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UTILITY ASSESSMENT OF A MULTISPECTRAL SNAPSHOT LWIR IMAGER

Jeffrey Mercier [1], *Toby Townsend* [1], *Robert Sundberg* [2]

Sandia National Laboratories [1], Spectral Sciences, Inc. [2]

ABSTRACT

The purpose of this study was to assess the utility of a Long Wave Infrared (LWIR) snapshot imager for remote sensing applications. The snapshot imager is made possible by the utilization of a color filter array that selectively allows different wavelengths of light to be collected on separate pixels of the focal plane in same fashion as a typical Bayer array in the visible portion of the spectrum [1]. Recent technology developments have made this possible in the LWIR [2]. The primary focus of the study is to develop a band selection technique that is capable of identifying both the optimal number and width of the spectral channels. Once selected, the theoretical sensor performance is used to evaluate the usefulness in a typical remote sensing application.

***Index Terms*—**LWIR, Multispectral, Color Filter Array

1. INTRODUCTION

There are many documented advantages to using multispectral or hyperspectral sensors in the remote sensing community. Applications of such sensors cover a wide range including material identification, atmospheric studies, global change detection or meteorology. The primary focus of this study is on passive, optical remote sensors that are either ground based or airborne. Multispectral sensors are typically designed to have spatial, spectral, and temporal resolution that is most advantageous to the mission requirements. Typical remote sensing multispectral systems construct three dimensional data cubes D(x, y, λ) by one of two methods. The first general category is spatial scanning, where one dimension of the focal plane is used for spatial sampling and the other for spectral. From that configuration, the second spatial dimension is collected by a technique like scanning or simple along track platform motion. The second general category is spectrally scanning, where both dimensions of the focal plane are used to collect spatial information and wavelength is temporally varied by one of several technologies.

A significant technology limitation exists in these types of sensors that is a result of the fact that the entire spatial and spectral regime is not simultaneously sampled.

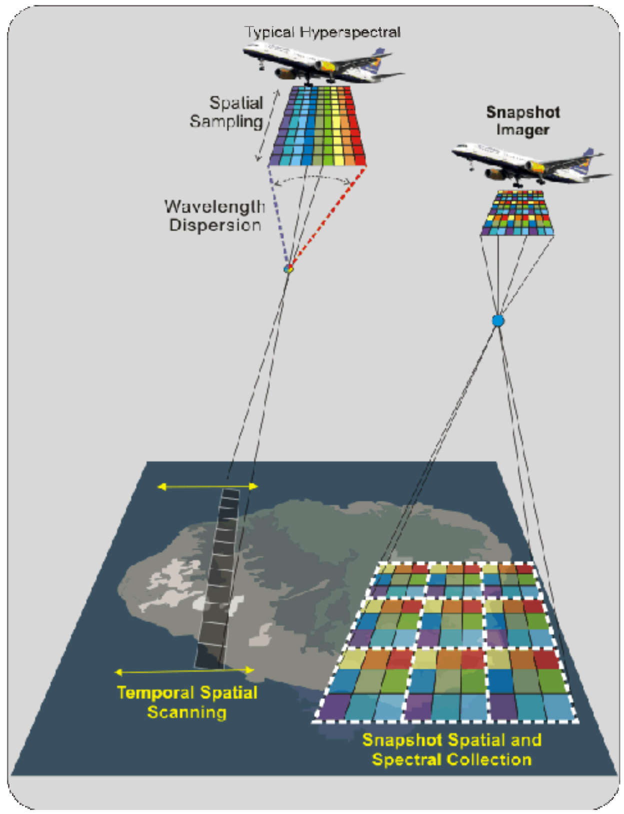

Figure 1: Typical hyperspectral collection compared to a snapshot color filter array sensor.

Because of this limitation, taking a snapshot spectral image is not possible, and building temporal resolution can be difficult or impossible depending on the platform. One new technology development that does not suffer these limitations is the Bayer or color filter array. As seen in Figure 1, the focal plane samples the entire spectral region simultaneously at the cost of spatial resolution. Many spatial resampling algorithms have been developed to help overcome the losses [3].

