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Lunar terrain and mineral's abundance automatic analysis

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ABSTRACT

The image is the important data in the lunar exploration. The main objective of this work is to detection lunar craters with the multi-information fuzzy logic method, and to quantify the image's terrain and the abundance of lunar surface minerals based on crater distribution law and soil characterization consortium data set with lunar surface reflectance. We implement image processing to recognize lunar crater and analysis lunar terrain; use lunar reflectance model to solve mineral reflectance question; joint commonly used look-up lunar reflectance tables and least squares to solve lunar surface reflectance questions; and calculate the minerals reflectance, region reflectance, and then estimate abundance of lunar surface soil minerals. An actual lunar image (Apollo 15 landsite, Clementine mission) of Mare region as an example, this method analysis results of the terrain and mineral's abundance are basically same with published literature. In the future, this method can be simple rapid in-time implemented in real-time lunar exploration.

1. Introduction

Since 1960s, the moon has been a hot point of space explorations. The lunar landform is similar with the Earth [1,2], and its regolith contains high-concentrated minerals, which is one of the reasons that humans are interested with exploring it. As the only unearth body that human landed, lots of lunar data has been accumulated during longtime explorations especially image data. In these data, much of them were captured by earth-analysis [3–6]. Image data contains the global topography and reflectivity data of the moon. How to utilize the global data is key for lunar research, especially selecting the landing point and safe-landing. At present, researchers are mainly concentrated in the processing and analysis of these data rather than analyzing the relationship between these geological, physical and chemical information. So, we propose a method of analyzing characteristics of lunar surface with optical images.

Variations of lunar soils in minerals and physical properties relate with terrain on moon [7]. One of the most important indicators for the maturity is the mineral's abundance [6]. The mineral's abundance has important value in lunar exploration. Remote sensing has been used as an efficient approach to the estimation of lunar surface mineral abundance. But this method that cannot real time analysis mineral's abundance from the optical image. This paper proposed a method that is utilize the lunar surface image, craters distribution, lunar surface reflectance, and Hapke model analyze image's area terrain and the abundance of important minerals.

2. Multi-information fuzzy logic lunar crater recognition

Impact craters (Fig. 1), formed by collisions of meteoroids with lunar surfaces, are among the most studied geomorphic features in the moon because they include the information about the past and present geological processes and provide the only tool for measuring relative ages of observed geologic formations. So, lunar impact craters recognition is foundation thing. Currently, most of the recognition researches on craters are mainly focused on lander landing or navigation [8]. We carried out the recognition of craters by analyzing obtained images from Clementine mission. There are two parts in the method of crater recognition. The first part is to detect craters, and the second part is to recognize craters. The recognition processing of carters is shown in Fig. 2.

For accurately recognizing craters, the detection is carried out with three methods: GAC (geometric active contour), HCT (Hough circle translation), Watershed method; these methods can be processed with parallel computation for the real time requirement. Because detection algorithm changed with the change of fields-of-view, through voting weight multi-information voting recognition algorithm fuses three detection's information. We use the concept of "behavior integration" in behavior based control architectures, in which recommendations from different behaviors are integrated from a unified control action [9,10], and blend together individual detection results to ensure that each algorithm is allowed to

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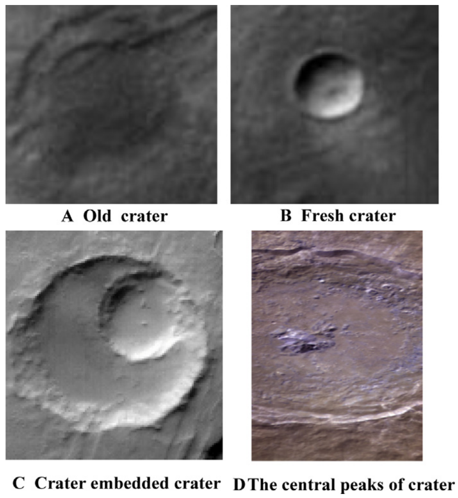

Fig. 1. Different shapes of impact craters.

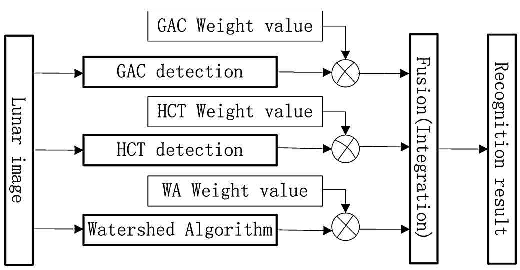

Fig. 2. Multi-information voting recognition lunar crater.

