ACCURACY ANALYSIS OF LUNAR MINERAL ENDMEMBER EXTRACTION USING SIMULATED CHANG'E-1 IIM DATA

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KEY WORDS: Lunar, Endmember Extraction, Chang'E-1, IIM, Simulation

ABSTRACT: The Interference Imaging Spectrometer (IIM), as one of the most important payloads on Chang'E-1 satellite, has acquired large amount of hyperspectral data for retrieving element and mineral information of the lunar surface. It's still a great challenge to retrieve mineral distribution with IIM data, due to the fact that the spectral range of IIM data is limited to 480-960nm which does not covers the main lunar minerals' absorption centers. At present, there is few precise quantitative mineral distribution of the lunar surface to be used for the validation of the retrieved results. In this study, we implement a linear simulation of IIM data to analyze the accuracy of mineral endmember extraction with IIM data.

In the linear simulation, Gaussian response model is used to resample the lunar mineral sample spectra, which are measured by RELAB of Brown University, to the same spectral center and resolution with IIM data, and random noises of the same trend with IIM data are added into the simulated data. The lunar mare and highland are simulated according to the different composition of plagioclase, clinopyroxene, olivine and ilmenite. Four endmember extraction approaches (VCA/ICA/MVSA/ SISAL) are employed to extract endmembers and spectral angle distance (SAD) is used as criterion for accuracy analysis.

The results show that all the SADs of endmembers extracted by MVSA and SISAL are lower than 0.1, and that of MVSA is a little lower than SISAL. Plagioclase, of which the SADs are lower than 0.015, can always be extracted by all approaches. All SADs of pyroxene and ilmenite are lower than 0.1. Olivine, of which the SADs are high to 0.35 when the ICA approach is implemented, has the lowest extraction accuracy. This may be caused by the unobvious V-NIR spectral features of olivine spectrum.

1. INTRODUCTION

Interest in the Moon started to increase at the beginning of the 21st century as many countries focused their space exploration programs on the Moon, such as the SELENE/Kaguya mission of Japan (2007), Chandrayaan-1 mission of India (2008), Lunar Reconnaissance Orbiter of USA (2009), and Chang'E mission of China (2007). One common aim of these missions is to transport humans onto the moon surface in the future. But for the present stage, the geological exploration of the moon is one of the major tasks of each country.

The Interference Imaging Spectrometer (IIM) (Tab.1), which is one of the major payloads on Chang'E-1 satellite, is aimed to acquire the composition of the Moon surface by the high-resolution spectrum information. But the spectral range of IIM data is limited to 480-960nm which does not covers the most lunar minerals' absorption center, and there is not obvious distinguishing spectral features either. Thus, it is a big challenge to identify minerals within the limited spectral range. However, some researches on IIM data have been done (Liu, Qiao et al. 2010; Wu, Zhang et al. 2010). At present, there is few precise quantitative mineral distribution of the lunar surface to be used for the validation of the retrieved results. In this study, we implement a linear simulation of IIM data to analyze the accuracy of mineral endmember extraction with IIM data.

Tab.1 Chang’E-1 IIM specification

Image width	25.6km
Resolution	200m
Image coverage	75 °N~75 °S
Spectral coverage	480~960nm
Bands number	32
Bit	12bit
MTF	⩾0.2

The remainder of this paper is organized as follows. Section 2 describes the resample of the lunar sample spectra and the simulation method. Section 3 analyzes the extraction accuracy of the main lunar minerals with four endmember extraction algorithm in different situations. In section 4, a conclusion is given and the difficulties of the mineral extraction in true IIM data are discussed.

2. SIMULATION OF CHANG’E-1 IIM DATA

The mineralogy of the Moon is relatively simple, most lunar rocks being dominated by mixtures of feldspar, pyroxene, olivine and ilmenite. The spatial resolution of IIM data is 200m, and it is supposed that the pixels of IIM image are linear mixed (Singer and McCord 1979). Thus, the Chang’E-1 IIM data is linear simulated with lunar sample spectrums of plagioclase, pyroxene, olivine and ilmenite[1]. The pyroxene specifically refers to clinopyroxene, due to that the abundance of clinopyroxene is much higher than orthopyroxene (Lucey 2004).

The lunar mineral spectrums, which are measured by Brown university reflectance experiment laboratory with the samples taken back to the Earth by Apollo and Luna missions, are collected and resembled into the same spectral range and spectral resolution with IIM data using Gaussian response model (Fig.1).

Mare and highland are the two main landform types on the Moon. Mare accounts for 17% of the total lunar surface while highland 83%. The main difference of mare and highland is that mare is mostly covered by basaltic lava while highland is not. So mare contains more ilmenite than highland, and highland contains more plagioclase than ilmenite (Ouyang 2005).