2. OPTIMAL SPECTRAL CHANNEL SELECTION

The technology that has made LWIR patterned color filter arrays possible restricts the channels to have a spectral response that is shaped like a Lorentzian function. For the purposes of this study a simplified and ideal transmission function is used to calculate the response of each channel as follows:

$$T(\lambda) = \frac{1}{1 + A * \sin^2(d/\lambda)} \qquad (1)$$

Where 'd' controls the spectral peak location of the filter, and 'A' controls the shape and width of the filters. Figure 2 shows an example set of spectral filters which span the LWIR spectral domain with 25 equally spaced filters. The filters are always equally spaced, and the optimization is to identify the ideal Full Width Half Maximum (FWHM) of each filter. Filters of the form given in eq. (1) vary in width, with the widest filters occurring at longer wavelengths, as can be seen by comparing the three filters colored as red, green and blue.

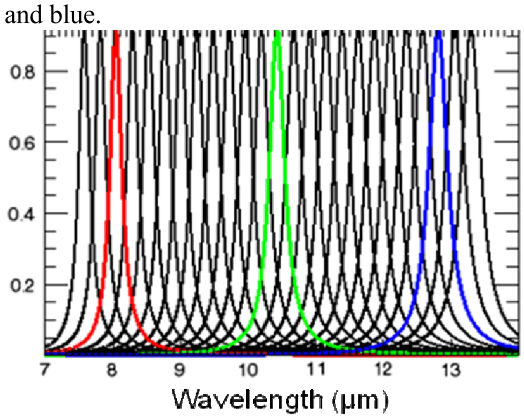

Figure 2: Responses of 25 equally spaced spectral filters which span the LWIR spectral domain.

A trade study was conducted to determine the number of bands that were necessary to adequately sample the LWIR spectral domain from 7 to 13 μm and resolve the spectral features of interest. The number of bands where varied from 9 to 100, always in an n^2 configuration (3^2, 4^2, 5^2, etc.), and the band widths were independently varied. In all cases the filter centers are equally spaced. Two metrics are used to evaluate the filter configuration: 1) Root Means Squared (RMS) error between the original input signal and the reconstructed signal after filtering and spectral deconvolution; and 2) a reconstructed mean SNR for an assumed detector detectivity.

3. TYPICAL BACKGROUND SIGNAL SIMULATION

A series of input spectra were generated using MODTRAN for a sensor at 20km altitude looking down onto various materials [4]. Figure 3 shows spectra at 5 cm^{-1} spectral resolution for a hot sandy region and for an ocean pixel.
Both spectra show a large ozone feature at 9.6 μm and characteristic drops in signal below 8 μm and above 13.5 μm due primarily to water transmission effects.

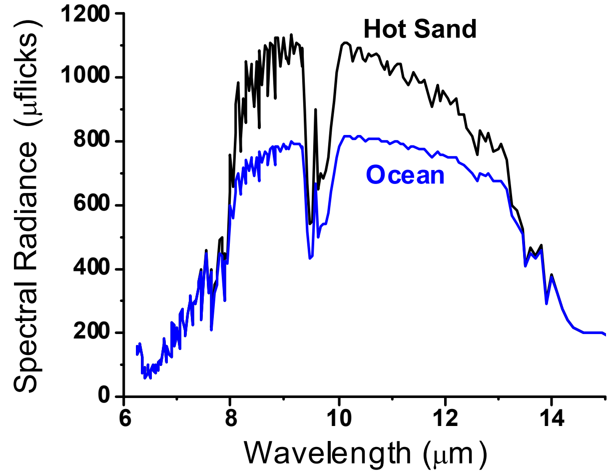

Figure 3: Representative input signals used in band selection analysis.

4. SPECTRAL RECONSTRUCTION

The RMS error between the original input spectrum and the spectral reconstruction of the signal is one of the two metrics being used to evaluate different filter configurations. The basic methodology for filtering and reconstructing the signal is described here. The filtered signature can be written as:

$$S_i = \sum_j F_{ij} L_j$$

Where the i^{th} filter is represented with j spectral points and the input signal is L_j. The reconstructed signal is then given by:

$$R_j = \sum_i P_{ji} S_i$$

Where P_{ji} is the pseudo inverse of the filter transform, as seen in Figure 4, and R_j is the reconstructed signal.

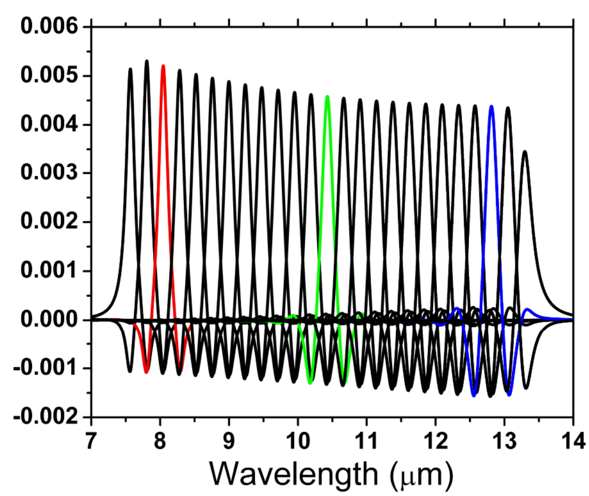

Figure 4: Pseudo inverse of the 25 spectral filters.

