Remote Sensing

Detecting gas signatures in hyperspectral imagery using wavelet packets

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A new pixel-by-pixel method allows for easy parallel processing of hard-to-detect signals while performing as well as matched filter techniques.

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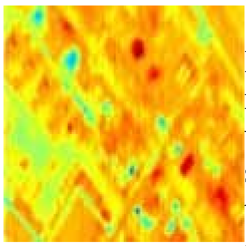

Every solid, liquid, and gas has a unique spectral signature. This signature represents the reflection, emission, or absorption of energy at each wavelength across the electromagnetic spectrum. Hyperspectral imaging sensors measure this signature for hundreds of wavelengths. By analyzing these signatures, a material can be remotely identified by comparing the collected signature to a reference library. Many of the existing signature-matching methods, such as matched filter, are statistics-based approaches. These techniques cannot always be easily parallelized for high-performance computing applications and architectures. As spectral imagers become more widely available, processing requirements are shifting from analysis of individual collection campaigns to daily processing for globally collected data. The advent of persistent hyperspectral applications will require the capability to work with extremely large data sets and more computationally tractable methods for real-time processing.

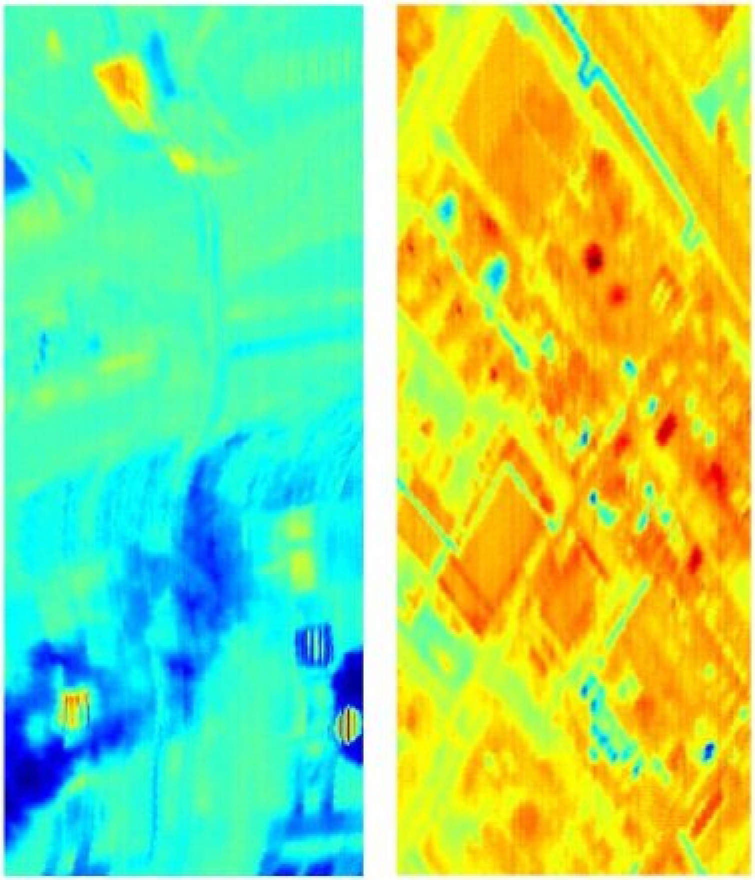

Figure 1. Sulfur dioxide (SO_2) plume (left) and benzene plume (right).

We suggest, in contrast to matched filter methods, a pixel-by-pixel approach to weak signature detection in hyperspectral imagery.[1] By this method data analysis can be easily parallelized for multicore, multi-cpu, or multinode computer architectures. This approach also lends itself to both airborne real-time and large-scale ground-based data processing. The image formed by each individual wavelength in hyperspectral imagery is contained within an *x*-*y* plane. Because the imagery collects data for hundreds of wavelengths, that information is contained within the *z*-axis. A cube of data is formed in which the *z*-axis of each pixel represents its spectral signature. In this pixel-by-pixel approach, the wavelet packet transform (WPT) is applied to the spectral signature of each individual pixel.

