Hyperspectral Detection and Identification with Constrained Target Subspaces

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Hyperspectral imaging (HSI) from airborne or space-based platforms has proven to be a valuable technology for detecting and classifying materials and objects on the Earth's surface based on their spectral signatures. Analysis of these data can be quite challenging, however, as the signatures contain variable atmospheric components and surface spectral properties. In the visible to near-infrared wavelength region there are well-established atmospheric correction or "compensation" methods for converting the HSI data to reflectance spectra, thereby eliminating atmospheric effects and enabling detection, classification and identification with material spectral libraries. For thermal infrared (IR) HSI sensors, analogous methods exist that characterize and remove atmospheric emission and transmittance contributions and retrieve surface emissivity; however, these algorithms are more complex, less accurate, and more computationally intensive due to the need to retrieve additional information on surface and air temperatures.

An alternative analysis approach that may be especially attractive for the thermal IR regime is based on radiance spectrum simulation. Here a comprehensive dataset of potential target spectral signatures, encompassing a sufficiently broad range of atmospheric conditions, surface temperature, etc., is simulated, and the results are compared to the measured pixel spectra. A good match (low residual) strongly suggests that the pixel contains the target in question; a poor match indicates otherwise. The key is to develop a highly efficient matching algorithm, one that does not require numerous case-by-case comparisons. In an "invariant" subspace approach described by Healey and Slater, the target dataset, which includes all possible sources of variability, is compressed down to a small subspace of orthogonal basis vectors derived from singular value decomposition (SVD). To find a whole-pixel target, the pixel spectra are least-squares fit using this basis set, and an error residual is computed and thresholded. The invariant approach was later extended to the detection of subpixel targets by Thai and Healey by modeling the subpixel background as a second subspace, using background SVD basis vectors as additional fitting components. More recent work on subpixel detection has focused on the use of different types of basis sets, including endmember basis sets.

One limitation of present subspace methods is that the size (as distinguished from the dimensionality) of the subspace spanned by the basis vectors is not constrained, since the basis vector coefficients in the spectral fits are allowed to take on any values. Potentially, non-target spectra might be closely fit with the target basis set using unphysical coefficient values, resulting in false detections. To overcome this problem we have investigated two different constrained fitting methods for whole-pixel detection. In the first method, bounds are placed on the SVD fitting coefficients. That is, the best-fit representation of each pixel is constrained to lie within a hyperrectangle in the SVD coordinate space, whose size is limited by the target dataset. The error of the pixel spectrum fit is then evaluated using the bounded coefficients. In the second method, non-orthogonal spectral endmembers rather than SVD basis vectors are used to fit the pixel spectra. All targets are represented by positive, sum-to-unity combinations of the endmembers to within a small tolerance. The endmember-finding and fitting are performed using a variant of the Sequential Maximum Angle Convex Cone (SMACC) method of Gruninger. We report results from applying both constrained and unconstrained subspace methods to the detection of test panels in LWIR hyperspectral imagery.