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Hand held dual-sensor ALIS developed for humanitarian demining

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1. Introduction

Dual sensor systems, which use a GPR (Ground Penetrating Radar) and a metal detector are now being developed for humanitarian demining. A few systems including ALIS will be commercialized soon. However, the method of combining two sensors must still be developed. Most of the conventional dual sensor systems use a metal detector as a primary sensor, and if the metal detector detects anomaly, GPR is used for confirmation [1], [2]. However, both the system alarms only by audio sound, and rich experience is required for better operation. We have been developing a dual sensor system, namely, Advanced Landmine Imaging System (ALIS) since 2002. The unique feature of ALIS is in its novel technique of tracking the sensor position, even though it is scanned by hand by deminers. Then, ALIS can provide 3-D GPR image and it will help to understand the subsurface conditions much better than the conventional audio signal. It leads to the higher efficiency of detection of buried landmines. The latest ALIS uses a compact vector network analyzer (VNA) as a GPR system. At the same time, the sensor tracking system does not need any standard marks on the ground surface. We have tested ALIS in various conditions, including in test sites in mine affected country such as Afghanistan and Croatia. In this paper, we introduce the latest status of ALIS development.

2. ALIS System

2.1 System configuration

Since 2002, ALIS has been developed and the current system has a few variations dependent on its applications. ALIS can select one from two different GPR systems, namely a stepped-frequency radar by using a VNA (Vector Network Analyzer) and an impulse GPR. The two systems use the same sensor tracking system and a sensor head.

The VNA is developed by Tohoku University under support from Japanese Science and Technology Agency (JST). It is small, approximately $30\times20\times8$ cm, and light weight, less than 1.7 kg, but it has almost the same performance as the conventional commercial VNA especially for the sweep speed and the measurement accuracy. VNA is a combination of a synthesizer and the synchronized receiver. It is controlled by a CPU and can store the measured data in its memory. The operation frequency of the GPR system can be adjusted depending on the soil condition by using the VNA, which is not easy for a impulse radar system. The calibration data can be stored in the

Figure1: ALIS system in operation in CMAC test site, Cambodia.

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memory of the VNA, and the output data can be calibrated by using this stored data. This calibration function is useful for better antenna impedance matching, and can improve the radar data quality, because it suppresses the reflection from the antenna.

The ALIS system is operated by one palmtop PC. All the instruments in this system can work with a rechargeable battery in a backpack. MIL-D1 metal detector (CEIA, Italy) is used as a base metal detector. The data sampling is repeatedly done. When the data is acquired, the position of the sensor is calculated from a CCD picture. A deminer carries a backpack as shown in Fig.1. The VNA based GPR unit, a metal detector controller and a rechargeable battery unit are equipped in the backpack. The weight of the backpack is about 3 kg.

In the prototype of ALIS, we tested two different antennas including the Vivaldi antenna and a cavity back spiral antenna. In the latest ALIS, the cavity back spiral antenna is molded with a metal detector sensor as can be seen in Fig.1. The weight was reduced to 2kg, and now the operation of ALIS is much easier than before. The cavity spiral antenna is suitable for most normal operation of ALIS, but we can obtain better performance due to its wider frequency operation range by using the Vivaldi antenna. Therefore, we use the Vivaldi antenna in the vehicle mounted ALIS.

2.2 Sensor tracking system

The most unique feature of ALIS is its sensor tracking function. During the operation, the sensor operator can observe the metal detector response image together with a picture of the ground surface displayed on the palmtop PC in real-time. Thus, the area, which shows a high metal detector response, can be scanned thoroughly.

For imaging, the sensor position information is necessary. Since the trajectory of the sensor is unpredictable in a handheld system, images cannot be constructed without a sensor tracking method. ALIS uses a CCD camera fixed on the handle of the metal for the sensor location tracking. The CCD camera captures several images of the ground surface per second, and the relative movement on the ground surface is calculated, and the sensor position can be tracked. Fig.2 shows an example of the tracked sensor position acquired. The dots indicate the positions, where ALIS acquired the data including GPR, metal detector and the sensor position. Fig.3 shows an example of the metal detector signal image superimposed on the CCD captured ground surface image, which the ALIS operator observes during the hand scanning. This image is displayed on the PC screen which the deminers hold in the hand, and the deminer can monitor in the real time.