In general, the wavelet transform and WPTs find widespread use in signal processing.[2] The idea behind applying the transform to hyperspectral data is to generate features for improved pattern recognition between the pixel signature and a reference (or target) signature. Fundamental to wavelet and wavelet packet transforms is the application of multiple resolution signal analysis[3] to separate the fine and large-scale properties of the input signal. Applying the WPT to individual spectra obviates the need to calculate the statistics of the entire data set. This procedure is thus unlike matched filter methods, which require access to the entire data cube to calculate a covariance matrix.

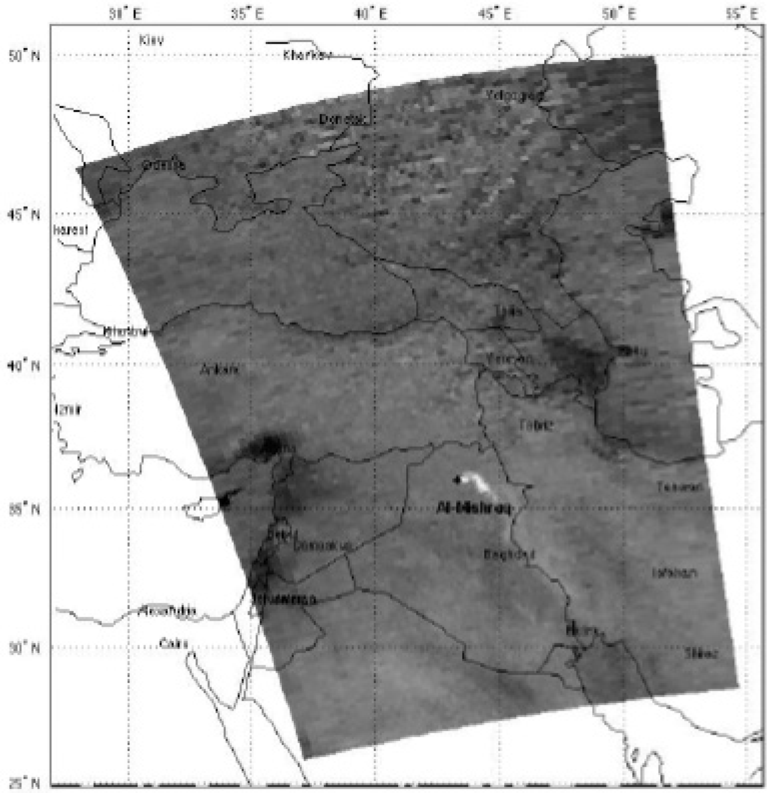

Figure 2. Wavelet packet subspace (WPS) SO_2 detection, Al-Mishraq, 29 June 2003.

Using the WPT, it is possible to find an orthonormal basis that best represents the weak target signature according to some selected measure. This parallels principal components analysis (PCA) in generating an orthogonal basis. The difference is that PCA depends on variance of the data, and the wavelet packet on a user-defined cost function. Finally, for the weak target detection problem, an orthonormal basis is selected from the wavelet packet library that best represents the associated spectrum. This is referred to as the wavelet packet subspace (WPS).

The WPS method has been applied to both airborne[4] and spaceborne spectral data with good results. Figure1, for example, shows detection of sulfur dioxide (SO_2) and benzene (C_6H_6) gas plumes. SO_2 is visible in the dark blue areas within the image, while the C_6H_6 plume is the dark red area in the middle upper portion of the image. In Figures 2 and 3, data from NASA's Advanced Infrared Sounder is used to detect SO_2 from the Al-Mishraq sulfur plant fire in 2003. The plume is clearly visible in both figures, which were generated several days apart, as the bright area emanating from Al-Mishraq.

