Modeling of near-surface structure and Response simulation of GPR in the Jezero crater, Mars

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Abstract. NASA's upcoming Mars 2020 will carry Ground Penetrating Radar (GPR) named RIMFAX to Mars for exploration. Mars 2020 will land at Jezero crater, located to the northwest of the Isidis basin. The landing site experienced series of geological processes such as delta formation, lavas coverage and surface weathering. Establishing the electromagnetic model here, which is used for forward simulation of RIMFAX will help the later data processing and interpretation. This paper considers the interface fluctuations, the randomness of the background medium, and the randomness of the cracks to establish a Mars near-surface electrical model, and performs forward result based on the parameters of RIMFAX. The research will support the later data processing and interpretation.

1. Introduction
The next rover NASA will send to Mars in 2020 will carry seven carefully-selected instruments to conduct unprecedented science and exploration technology investigations on the Red Planet. One of the selected payload proposals is the Radar Imager for Mars' Subsurface Exploration (RIMFAX), a ground-penetrating radar that will provide centimeter-scale resolution of the geologic structure of the subsurface.

RIMFAX will add a new dimension to the rover’s toolset by providing the capability to image the shallow subsurface beneath the rover. A significant challenge in Mars rover missions has been the lack of access to vertical stratigraphy. The principal goals of the RIMFAX investigation are to image subsurface structure, and to provide information regarding subsurface composition. RIMFAX has the potential to provide a view of the stratigraphic section and a window into the geological history and associated environmental history [3].

The early modeling and simulation are beneficial to the design of the instrument, the collection of field data, and the interpretation of data. This paper first analyzes the near-surface geological structure of the Mars 2020 scheduled landing range. Then after taking into account the interface morphology, the random background media, and cracks, a prior near-surface electrical model is established. At last, a radar response image is obtained from the simulation.
2. Regional geology

NASA has chosen Jezero Crater as the landing site (Figure.1) for its upcoming Mars 2020 rover mission after a five year search, during which every available detail of more than 60 candidate locations on the Red Planet was scrutinized and debated by the mission team and the planetary science community.

Jezero crater is located at 18.4°N, 77.7°E in the Nili Fossae region of Mars. The Jezero crater is about 49 kilometers in diameter and formed in the Noahian period.

After the formation of Jezero crater, two river systems drained the Nili Fossae region and poured into Jezero crater, filling it with a lake as much as 250 meters deep. As the two inlet streams spilled into Lake Jezero, they dropped loads of sediment, forming deltas, including the spectacular southern one that will be Mars 2020's target.

![Figure 1. Mars 2020 Scheduled landing range](image)

After the stream activity petered out some time in the middle Hesperian age of Mars’ history, the delta started eroding away. What we see today isn’t what the delta looked like after the last stream flowed across it; Mars’ winds were already attacking it.

Then the Syrtis Major volcano got going to the southwest, and its eruptions continued into the most recent, Amazonian era of Mars’ history. Lavas from Syrtis spilled into Jezero, covering its floor and lapping up on to the bottom of the delta, but not covering the delta completely. Based on crater counting, that volcanic filling probably happened around 3.5 billion years ago, still during the Hesperian era.

After the lavas, the delta — made of material that is less resistant to erosion than lava is — continued to erode away from wind action, probably right down to the present day.
Figure 2. The stratigraphic column for the geomorphic units within the Jezero crater

Based on the evolutionary relationship, a stratigraphic relationship (figure 2) was established, and the horizon can be divided into [2]:

1. Jezero Crater Rim and Wall Within the basin: the lowest stratigraphic unit is the Jezero crater rim and wall material defined based on topography as well as the generally massive nature of the exposed portions.

2. Light-Toned Floor Unit: Stratigraphically above the Jezero crater rim and wall material is the light-toned floor unit. The light-toned floor unit is light toned, is often covered by aeolian dunes, and appears pervasively fractured when exposed below the dunes. This unit extends across much of the Jezero crater floor and is exposed in erosional windows below the stratigraphically higher volcanic floor unit.

3. Jezero Fan Deposits: Above the light-toned floor in the stratigraphic column are the sedimentary fan deposits. The fan deposit is emplaced directly onto the light-toned floor unit and have been interpreted as delta deposits formed when Jezero crater hosted a paleolake.

4. Volcanic Floor Unit: The volcanic floor unit was deposited on top of the light-toned floor unit, and embays the fan deposits. This unit appears to be <10m thick.

5. Surficial debris cover: Small patches of surficial cover that are typically aggregated into dunes, although can also appear as mass wasting or general dust cover. Always the most surficial deposit observed.

