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Detection of Buried Detonatory Objects Using GPR

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Abstract

Detonatory Objects are affecting the lives and livelihoods of millions of people around the world. The small size and the fact that many have little or no metal make them extremely difficult to detect using conventional metal sensing detectors. Ground Penetration Radar (GPR) has a role to play in the detection process but the challenge is to translate that potential into practical systems that will make a real impact on this serious humanitarian problem. GPR can be used in a variety of media, including rock, soil, ice, fresh water, pavements and structures. It can detect objects, changes in material, voids, cracks and other inhomogenities. This paper is about the use of Stepped Frequency Continuous Wave (SFCW) GPR in the detection of land mines beneath the earth's surface. Kirchoff Migration (KM) algorithm is used for the detection**.**

Keywords: GPR, Stepped Frequency Continuous Wave Radar, KM Algorithm.

Introduction

Ground Penetration Radar (GPR) is a high-resolution electromagnetic technique that is designed primarily to detect buried objects. The GPR defines the location, size and electromagnetic (EM) reflectivity of objects. In Bscan GPR imaging [1], the antenna will be moving in one direction and at each point the reflected data is collected generating a 2D space frequency matrix. With inverse Fourier transform, data gets mapped in space-time domain. The Bscan image in this domain gives a hyperbola for a point scatterer. Migration algorithm is used to focus this data. Several migration techniques are in use in acoustic, seismic and geophysical engineering and was originally developed in two-dimensional form by Hagedoorn [2]. I have developed and applied a frequency domain GPR focusing technique based on Synthetic Aperture Radar (SAR) to mitigate the undesired hyperbolic effects in the Bscan GPR image [1].

Existing Detection Techniques

Various techniques are used for the detection of landmines. Some are: -

1. Metal Detector Technologies
2. Electromagnetic Methods
3. Acoustic/Seismic Methods
4. Biological Methods

Mine action programmes have traditionally relied on manual practices, procedures and drills, which are slow and labour intensive. Conventional hand-held metal detectors are not practical since Anti-personnel (AP) mines have little or no metal. Thermal methods are also available but they suffer from a high false alarm rate and lack of sensitivity to mines that have been buried for more than a year or so. It is also impractical if the detonating objects are very deep inside soil. Ground penetrating radar (GPR) is an existing electromagnetic technique that appears to offer at least part of the solution for detecting non-metallic AP mines.

Ground Penetration Radar (GPR)

A ground penetration radar system [3] includes a radio transmitter and receiver, connected to a pair of antennas coupled to the ground. The transmitted signal penetrates a short distance into the ground and some of it reflects off any object with different electrical properties than the host dirt. The depth of penetration depends upon properties of host material, i.e. soil and, frequency of operation. The extent of reflection depends upon the difference in the refractive indices of the host material and the suspected object. To construct an image that the operator can interpret, the radar plots the echo from the object on the display of a computer. When enough of these signals are plotted side-by side, the operator can see a pattern that he can interpret as an object. I have simulated with dry sand with a dielectric constant of 4.The figure 1 gives a block diagram of GPR system.

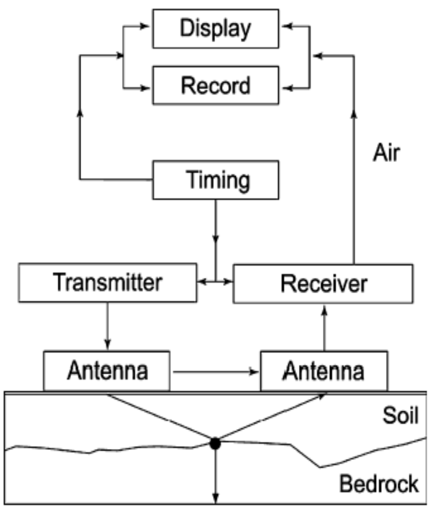

Figure1. Ground Penetration Radar (GPR) system

Stepped Frequency Ground Penetration Radar

A Stepped Frequency Continuous Wave Radar (SFGPR) [4] incorporates an RF source or a direct digital synthesis (DDS) source, and DSP. The source is stepped between a start frequency, f_0, and a stop frequency, f_{N-1}, in equal, linear increments. The figure 2 shows the arrangement of a SFGPR.