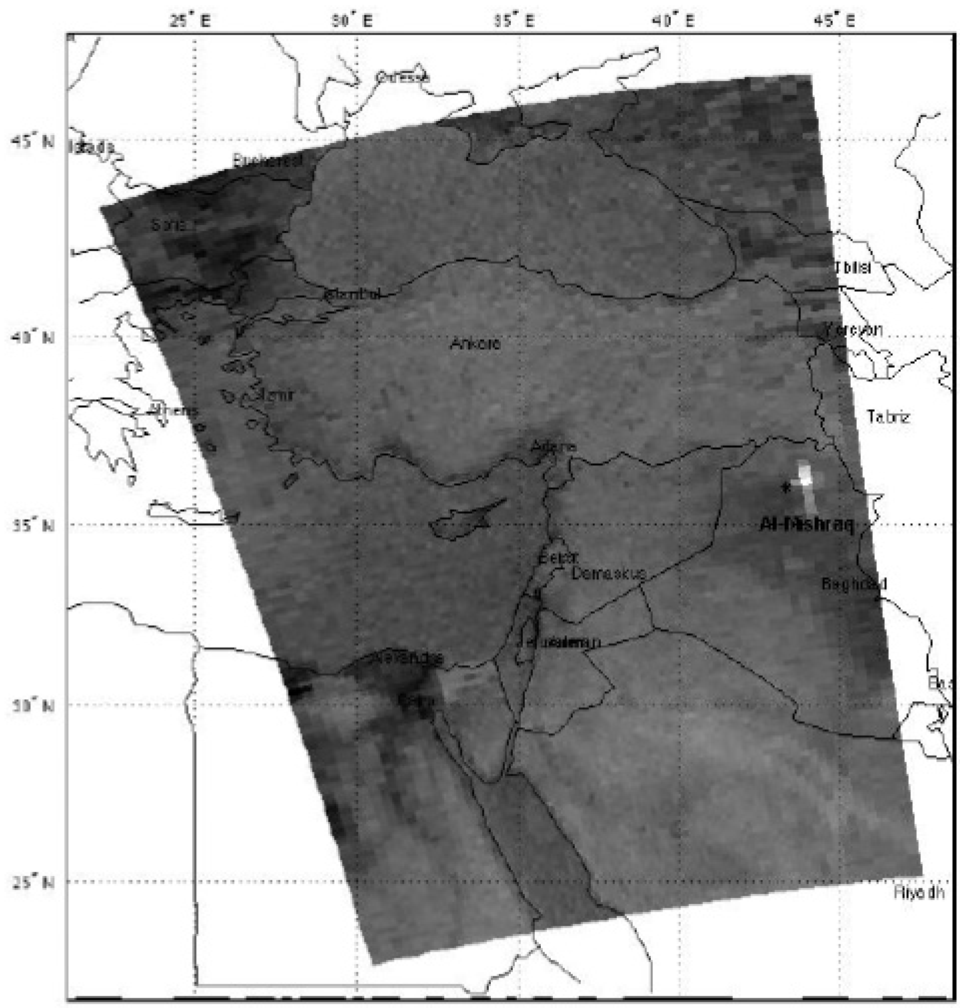

Figure 3. WPS SO_2 detection, Al-Mishraq, 3 July 2003.

Results show that, using the WPS method, it is possible to detect weak gas signatures in hyperspectral imagery. This procedure has been demonstrated for both airborne and spaceborne sensors. The pixel-by-pixel approach facilitates parallel processing of hyperspectral imagery and is suitable for either real-time applications or large-scale ground processing. Future work will examine other gases and weak target signatures with a view to applying the method to reflective regions of the spectrum.

The data used for the WPS result in Figure 1 was collected by the Airborne Hyperspectral Imager and provided by David Williams at the Environmental Protection Agency. The AIRS data used to generate the WPS result in Figures 2 and 3 was downloaded from NASA's Data and Information Services Center.[5]

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