Figure 5 shows the filtered signal for the hot sand input spectrum and the resulting reconstructed signal for a 49 channel spectral system with a mean FWHM of 0.2 µm. It is important that the mean width of the filters is comparable to the size of the spectral features that one is trying to measure. If the channels are too wide, as shown in Figure 6 (red line) with FWHM of 1.2 µm, the spectral features of interest may be smoothed out, and if the channels are too narrow, Figure 6 (blue line) with FWHM of 0.07 µm, the input spectrum is under sampled and the resulting reconstructed spectrum is a poor representation of the input spectrum. The black line in Figure 6 represents the reconstructed spectra for the optimal 0.2 FWHM. The original input spectrum is also plotted in Figure 5 for reference.

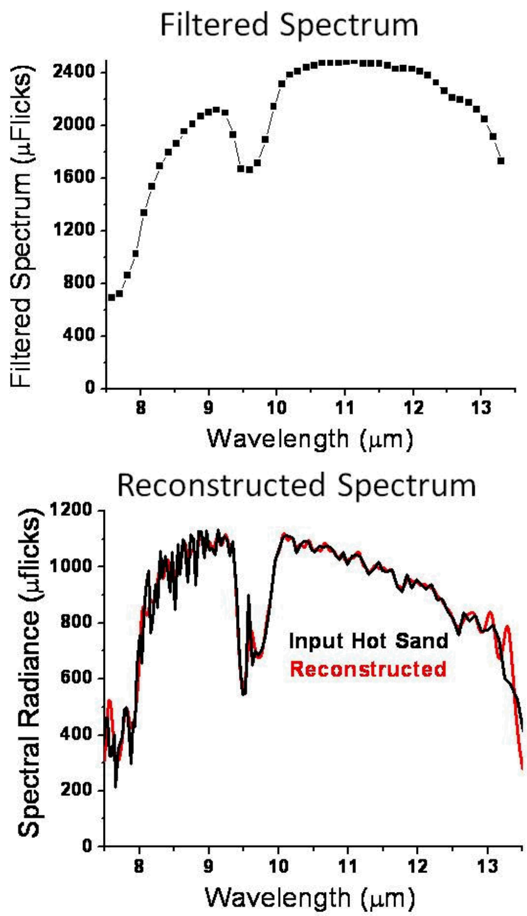

Figure 5: Filtered hot sand spectrum (top) and reconstructed signal (bottom) for 49 bands.

As seen in Figure 6, the RMS error between the reconstructed spectrum and the original input spectrum can be a useful metric for evaluation of the band widths. The second metric used for the analysis was the SNR determined for the reconstructed signal using a detector with a detectivity, or D* equal to 10^9 cm-Hz$^{1/2}$/W.

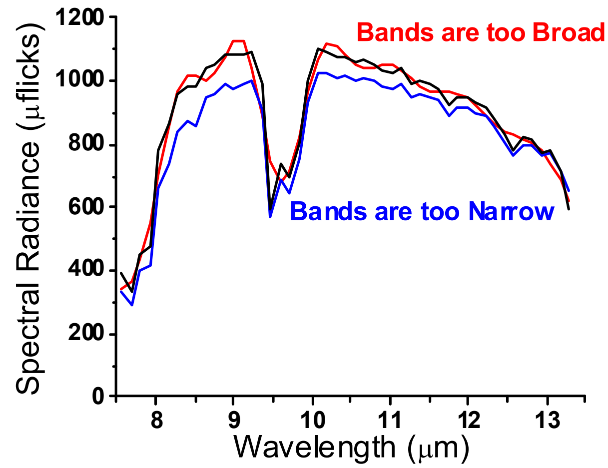

Figure 6: Reconstructed signal with channels that are broad (red line) and too narrow (blue line).

Figure 7 shows a comparison of the SNR (black line) and RMS error (red line) metrics for 16 and 64 spectral channel systems as a function of the mean width of the spectral channels for equally spaced channels from 7.5 to 13.5 µm. The minimum RMS error and best SNR occur at a similar value of the FWHM. Because the optimal number of bands would maximize the SNR and minimize the reconstruction error, a final selection metric has been identified by taking the ratio of the two: SNR/RMS Error. The peak of the ratio would then identify the optimal FWHM for a given number of bands, as seen in Figure 7 (blue line).

