A Web-based Search Service to Support Imaging Spectrometer Instrument Operations.

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Introduction: Imaging spectrometers yield rich and informative data products, but interpreting them demands time and expertise. There is a continual need for new algorithms and methods for rapid first-draft analyses to assist analysts during instrument operations. Intelligent data analyses can summarize scenes to draft geologic maps, searching images to direct operator attention to key features. This validates data quality while facilitating rapid tactical decision making to select followup targets. Ideally these algorithms would operate in seconds, never grow bored, and be free from observation bias about the kinds of mineralogy that will be found.

Approach: We have developed a method for operator-directed search within imaging spectrometer data. Analysts can use a pure web interface to build a library using spectra from libraries or previous images, and then search for similar spectra within catalog images. The service is analogous to a search engine capable of finding a match to a user query. The results appear in the form of a map identifying spectral signature matches to the target. Searching within a single image reveals areas of similar reflectance to assist understanding of scene composition. Searching across images can help discover mineral anomalies as well as understand trends in composition on planetary scales.

Just as web search involves more than matching phrases, spectral search is more challenging than simply matching the shape of the spectrum. The background substrate and illumination changes can cause the same signature to appear very different across scenes. Here, the search service uses an adaptive matched-filter approach that compensates for the context and background characteristics of each scene. It searches millions of candidate pixels in less than a second. An additional benefit is that the inverse covariance matrix (a natural byproduct of the signature matching) can be used for anomaly detection with the classic Reed-Xiaoli (RX) algorithm.

Search Algorithm: Background-matched filters have a long history and wide acceptance in subpixel detection problems. Although they have not been widely applied to planetary scenes, we find they effective for many of the small outcrops, concentrations of volatiles and other features of interest that investigators seek on planetary surfaces. Following [1], we express the target as a vector $\boldsymbol{t}$ and the test spectrum as a vector $\boldsymbol{x}$. We compute a background covariance matrix Σ and mean $\boldsymbol{\mu}$ using data from the test image. We then invert the covariance using dominant mode rejection and diagonal loading as per [2]. The matched filter output $\boldsymbol{y}$ approximates the mixing fraction of the target. We compute this quantity by first whitening the background to have unit spherical covariance, and then evaluating the dot product projection of the target and candidate spectra.

$$\boldsymbol{y} = \frac{(\boldsymbol{x}-\boldsymbol{\mu})^T\Sigma^{-1}(\boldsymbol{t}-\boldsymbol{\mu})}{(t-\boldsymbol{\mu})^T\Sigma^{-1}(\boldsymbol{t}-\boldsymbol{\mu})}$$

Finally, we compute the Mahalanobis distance $\boldsymbol{m}$ from the target to the background, forming a second score that penalizes large magnitudes orthogonal to the target vector. This indicates potential false positives due to localized artifacts or other non-target anomalies [3].

$$\mathbf{m} = (\boldsymbol{x}-\boldsymbol{\mu})^T\Sigma^{-1}(\boldsymbol{x}-\boldsymbol{\mu})$$

Performing this computation for each candidate image pixel yields a map for each query spectrum. The most computationally expensive step of computing the background covariance can be performed offline in advance, resulting in a very efficient and fully-parallelizable procedure.

Web Integration: We have developed architectures to present this capability as a web service in conjunction with ongoing standardization projects underway by the NASA Advanced MultiMission Operations System (AMMOS). This permits the service to be used by any client device containing a web browser. It obviates the need to download large hyperspectral data cubes, permitting fast and efficient image browsing by all members of a distributed operations team.

Demonstration: Figure 1 shows a typical web interface showing the result of a typical search within an AVIRIS scene [5]. We also considered multiband images from the Dawn Framing Camera [6] to demonstrate the system's utility for these products. The web interface provides a convenient method for exploring and browsing these data without the licensing requirements of full commercial hyperspectral analysis software or the challenge of distributing many Gigabyte-scale data cubes to multiple members of a distributed instrument team.

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