Real time detection of buried objects by using GPR

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ABSTRACT

In this work the detection process of buried objects is presented utilizing Ground Penetrating Radar (GPR). Background removal algorithm is used to obtain the target signature and correlation process is performed to reveal the reflected target energy. Then, a detection warning signal is created depending on a special process. In this work, pulsed GPR system with 1 GHz bandwidth is used. Scanning speed is 0.33 cm/sec in the sweeping direction and this process is repeated in the walking direction with 4 cm spatial resolution.

Keywords: GPR, buried object detection.

1. INTRODUCTION

Ground Penetrating Radar has a wide range of applications, such as localization of unknown ancient graves, tunnels, pipes, buried explosives, mines, etc. There are millions of buried mines over the world to be exploded. It is a challenging problem to detect the mines with %100 rate, especially non metallic ones. Since the background clutter is severe and medium is lossy and dispersive, detection and classification of buried objects in sand and soil offers considerable challenges for signal processing algorithms.

2. UNDERGROUND OBJECT DETECTION

GPR systems evaluate the reflection of transmitted signals from the environment. Shape and modulation of transmitted signals are application dependent. Transmitted signal can be a short pulse or stepped frequency (FM) shaped. System parameters must be determined considering the dielectric properties of the environment, depth, target size and target shape [1]. FM modulated systems have more immunity against the noise, but its computational complexity is high. Although, pulsed GPR systems has less immunity against to the noise but its computational complexity is better [1]. A block diagram of a typical GPR system to detect underground objects, is given in the following figure.

![Block Diagram of GPR System](https://example.com/gpr-block-diagram.png)

Let’s consider the co-ordinate system of spatial data collection scheme. A typical received GPR A-scan signal and B-scan image are illustrated in the following figure. The operator scans the path along the x-axis and A-scan signals are acquired over the grid depicted in Figure-2.a. This action is repeated in the y (walking) direction sequentially up to a warning signal is created.
An acquired A-scan signal in the position of \((x_i, y_j, z_k)\) can be represented in the following form.

\[
a(x_i, y_j, z_k), \quad (i=1, \ldots, N; \; j=1, \ldots, M; \; k=1, \ldots, L)
\]  

(1)
where N, M and L are the spatial boundary indices determining the scanning region. Depth variable \( z \) contains the equivalent information in time with a difference of scaling factor proportional with propagation velocity of the electromagnetic wave.

### 2.1. Signal Processing

Since the received GPR signal exposed to different noise and clutter signals, it must be cleaned as far as possible. In order to increase the signal to noise ratio of the received signal, a few methods can be applied. Two of them are averaging and background removing [1].

**Averaging:**

Due to the impulsive nature of GPR system, noise is unavoidable in A-scan signals. In order to prevent this noise in a certain range, each sample is acquired by taking average of received \( R \) samples given in the following equation.

\[
a_A(x, y, z) = \frac{1}{R} \sum_{r=1}^{R} a(x, y, z_r)
\]  

(2)

where \( R \) represents the repetition of transmission for each A-scan sample. Typical value of \( R \) can be chosen as \( R=4 \) or \( R=8 \). It is assumed that there is no considerable location difference in each sequential samples to be averaged, this creates a constraint in scanning speed.

**Background removing:**

If it is guaranteed that the starting location does not contain any target signature, a pre-defined number of A-scan signal is averaged and the difference calculation is performed to reveal target signature along the path given in the following equation.

\[
a_B(z) = \frac{1}{P} \sum_{i=1}^{P} a_i(x, y, z)
\]  

(3)

\[
a_{BB}(x, y, z) = a(x, y, z) - a_B(z)
\]  

(4)

where \( P \) represents the number of A-scan signals obtained from initial clear region, \( a_B \) and \( a_{BB} \) represents background signal estimate and background removed A-scan signals, respectively in the following figure.

### 2.2 Buried object detection

There are different methods to obtain a detection warning signal (DWS) from GPR B-scan data. If the reflected target energy is high, the cumulative energy distribution (CED) given in the following equation may be adequate to make visible the target energy [2].

\[
CED(x, y, z) = \sum_{k=1}^{L} a(x, y, z_k)^2
\]  

(5)

An example of GPR B-scan metallic object data and spatial cumulative energy distribution in depth is given in the following figure. In this figure, vertical and horizontal axis represents depth \( z \) and scanning direction \( x \), respectively. The reflection of buried object signal is obviously seen in the cumulative energy distribution profile.
Since the target does not give high reflection in most cases, more robust methods is needed to detect the buried objects. Spatial correlation summation of specified number of A-scan signals is convenient for this purpose, given in Figure-4.

