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Symmetry filtering method of clutter reduction for GPR based buried landmine detection

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ABSTRACT

Modern landmines are mainly non- metallic or contain small amount of metal, that they cannot be detected using conventional detectors. Ground Penetration Radar (GPR) is capable of detecting shallowly buried non-metallic objects. GPR is the best alternative for detecting non-metallic landmines. But, GPR also performs inadequately due to the presence of clutter which dominates the data and obscures the main information. In this paper symmetrical filtering method is going to be applied on measured B-scan data to reduce unsymmetrical clutter. Results of the symmetry filtering and symmetry point location algorithm are presented.

Introduction

Ground Penetration Radar (GPR) is an alternative sensor for detecting shallowly buried targets such as Anti-personnel (AP) mines, pipes, cables, and underground structures such as tunnels, bridges, graves etc. [1-3]. GPR has some advantages over other subsurface investigation and sensing devices in locating less metallic or non-metallic objects. GPR is also very sensitive to the changes in the electromagnetic characteristics (permittivity, conductivity and magnetic permeability) of the medium.

GPR can survey an area in front of it unlike other sensors that can only survey an area beneath them. Impulse time-domain GPR is capable of detecting buried landmines that have little or no metal content, provided that adequate contrast or discontinuity exists between the landmine and the surrounding [3]. GPR measured signatures of shallowly buried landmines are normally obscured by strong background signal comprised of reflections from the ground surface, surrounding noise, reflection from non-mine objects and the cross communication of the receiving and transmitting antennas, called clutter. Clutter may be defined as in [1], “those signals that are unrelated to the target scattering characteristics but occur in the same sample time window having similar spectral characteristic to the target wavelet”. Statistics of this signal also depend on the environmental conditions such as soil type, amount of moisture, composition and roughness.

The conventional methods used to reduce clutter, such as background subtraction, trimmed average power; PCA, ICA, Kalman filtering and parametric models are effective methods in reducing background clutters. Antenna cross talk can be eliminated by window time gating [4, 5] and the noise component can be reduced or eliminated by using moving average smoothing techniques.

The conventional techniques have shown good performance in reducing the three clutter components. However they show poor performance in reducing the random (variable) clutter. They are unable to discriminate mines from friendly objects such as rocks, tree roots cracks in the ground.

Most landmines are symmetrical that either they have either cylindrical shapes or cylinders of different diameter are ordered vertically, or they have box like shapes. But, the external anomalies (Buried non-mine and surface lying objects) exist randomly and they lack symmetry. They are neither cylindrical nor box shaped objects. The main objective of the paper is to present symmetry filtering techniques to reduce non-symmetrical random clutter and to locate the symmetry position in the presence of single and multiple symmetric objects.

The rest of the paper is organized as follows. In section II we will briefly discuss about the symmetry property of the received signal and the methodology. In section III we will discuss about the steps in symmetry filtering design method and symmetry location in the presence of single and many targets. We will present the real data collection approach in section IV. In section V we will present results and we will conclude about the methodology in section VI.

General Signal Model

Let us consider a B-scan image be represented by the rectangular matrix u(t, x), with dimensions M×N. The B-scan signal measured at the receiver antenna at time “t” and position “x” is given by

$$u(t,x) = s_c(t,x) + s_b(t,x) + s_t(t,x) + s_n(t,x) \qquad (1)$$

where u(t,x) is total received signal, $s_b(t, x)$ is signal bounced from the air-ground interface, $s_c(t, x)$ is signal due to communication between the two antennas $s_t(t, x)$ is signal reflected from the target and $s_n(t, x)$ is added noise.

When the radar moves against a target contained ground, a parabola is created due to the relative position of the radar and a point on the target as shown in Figure 1 and 2. The center of the parabola appears when the antenna is just above the point on the target, which implies the shortest distance between the point target and the antenna or it is the position of shortest time delay.

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Each point in the object creates a parabola and the summations of the many parabolas of symmetrical object create a bold symmetrical parabola centered at the center of the object. However, the summation of parabolas of unsymmetrical object creates asymmetrical image as shown in Figures 1-3.

