MTF CHARACTERIZATION AND DECONVOLUTION OF RAPIDEYE IMAGERY

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1. INTRODUCTION

The achievable resolution in remotely sensed digital imagery is dictated by a combination of limits imposed by the optical system, including the aperture, the optical bench and the CCD array. Often the spatial resolution and quality of the imaging system is parameterized by the Modulation Transfer Function (MTF), which is typically quoted at the Nyquist sampling limit [1]. A higher MTF implies that the optical system has a higher resolution. However a higher MTF also results in a greater amount of artifacts such as aliasing since the input signal (i.e. the remotely sensed scene) is rarely band limited in terms of the spatial frequencies it contains.

The paper will discuss the techniques used for both on-ground and on-orbit [2, 3] characterization of the MTF of the RapidEye optical system, how these measurements were used to create an optimized deconvolution filter which has been incorporated into the on-ground processing system. We will demonstrate how the RapidEye imagery products have been significantly improved due to this MTF deconvolution process.

2. BACKGROUND

RapidEye AG is a private German provider of satellite-based geospatial information and services. The RapidEye constellation represents the first of a new generation of operational small satellites designed to meet the growing needs for purpose-driven remotely sensed satellite imagery. Based around a constellation of five identical satellites operating in a sun-synchronous low earth orbit, each carrying a 6.5 metre 5-band multi-spectral (blue, green, red, red-edge and near infrared) imager able to acquire at a wide range of roll angles, the RapidEye system is capable of daily access to any point on the surface of the earth between latitudes of -84^{o} to $+84^{o}$ and can acquire more than 4,000,000km^2 of imagery each day. These high-repeat, moderate-resolution and wide-area coverage capabilities make RapidEye imagery ideally suited to satisfying many multi-spectral and multi-temporal applications, for which product quality is critical.

3. MTF ASSESSMENT

One of the drivers of the MTF requirements for the RapidEye system is the need to determine field boundaries in an automated way. To satisfy this business-driven need, the technical requirement for the system specifies an MTF of greater than 10% at Nyquist for across-track and along-track for all five bands.

The MTF was measured pre-launch using the conventional approach whereby a narrow slit is stepped across the imager to obtain a Line Spread Function, from which the MTF response is then derived assuming the expected orbital motions. On-orbit, the MTF was measured using techniques originally developed to assess the MTF of the QuickBird sensor [2]. As illustrated in Figure 1, an image chip containing a high-contrast edge (typically land-water boundaries roughly aligned along or across track) is analyzed to obtain an Edge Response Function, from which the MTF response is then derived. Table 1 summarizes the results of these tests, averaged over 5 spacecraft and many image chips, thus confirming that the on-orbit measured MTF agrees well with the pre-launch measured MTF in all bands.

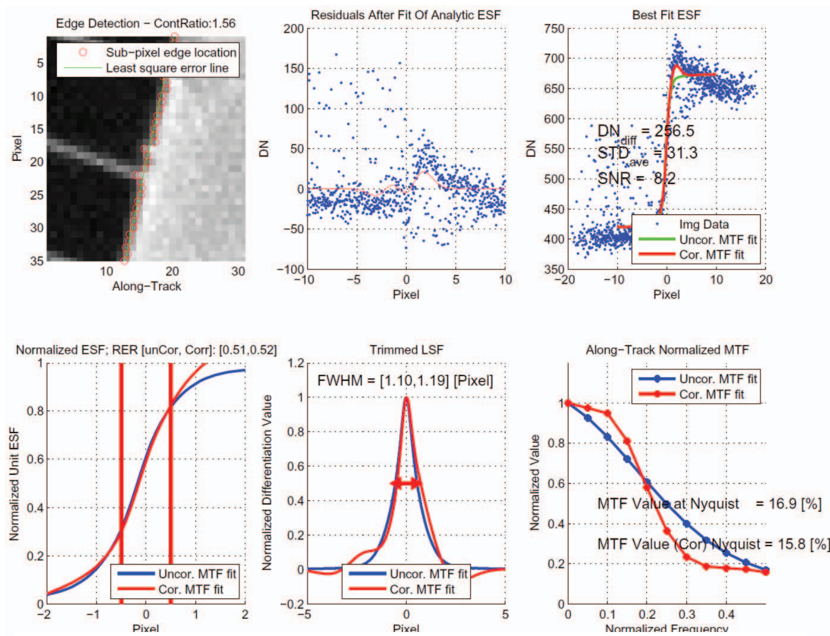

Figure 1 Example output produced by the MTF measurement tool using on-orbit acquired imagery.

Table 1 Summary of the on-orbit and pre-launch MTF measurements.

