Bayesian Methods In Ground Penetrating Radar

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Abstract. Conventional Ground Penetrating Radar [GPR] suffers from displays that are difficult to interpret. In contrast, Bayesian methods allow description of target location probability that simplifies interpretation. We demonstrate the application of these methods to underground pipe identification. The instrumentation chosen shows only changes in targets, thereby eliminating targets such as layers of sediment which provide constant reflections.

A low frequency interferometer is used to collect data on subsurface obstacles. A simple model for the near-field reflection allows computation of the probability of the target location. The antennas of the interferometer are orthogonally polarized, and a balancing mechanism allows minimizing the effects of direct transmission of signals. Thus, the interferometer shows, mainly, reflections from changes in the target geometry. Using PIXON methods, resolution improvement was achieved. Applications tested were land mine location and utility pipe location. An added benefit is that reflections from layers of soil, due to the constant reflection from the layer, do not appear as distracting false targets.

Keywords: Ground Penetrating Radar, Bayesian, pixon.
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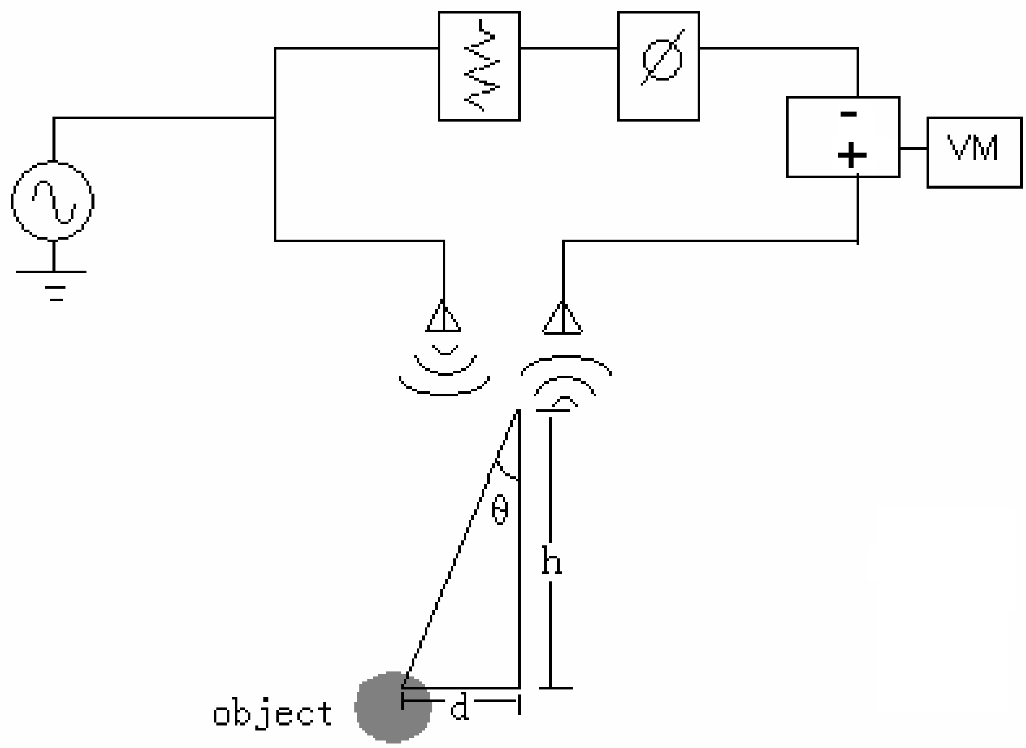
BACKGROUND

Locating utility structures such as water, gas, and sewer pipes is of considerable concern to municipal utilities. Common methods include use of GPR to locate such structures. Unfortunately, many areas have soil of high conductivity due to the presence of clay and water [1]. The high conductivity rapidly attenuates the signals which are typically chosen for high resolution in conventional radar systems. Many systems are in the 100 MHz – 10 GHz range.

Further, even using high frequencies, the broad beam-width of the antennas used in commercial systems creates artifacts which must be interpreted. Point targets often appear as parabolas, due to beam width inclusion of reflections from adjacent traces.

In contrast, we chose an interferometer at low radio frequencies (low MHz range). Figure 1 shows the signal splitting into an upper branch which serves as the reference signal, and a lower branch consisting of two orthogonally polarized antennas. Since there will always be some stray coupling of the antennas, or parasitic reflections to be cancelled, the reference branch (upper branch) allows obtaining a low level of signal for comparison to the received signal. The reference branch of the interferometer contains an attenuator to reduce signal levels when the reference and signal paths are recombined (typically, in a difference circuit). To simplify signal processing, the signal is modulated with a low frequency square wave. Since the modulation envelope of the signal source is detected, phase shift of the carrier is ignored. A voltmeter is used to measure the difference signal. Signal levels are amplified in both branches to provide convenient signal levels and signal isolation.



