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A GPR FOR LANDMINE DETECTION USING AN ARRAY ANTENNA

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1. Introduction

Since 2002 when Japanese government officially addressed support for the postwar reconstruction of Afghanistan, we have developed a Ground Penetrating Radar (GPR) for landmine detection which is to be provided to remediation work in mine contaminated areas of the country by 2005[1].

The primary target of the GPR is anti personnel (AP) mines that are deployed in shallow subsurface, only a few cm below the ground surface, so that a human step triggers the detonator of the mine. This characteristic property of the target defines following two requirements to the GPR :

(1) the GPR must be able to detect shallow target which tends to be masked by strong ground surface clutters,

(2) the system should be a stand off radar system in order to avoid ground surface contact.

The design requirements to the system come from actual operation as follows:

(3) GPR measurement must be carried out in a practical time period,

(4) the measurement result must be presented to the operator in a form of comprehensive manner.

The GPR system was designed to meet these requirements. The system operates in a wide frequency band (6GHz at the maximum) to fulfil the first requirement. The second requirement was satisfied by employing bipodal Vivaldi antenna (Fig.1) as the transmission and receiving antennas. Selection of antenna design is also closely tied to the first requirement (Fig.2).

The required measurement time is 10 minutes for the measurement area of $1m^2$. A measurement protocol was established to meet the third requirement and was tested. Finally, the measurement results are provided in a form of 3 dimensional image data.

This paper reports the results of the measurement test of the GPR system.

Fig. 1. Bipodal Vivaldi antenna of the GPR.

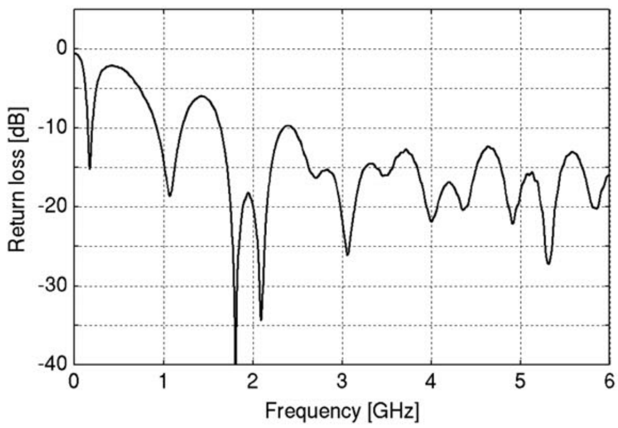

Fig. 2. Measured return loss of the bipodal Vivaldi antenna.

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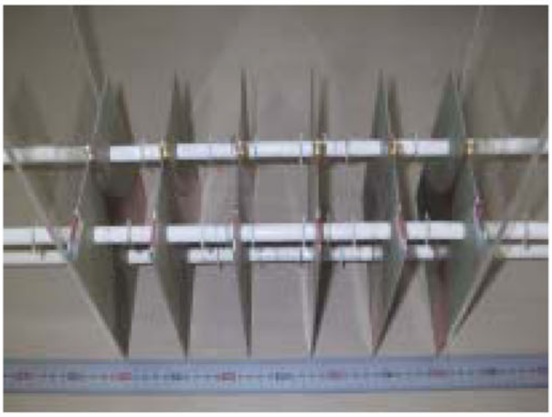


Fig. 3. Top view of array antenna.
6 pieces of Vivaldi antennas (Fig. 1) configure a CMP array. The antenna spacing is 6cm.

Fig. 4. Targets for the GPR experiment. On the top are the mock model of Type-72 and the stone lump. The bottoms are M8 bolt and the mock model of PMN2.

2. GPR system

The GPR system is a stepped frequency radar system that is constructed on a commercial vector network analyzer, and was designed to meet the requirements described above. A wide frequency range (30kHz to 6GHz) is covered to obtain a fine range resolution. A unique feature of the GPR system is the array antenna system (Fig. 3). 3 pairs of Vivaldi antennas configure a Common Mid Point (CMP) array: they are disposed symmetrically to the mid point of the array base line so that the center point of each T/R antenna pair coincides with the mid point. The antenna spacing is 6cm. Three measurements are carried out using each pairs of T/R antennas of the CMP array. CMP stacking process[2] is applied to the measurement data which reduces the ground surface clutter.

