3D SAR FOCUSING FOR SUBSURFACE POINT TARGETS

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1. INTRODUCTION

The ability of detecting buried objects or characterizing subsurface structures remotely has long been of great interest in many scientific and operational applications. The application areas include mapping ice depth and layering properties, characterizing objects or soil properties under forest canopies, detecting buried landmines, locating sources of water or oil deep below the surface, and exploring ancient artifacts and structures [1,2]. Although a number of techniques have been proposed in the literature to solve this problem, so far there has been no single approach that has been able characterize the ground, including buried objects, in a general case. The available techniques are usually application-specific since the data acquisition method, hardware design, and analysis techniques are all dependent on a given expected subsurface target and its surroundings [1]. The term ground penetrating radar (GPR) is commonly accepted for such applications and it is used to refer to different electromagnetic techniques designed mainly to detect the location of objects or characterize interfaces buried beneath the earth's surface or located within a visually opaque structure [1]. There are different types of GPR systems, many of which need to be close to, or in contact with, the ground. The airborne and spaceborne GPR systems using synthetic aperture radar (SAR) techniques have a significant advantage over the other systems due to their rapid and synoptic surveying capabilities.

The unique challenge of ground-penetrating SAR systems 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 usually not available a-priori. Additionally, even if the intervening media are known, standard range and Doppler processing techniques may not be readily applicable and must be modified to account for various target and media interactions

2. OBJECTIVE AND APPROACH

In this work, the initial objective is to render the true position of a subsurface point target using an airborne SAR system, in which process the subsurface medium is also characterized. 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 target, with no volume scattering. This medium is characterized by relative dielectric constant ε_r. Although the surface is assumed randomly rough with a nominal root-mean-square height relative to a smooth surface to ensure a backscattered signal exists, the transmission through the surface is assumed to be chiefly governed by Snell's law. No other interfaces are assumed to exist in the subsurface; this indicates scattering only by the point target while phase shifts due to transmission and propagation in the dielectric half space are also taken into account.

The algorithm estimates two variables, the dielectric constant (ε_r) and the depth of the buried point target (d) using the synthetic raw data. The image is constructed using a range-Doppler processing algorithm that generally parallels that of standard techniques [3] but modifies matched filter characteristics to account for non-constant background propagation characteristics. As is typical in SAR processing, the signals are first range-compressed, followed by azimuth compression using the Doppler spectrum. Initially, a standard Doppler effect is considered in the analysis, which is reasonable for shallow targets but must be modified for deeper targets. For deeper targets that are observable by lower frequencies, the Doppler spectrum needs to be carefully derived and utilized for proper placement of targets in 3D space, taking care to eliminate ambiguities between surface and subsurface targets. The final image is formed through a process that sequentially iterates between forming a focused image and estimating the subsurface wave velocity.

3. RESULTS AND CONCLUSIONS

The new processing algorithm, which integrates SAR focusing and subsurface velocity profile inversion, is applied to a single shallow target, a single deeply buried target, several shallow targets, and several deeply buried targets. The sensitivity of results is investigated with respect to various parameters such as the ground wave velocity (or equivalently, the dielectric constant), proximity of point targets to the surface and to each other, radar frequency, and bandwidth. The errors in locating the target, image resolution in lateral and depth dimensions, and errors in estimates of the ground dielectric properties are quantified and suggestions for improvement are provided.

The current work concerns the development of the 3D processing algorithm for discrete point targets in a homogeneous half space. Future extensions of this work will need to consider application to distributed targets and targets that extend to multiple resolution cells, in addition to considering multiple subsurface interfaces.

4. REFERENCES

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