A MONTE CARLO RAY TRACING MODEL FOR LUNAR SOIL AND ITS APPLICATIONS TO CHANG'E-1 TOPOGRAPHY DATA AND LSCC DATA SET.

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Introduction: Using the spectra to determine the chemical compositions of a mineral is one of the most important objectives in remote sensing. The optical constants of a mineral are still hard to be determined accurately. Geometrical optical models and radiative transfer models are commonly used for this purpose. While geometrical optical models are used to investgate the ray's reflection/refraction between particles, radiative transfer models focus on the reflectance intensity of different compositions of a mineral. Hapke's model is a radiative transfer model which well describes the relationship of the optical constant and the reflectance spectrum of a mineral.

Computer simulation had become a powerful tool in analyzing and modeling phenomena in a wide range of applications, especially for the research topic where it is difficult or high cost to measure data, such as Astrophys-ics and Space Science, Monte Carlo method and Ray-tracing algorithm is widely used in simulating analysis the optically contrast structure of particles with complex shapes [1]~[4].

Excellent works have been done by Lucey et al. [5]~[7], not only found out the relationship between the optical constants and the compositions of the proportion of Fe and Mg of olivine, pyroxene, etc., but also provided a well approximation to find out the optical constants from a known reflectance spectrum using the inverse Hapke's model.

Pieters and Hiroi [8] made great contribution, most of the lunar mineral samples taken back in the Apollo projects had been tested, the reflectance index of those tested sample is provided - the LSCC data set.

In this paper, a Monte Carlo ray tracing model for lunar soils is proposed for the purpose of simulating the reflection/reflection attributes of the visible spectrum of lunar soils. In our model, a volume representing the topography and the type of the mineral of lunar soils is constructed. For the ray tracing, a ray traces back from the spectrometer to the volume and then to the light sources. The intensity of the reflected ray is calculated using the reflectance spectrum of the encountered mineral with Hapke's model. The reflectance spectrum provided by RELAB and Lucey's method (inverse process of Hapke's model [9]) were used to obtain the optical constants of the lunar mineral. Then the reflectance spectrum of any phase angle could be calculated using the Hapke's model. Shadows will be provided if the ray is blocked.

Our approach provides the reflectance of the lunar surface based on Hapke's radiative transfer model and the reflectance spectrum of the lunar mineral sample of the Apollo projects. Once the mineral of the lunar surface is determined/defined, the reflectance can be provided for any direction of the incident light (based on the light sources) and reflected light (based on the viewing position).

A volume is used to represent the topology of the lunar surface. Each voxel(an element of a volume) represents a bulk of the lunar soil. The mineral composition of the lunar surface is complex. And the soil is composited by particles such as sands, rocks, etc. Modeling a lunar soil as a volume is more suitable to represent its structure in our simulation.

Monte Carlo ray tracing model and the simulation process: The BRDF(bidirectional reflectance distribution function) and Monte Carlo ray tracing has been applied to remote sensing to investigate the characteristics of the electromagnetic radiation transport between the objects in both macro scale and micro scale, from the surface of the Earth to the internal reflection of the particles in a mineral. The simulation model we proposed is also based on the Monte Carlo ray tracing method, tracing the path of the reflected ray between the light source and the encountered object (the lunar surface). Hapke's radiative transfer model is used to adjust the intensity of the reflected ray instead of analyzing the internal scattering of the mineral.

To find out the contribution of the mineral of the lunar surface, a path tracing is processed. If the incident ray is not blocked, calculate the phase angle, and then use the phase angle to find out the reflectance spectrum with Hapke's model.

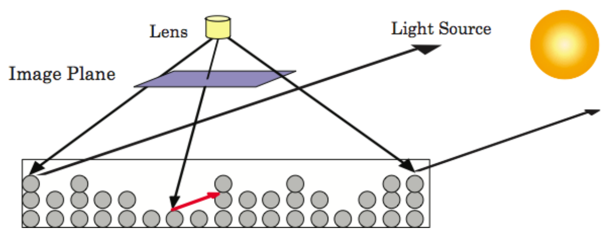

Figure 1: Path tracing of our simulation, spheres represented the voxels of the lunar soil volume, the red arrow is the blocked ray.

