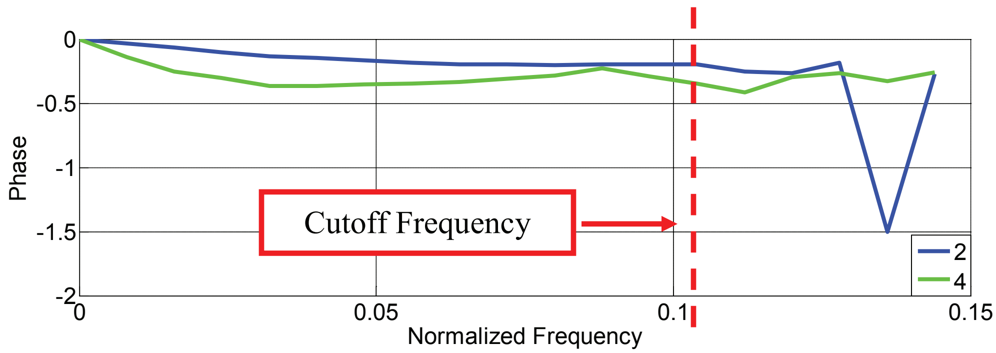

Figure 3: Detector 2 and 4 Relative MTF (Phase).

Figure 4 shows an image of an airstrip before and after relative MTF correction. The image contains at least two lines of data from each detector. The left image shows significant blurring and shifting of the airstrip in both detectors 2 and 4 with the response of detector 4 being much more pronounced. The blurring has been greatly reduced in the right image, but there may be a slight amount of ringing present.

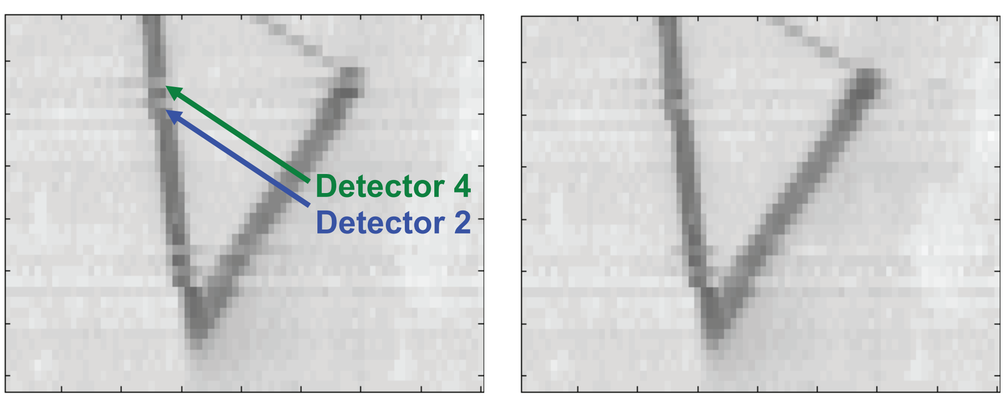

Figure 4: Coastline Image (a) Before and (b) After Relative MTF Correction.

Figure 5 plots detector 4 before and after correction. It can be seen that the position of the pulses have been shifted slightly, the width of the pulses have been reduced, and the amplitude increased.

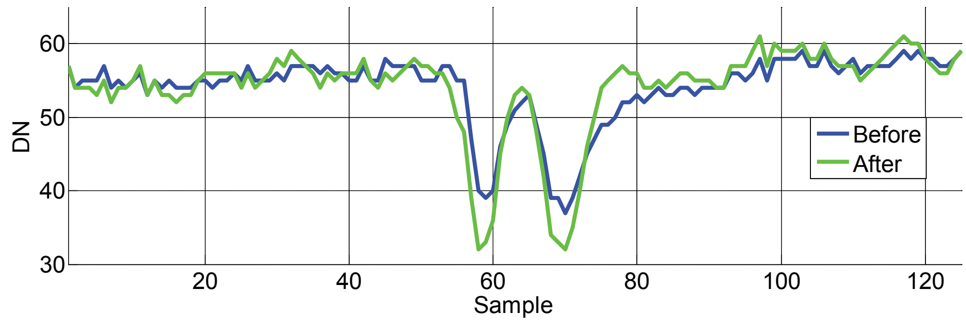

Figure 5: Detector 4 Before and After Correction.

CONCLUSIONS

Results from this effort clearly indicate that it is possible to estimate relative MTFs of degraded detectors in Landsat 4 TM by modifying established techniques that have been developed for sensor MTF estimation. Fortunately, the resulting blurring function is well behaved at those frequencies which are critical to the restoration process, and lends itself well to a relatively simply pseudo-inverse filtering approach. Restoration examples have indicated a high quality product can be developed with minimal artifacts that has the potential to recover the information from two of the 16 detectors in band 2—or a recovery of more than 12% of the data in this band. While there are over 50,000 Landsat 4 TM scenes with nearly 6000 lines containing 6300 samples each, a full scene correction only takes roughly 1.3 seconds on a standard desktop machine, so correcting the entire Landsat 4 database can be done quickly and efficiently.

REFERENCES

[1] M. Rangaswamy, "Two-dimensional On-orbit Modulation Transfer Function Analysis Using Convex Mirror Array," M.S. thesis, South Dakota State University, Brookings, SD, US, 2003.

[2] R. Gonzalez and R. Woods, *Digital Image Processing*, 2nd Ed. Upper Saddle River, NJ: Prentice-Hall Inc. 2002.

[3] Helder, D., Choi, J., Anderson, C., "On-orbit Modulation Transfer Function (MTF) Measurements for IKONOS and Quickbird," Civil Commercial Imagery Evaluation Workshop, Reston, VA, 2006.