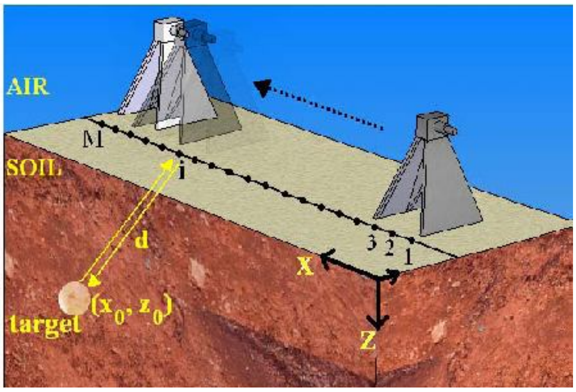

Figure 2. Stepped Frequency GPR

In this paper for synthetic generation of GPR data I have simulated a monostatic antenna for a frequency range of 500 MHZ to 3.3 GHZ. The purpose of the synthetic GPR data is to check and ensure that the migration algorithm is fully able to indicate the spatial location of buried targets.

Kirchoff Migration Algorithm

The hyperbolic defocusing of an object in Bscan image can be corrected for in the data processing, which is called migration or SAR processing. The aim of migration technique is to focus target reflections in the recorded data back into their true position and physical shape. In this respect, migration can be seen as a form of spatial deconvolution that increases spatial resolution. In my simulation I have used Kirchoff Migration Algorithm [1,3,5]. The following equation explains the KM algorithm. Kirchoff Migration is based on the integral solution of the scalar wave equation: -

$$\nabla^2\psi(r,t) - \frac{1}{{v_m}^2}\frac{\partial^2}{\partial t^2}\psi(r,t) = 0$$

The final KM equation in 2D is given by:-

$$F_{KM}(y,z) = \frac{1}{2\pi v_m}\sum_{i=1}^{I}\frac{\partial}{\partial t'}\psi(y'_i, z' = 0, |r - r'|/v_m)\frac{\cos(\theta)}{|r - r'|}$$

Experimental Results

The synthetic GPR data was generated using Matlab. Since GPR data is in the form of a matrix, Matlab is one of the obvious choices for GPR data processing. The Stepped-

Frequency Ground Penetrating Radar (SFGPR) (Figure 2), with a minimum carrier frequency of 500MHz, and with a frequency step size of 20MHz for 128 steps. The frequency of the ith frequency step can be written as fi=fo+iΔf. The radar signal measurement at the frequency fi can be written in complex form as

$$C(i) = I(f_i) + jQ(f_i)$$
$$= A_M(i)e^{-j2\pi f_i \tau}$$

Where Am is the range in the radar equation

$$P_R = \frac{P_T G^2 \sigma (\lambda/\varepsilon_r)^2}{(4\pi)^3 R^4 L_p}$$

where PR=received Power, PT=transmitted Power, G=antenna gain ,σ=radar cross section of the target, λ=wavelength, εr=dielectric constant, and R=range to target and Lp is the path loss.

When the antenna has scanned each offset at each frequency step, the resulting data is stored in a matrix. To convert this data from the frequency domain into the time domain, the Inverse Fast Fourier Transform is applied. Zero padding is used to give a better interpolation between points when the transform is applied. Three targets located at three different locations with ground permittivity of 4 (dry sand) is chosen. The 2D B-scan GPR image in spatial depth domain is obtained by taking the 1D IFT of the back scattered signal data along the frequency domain .As expected the raw GPR image of the simulated object exhibits the hyperbolic defocusing behavior. Using Kirchoff Migration algorithm i have focussed the exact target location as shown in figure 4,6.