Simulation result: To represent the topography and the mineral of an area of the lunar surface, reflection data of 6 samples of Apollo 16 from the LSCC data and Cheng'E-1 (CE-1) height map data are used. The polar angle and the azimuth angle of the incident light are both set to 45 degrees. Phase angle between the incident light and reflected light is calculated and then the result will be found out using the reflectance spectrum of Hapke's model of the mineral.

The reflectance spectrum of the sample by Apollo 16 project is used, and the topography of the lunar soil volume is reproduced by the result laser altimeter of CE-1 of the area around the Apollo 16 spacecraft landing-site (from 9.9375 E to 19.9375 E. longitude, 5.0625 S to 15.0625 S. latitude). The resolution of the of the height map is 256×256.

Reflectance of wave length λ = 645 nm is used in the simulation. 6 kinds of the mineral placed in 6 locations in the area. When sampling, each point of the surface produce a reflectance intensity with probability of which kind of the mineral it was. The probability is based on the distance of between that point and the 6 locations of the samples.

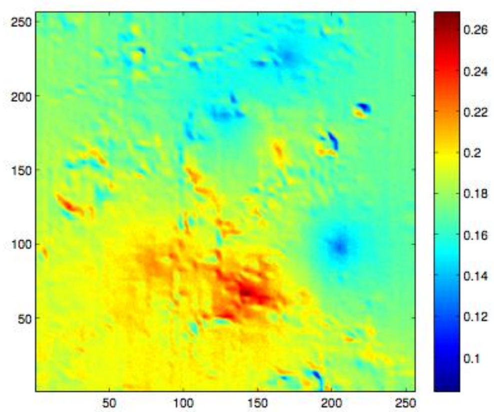

Figure 2: Simulation results of the location based distribution of the minerals (sample rate = 1000).

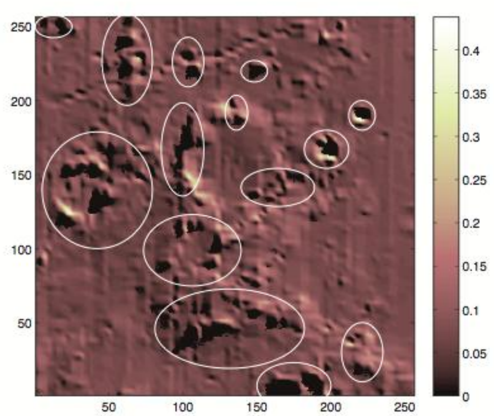

Figure 3: Another simulation result, shadow caused by the blocked ray is shown.

Application of the model: Our simulation model can be applied for Computer aided spectrum analysis. In building and analysis the simulation model, both the reflectance by the topography and the mineral were considered. Mineral spectrum measured by the spectrometer is a combination of the mineral composition and the shape of the topography. Therefore, inverse process of the simulation can be useful in removing the reflectance factor of the topography from the raw measured spectrum data.

Figure 4 shows a track of the lunar surface spectrum (λ = 705 nm) measured by CE-1 in the longitude 15.8018 E to 16.4707 E and latitude 5.0619 S to 15.0495 S. The diffusion of our simulation and the result of simply divided the spectrum by the diffusion are shown. The diffusion of each point was calculated with the same incident angle and azimuth angle as the time while the orbiter is measuring the spectrum.

Without consider the noise and other reasons coursing the variation of the measured, we only divide the measured data with the diffusion of our simulation result. It can be noticed that some slopes of the spectrum data were somehow adjust to a horizontal line, it might telling us those mineral at the slope of the lunar surface is actually the same kind of lunar mineral(At least, their reflectance at the specific spectra were similar), but produced different reflectance because of the topography of the surface.

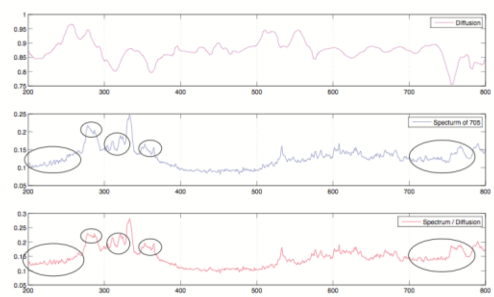

Figure 4: Simulated diffusion result(top), the measured spectrum (middle, λ = 705 nm) of a orbiting track of the CE-1 Orbiter, as well as the result of (spectrum / diffusion) (bottom) are shown. The most clearly parts to show the changes after dividing the diffusion are circled.

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