This method based on that the target signals are correlated with each other (matched) near to the target. The correlation summation function at position \((x,y,z)\) is given in the following equation [3], [4], [5]:

\[
CSF(x, y, z) = \sum_{m=-W}^{W} a(x, y, z) \ast a_m(x, y, -z)
\]  

(6)

Where \(\ast\) denotes the convolution operator, \(a_m(x,y,-z)\) represents \(m^{th}\) A-scan signal with flipping. Typical \(W\) value can be chosen as 3. In order to decide target existence, a special process must be performed explained in the following.
2.3 The proposed buried object detection method

Due to the soil properties may change within a short distance, it is not possible to use simple methods in real time application of buried object detection operations. So, we proposed an effective detection warning signal creation algorithm [2] to prevent this handicap, given in Figure-5.

In the proposed algorithm, A-scan signals are acquired and target-free initial P A-scan signals are averaged in each sample point to estimate a background A-scan signal. The background A-scan signal is updated by taking the moving average of last P A-scan signal, until a detection warning signal is created, in each discrete location. If detection warning signal is activated, background update is not performed. After a detection has been completed, background update is performed by taking the last target free P A-scan signals average. The moving average of delayed correlation function ($DCFM(x,y,z)$) and error function ($E(x,y,z)$) are calculated to activate the detection warning signal, given in the following equations.

$$DCFM(x,y,z) = \frac{1}{D} \sum_{n=0}^{D-1} CSF(x-n,y,z)$$  \hspace{1cm} (7)

$$E(x,y,z) = [\max\{CSF(x,y,z)\} - \max\{DCFM(x,y,z)\}]^2$$  \hspace{1cm} (8)

The decision of target detection is performed by calculating the difference between maximum value of ($CSF(x,y,z)$) and maximum value of its delayed average ($DCFM(x,y,z)$). If the difference ($E(x,y,z)$) exceeds level V, a detection warning signal is activated until the $E(x,y,z)$ function fall down to the its triggered level. D parameter selection is dependent to the scanning speed.
3. EXPERIMENTAL RESULTS

In this section experimental result of buried object detection operation will be presented. The parameters R and D are selected as R=8 and D=10 experimentally. Number of average A-scan signal parameter is selected P=20, correlation summation number parameter CSN=7 and error threshold value V=25.10^-15. We tested the proposed algorithm over a real test data set.

In the following figures the maximum value of correlation summation function CSF(x,y,z), delayed mean of its maximum value, DCFM(x,y,z) and detection warning signals are depicted for different type of buried objects. In these figures, solid lines, dashed lines and dark region represents the maximum value of correlation summation function CSF(x,y,z), maximum value of delayed mean function, DCFM(x,y,z) and detection warning signal (DWS) respectively.
a) Original B-scan data

c) Background removed B-scan data

e) Detection result of the above data

Figure-6 The detection result of 10 cm disc

a) Original B-scan data

c) Background removed B-scan data

e) Detection result of the above data

Figure-7 The detection result of 6 cm disc
a) Original B-scan data

b) Background removed B-scan data
c) Detection result of the above data

Figure-8 The detection result of 8 cm disc

a) Original B-scan data

b) Background removed B-scan data
c) Detection result of the above data
d) The detection result of 25 cm disc

Figure-9 The detection result of 25 cm disc
It is shown in the above figures that the proposed method works efficiently in the detection of buried objects, especially in smooth ground. So, this method is applicable for path and road inspection. The proposed algorithm adapts itself to the environment in the estimation of background signal. However, false detection signals can be occurred like in Figure–8, originated by clutters in the soil contaminant. This problem can be solved by further processing and sensor fusion algorithms.

4. CONCLUSION

In this study an efficient buried object detection method is presented utilizing GPR. Satisfactory results have been obtained in the both test site and terrain. So, non-metallic objects has been made detectable by utilizing GPR and signal processing.

Since GPR systems detects all discontinuities, they may give warning to the all buried objects such as stones and roots including the other objects. In the next step, object identification problem must be solved by using some pattern recognition methods such as neural network based classifiers, etc.

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