[1] http://www.planetary.brown.edu/relabdocs/relab_disclaimer.htm

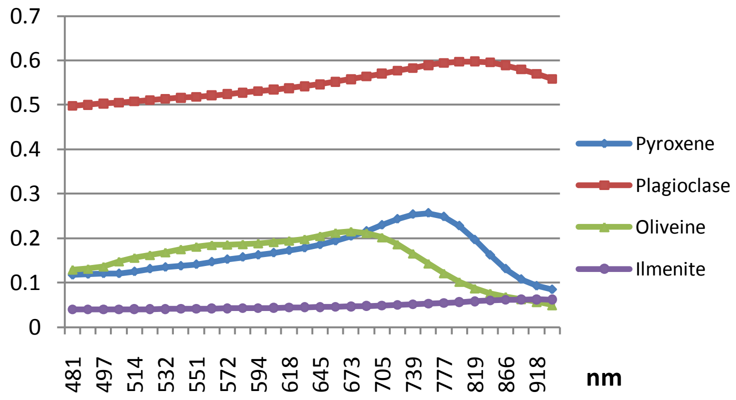

Fig.1 Lunar minerals' spectrums resampled to IIM resolution using Gaussian response model. The spectral coverage of 480-960nm does not cover any mineral's absorption center. The spectral features to distinguish these minerals are only the single peak position and the absolute value of reflectance.

The abundance of plagioclase to ilmenite of simulated mare is set 60%:40% while simulated highland is set 90%:10%. Because the abundance of mare and highland are not distinguished strictly, a transitional area is set with the abundance of plagioclase and ilmenite 80%:20%. The above mixed minerals with different ratio of plagioclase and ilmenite are the background minerals of mare, highland and the transitional area. Then the four minerals mixed with the corresponding background with the ratio marked on the left of Fig.2. Considering the visual effects, each block is set 8 pixels by 6 pixels, and each pixel in the same block has exactly the same spectrum.

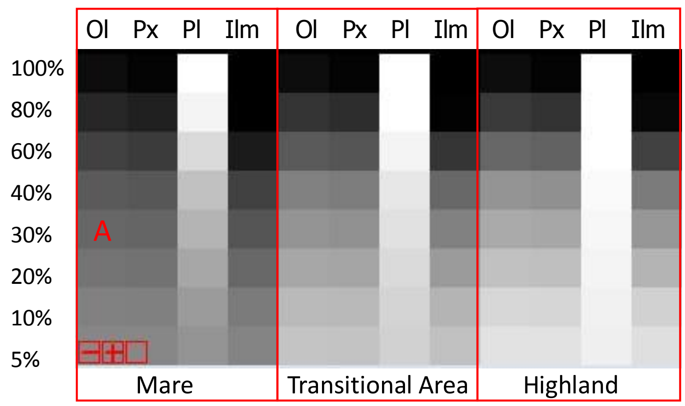

Fig.2 Simulated IIM data of lunar mare, highland and the transitional area (band 1 of IIM). Take block A as an example. The background of mare contains 60% plagioclase and 40% ilmenite, then 30% olivine and corresponding 70% background mixed to form block A. So block A contains 30% olivine, 70%×60% plagioclase and 70%×40% ilmenite (Ol-olivine, Px-pyroxene, Pl-plagioclase, Ilm-ilmenite). Thus, the blocks in first line are pure endmembers.

3. ACCURACY ANALYSIS OF LUNAR MINERAL ENDMEMBER EXTRACTION

The Endmember Extraction Algorithms (EEAs) can be categorized into two classes: Endmember Identification Algorithm (EIA) and Endmember Generation Algorithm (EGA) based on the hypothesis of the existence of the pure pixels. EIAs directly choose 'pure' pixels as endmembers from the data while EGAs generate new endmembers based on the origin pixels of the data. In the paper, two EIAs and two EGAs are employed in the endmember extracting of the simulated data. They are Vertex Component Analysis (VCA) (Nascimento and Dias 2005), Independent Component Analysis (ICA)(Hyvarinen and Oja 2000) and Minimum Volume Simplex Analysis (MVSA)(Li and Bioucas-Dias 2008), Simplex Identification via Split Augmented Lagrangian (SISAL)(Bioucas-Dias 2009).

3.1 The endmember extraction of the simulated IIM data

The four EEAs mentioned above are implemented on the simulated IIM data to analyze if the EEAs can extract exactly the pure pixels. The results show that VCA and MVSA algorithm can extract exactly the four endmembers while ICA and SISAL cannot. The ICA algorithm can not identify the pyroxene endmember totally, and the plagioclase spectrum generated by the SISAL algorithm is different from the pure spectrum on the absolute value. Reviewing the above analysis, it is easy to find that the VCA and MVSA algorithm perform best with SISAL followed, and ICA performs worst.

3.2 The anti_noise analysis on the noise_added IIM simulated data with pure pixels

To ensure the fidelity of the simulated IIM data, noises with the same signal to noise ratio (SNR) level in each band of the true IIM data were added to the simulated IIM data shown in Fig.2. Fig. 3 shows spectra with noises and without noises. Then the four algorithms are implemented on the noise_added IIM simulated data with pure pixels. Spectral angle distance (SAD) of the extracted endmember and the pure endmember is used as criterion for accuracy analysis. The equation for calculating SAD is expressed by Eq.1, where a and â denote the pure spectrum and the extracted spectrum, respectively. The extraction accuracy is illustrated in Fig.4, and the analysis will be described in next subsection.