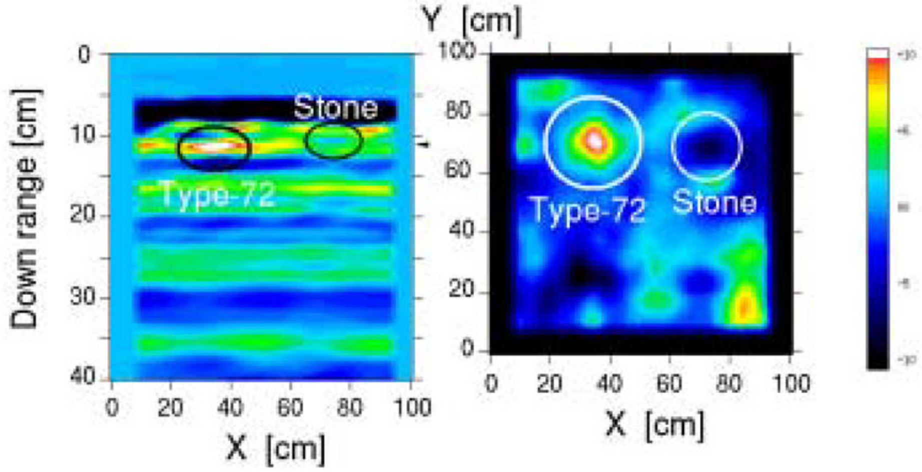
The antenna scans 2 dimensionally above the mine field carrying out the measurement. After CMP stacking process, diffraction stacking process is applied to reconstruct the image of subsurface objects. The GPR measurement points are chosen on the lattice points on the scanning plane. The spatial interval of the measurement points is 4cm in both orthogonal directions of the lattice. The value was so chosen that the GPR system performance meets the requirement.

3. Experiment

A laboratory experiment on GPR measurement was carried out under a rough ground surface condition. Roughness parameters were obtained after measuring the height distribution of the surface by a laser range finder: the RMS height and the correlation length of the surface were 30mm and 240mm, respectively, which make the RMS gradient 10 degrees for a Gaussian rough surface. The subsurface material was slightly wet sandy soil. The water content was found to be 8%. Applying Topp equation [3], the dielectric constant of the subsurface medium was estimated to be 4.7.

4 different targets were deployed in measurement area (Fig. 4), 40cm apart from each other, at the depth of 10-5 cm. The targets were a mock model of Type-72 landmine that was 78 mm in diameter and was 40mm thick, a mock model of PMN-2 landmine that was 122mm in diameter and was 54mm thick, a M10 bolt which was 42mm long, and a lump of stone that was about 10cm in diameter and was about 5cm thick.

The GPR antenna scans two dimensionally above the surface. The antenna standoff was about 9cm. The exact antenna standoff could not be defined since the ground surface is a rough surface. The scanning area was a square of 1m by 1m. The array antenna was mounted on the moving head of the



(a) Vertical cross section (b) Horizontal slice

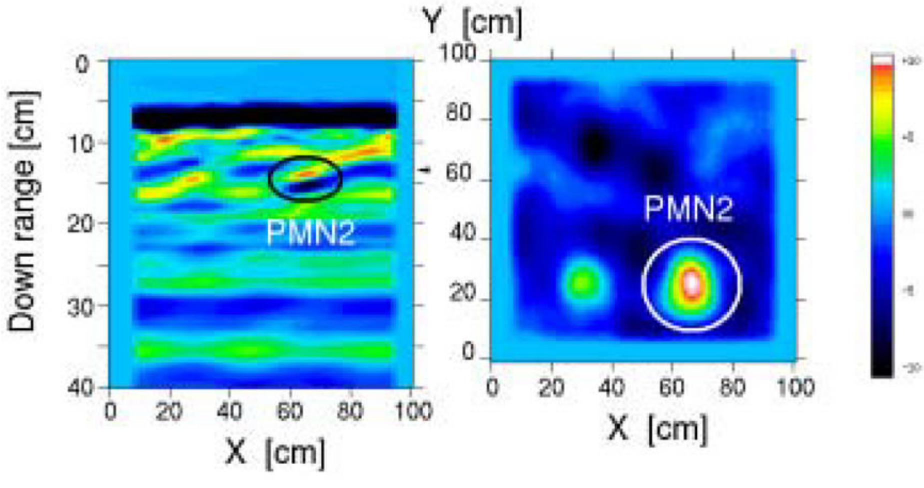
Fig. 5. Reconstructed image of the Type-72 mock model and the stone lump. The target images are encircled. The depth of the horizontal slice image is indicated on the right side of the vertical cross section.

antenna positioner that control the move and the position of the antenna with the precision of 1mm. GPR measurements were carried out at the lattice points on the scanning surface. The spatial interval of the lattice points were 4cm in both orthogonal directions.

