IDENTIFICATION OF MINE-LIKE OBJECTS UNDER ROUGH GROUND SURFACE USING GROUND PENETRATING RADAR

Masahiko NISHIMOTO and Shuichi UENO
Department of Electrical and Computer Engineering, Kumamoto University
Kurokami 2-39-1, Kumamoto, 860-8555, Japan.
E-Mail nisimoto@eecs.kumamoto-u.ac.jp

1. Introduction

Since many people are killed or injured in landmine related accidents each year, it is highly desirable that reliable methods for detecting and identifying buried landmines are developed. Compared with a metal detector that is widely used for landmine detection, a ground penetrating radar (GPR) based approach would appear to offer many advantages, particularly for the detection of plastic landmines with little or no metal content [1]. However, reliability of the GPR system applied to detection and identification of shallowly buried landmines is not sufficient because the GPR also receives returns from other subsurface objects such as rocks, tree roots, or metal fragments in the ground, which yields high levels of false alarms. Accordingly, development of highly reliable algorithms for target detection and identification that are applied to GPR data is highly desired [2]-[6].

In this paper, we study an identification problem of mine-like objects under rough ground surface using the GPR. In the process of target identification, it is required to discriminate between targets and clutter objects using target features extracted from reference data prepared through prior experiments and/or numerical simulations. In general, the selection of the target features plays a key part in target identification because the identification performance strongly depends on the target features. In this study, we employ a time interval between two pulses reflected from top and bottom sides of landmine-like object as a feature and examine the identification performance. Since the time interval is closely related to the thickness and permittivity of the objects, we can expect that this simple feature is available and suitable for target identification. Through a Monte Carlo simulation using data set generated by a two dimensional finite difference time domain (2D FDTD) method, we show that good identification performance is obtained by using this feature even when the target is located at shallow depth under a rough ground surface.

2. Feature for target identification

First, we roughly estimate a time resolution that is required in detecting object thickness from GPR data. Let us consider electromagnetic pulse reflection from a dielectric slab of thickness d. Time interval between two pulses reflected from top and bottom sides of the slab is expressed as

$$T = \left(2d / c_0\right)\sqrt{\varepsilon_r} \tag{1}$$

where ε_r is the relative permittivity and c_0 is the speed of light in free space. Change of the thickness Δd leads to the following time difference:

$$\Delta T = \left(2\Delta d / c_0\right)\sqrt{\varepsilon_r} \tag{2}$$

Since a relative permittivity of trinitrotoluene (TNT) is about $\varepsilon_r = 3.0$ [7], it can easily be found that the difference of the thickness $\Delta d = 1.0$ cm corresponds to the time difference $\Delta T = 0.12$ ns. This indicates that if the detection ability of the time difference is less than 0.12ns, we can distinguish two objects that are more than 1.0cm different in thickness. Thus, we can expect that good identification performance will be achieved by employing the time interval T as one of the target features. However, it may be difficult to identify shallowly buried objects under rough ground surface using this feature,

ISBN: 89-86522-79-9 94460©KEES

because ground surface clutters caused by surface roughness and target/surface interaction effects make significant contributions to measured target signals. Furthermore, low contrast in relative permittivity of the buried targets and their surrounding soil makes the target signals weak and obscure. In the next section, in order to examine the ability of this feature to identify the targets when it is applied to more realistic GPR data, we carry out a Monte Carlo simulation using a data set that includes various GPR data samples.

3. Evaluation of identification performance using two landmine-like targets

Figure 1 shows the GPR measurement system considered in the numerical simulation. A Monte Carlo simulation is carried out for data generated by a two-dimensional FDTD method. Of course, a three-dimensional FDTD method may provide more accurate and realistic data, but it would require large computation time to generate the hundreds of data required for a Monte Carlo simulation. Thus, here we employ a 2D version for data generation. The measurements are made at multiple observation points above the rough ground surface using transmitting and receiving antenna pair. As the target models, we use two landmine-like objects with 9.0cm in width and 4.0cm and 5.0cm in height. Simulations are carried out for 100 rough surface realizations with Gaussian distributed height and slope generated by the method proposed by Thorsos [9]. Figure 2 shows one of the realizations of surface roughness that we used for numerical simulations. The root mean square (RMS) height and the correlation length of the surface roughness are set to be both 1.0cm. In the simulation we assume the surrounding dry soil with permittivity of $\varepsilon_r = 4.0$ and conductivity of $\sigma = 0.0842$ S/m is non-dispersive. The depth of the target is varied between 2.0cm and 4.0cm.

For accurate estimation of the time interval T, selection of an incident pulse is important, because it strongly affects the estimation accuracy. As an incident pulse that is convenient for measuring the time interval between two pulses, we employ here a monocycle pulse that has narrow width and sharp peaks. The pulse used for the simulation is shown in Fig.3. Parameters that determine the pulse width and bandwidth are chosen such that the pulse has most of its energy in the frequency band between 1GHz and 6GHz.

