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Surface ε_{r} reconstruction of Phobos

Extended Abstract

S. Hegler (1), C. Statz (1), D. Plettemeier (1), A. Cicchetti (2), A. B. Ivanov (3), R. Orosei (2)
(1) Communications Laboratory, Technische Universität Dresden (sebastian.hegler@tu-dresden.de),
(2) Sapienza University of Rome, (3) Planetary Science Institute

1. Introduction

In the scope of the MARSIS experiment (*Mars Advanced Radar for Subsurface and Ionosphere Sounding*) aboard the European Spacecraft MarsExpress, the Martian moon Phobos was sounded several times.[1]

Using a simulation tool based on the method of Physical Optics, given the trajectory data and a digital elevation map of the terrain, we analyze the signal that is backscattered from the surface of Phobos.

2 Surface Backscattering & Clutter

Radar clutter is loosely defined as "the part of the received signal that is undesired." For ground penetrating radar systems, this definition applies to the part of the signal that is backscattered from the surface of the sounded object. Separating surface clutter from the received signal is a tremendous aid for the correct interpretation of radar images. As a – in this case, desired – side effect, the surface clutter also contains information about the surface permittivity distribution.

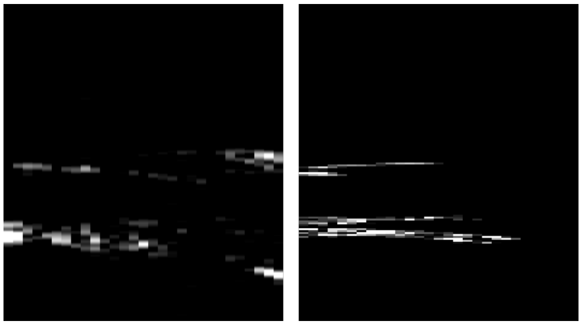

Figure 1: Radargram image of measurement (left) vs. simulation result (right), of orbit#4814, approach segment.

In order to calculate the backscattered signal of known terrains, a simulation tool based on the method of Physical Optics[2] was developed. The development of this tool was driven by the need to simulate huge objects, i.e., entire moons or planets, and the possibility to choose arbitrary radiation patterns for the sender and receiver. It is implemented in C++, using OpenMP for parallel parts.

3 Reconstruction Approach

As can be seen in figure 1, data received in the measurement shows good agreement with the results of the simulation, suggesting that the radar echoes stem from Phobos' surface features. This lays the basis for a reconstruction approach using gradient based optimization.

3.1 Notes on accuracy

In order to attempt a reconstruction of the permittivity profile of Phobos based on the MARSIS measurements, it is important to understand the factors that influence the quality both of the measured signal as well as the simulation results, and to quantify their influence.

For the simulation, this is the discretization chosen for the terrain, the quality of the DEM, and the limitations inherent to the method used for the simulation, i.e. the Physical Optics method.

In case of the measurements, one has to take into account the data processing aboard the MarsExpress Spacecraft, and the signal-to-noise-ratio (SNR) of the measurements.

The ephemeris data, both in regard to position of the S/C, as well as the MARSIS antenna alignment, is important to both the simulations and the measurements.

Taking all these factors into consideration, it seems unlikely that absolute values for the permittivity distribution can be obtained. However, statements about a relative permittivity distribution can be made.

3.2 Gradient based optimization

For a gradient based optimization approach, a target functional has to be defined, which will have to be minimized. ε_r serves as our target parameter; the target functional aims to minimize the mismatch between the measurements and simulation for several flybys:

$$j(\vec{p}) = \frac{\vec{f}_m}{2} \sum_{m=1}^{M} \int_T \int_\Omega \|(\vec{u}(\vec{p}) - \vec{u}_m)\|^2 \, d\Omega \, dt \, \delta(m)$$

where $\vec{u}(\vec{p})$ is a simulation state, $\vec{u}_m$ is a measured state, Ω is the surface, m represents an orbit point containing all relevant parameters (S/C position and antenna alignment), T is the time, M is the number of orbital positions taken into account. $\vec{f}$ is a weighing function taking into account the signal quality for a certain orbit point, $\delta(m)$ is a Dirac delta function.

The information for a single measurement is represented by u_m, it is – as described in the PDS documentation – the time series of a transmitted an received radar pulse, using only the exponent of a 32bit floating point number, normalized to the maximum value.

u_p is the result of a single simulation for an orbital position m, obtained by the Physical Optics method as described in [2], transformed into time domain.

$\vec{p}$ is the target parameter, i.e. the permittivity distribution on the surface Ω, actually.

Using a Lagrangian approach as described[3], we can obtain the gradient of our target functional j with respect to our target parameter $\vec{p}$ (i.e., the permittivity map).

With this information, we can employ an optimization algorithm such as IpOpt[4] for an iterative estimation.

References

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