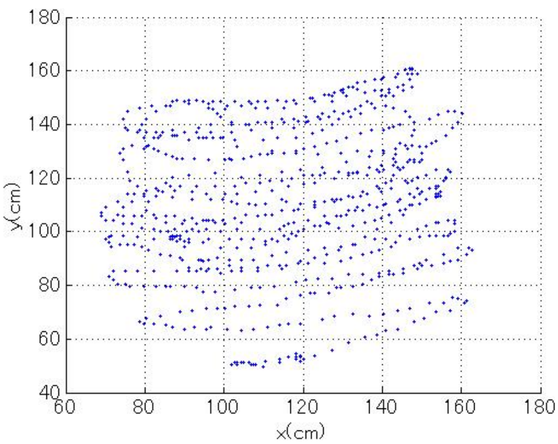


Figure 2: The locus of the sensor trace.

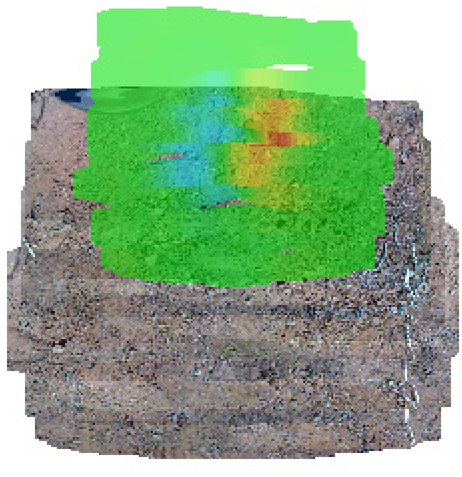


Figure 3: Visualized metal detector data.

This sensor tracking function has significant advantages as follows:

(1) The handheld scanning operation can be visualized, which improves the reliability of detection by a deminer.

(2) A deminer can monitor the locus of scanning, and can avoid the scanning blank area.
(3) The record of the locus of the scanning by the deminer can be recorded and it can be monitored in real time, and can be checked afterward. This record can be used for quality control of the demining. In addition, it can be used for training of deminers, and can be used also for the determination of the cause of mistake, in the case of accident.

2.3 Data processing and display

The GPR data acquired with the sensor position information is processed after the scanning the ALIS sensor over the area of about 1m by 1m. At first, all the acquired data set was relocated on a regular grid points. Interpolation algorithm is used for this process. After the relocation of the data sets, metal detector signal can directly be displayed in a horizontal image as shown in Fig.6.(a).

3-D GPR image is reconstructed by Kirchhoff migration algorithm. The Kirchhoff migration gives the output wave field $P_{out}(x_{out}, y_{out}, z, t)$ at a subsurface scatter point (x_{out}, y_{out}, z) from the input wave field $P_{in}(x_{in}, y_{in}, z=0, t)$, which is measured at the surface (z=0). The integral solution used in migration is given by:

$$P_{out}(x_{out}, y_{out}, z, t) = \frac{1}{2\pi}\iint\left[\frac{\cos\theta}{r^2} P_{in}\left(x_{in}, y_{in}, z=0, t+\frac{r}{v}\right) + \frac{\cos\theta}{vr}\frac{\partial}{\partial t}P_{in}\left(x_{in}, y_{in}, z=0, t+\frac{r}{v}\right)\right]dxdy \qquad (1)$$

where v is the RMS velocity at the scatter point (x_{out}, y_{out}, z) and $r = 2\sqrt{(x_{in}-x_{out})^2 + (y_{in}-y_{out})^2 + z^2}$, which is the distance between the input point $(x_{in}, y_{in}, z=0)$ and scatter point (x_{out}, y_{out}, z). $\cos\theta$ is obliquity factor or directivity factor, which describes the angle dependence of amplitudes and is given by the cosine of the angle between the direction of propagation and the vertical axis z. $1/vr$ is the spherical spreading factor. The time derivative of the measured wave field yields the 90-degree phase shift and adjustment of the amplitude spectrum. In this signal processing, the vertical inhomogeneity of the soil is considered.

