HIGH RESOLUTION SUBSURFACE IMAGING OF DEEP TARGETS BASED ON DISTRIBUTED SENSOR NETWORKS

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I. INTRODUCTION

Interest in distributed sensor networks for subsurface sensing has justifiably increased in recent years due to the growing need for high resolution detection and imaging techniques for various applications. Such Sensor networks can be useful in many areas including the military, homeland security and civilian applications. Detections of buried pipelines, wires and cables are examples of civilian applications. Military and Homeland security applications include the detection of Unexploded Ordnance (UXO), tunnels and underground facilities. Imaging based on distributed sensor networks could also be utilized for biomedical applications such as detection of cancer. A significant amount of work has been devoted towards development of hardware and signal processing for mono-static and bi-static radar systems for subsurface detection. Tegan et al have developed a Multi-static ground penetrating radar system using beamforming [1]. Several other researchers have focused on developing various inversion algorithms and carried out experiments for multi-static systems. Research related to the development of a 3-D high-resolution technique for deep subsurface imaging using distributed sensor networks is little. In this work, a realistic forward model based on a distributed sensor network for a target buried under a multilayer soil with lossy dielectric profile is devised. Simulation results of an inversion technique with high transverse and depth resolution for 3-D detection of deep targets (in the range of several meters) and retrieval of the dielectric profile of the region under investigation are also presented. To make the inversion algorithm more efficient, a semi-empirical model to predict the real and imaginary parts of the dielectric constant based on volumetric soil moisture content and soil type is developed for the frequency of interest (VHF range). This soil dielectric model which is based on the work of Ulaby et al [2] reduces the number of unknowns in the inversion making the inversion more efficient.

II. FORWARD MODEL

The goal is to detect a dielectric or metallic object buried under a background medium with high lateral and depth resolution. We start with a transmitter antenna illuminating the region under investigation and we want to somehow use the backscattered field to image any possible inhomogeneity (other than the stratified media representing the background). Our approach is to put a number of receivers above ground and use the received signals to image the region. By putting these sensors at various points around the transmitter, a synthetic aperture related to the overall length of the sensor setup is formed which will improve the lateral resolution.

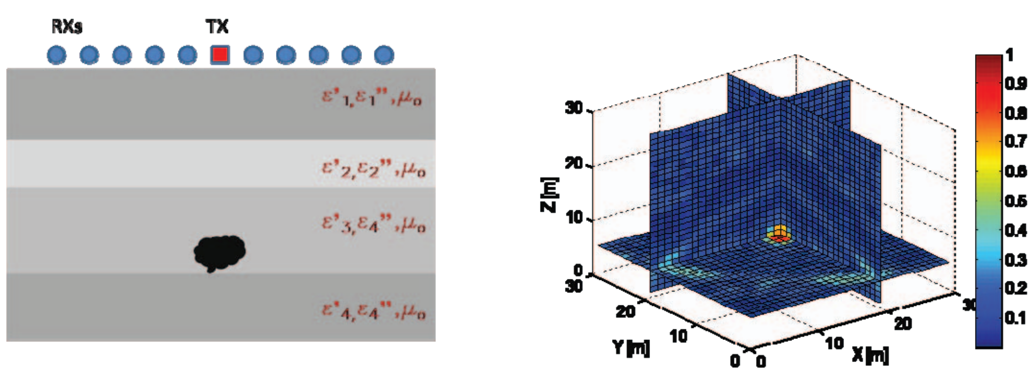

Fig. 1: Forward model Set up (Cross-Sectional View) and Reconstructed point target

The forward model is based on a planar stratified medium with varying complex dielectric constant and thickness and a target embedded in one of the layers. A rectangular transceiver grid is set up just above the top layer. The received field at each sensor is calculated,: 1) by using geometrical optics, and 2) by using the green's function in the presence of multiple dielectric layers and the back propagation algorithm. The second approach is more realistic; both models were used to verify the inversion technique.

III. INVERSION TECHNIQUE

In the inversion, the goal is to detect buried objects with the best possible resolution which also requires estimation of soil dielectric profile. An iterative approach was used to achieve this. First, we make a best guess for the dielectric constant of soil assuming constant soil moisture content, then the geometric optics approach in conjunction with back propagation algorithm is used to create a 3-D image of the subsurface domain. If there are buried targets, these targets are imaged with poor resolution. Then the image is sharpened by searching for the correct soil dielectric profile. This is done in two ways,: 1) by maximizing the power from a pixel within a target region, and 2) by considering moving resolution boxes around the detected targets and trying to fit the response to the ideal point spread function of the system. To minimize the search the real and imaginary parts of the dielectric constant are related by a single variable, namely, the soil moisture content though a semi-empirical model developed by Ulaby.

$$O(xi, yi, zi) = \sum_{fl}^{fu}\sum_{r1}^{rn} Ern * e^{j*k(f,mv)*r(xi,yi,zi)}$$

As it was alluded to in the previous section, the lateral resolution depends on the synthetic aperture which is implemented by the inner sum in the above objective function where the contribution from each antenna element is added to form each pixel. To improve the depth resolution, bandwidth is used. The transverse and depth resolutions are shown in the figure below.

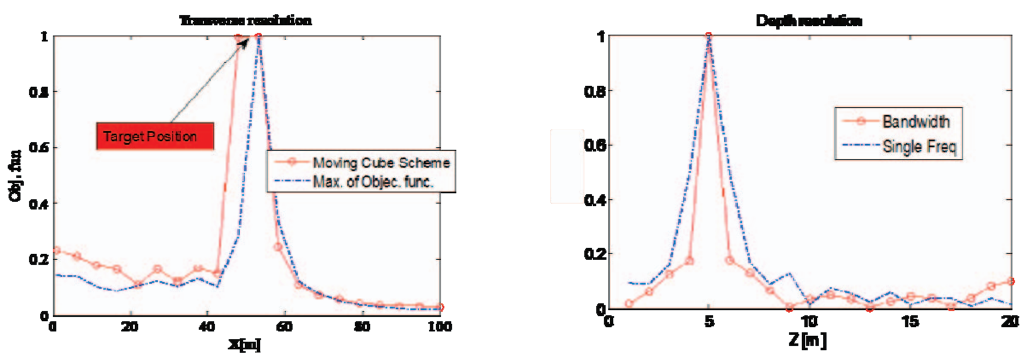

Fig. 2: Simulation results for transverse and depth resolutions

There are two important aspects of this project that call for further investigation. The distribution and polarization of the receivers need to be optimized with two objectives: minimizing the signal directly coupled from transmitter to receivers and achieving the best possible resolution. Also, for Unattended Ground Sensors (UGS) type applications, the proximity of the sensor network to ground will dramatically change the characteristics of the antennae [3]. To include such effects, experiments will be carried out and results will be used for sensor network optimization.

IV. REFERENCES

[1] Tegan Counts,Ali Cafer Gurbuz, Waymond R. Scott, Jr, James H McClellan and Kandwook Kim, "Multistatic Ground Penetrating Radar Experiments," *IEEE Trans. Geosci. Remote Sensing,* vol.45, no. 8, August 2007

[2] Fawwaz T. Ulaby, Richard K. Moore, and Adrian K. Fung, "Microwave remote sensing-Active and passive," Feb,1982

[3] DaHan Liao, Kamal Sarabandi, "*Terminal-to-*Terminal hybrid hull-wave simulation of low-profile, electrically-small , near-ground antennas," IEEE Trans. on antennas and propagation, March 2008