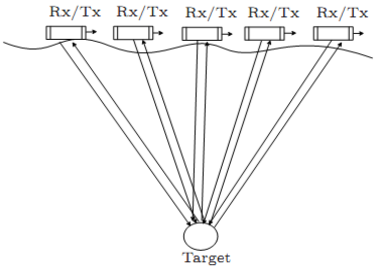

Figure 1. Transmit receive at different positions

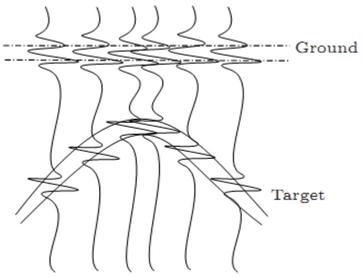

Figure 2. Parabola due to point on the target

In GPR based landmine detection, the bounced signal consists of mainly four components: the noise from the interference of electromagnetic devices, mobile phone waves and electromagnetic wave carrying cables; the antenna cross-talk between the receiver and transmitter antennas, the refection from the air-ground interface, and the scattered signal from other objects (buried non-mine objects and on surface objects) and also the background resulting from scattering with in the soil. The detection problem is then the ability to separate the landmine and friendly objects.

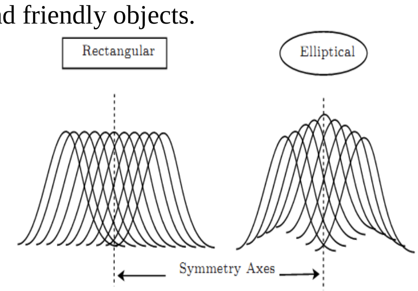

Figure 3. Shapes due to symmetrical objects

Three of the clutter components can be removed using the conventional techniques and some simple signal processing techniques. The main focus of this paper is to reduce the random clutter due to the external anomalies using symmetry filtering techniques.

Signal Processing Techniques

Assumption of the symmetry properties of landmines helps to make classification between landmines and random clutter. The symmetry difference between the target reflection and variable clutters in B-scan is one of the important signal properties. There is high correlation, if the lateral signal has a strong symmetry [6]. Designing a symmetry filter addresses the problems associated with discrimination of the landmines from friendly objects.

The objective is to design a symmetry filter which suppresses signatures from unsymmetrical clutters.

Antenna crosstalk, noise and constant clutter components of the received signal are removed first and then the symmetry filtering follows next.

Li Ting-jun et.al. has explained the symmetry filtering method for clutter reduction. But, the paper didn't include the noise, antenna crosstalk and offset removal techniques. Unless we reduce this components, a symmetrical object may appear to be non symmetrical in the presence of the clutter. Moreover, the paper didn't explain how the symmetry locations are determined in the presence of many symmetric targets or if the numbers of targets are unknown. The presence of noise and offset affects the symmetry properties of the received signal.

Steps in symmetry filtering method are stated as follows.

Step 1: Antenna Crosstalk Removal

Antenna crosstalk occurs when the pulse signal sent by the transmitter is measured by the receiver before reaching the ground. This clutter component can be removed by time window gating [4, 5].

$$u'(t,x) = \begin{cases} u(t,x) & \text{if } t \geq 2t_c \\ 0 & \text{if } t < 2t_c \end{cases} \qquad (2)$$

where $t_c = h_c /C$, t_c is the shortest time delay and h_c is height of the antenna from the ground and C is speed of light in free space.

Step 2: Noise removal

The noise component can be removed using moving average techniques.