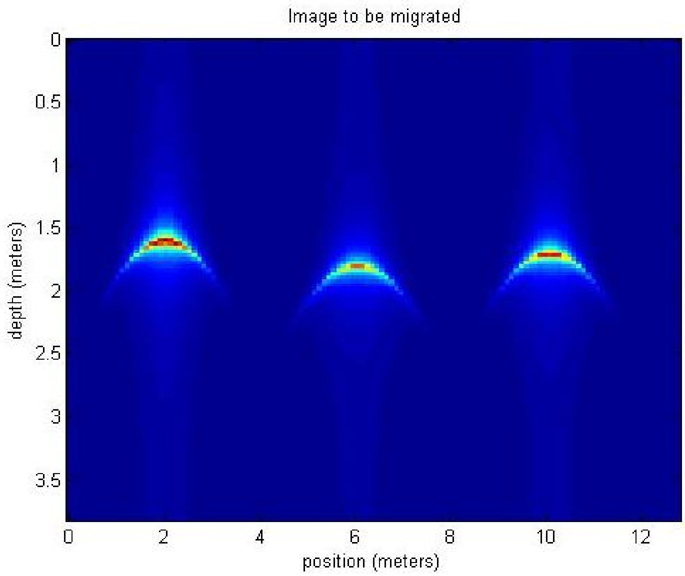

Figure 3. Generated GPR data

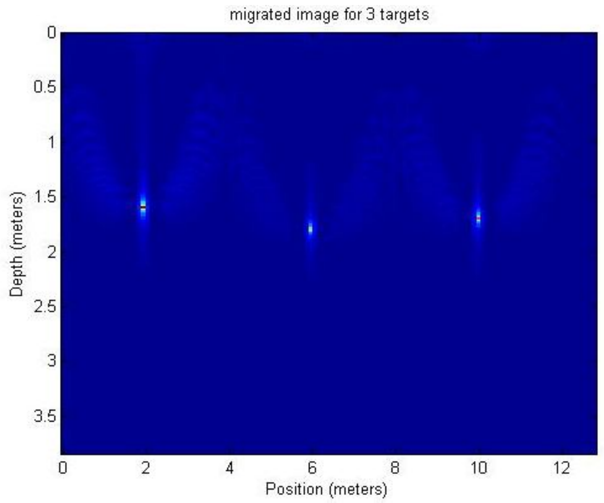

Figure 4. Migrated Data

Also for three targets with two of them closer is also simulated.

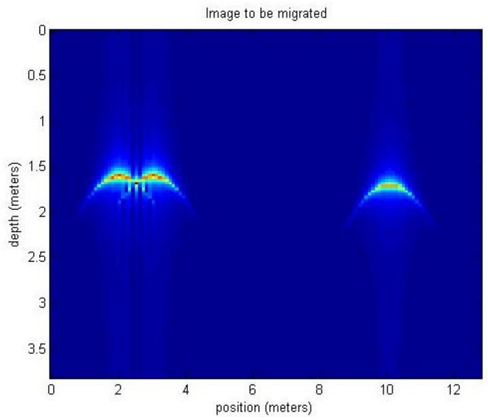

Figure 5. Two targets very close to each other

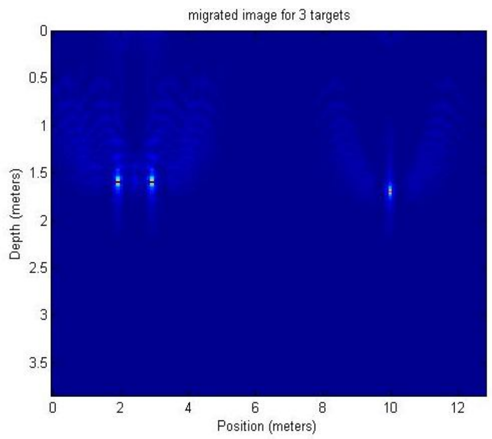

Figure 6.Migrated image for two targets very close to each other

Conclusion

A detailed study about the land mine detection using ground penetration imaging techniques and migration has been done in this paper. The algorithm is tested with a set of simulated data .Almost perfect focusing was achieved after applying the proposed technique to the simulated GPR data.

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