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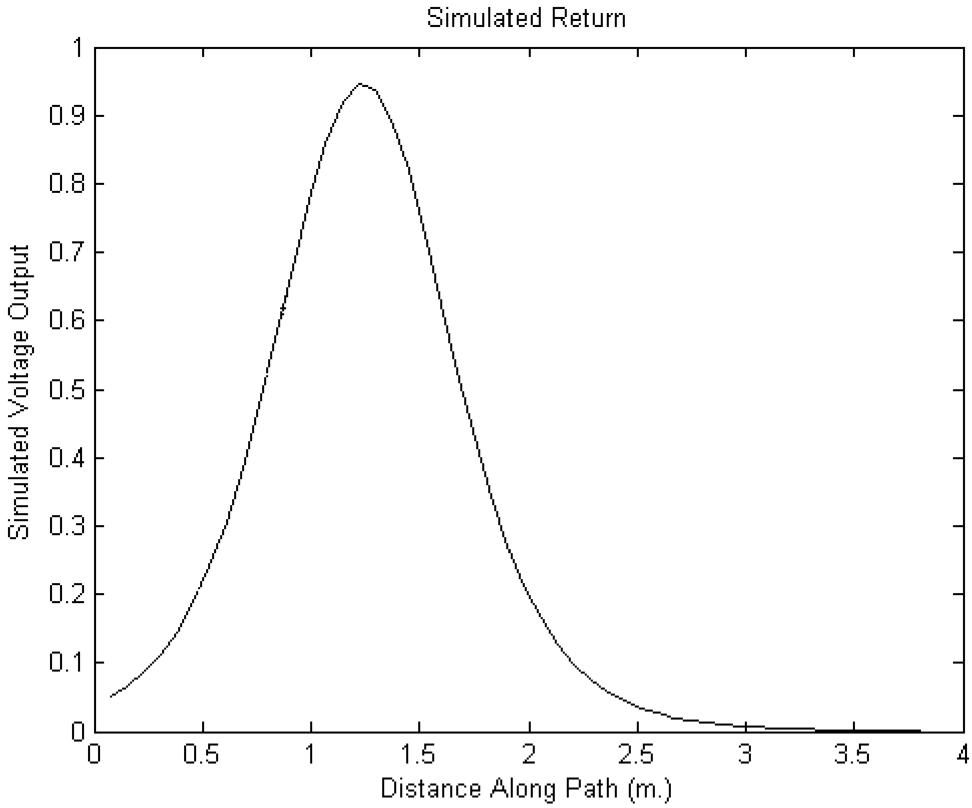

FIGURE 2. Typical response vs. displacement of antenna array, based on magnetic dipole model.

The analytic model for the two antennas, treated as infinitely short dipoles, has been adequate for this study. In other work, we have found that numerical models work equally well if one is concerned with the finite length of array elements.

Instrumentation And Signal Processing

The signal source is chosen in the low frequency range (80 m. wavelength band) for simplicity in testing. Low frequencies help reduce signal attenuation in the earth. The signal source is modulated with an audio frequency square wave. This simplifies the need to observe the phase of the radio frequency wave or correct for phase shift. A simple envelope detector is provided in both the reference branch and the signal branch of the interferometer. Signal processing is at low frequencies, due to the audio detection of the signals.

The methods of Bretthorst [2] were employed to locate the targets. A uniform prior is used in that work. The model functions are described in many elementary electromagnetics books [3]. The near field is the principal contributor to the signal signature.

Two examples of targets are shown. The probability contours for target location are shown. Figure 3 shows an iron pipe, 5 cm outer diameter (2 inch). This target was buried in a test bed at known depth and position, indicated on the drawing. Figure 4 shows a polyvinyl chloride [pvc] plastic pipe, 5 cm outer diameter (2 inch), which is used in water delivery systems. The pipe was filled with water and sealed on the ends. In both cases, iron and plastic pipes, accuracy adequate for utility location was obtained.

In the example of the plastic pipe, we used PIXON processing, which was introduced by Puetter and Piña [4]. This processing weights the data points proportional to the signal to noise ratio of the region in which data is taken. The high signal level in the vicinity of the target gives large signal to noise ratios. However, the signal response fades as the antenna array leaves the target region. Weighting this low signal level at the same level as the central signal would weight the noise heavily, in spite of the known low level of signal [5,6]. Figure 4 benefits from this processing over the uniform prior.