a. Weighted moving average: The filtered signal is given by

$$s[i,j] = \frac{n.u'[i,j] + (n-1).u'[i-1,j] + \ldots + u'[i-n+1,j]}{n + (n+1) + \ldots + 2 + 1} \qquad (3)$$

b. Exponential moving average: The filtered signal is given by

$$s[i,j] = \frac{N-1}{N} s[i-1,j] + \frac{1}{N} u'[i-1,j] \qquad (4)$$

where N is any positive integer greater than 2

Step 3: Offset removal

The mean value of an A-scan is close to zero. This assumes that the amplitude probability distribution of the A-scan is symmetric about the mean value [1]. Offset removal is obtained using the following formula

$$s'[i,j] = s[i.j] - \frac{1}{tsize} \sum_{j=1}^{tsize} s[i.j] \qquad (5)$$

where, 's'[i, j] is the discrete version of s(t, x), the time index is transformed to pixels as

$$i = t \ . \ \frac{\text{Samples per scan}}{\text{range}}$$

Samples per scan and range belong to the measurement setup. For 1.5GHz GPR antenna, [12] recommends samples per scan of 512 and range 12 ns. "tsize" is the total number of pixels along A-scan which is equivalent to the number of samples per scan.

Step 4: Stationary clutter removal

Stationary clutter corresponds to the signal bounced from a uniform air-ground interface. This component can be removed using background subtraction techniques, such as subtracting the average or median along the space from each signal in the same depth. Bounced signal from a non uniform ground is considered as a non symmetric clutter and will be removed by symmetry filtering. Stationary clutter removal is given as:

$$r[i,j] = s'[i,j] - \frac{1}{xsize}\sum_{j=1}^{xsize} s'[i.j] \qquad (6)$$

where xsize is the total number of traces, r is processed signal and s′ is unprocessed signal

Step 5: Symmetry filtering

The symmetry filtering algorithm is given by

$$g[i,j] = \sum_{m=-M}^{M}\sum_{k=1}^{K} r[i-m, j-k]r[i-m, j+k] \qquad (7)$$

where M is related to the width of the radar pulse.

Step 6: Locating the symmetry position

The symmetry position for a single target assumption is given as explained in [6]

$$J_o = \underset{j}{\arg Max}\; g[i,j] \qquad (8)$$

If there are many targets or the number of targets are unknown, we use a search algorithm to locate the points of symmetry

a. Determine the test statistic

$$y_j = \max(g[i,j]) \qquad (9)$$

b. Search for j such that γ_j is greater than γ_j times the average of γ_j

$$J = j : y_j > \frac{\gamma}{N}\sum_{j=1}^{N} y_j \qquad (10)$$

c. Declare J is the symmetry point if the following condition is satisfied

$$J_o = J : y_J > \{y_{J-k}, y_{J+k}\} \text{ for k = 1, 2, …, R} \qquad (11)$$

where R and K are related to the valid aperture of the radar, γ is correction factor which implies that a peak is considered as a target if the value of the maximum is more than γ times the mean of the maximum and J_o is the symmetry position of the reflected signal.

Step 7: Computing the range direction symmetry weighting matrix for all possible values of J_0

$$\rho[i] = \frac{\sum_{m=-M}^{M}\sum_{k=1}^{K} r[i-m, J_o-k]r[i-m, J_o+k]}{\sqrt{\sum_{m=-M}^{M} r[i-m, J_o-k]^2 \sum_{k=1}^{K} r[i-m, J_o+k]^2}} \qquad (12)$$

Step 8: Computing the lateral direction symmetry weighting matrix

$$a[i, J_o+j] = a[i, J_o-j] = \frac{r_{12}}{\sqrt{r_{11}r_{22}}}$$

where

$$r_{12} = \sum_{m=-M}^{M}\sum_{n=-N}^{N} r[i-m, J_o-j-n]r[i-m, J_o+j+n]$$

$$r_{11} = \sum_{m=-M}^{M}\sum_{n=-N}^{N} r[i-m, J_o-j-n]r[i-m, J_o-j-n]$$

$$r_{22} = \sum_{m=-M}^{M}\sum_{n=-N}^{N} r[i-m, J_o+j+n]r[i-m, J_o+j+n]$$

where M and N are related to radar pulse width

Step 9: Computing the synthetic symmetry filtering weighting matrix

$$w[i,j] = e^{\rho_n[i]}\, e^{a_n[i,j]} \qquad (13)$$

where $\rho_n[i]$ and $a_n[i, j]$ are the normalization of $\rho[i]$ and $a[i, j]$, respectively.

