Robust Hyperspectral Detection with Algorithm Fusion

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Detection algorithms for hyperspectral imagery can vary significantly in their relative performance, depending on the scene and object of interest, even within a single class of problems. Often no single algorithm is a clear "winner" or "loser" across test cases. A robust, effective, and automated hyperspectral detection system can therefore benefit from a method to assess the performance of candidate algorithms and select the "best" one, or a method that would provide comparable performance by fusing the algorithms.

This paper presents two mathematically simple fusion methods that are effective with a family of maximum likelihood-based detection algorithms that includes the spectral angle mapper (SAM), ACE (adaptive covariance estimator) detector, and subspace projection [Manolakis and Shaw, 2002; Keshava, 2006]. The algorithms outputs contain reciprocals of modeling residuals, such that large positive values correspond to a high likelihood of object presence. These outputs are concatenated into a multichannel image stack, and standard detection methods are applied to the stack.

The first fusion method can be motivated by assuming that the object of interest is present in the scene, and that the algorithm outputs for that object are among the largest in the image. A target vector for the stack is defined using the maximum algorithm outputs, and a matched filter is used to search for the vector. This approach amounts to weighting the algorithm output images to optimize signal-to-background noise, where the "noise" is the de-meaned, covariance-whitened stack data, and the "signal" is the correspondingly transformed target vector. The second fusion method is a simple anomaly search using Mahalanobis distance. This is a standard method used for fusing multimodal data, such as hyperspectral plus synthetic-aperture radar [Nasrabadi, 2008] or time series of multispectral images [Theiler and Adler-Golden, 2008].

We have used the two fusion methods with four detection algorithms that apply different linear transformations to the hyperspectral data. An algorithm for whole-pixel objects, representing the SAM algorithm, applies no transformation. The remaining algorithms are suitable for either whole-pixel or subpixel objects. A subspace projection (linear unmixing) algorithm projects out background endmembers obtained from an automated procedure based on the Max-D algorithm [Bajorski et al., 2004]. Another algorithm whitens the data using the image covariance or correlation matrix; the latter case represents the ACE detector. The fourth algorithm is similar but uses a background covariance or correlation matrix computed by reconstructing the data from the background endmembers. This algorithm is more robust in the presence of a large, spectrally anomalous target that might otherwise contaminate the covariance.

This paper presents some example results from applying the fusion methods to two different types of hyperspectral imagery. The first data set consists of emissivity retrievals from SEBASS long-wavelength infrared (LWIR) imagery [Adler-Golden et al., 2008] containing panels of measured spectral emissivity occupying multiple full pixels. The second set, taken from the Rochester Institute of Technology "blind test" data [Snyder et al., 2008], consists of reflectance retrievals from a visible/near-infrared/short-wave-infrared (visible/NIR/SWIR) HyMap image containing subpixel fabrics and vehicles of measured reflectance. The individual detection algorithms and two fusion methods were run on these datasets, and receiver-operator characteristic (ROC) curves for object detection were computed and compared.

With these data sets the fusion methods are found to provide more consistent detection performance across all test cases than any single algorithm, and for a given test case they usually perform as well as one of the top two algorithms. We have observed similar behavior with other data not presented here. As the methods are not inherently specific to a particular wavelength range, type of scene, or object of interest, they may be useful in a wide range of applications. The sensitivity of the results to the mathematical form of the algorithm outputs remains to be investigated. The outputs used here have a signal-to-noise interpretation. Other quantities that are monotonically related to them would yield equivalent ROC curves with the individual algorithms but not with the fused algorithms.

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