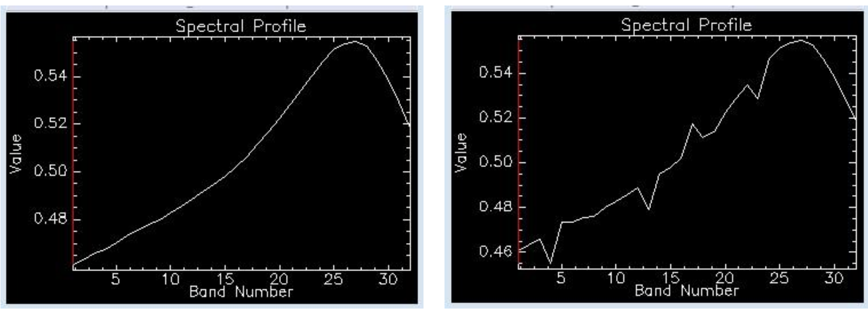

Fig.3 Comparison of spectrums before (Left) and after (Right) adding noises

$$\mathrm{SAD} = \cos^{-1}\left(\frac{\mathrm{a}^{\mathrm{T}}\hat{\mathrm{a}}}{\|\mathrm{a}\|\cdot\|\hat{\mathrm{a}}\|}\right) \tag{1}$$

3.3 Anti_noise analysis on the noise_added IIM simulated data without pure pixels

In this subsection, the first line of blocks in the simulated data, which are pure pixels as previously mentioned, is removed to form a simulated data without pure pixels. Then the four EEAs are implemented again on this simulated data with SAD as accuracy criterion (Fig.4).

After removal of the pure pixels, the extraction accuracy drops a lot with each EEA except plagioclase. But most of the spectral angle distances (SAD) are less than 0.1, which means the extracted results can be used as endmember for further applications. For the simulated data with pure pixels, the extracted results show little obvious difference with each EEA except olivine extracted by ICA algorithm. But for the simulated data without pure pixels, MVSA algorithm performs best, followed by SISAL algorithm. This means that EGA performs better than EIA in the image without pure pixels. In both situations, the olivine SADs of ICA algorithm is greater than 0.3, which can be treated as wrong endmembers.

Viewing from the mineral endmember extractabilities, the SADs of plagioclase with each EEA in both situations are less than 0.02 which have the highest accuracy. Undoubtedly, plagioclase is the easiest mineral to be extracted on lunar surface. All the SADs of pyroxene and ilmenite are less than 0.1, though not as small as plagioclase, they are small enough to make the extracted spectra as the endmembers. Olivine is the mineral hardest to be extracted due to the large SADs, followed by pyroxene.

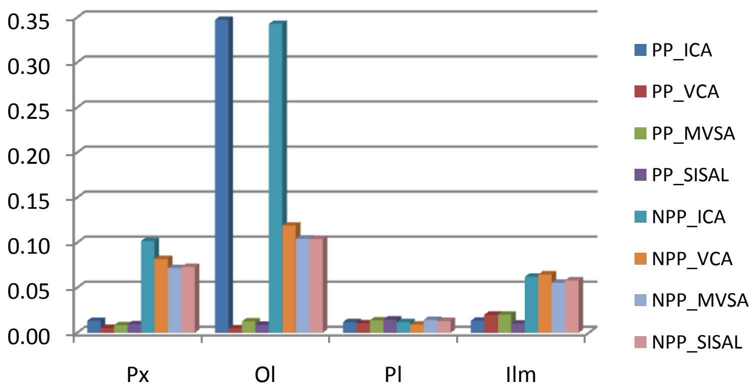

Fig.4 SADs of the extracted endmembers by each EEA and the pure endmembers. PP denotes the simulated data with pure pixels and NPP denotes the simulated data without pure pixels. The unit of SAD is degree.

4. CONCLUSION AND DISCUSSION

The spectral range limit of IIM data indeed causes some difficulties in the further applications in extracting mineral information. This simulation experiment for endmember extraction is implemented to see if the main minerals can be extracted with this limited spectral range. So the comparisons of the four EEAs will not be discussed. The results show that basically the main lunar minerals can be distinguished and extracted in this spectral range (namely 480-960nm), and some minerals have high extraction accuracy, such as plagioclase. Besides, other minerals can also have good extraction accuracy by choosing suitable endmember extraction algorithm.

Plagioclase, due to the high spectral reflectance, is the easiest mineral to be extracted. It is the most abundant mineral on the lunar surface, so the extraction with true IIM data will not be difficult. Pyroxene and olivine have the similar reflectance value and close spectrum peak, so there may be a problem in distinguishing them as showed in the experiment. Ilmenite has good extraction accuracy in the experiment, but it will not be so easy to extract it in the true IIM data due to the low reflectance value and complicated mixing situation on the Moon. So there is a lot of work to do in applying the IIM data for mineral information extraction or mapping. However, the experiment results give much confidence to the application of the IIM data.

5. ACKNOWLEDGEMENT

This research was supported by China 863 High Technology Development Program "Study on identification and

Quantitative Retrieval of the Lunar Surface Compositions"（2010AA122203）

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