Step 10: Performing symmetry filtering

The overall filtering is considered to each symmetry position J_0 and given by

$$f[i,j] = s[i,j].\, w[i,j] \qquad (14)$$

Experimental data

A series of measurements has been taken using a set of targets buried in various types of soils at different moisture levels. A 1.5 GHz, 80% bandwidth bistatic, shielded antenna developed by Geophysical Survey Systems Inc. (GSSI), USA, has been used for the survey.

We have used a distance mode of collection and the system collects 330 returns per feet, each composed of 512 samples with 16 bit accuracy.

The antenna has a survey wheel, which suspends the antenna at a height of 2 cm above the ground. SIR3000 with black cable has been used as a controller.

We setup an experiment of three true targets (M14, PMN1 and PMN2), pieces of rock and wood as random clutters, in different types of soils (Man made sand, pure sand, clay and mixture of soils) at different moisture levels. We placed the targets at a depth between 2.5 to 5 cm below the ground surface. In the distance mode of data collection, there is no need of controlling the velocity of the antenna as far as the speed allows to measure 330 scans/ft, 512 samples/scan and it takes 12 nano-seconds/scan. If the speed is more than the limit, the device beeps twice for failure to record the unavailable data.

The targets were made from PVC cylinders of recommended sizes. The PVC cylinders were filled with wax and a small metal at the center of the cylinder. A table of target dimensions is given below. Some of the targets we used in the experiment are listed in Table 1.

Note that, the rock and the piece of wood are irregular shaped their sizes are to the size of the average landmine

We have applied the elementary signal processing to remove some clutter and then followed by the symmetry filtering method to discriminate the mines from mine like friendly objects.

Results

The following results are presented for two types of measurements where, PMN1 and M14 in the first setup and PMN2 and PMN1 in the second measurement. The results after the symmetry filtering and symmetry position determination are presented in Figure 4 and Figure 5 respectively.

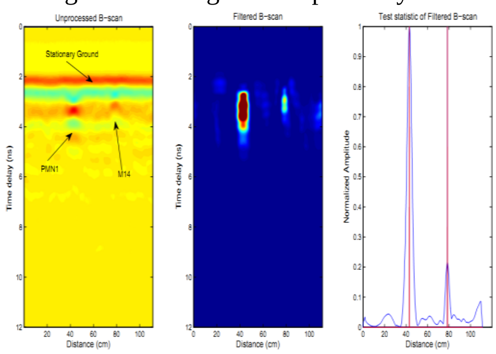

Figure 4. Symmetry filtering for PMN1 and M14 in the presence of clutter

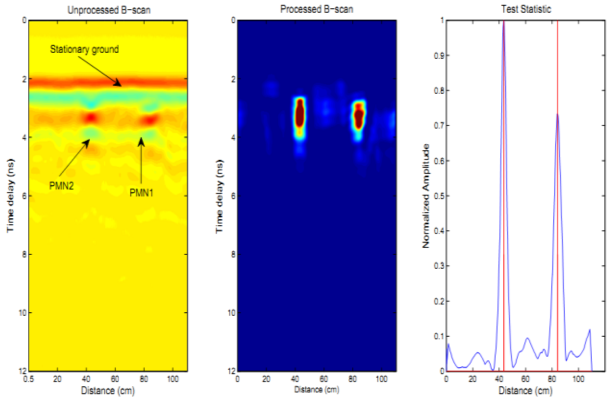

Figure 5. Symmetry filtering for PMN1 and PMN2 in the presence of clutter

Conclusion

Symmetry filtering method is very effective technique in reducing clutters due to undulated ground bounce, soil roughness scattering and external anomalies. This method reduces clutter components which are difficult using conventional techniques. The symmetry position search algorithm also effective in locating the symmetry position in the presence of single, or many even if the numbers of targets are not known.

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TABLE I. DIMESNIONS OF MINE-LIKE SURROGATE TARGETS AND FLASE TARGETS

	True Targets				False Targets	
Targets	M14	PMN1	PMN2	Pepsi can	Wood	Rock
Width/ Diameter	52 mm	120 mm	115 mm	60 mm	Irregular	Irregular
Height	42 mm	50 mm	53 mm	125 mm	Irregular	Irregular