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Minerals detection tools for hyperspectral images

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Abstract

Detecting minerals on a very large hyperspectral dataset (> To) is a difficult task that may be solved using fast linear unmixing techniques under contraints of positivity and sum-to-one. We test different algorithms and different reference database on synthetic data simulating the observation. We show that new algorithms can handle linearly dependent spectra in the database as expected theoretically. This possibility offers a new opportunity to detect minerals in very hard condition such planetary surfaces.

1. Introduction

In remote sensing hyperspectral imaging, a set of images is recorded at various spectral bands by the sensor that measures the solar light reflected and scattered back from the surface and from the atmosphere. We modeled this transfer as a linear mixture of the scene component spectra (endmembers) and additional spectra. Using matrix notations, one can write:

$$\mathbf{X} \approx \mathbf{AS} \quad (1)$$

where each row of **X** contains the p-th pixel spectrum and matrix **S** contains the endmember spectra. In this model, the weight A of each component spectrum S is related to its abundance in the surface area corresponding to the underlying pixel. Supervised linear unmixing problem consists of estimating matrix A knowing X and S, in contrary to unsupervised unmixing that consists of estimating matrix A and S, knowing only X [1]. A first hard constraint is the non-negativity of the elements of A since they correspond to abundances of the surface components:

$$A_{p,r} \geq 0, \ \forall p,r \quad (2)$$

A second constraint that may be imposed is the sum-to-one (additivity) constraint on the abundances that should sum to unity for each pixel p:

$$\Sigma_r A_{p,r}=1, \ \forall p \quad (3)$$

Thanks to both constraints (2) and (3), the problem is not undetermined using some linearly mixed spectra **S**. We tested here the behavior of two algorithms to fit the continuum using this possibility.

2. Methods

On order to estimate the detection limit in a realistic but very hard condition, we created a synthetic dataset made of 1000 spectra: 90% of flat spectra and 10% of a random binary mixture. We then alterate these spectra by using a radiative transfert model to simulate the reflectance observed at the spaceraft using the aerosols optical properties from Vincendon et al. [2]. The aerosols content is defined by the Aerosols Optical Thickness (AOT). Then we add the noise simulating the instrument noise (from OMEGA dark current).

The FCLS method solves the unmixing problem under non-negativity and sum-to-one constraints [3]. Since no closed form expression of the optimal abundance vector can be derived under these two constraints, an iterative scheme is developed. The non-negativity constraint is classically handled by introducing the Lagrange function associated with the criterion to be optimized. The sum-to-one constraint is considered as an additional measurement equation leading to a new cost function. This method was previously tested to detect ices and liquid water on Mars [4]. An alternative approach, called IP-FCLS was recently developed [5] using primal-dual interior point optimization approach.

For both algorithms, we tested different reference spectral database **S**, including several linearly dependent data.

3. Results

Figure 1 presents the collection of 32 reference spectra from laboratory measurements and synthetic data [6] that from our expertise is the best compromise to fit the data using FCLS. It corresponds to the maximum linearly dependent spectra allowed in the algorithm. If one adds the positive slope for instance, the matrix inversion of the FCLS algorithm fails.

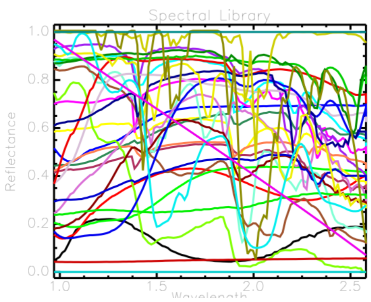

Figure 1: Reference database of 32 spectra, including two flat at 0.01 and at 1.0 and the negative slope.

This behavior is not present for the IP-FCLS algorithm since no matrix inversion is involved. One can add many linearly dependant spectra, opening the possibility to better fit the continuum and tackle the non-linearity due to complex radiative transfer in the surface and atmosphere. In practice, the most reasonable additional artificial spectra are a basis of sine and cosine at very large wavelength in order to fit the general shape of the continuum (4x and 2x period in order to prevent from specific absorption bands of some minerals, like pyroxenes).

In the case of the slope, figure 2 shows that more than 80% (false detection < 5%) of the minerals can be detected with our methods with a decreasing efficiency with increasing aerosols optical thickness. When, the raw spectra are directly used, the detection limits is below 60% (false detection > 30 %), showing clearly the usefulness of the additional spectra. The dependance on aot is very low for AOT <0.1 but the detection rate is still 70% for AOT=1.

4. Summary and conclusion

We showed that recent algorithms of linear unmixing including positivity and sum-to-one constraints could provide new possibility to fast fit the continuum in addition to “spectral abundance” estimation.

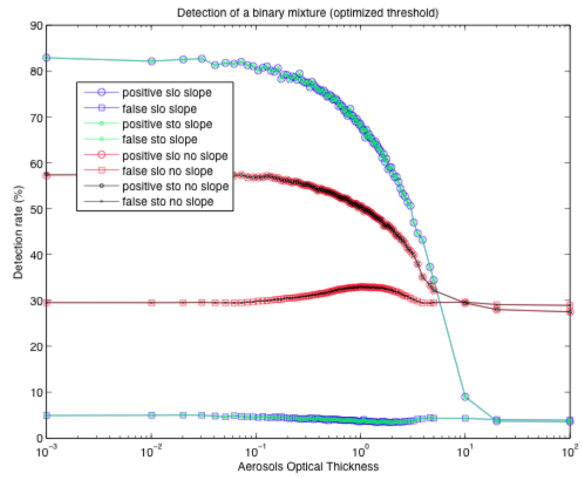

Figure 2: Positive detection rate (circle) and false detection rates (square) with optimized threshold as a function of AOT for IPLS. For each algorithm, the positive/false detection rates are computed using 32 endmember spectra only (no slope), or 44 endmember spectra including additional spectra (slope). IPLS has an option of sum-lower-than-one (slo) or sum-to-one (sto). The case without aerosols is plotted at AOT=10^{-3}.

References

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