As mentioned previously, it is difficult to estimate the time interval from raw GPR data due to the effects of surface roughness. Thus, a signal processing for reducing ground clutter contributions is required. In our approach, we first reduce the ground clutter contribution by subtracting a dominant coherent component of the ground surface reflection, where the coherent component denotes the reflection from a *flat* ground surface without the presence of any buried targets lying beneath it. Next, we further reduce the effect of the residual incoherent components of the ground surface reflection by exploiting the difference of statistical property between the target signals and the incoherent components of the ground surface reflection. This reduction procedure includes the following two steps: 1) ensemble averaging of the aligned GPR signals measured at the multiple observation points; 2) multiplying the ensemble averaged signal by a diagonal matrix whose elements include inverse of the variance of the averaged signals. In Fig. 4 we show an example of the processed GPR signal together with the original raw GPR signal. We can see that for this example the ground surface reflection is suppressed and peaks of the target signal are enhanced through this signal processing. Consequently, an accurate estimation of the time interval becomes possible.

In Fig. 5(a) we show a histogram of the time interval T obtained by using 100 data samples. For comparison, we also show in Fig. 5(b) a histogram for raw GPR signals (without the signal processing for ground clutter reduction). This result indicates that we can successfully distinguish two model targets that are 1.0cm different in thickness by using the time interval T. We also show, in Fig. 6, histograms of the time interval for two kinds of surface roughness. Although the variance of each distribution increases as the surface roughness increases, the time interval T still gives good identification performance for this example. Consequently, we can confirm from these results that the time interval T is available for one of the features for identification of mine-like targets even when the targets are located at shallow depths under rough ground surfaces where the responses from the ground surface and that from the target overlap in time.

4. Conclusions

We have proposed the simple feature for identifying shallowly buried mile-like objects using GPR systems and have evaluated its identification performance. This feature is the time interval between two pulses reflected from top and bottom sides the object. Through the Monte Carlo simulation using data set generated by the 2D-FDTD method, we have confirmed that good identification performance has been obtained by using the feature even for targets buried at shallow depths under rough ground surfaces. This result indicates that the time interval is available and suitable for discriminating between landmines and confusing clutter objects.

In our simulation, we have assumed that the surrounding dry soil is homogeneous and non-dispersive because we wished to focus on the effects of the surface roughness. Effects of inhomogeneity and dispersion of the soil should also be considered. Furthermore, performance evaluation using actual GPR data obtained through field experiments should also be undertaken. These important research problems are currently under investigation.

Acknowledgement

This work is supported in part by a Grant-In-Aid for Scientific Research ((c)15560300, 2004) from the Japan Society of the Promotion of Science.

References

[1] L. Peters, J. J. Daniels, and J. D. Young, "Ground penetrating radar as a subsurface environmental sensing tool," *Proc. IEEE*, vol. 82, pp.1802–1820, Dec. 1994.
[2] H. Brunzell, "Detection of shallowly buried objects using impulse radar", *IEEE Trans. Geosci. Remote Sensing*, vol. 37, No.2, pp.875–886, March. 1999.
[3] A. Merwe and I. J. Gupta, "A novel signal processing technique for clutter reduction in GPR measurements of small, shallow land mines" *IEEE Trans. Geosci. Remote Sensing*, vol. 38, No.6, pp.2627–2637, Nov. 2000.
[4] K. C. Ho and P. D. Gadar, "A linear prediction land mine detection algorithm for hand held ground penetrating radar" *IEEE Trans. Geosci. Remote Sensing*, vol. 40, No.6, pp.1374–1384, June. 2002.
[5] P. D. Gadar, M. Mystkowski, and y. Zhao, "Landmine detection with ground penetrating radar using hidden Markov models" *IEEE Trans. Geosci. Remote Sensing*, vol. 39, No.6, pp.1231–1244, June. 2001.
[6] T. Kobayashi, X. Feng, and M Sato, "A GPR for landmine detection using an array antenna" Proc. of the Int. Sympo. Amtennas and Propagat.'04, 2D2-5, pp.613-516, Sendai, Japan.
[7] B. Sai, L. P. Ligthart, "GPR phase-based techniques for profiling rough surfaces and detecting small, low-contrast landmines under flat ground", *IEEE Trans. Geoscience and Remote Sensing*, vol. 42, No.2, pp.318–326, Feb. 2004.
[8] E. Zazit, "Improved design of the Vivaldi antenna", *IEE Proc*., pt. H, vol. 135, 2, pp.89-92, 1988.
[9] E. I. Thoros, "The validity of the Kirchhoff approximation for rough surface scattering using Gaussian roughness spectrum," *J. Acoust. Soc. Am*., vol. 83, No.1, pp. 78-92, Jan. 1988.