	Pre-launch Measured MTF at Nyquist Averaged over 5 spacecraft		**On-orbit Measured MTF at Nyquist Averaged over 5 spacecraft**	
Band	**Along-track MTF**	**Across-track MTF**	**Along-track MTF**	**Across-track MTF**
Blue	19.7	26.8	18.3	19.9
Green	21.5	28.5	15.1	18.6
Red	18.8	22.1	19.6	17.0
Red edge	18.6	20.1	21.2	16.7
NIR	17.1	15.9	14.4	13.1
Requirement	**10.0**	**10.0**	**10.0**	**10.0**

4. IMAGE SHARPENING

Figure 2 below shows how the on-orbit measured MTF (solid red line labeled “Measured”) is used to design resampling kernels for each band, one for the along-track direction and the other for the across-track direction, such that their spatial response is equal to the inverse of their corresponding MTF curves (dashed red line labeled “Inverse”). To avoid over sharpening the imagery yielding visually displeasing imagery, the amount of boost that is applied at the higher spatial frequencies must be damped (blue line labeled “Resampling Kernel”).

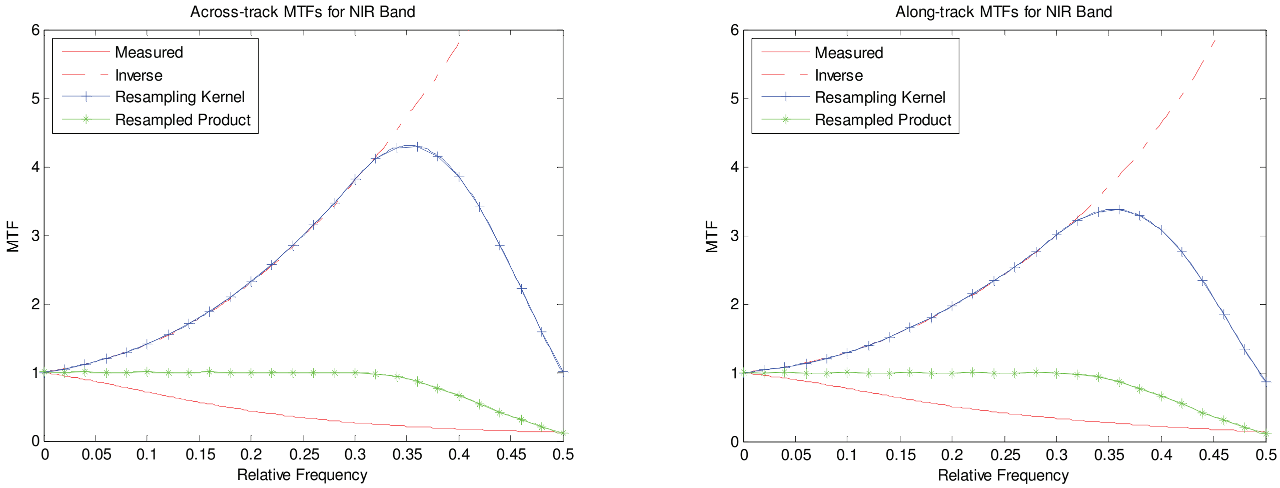

Figure 2 Design of the across and along-track MTF deconvolution resampling kernels for the NIR band.

Multiplying the on-orbit measured MTF with the resampling kernel MTF yields the final image product MTF (green line labeled "Resampled Product") which is virtually flat for all spatial frequencies up to 0.35 and then gradually trends downward for higher spatial frequencies up to Nyquist. The example image product chips below compare the performance of the cubic convolution and the MTF sharpening image resampling kernels.

Figure 3 Example RapidEye image processed with a Cubic Convolution resampling kernel.

Figure 4 Example RapidEye image processed with the MTF deconvolution resampling kernel.

5. CONCLUSIONS

Using the on-orbit measured MTF, we were able to compute a set of deconvolution filters, optimized for each band of the RapidEye sensor. These filters were derived in the form of resampling kernels to avoid degrading the image by application of a separate image resampling step. As a result, we have implemented a quantitative MTF deconvolution filter which accurately reconstructs image content and leads to significant visual improvement in overall image quality and sharpness of RapidEye imagery products.

6. REFERENCES

[1] Arnold Daniels, "Modulation Transfer Function," Encyclopedia of Optical Engineering, USA, 2003.

[2] Paul W. Scott, "On-Orbit Spatial Image Quality Assessment of the DigitalGlobe Quickbird Instrument – Panchromatic Band", in Proceedings from the 2004 ASPRS Annual Conference, Colorado, 2004.

[3] C. Valorge, "On-Orbit MTF Assessment of Satellite Cameras," in Proceedings of the International Workshop on Radiometric and Geometric Calibration, Mississippi, 2003.