3D SAR IMAGE FORMATION FOR A COLLECTION OF POINT TARGETS BURIED UNDER A ROUGH INTERFACE

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1. INTRODUCTION

Subsurface sensing is of great interest in a variety of applications such as resource exploration, buried object detection, surveillance, root zone soil moisture estimation, and ice characterization, just to name a few. Some of the these problems can be addressed using localized ground penetrating radar (GPR) systems [1], but airborne and spaceborne radar systems using synthetic aperture radar (SAR) techniques, if realizable for subsurface imaging, have a significant advantage over the surface-based ones due to their rapid and synoptic surveying capabilities. Currently such systems are not common, and except for a few instances (e.g., in [2]), the existing low-frequency radar systems have rarely been used for 3-dimensional (3D) (subsurface) image formation. Airborne SAR systems flying at multiple altitudes - that is in a tomographic mode - have been recently shown promise to produce 3D images of vegetation over surfaces but not of the subsurface [3]. Here we describe a technique to accomplish this objective with a single-pass radar. The unique challenge of this task is that in order to form the image by way of focusing the received backscattered signals, one must know the electrical properties of the media in which the signals propagate to properly account for phase shifts along the signal path. This information is not available a-priori. Additionally, even with the knowledge of subsurface medium properties, standard range and Doppler processing techniques are not readily applicable and must be modified to account for various target and media interactions. We have previously reported a preliminary version of this technique for a single point target [4]. We identified several shortcomings, such as inaccuracies in estimation of subsurface medium properties and effects of conductive losses. In this work, we address these problems to extend the range of validity of the technique, and furthermore, extend the solution to multiple point targets that may be in close proximity.

2. OBJECTIVE AND APPROACH

In our previous work [4], we managed to render the true position of a single subsurface point target using an airborne SAR system assuming lossless medium. The present work makes the characterization of the subsurface medium more realistic by considering a lossy medium. Synthetic data are used to develop and validate the technique. A number of assumptions are made in the analysis: the raw data were built assuming a homogeneous half space medium (e.g., sand) housing the point targets, with no volume scattering. This medium is characterized by relative dielectric constant ε_r. The surface model is also enhanced in our new work, and is implemented randomly rough with a nominal root-mean-square height relative to a smooth surface to ensure a backscattered signal exists. Therefore transmission through the surface is modified from that predicted by Snell's law through an approximate model (Small Perturbation Model – SPM). No other interfaces are assumed to exist in the subsurface; this indicates scattering only by the point targets while phase shifts due to transmission and propagation in the dielectric half space are also taken into account.

The new algorithm improves the estimation of the two pertinent sets of variables, the dielectric constant (ε_r) and the depths of each of the buried point targets (d) using the synthetic raw data. The estimation of the subsurface medium wave speed requires the use of two polarizations along with the surface model noted above. Depth estimation is achieved through analysis of the Doppler spectrum of the received signal, along with the corresponding geometrical considerations. The image is constructed using a modified range-Doppler processing algorithm that generally parallels that of standard techniques [5,6] but has a new matched filter to account for non-constant background propagation characteristics from the radar to the subsurface target. To accomplish this task, the estimated subsurface wave speed and target depth are used to define a modified phase function in the range compression filter, and similarly in the azimuth filter. If the point targets are in difference resolution cells, each one can be imaged independently by using its respective depth. Since it is assumed that the subsurface medium is homogeneous (same for all point targets), having information from multiple targets could indeed enhance the estimation of the subsurface wave speed (permittivity).

3. RESULTS AND CONCLUSIONS

The current work concerns the development of a 3D SAR processing algorithm for multiple discrete point targets in a homogeneous half space. Several synthetic cases are simulated to study the sensitivities and limitations of this algorithm. In particular, the effect of medium parameters (dielectric constant and conductivity (or complex permittivity)), target depths, and target separation are investigated. There is a tradeoff between target depth and medium conductivity (loss) in terms of focusing accuracy and resolution. Future extensions of this work will need to consider application to distributed targets and considering multiple subsurface interfaces.

4. REFERENCES

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