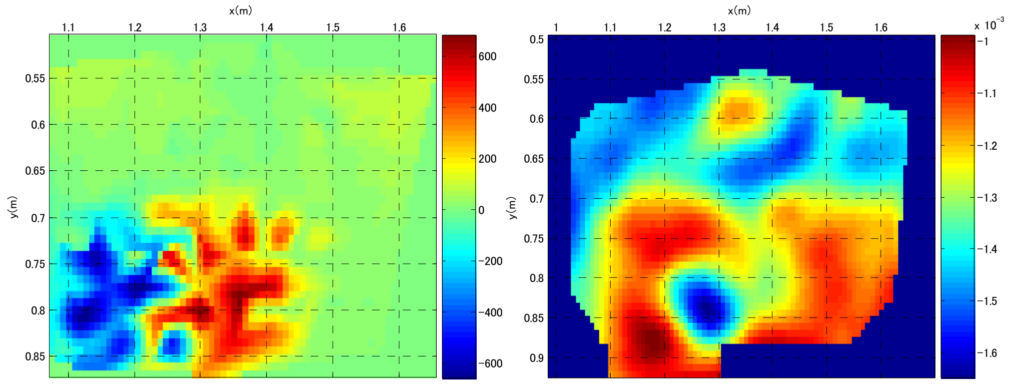
The migrated GPR data gives 3-D reconstructed subsurface image. However, we normally use only horizontal slice image (C-scan) as shown in Fig.4(b) for data interpretation. This is due to too much clutter in 3-D image and from many trials, detection of buried landmine image in the horizontal slice is most reliable.

3. Evaluation test of ALIS in Mine Affected Courtiers

After laboratory tests, we have conducted field evaluation test of ALIS in several different locations. The first field trial test was carried out in Kabul city, Afghanistan in December 2004. In this trial, we found that ALIS can detect PMN-2 and Typoe72 landmines buried at 20cm can be detected. Then in April 2005, we demonstrated ALIS in JRC in Italy, SWEDEC in Sweden under the support of ITEP. In May 2005, we also carried out test in Egypt, where most of the landmines are buried in dry sand. We found that the condition in Egypt is suitable for operation of GPR, but due to its extremely large area for land mine detection, we believe unmanned vehicle based ALIS is good to be used in Egypt.

Under the joint research work of JST and CROMAC, we carried out evaluation test of ALIS in Croatia in February 2006. ITEP also supported this field trial test, and the detection results were evaluated by ITEP. Several test lanes having different soil properties were prepared and three robotic machines equipped with dual sensor sand one hand-held sensor were evaluated. Fig.4 shows one example of ALIS output in Croatia. The soil was wet condition, occasionally we had strong rain during the test.

The most recent field evaluation test was conducted in Cambodia in October to December 2006. This test was supported by the Ministry of Foreign affairs of Japan, as a part of ODA to Cambodia. CMAC (Cambodia Mine Action Center) conducted the test. We trained the operation of ALIS to local deminers, then the local deminers carried out two moth blind test. During the blind test, we may not be able to access the site nor the deminers, and all the operation were conducted only by the local deminers. We found no problem in the operation of ALIS, and could confirm that ALIS can be acceptable for local deminers.



(a)Metal detector image (b) GPR image

Figure 4: ALIS visualization output in CROMAC test site, Croatia. Lane 3 area40

4. Conclusion

We developed ALIS, which has high efficiency with better reliability for landmine detection by MD-GPR sensor fusion. The developed ALIS can visualize the signal, although it is a hand-held sensor. We are now planning the commercialization of the ALIS systems. The VNA based ALIS is almost ready and the impulse GPR based ALIS will be available after October 2007. We are planning to test ALIS in the ITEP hand held dual-sensor trial in Benkovac Croatia in May 2007. The unique feature of visualization of ALIS will be compared to the other non-visualization hand held sensors.

Acknowledgments

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