Inversion of Lunar Regolith Layer Thickness with CELMS Data using BPNN Method. Meng Zhiguo[1, 3], Xu Yi[2], Xu Aoao[2], Zhong Yongchun[3], Tang Zesheng[2], Zhu Yongchao[3], Chen Shengbo[1], [1]College of Geoexploration Science and Technology, Jilin University, Changchun, 130026, China (mengzg@jlu.edu.cn). [2]Space Exploration Laboratory, Macau University of Science and Technology, Macau. [3]Key Laboratory of Lunar and Planetary Exploration, National Astronomical Observatories, CAS, Beijing, 100012, China.

Introduction: Knowledge of the structure of the lunar regolith will provide important information to understand the geology of the Moon[1, 2]. One of the scientific objectives of Chinese Chang'E mission is to evaluate the thickness of the lunar regolith layer with the microwave radiometer (CELMS) data. However, the inversion of the lunar regolith layer thickness with the CELMS data is critically restricted by the poor knowledge about the regolith parameters, such as the temperature profile, dielectric constant profile, particle size, buried-rock distribution and surface roughness [3, 4, 5]. How to avoid the errors brought from the uncertainties of the lunar regolith parameters remains as a crucial problem in current Moon research.

As an excellent no-linear fit theory, the back propagation neural network (BPNN) method is one of the most powerful ways to inverse the lunar regolith layer thickness with CELMS data regardless of the aforementioned problem. Therefore, the BPNN method is selected as an attempt to inverse the lunar regolith layer thickness in this paper.

Methodology: The BPNN consists of one input layer, one or more hidden layers and one output layer [6]. In this study, we applied a two hidden layers of nodes in order to obtain the results with high quality (Fig.1). Note that the input, X_{tj} (t = 1, 2, …, T; j = 1, 2, …, N), is the jth parameters of the tth sample, and N is the number of the specified parameters for every input sample; and the output, O_{ts} (t = 1, 2, …, T; s = 1, 2, …, M), is the *s*th parameters of the corresponding tth sample, and M is the number of the given parameters for every output sample. T is the total sets of the available training data.

Due to the limitation of the number of the lunar regolith samples, only the regolith parameters in the six Apollo landing sites, T = 6, are chosen as the training pairs for the artificial neural network. The radiative transfer simulation indicates that the relationship between the observed CELMS data with the lunar regolith layer thickness is strongly influenced by the surface roughness, the slope, and the (FeO + TiO_2) abundance [3, 4, 5]. Therefore, for every site, the observed CELMS data T_{Bi} (i = 1, …, 4) and the corresponding surface roughness σ, surface slope θ_s, and the (FeO+TiO_2) abundance S are set as the input parameters. Thus the dimension N of the input is set as 7. Note that the input parameters have different value ranges, for example, the CELMS data is more than 100, θ_s is from 0 to 90, and σ and S are largely less than 1, this is not acceptable to get a good result with the BPNN method using such data. Therefore, all the parameters are normalized to the value between 0 and 1 in the BPNN array to avoid overweighing the parameters with large value range. Since the only output parameter is the regolith layer thickness, M = 1 used in this paper.

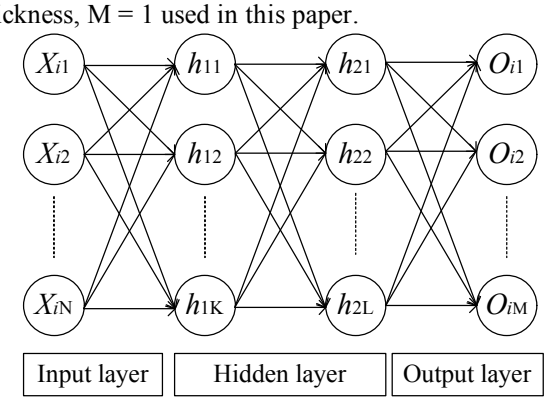

Fig.1 Structure of BPNN network

Results and conclusions: Up to now, the measured lunar regolith parameters are obtained at the six Apollo landing sites. T_{Bi} (i = 1, …, 4), σ, θ_s and S at the Apollo landing sites are normalized and set as the input of the BPNN network. The corresponding thickness d is selected as the output to train the BPNN network.