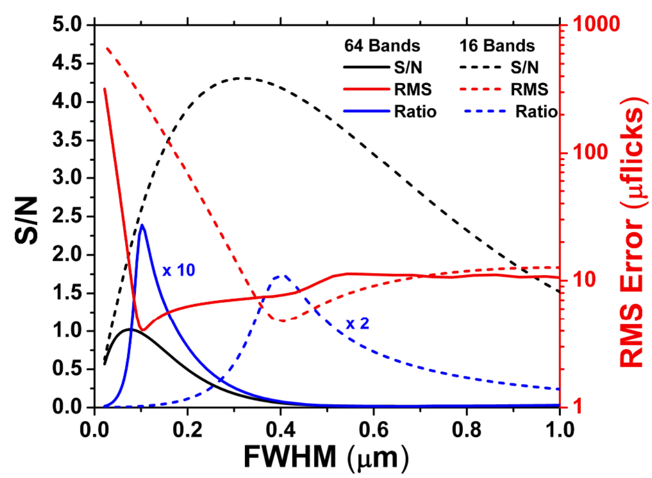

Figure 7: Reconstructed SNR and RMS error for spectral configurations of 16 and 64 channels as a function of the mean FWHM of the channels.

Number Channels	Optimal FWHM (μm)
9	0.830
16	0.410
25	0.300
36	0.190
49	0.140
64	0.110
81	0.087
100	0.070

Table 1: Resulting optimal FWHM bandwidth vs. number of channels spanning the LWIR region.

5. POTENTIAL UTILITY

One area that LWIR multispectral sensors have shown significant advantages over broadband sensors is in accurately identifying the temperature and emissivity of target materials [5,6]. Two materials with very different emissivities can have the same total in-band radiance at drastically different temperatures. Figure 8 shows a 300K blackbody (black) compared to a 380K graybody with an emissivity of 0.24 (red). The total radiance between 8 and 12 μm that a broadband sensor would collect would be the same in either case. Assuming blackbody radiation would result in a temperature error of approximately 80K for the hotter, lower emissivity material.

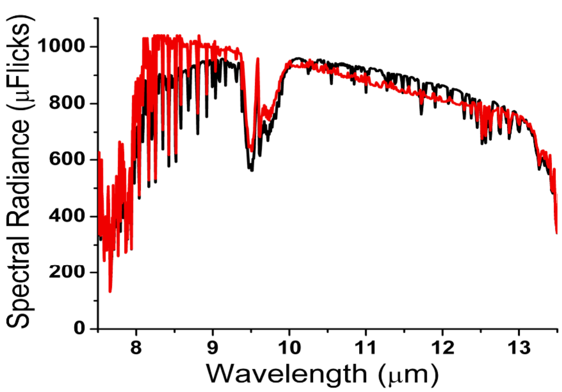

Figure 8: Spectral radiance from two graybodies at different temperatures and emissivities.

The two spectra were used as input to the 25 band theoretical sensor to evaluate the accuracy of the reconstruction. As seen in Figure 9, the two materials would be clearly distinguishable even though the total broadband radiance would be the same.

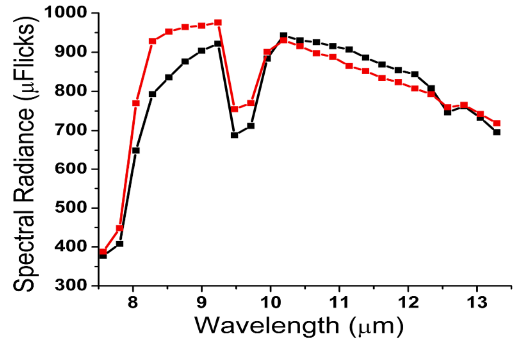

Figure 9: Reconstructed signal from varying emissivity graybodies for 25 channels at 0.3 μm FWHM.

6. CONCLUSIONS

Recent advances in material processing technology have made snapshot LWIR multispectral imaging possible. Due to the well known advantages for multispectral data exploitation, this technology has potential for a number of remote sensing applications. This work has presented a useful metric for identifying the optimal bandwidth that should be used based on the number of spectral channels that have been identified. An algorithm that uses the pseudo inverse of the filters has been developed that is capable of removing the spectral overlap of the channels and can perform an accurate spectral reconstruction of the original signature.

7. REFERENCES

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