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GPR Reverse-Time Migration for Layered Media: A Case Study at the Chang'E-4 Landing Site

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Chang'E-4 was the first mission to land a human object on the far side of the Moon. The landing site was at the Von Kármán (VK) crater at the South-Pole Aitken (SPA) basin, one of biggest craters in the solar system. SPA is believed that was created by a huge impact that penetrated the lunar crust and uplifted mantle materials. Evidence of these materials are expected to be found by the Yutu-2, the rover of the mission that is still active to this day, having covered more than 1km on the lunar's surface. Yutu-2 is equipped with a stereo camera, visible/near-infrared imaging spectrometer, alpha particle x-ray spectrometer and Ground-Penetrating Radar (GPR). In-situ GPR is a powerful geophysical methodology with a uniquely wide range of applications to civil engineering, archaeology and geophysics. In planetary science, it was first used in 2013 during the Chang'E-3 mission. Since then, GPR has become a very popular instrument in planetary missions, and has been included in the scientific payload of Chang'E-4, E-5, Tianwen-1, and Perseverance. It is also planned to be used in the future missions Chang'E-7 (2024) and ExoMars (September 2022).

Yutu-2 rover is equipped with three different GPR systems. One low frequency and two high frequency antennas. Unfortunately, due to interferences between the antenna and the metallic parts of the rover, the low frequency data have very low signal to clutter ratio making the interpretation of these data unreliable. On the other hand, the signal from the high frequency antennas is very clear, probably due the lack of ilmenite in the area, which results to low electromagnetic losses (compared to the Chang'E-3 landing site). This resulted to good quality radagrams that provided new insights into the structure and composition of the top ejecta layers at the VK crater.

In the current paper, we introduce a complete processing scheme, tuned for high frequency lunar penetrating radar. The first step of the proposed framework is an advanced hyperbola fitting (AHF) capable of inferring previously unseen layers due to their smooth boundaries. Subsequently, the reconstructed layered structure is used in a Reverse-Time Migration (RTM)

coupled with Finite-Differences Time-Domain (FDTD) method. Via this approach, the radagram is focused subject to a 1D model, avoiding homogeneity constrains that often deviate from reality. Lastly, an un-supervised thresholding is applied to cluster the migrated image into two categories i.e. A) the background host medium and B) rocks/boulders. The suggested scheme is applied to the high frequency data collected by the Yutu-2 rover at the first 100 meters of the mission. A layered structure is inferred at the top 12 meters, similar to the results presented in [1]. Moreover, using the proposed RTM, an abundance of rocks/boulders was revealed. The distribution of the rocks/boulders correlates with the permittivity/density profile, indicating the reliability of the proposed scheme.

References

[1] Giannakis, I., Zhou, F., Warren, C., & Giannopoulos, A. (2021). Inferring the shallow layered structure at the Chang’E-4 landing site: A novel interpretation approach using lunar penetrating radar. Geophysical Research Letters, 48, e2021GL092866