3. Methods

The detection distance of RIMFAX is about ten meters. The model we built mainly considers the surface weathering layer, volcanic floor layer, delta sediment layer and light-toned floor layer. There are three important factors in the establishment of these layers: the interface morphology, the random background media, and cracks. In this section, we introduce the methods of Perlin noise for interface morphology modeling, elliptic autocorrelation functions for random background media modeling, and modeling large cracks using small cracks to simulate cracks.

3.1. Generating Stochastic Terrain

Perlin noise is used to generate some seemingly messy and actually some transformation patterns (more close to nature), such as sea water, terrain, fog, etc. Perlin first described this noise generation method [5], and later improved the original Perlin noise generation method [6]. Steps as follow:

1. Set the calculation point grid: set the range and the step size of calculation points.
2. Set gradient point grid coordinates and corresponding random gradients: set gradient point grid coordinates based on the range of calculated points and generate random gradients at various gradient points.

3. Set empty matrix to store calculation points: generate an empty matrix consistent with the grid length of the calculation points to store the calculation results.

4. Calculate the value of each calculation point: find the dot product of the direction vector and the gradient vector and weighted final calculation point results.

5. Set the calculation points again to increase the calculation point grid range and the step size by multiples. Repeat the above steps to form several new calculation results.

6. Set weights and overlay calculation results to get the final Perlin noise-based terrain.

3.2. Building Random Medium

The typical character of a stochastic medium depends on its complexity and heterogeneity. Besides, inhomogeneous medium is usually equivalent to a combination of a homogeneous background medium and random perturbation media, satisfying the Gaussian distribution. Zeng et al. use an elliptical autocorrelation function to describe the stochastic effective medium:

\[ f(x, y) = \exp[-\left(\frac{x^2}{a^2} + \frac{y^2}{b^2}\right)^{(1+r)}] \]  

Where \( r \) is roughness factor (\( r = 0 \), Gaussian elliptical autocorrelation function; \( r = 1 \), exponential elliptical autocorrelation function; and \( 0 < r < 1 \), mixed autocorrelation function), \( a \) and \( b \) are respectively the autocorrelation lengths in \( x \) and \( y \) directions. Gaussian elliptical autocorrelation function is selected (\( r = 0 \)). By setting different values of \( a \) and \( b \), we can control the range and distribution of random medium.

3.3. Generating cracks

It is believed that large cracks with trending information are composed of small cracks. Based on this idea, we designed the method and steps for generating cracks:

1. Generate the length and direction of the main fissures.
2. Set the inclination range, length range and number of fine cracks.
3. In the category of main fissures, small fissures that follow normal distribution are generated.

4. Results

4.1. Modeling result

Based on the prior horizon information and the above simulation methods, we establish a near-surface model of the scheduled landing area of MARS2020. The model (figure. 3) is mainly divided into four layers, from top to bottom:

1. Surficial Debris Cove: relative dielectric constant is about 3, thickness is about 1m
2. Volcanic Floor Unit: relative dielectric constant is about 5, thickness is about 4m
3. Jezero Fan Deposits: relative dielectric constant is about 4.5 ± 0.5, thickness is about 5m. It is divided into 4 layers.
4. Light-Toned Floor Unit: relative dielectric constant is about 7, thickness is about 5m. Among them are rich in various cracks with relative dielectric constant at 5.
4.2. Forward result
According to the above model and the basic parameters of RIMFAX Radar [1], FDTD [4] is used for forward modeling, and the simulation result is obtained, as shown in figure 4, where the center frequency is 650MHz and the transceiver is 0.6m from the ground.

According to the simulation results, RIMFAX will be able to give a good guide to the distribution of underground horizons. Our model fits the near-surface information of the MARS2020 the scheduled landing area on the one hand, and on the other hand, is more in line with the actual formation situation, which will provide a good help for radar detection on the Mars rover.

5. Conclusions
Mars 2020 will land at Jezero crater, located to the northwest of the Isidis basin. The landing site experienced series of geological processes such as delta formation, lavas coverage and surface
weathering. Establishing the electromagnetic model here, which is used for forward simulation of RIMFAX will help the later data processing and interpretation. This paper considers the interface fluctuations, the randomness of the background medium, and the randomness of the cracks to establish a Mars near-surface electrical model. Perlin noise is used to simulate interface morphology. Elliptic autocorrelation function is used to simulate the random background medium, and we model large cracks by using small cracks. The simulation results were obtained by forward modeling based on the parameters set by RIMFAX Radar. This paper provides support for later data processing.

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