Obtained GPR data were first processed to produce the CMP stacking data of each measurement point then diffraction stacking technique was applied to reconstruct three dimensional image data of subsurface objects. Followings are the obtained target images.

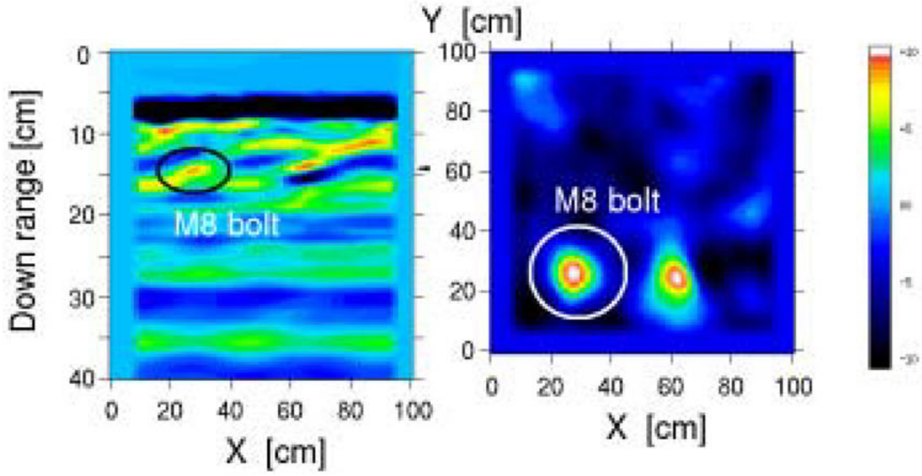
(1) Type-72 mock model and the stone

Figure 5 presents the vertical cross section image and the horizontal slice image of reconstructed subsurface image, which contain the images of Type-72 and the stone lump as indicated in the figure. Type-72 is easily detected among clutters in the image though its circular shape appears deformed mainly due to the sparse spatial sampling of the measurement. However, symmetry property of the image still holds and gives a strong hint that the target is non natural object. On the other hand, the image of the stone lump is obscure, thus difficult to detect. This is due to that the stone had by chance a very similar dielectric constant value to the ambient soil.



(a) Vertical cross section (b) Horizontal slice

Fig. 6. Reconstructed image of the PMN2 mock model. M8 bolt image appears on the left of the PMN2 image. The depth of the horizontal slice image is indicated on the right side of the vertical cross section.



(a) Vertical cross section (b) Horizontal slice

Fig. 7. Reconstructed image of the M8 bolt. The tip of PMN2 mock model appears on the right of M8 bolt image. The depth of the horizontal slice image is indicated on the right side of the vertical cross section.

(2) PMN-2 mock model

Figure 6 shows the subsurface image that contains the PMN2 mock model. As we have observed for the case of Type-72 image, the PMN2 image in Fig.5 also appears deformed. The cross section image (left panel of Fig.5) implies that this deformation is mainly due to the slant angle of its attitude. On the left of PMN2 image is a part of M8 bolt image.

(3) M8 bolt

Figure 7 shows the image of the M8 bolt. It is impossible to infer from the image that the object has a spindle shape. It even has rounder image than Type-72 image of Fig.4. The brightness and the shape of the image imply that the target is a small metal object. On the right of the M8 bolt image is a part of PMN2 image.

4. Conclusion

We have developed a GPR system for landmine detection. The operation frequency range was as wide as 6 GHz in order to realize a fine range resolution for detection of shallowly deployed AP mines. The system employed CMP stacking technique to reduce surface clutters before diffraction stacking is applied to obtain migrated subsurface 3D image data. The GPR measurement is carried out on lattice points with the spatial interval of 4cm in both orthogonal directions. The spatial interval of the lattice points was chosen so as to realize a fast scanning to meet the primary requirement to the scanning (measurement) speed: 10 minutes par $1m^2$ of scanning area. The present study confirmed that the GPR scan with the spatial interval of 4cm provides data sufficient enough to reconstruct migration image of subsurface objects.

Acknowledgements

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