Once trained, the regolith layer thicknesses over the Moon surface (Fig.2) can be rapidly inversed using the BPNN method with T_{Bi} (i = 1, …, 4) concluded from CELMS data from Chang'E-2 satellite [7], σ and θ_s reckoned with LOLA data from LRO satellite [8, 9], and S estimated from Clementine UVVIS data [10].

Fig.2 indicates that the distribution of the lunar regolith layer thickness is not evenly distributed over the Moon surface. In low latitude regions (from 30°S to 30°N), the regolith layer thickness is much thicker in the lunar highlands than that in the maria. The lunar highland is characterized by regolith layer thickness variations widely from 10 m to 31.5 m, and the mean thickness is about 16.8 m; while the

thickness varies from about 0.5 m to 12 m in the maria, and the mean is about 6.52 m. The thickness is close to that estimated with Earth-based 70-cm Arecibo radar data [2]. It indicates that the BPNN method is feasible to evaluate the lunar regolith layer thickness in low latitude region.

In the middle and high latitude regions, there isn't any clear boundary in terms of the Maria and the Highlands, indicating that regional variation data of the thickness may not be rational, especially in the north part of Oceanus Procellarum, Mare Serenitatis, Mare Imbrium including Sinus Iridum and Mare Frigoris. The main cause might be that the sampled parameters are collected from Apollo landing sites, which are all in low latitude regions. Hence, the BPNN method in this study may be not suitable for the regolith layer thickness evaluation in the middle and high latitude regions.

Comparisons between the thickness estimated by crater morphology method [11] and that estimated by Shkuratov and Bondarenko [2] show that, though the inversed thickness is a bit thicker than the latter one [2], they are fairly approximated to each other in mare regions. Especially in Mare Serenitatis, Mare Crisium, Mare Fecunditatis, Mare Imbrium, Mare Nectaris, and Mare Vaporum, the difference of the mean thickness between previous estimation [2] and ours is less than 1 m, impling that the BPNN method is a feasible approach to inverse the lunar regolith layer thickness.

In addition, the comparison between the ages, the ($FeO+TiO_2$) abundance and the inversed regolith layer thicknesses in the nine main maria indicates that the regolith layer thickness is directly related to its age if the basalt is of the same kind. Furthermore, the correlation between the inversed thickness and the severn input parameters along the Moon equator indicates that the surface roughness has the largest impact on the inversed thickness, followed by the CELMS data in 3 GHz and the slope.

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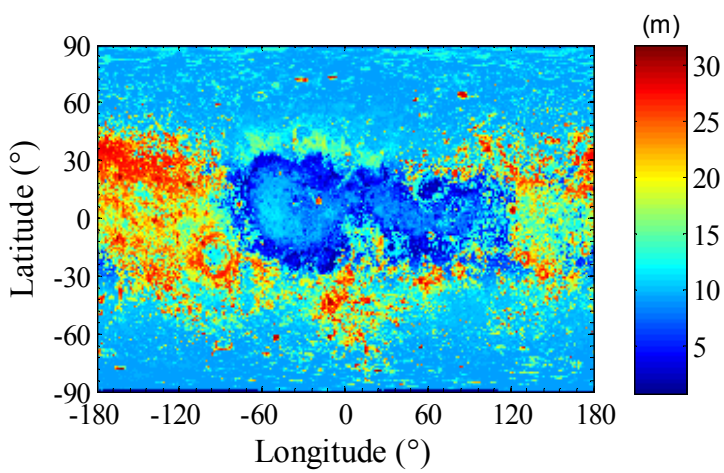

Fig.2 Lunar regolith layer thickness distributions