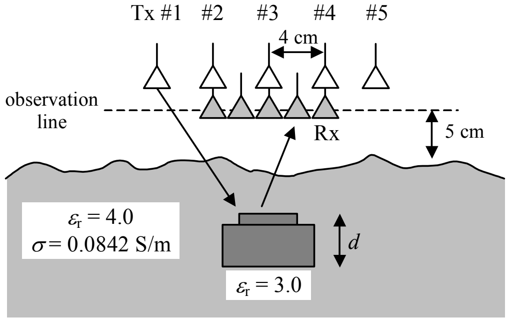


Fig. 1 Schematic of the GPR measurements for numerical simulation.(d = 4cm and 5cm)

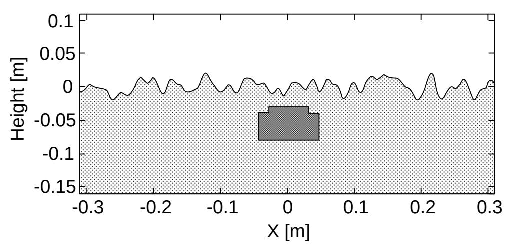


Fig. 2 An example of the rough ground surface. (RMS height and correlation length are both 1.0cm)

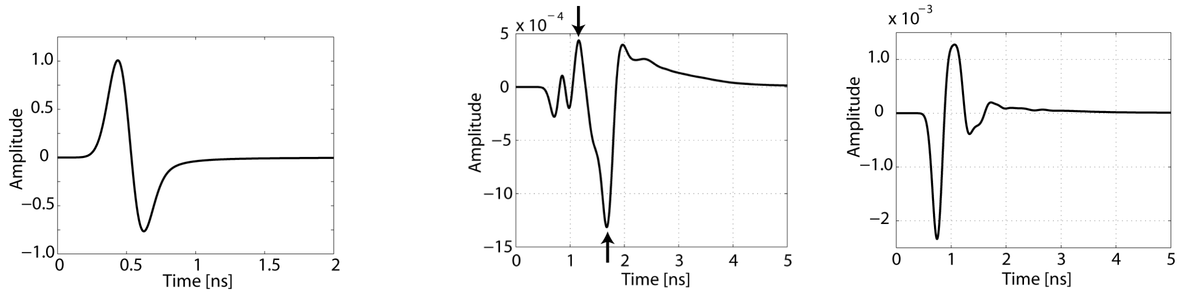
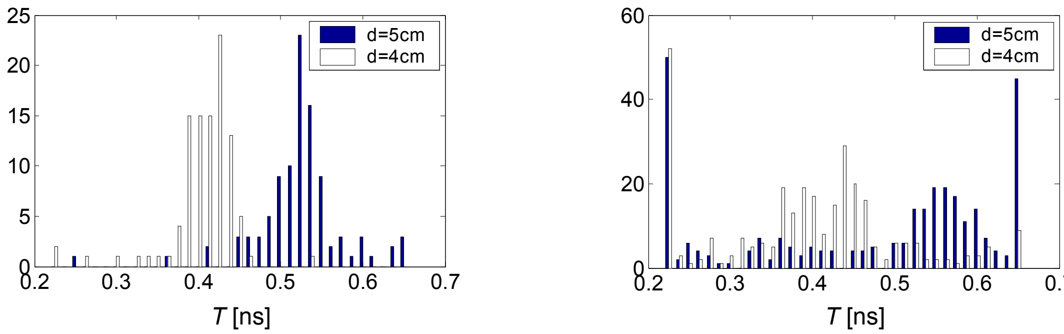


Fig.3 Incident pulse used for simulation.

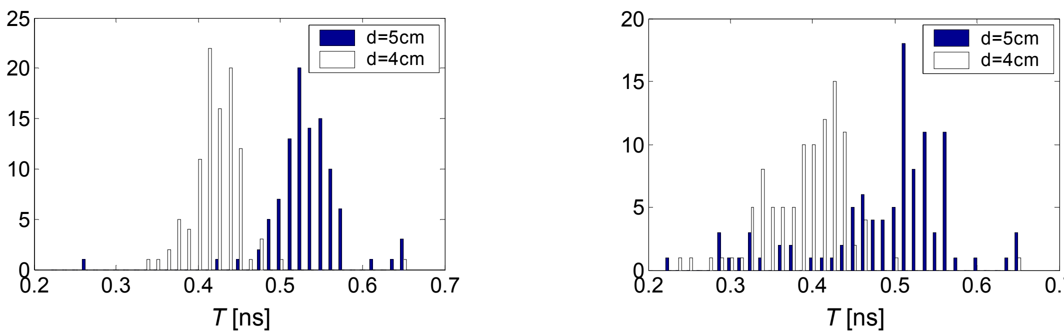
(a) GPR signal after processing (b) Raw GPR signal

Fig. 4 Example of the processed waveform.



(a) GPR signals after processing (b) Raw GPR signals

Fig. 5 Histograms of the time interval T obtained from 100 data samples. The RMS height and the correlation length of the surface roughness are both 1.0cm (Fig. 2).



(a) RMS height: 1.0cm, correlation length: 3.0cm. (b) RMS height: 1.5cm, correlation length: 3.0cm.

Fig. 6 Histograms of the time interval T obtained from 100 data samples. The RMS height and the correlation length of the surface roughness are (a) 1.0cm and 3.0cm, (b) 1.5cm and 3.0cm.