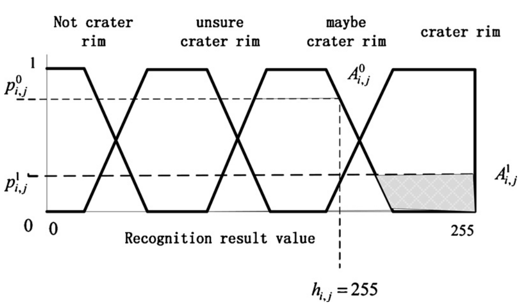

Fig. 3. Fuzzy recognition result.

influence the final recognition crater. The recognition result is computed by using the following

$$H_{i,j}=\frac{\sum_{k=1}^{n}\left(\beta_{i,j}^{k}\sum p_{i,j}^{k}A_{i,j}^{k}\right)}{\sum_{k=1}^{n}\left(\beta_{i,j}^{k}\sum A_{i,j}^{k}\right)} \tag{1}$$

where i,j is the index of each pixel in detection results, H_{ij} is the fused recognition computed value for each pixel, n is the number of the used detection algorithm. β_{ij} represents the certainty factor associated with each pixel, p_{ij} is the peak value associated with fuzzy the recognition values (h_{ij}) for each detection result, and A_{ij} is the area under the detection crater membership function associated with the gray value (Fig. 3).

Given that we currently utilize three detection results, GAC (geometric active contour), HCT (Hough circle translation) and Watershed, (1) becomes (2).

$$H_{i,j}=\frac{\beta_{i,j}^{G}\sum p_{i,j}^{G}A_{i,j}^{G}+\beta_{i,j}^{H}\sum p_{i,j}^{H}A_{i,j}^{H}+\beta_{i,j}^{W}\sum p_{i,j}^{W}A_{i,j}^{W}}{\beta_{i,j}^{G}\sum A_{i,j}^{G}+\beta_{i,j}^{H}\sum A_{i,j}^{H}+\beta_{i,j}^{W}\sum A_{i,j}^{W}} \tag{2}$$

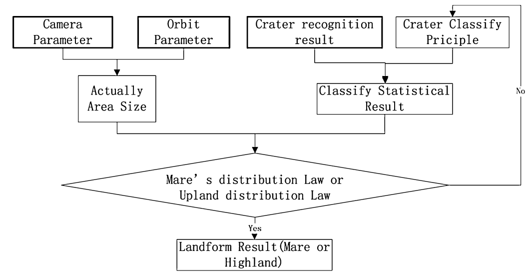

Fig. 4. lunar surface landform analysis flow chart value.

G, H, W represent the GAC detection result, HCT detection result, Watershed detection result, respectively, and the certainty factors $\beta_{i,j}^{G}$, $\beta_{i,j}^{H}$, $\beta_{i,j}^{W}$ represent the weight by which the individual detection result influences the final construction of the fused recognition crater.

3. The analysis of terrain and abundance

3.1. Image's terrain analysis

Lunar surface terrain includes Mare and Highland which dotted with all kinds of craters. Craters can be used for estimation of lunar terrain. Neukum. G supposed to approximate the cumulative crater frequency distribution in form of a piecewise three segment power law [11]. Various studies [12] show that craters in the Mare and in the Highlands are distributed at random [13].

We utilize the detection result analyze the surface landform through adopting Hartmann's proposal, and approximate the smooth Mare, and Highland terrains in form of a piecewise three segment power law, smooth Mare such as Eq. (3), Highland such as Eq. (4).

$$\log N=\begin{cases}-1.015-2.017\ \log D & D<38\ \text{m}\\ -1.187-1.914\ \log D & 38<D<100\ \text{m}\\ +0.1007-2.651\ \log D & D>1000\ \text{m}\end{cases} \tag{3}$$

$$\log N=\begin{cases}-1.015-2.017\ \log D & D<38\,\text{m}\\ -1.620-1.655\ \log D & 38<D<80\ \text{m}\\ +0.8929-2.964\ \log D & D>80\ \text{m}\end{cases} \tag{4}$$

where D (km) is the crater's diameter, N is the cumulative number of craters larger than D in diameter per km^2.

One area the number of craters calculation Eq. (5).

$$N_a=(N_{D_1}+N_{D_2}+\ldots+N_{D_n})\times A \tag{5}$$

where D_n is the crater's diameter in meter, N_{D_n} is the cumulative number of craters larger than D_n in diameter per km^2, A is image's area size in km2, N_a is total crater number.

We can count the craters using reverse way through the distribution law of craters Eq. (3) and (4), and then decide which landform they are as per the distribution of craters. Some lunar surface areas of images are decided by parameters of optical cameras, the orbit of parameters of spacecraft. The process is followed in Fig. 4. If the parameters of cameras and orbits are fixed, the terrain area of each image represents can be set. Substitute the terrain area and N value into formula (3) and (4) to judge the image's terrain.

3.2. Image's terrain reflectance analysis

Assuming that the surface of the moon is a mineral, the reflectivity of the surface of the moon and the reflectivity of the minerals is same. In fact, the surface of the moon can't be constituted by