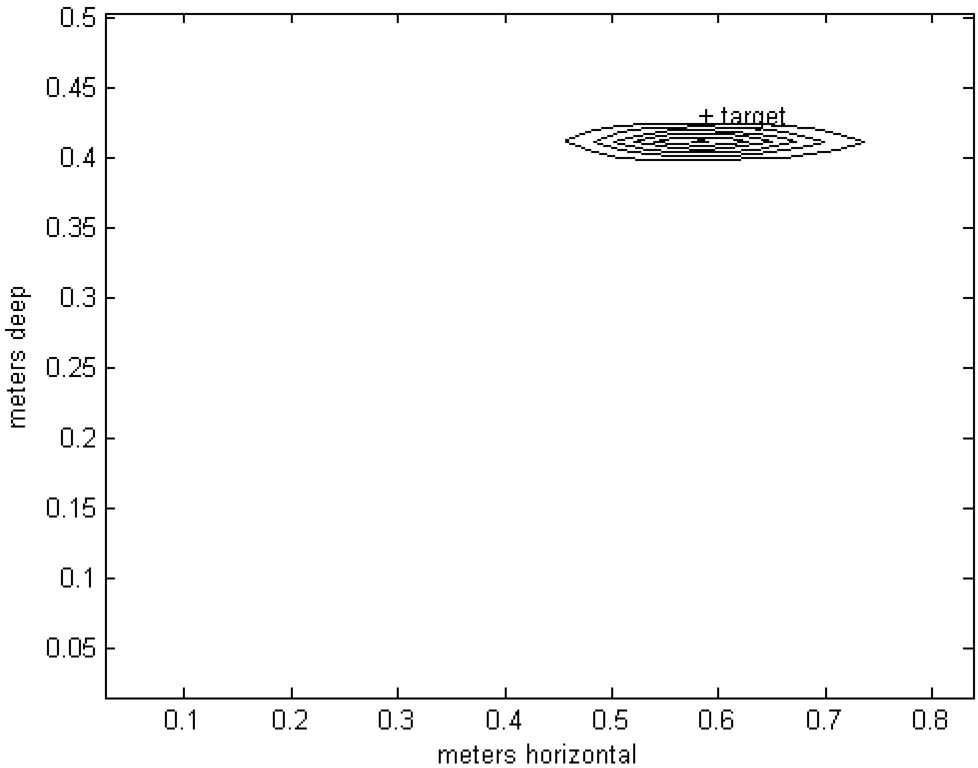

FIGURE 3. Probability contours for location of 5 cm diameter iron pipe..

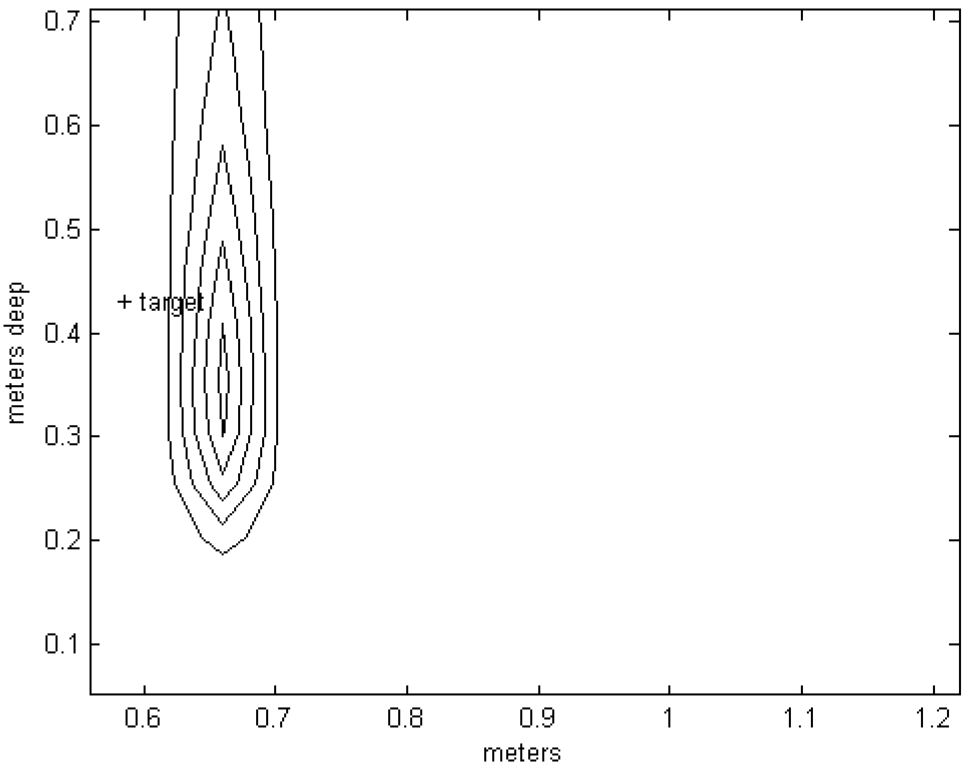

FIGURE 4. Probability contours for location of 5 cm diameter plastic water filled pipe.

The methods show promise in meeting an unfilled need. Higher sampling rates, spatially, would greatly improve the method which we have tested. Modeling, particularly for multiple targets located in close proximity, is also an area in need.

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