Evaluation of a Hand-held GPR MD sensor system (ALIS)

Motoyuki SATO[a*], Jun FUJIWARA[b], Xuan FENG[a], Zheng-Shu ZHOU[a] and Takao KOBAYASHI[a]

[a] Tohoku University, Sendai 980-8576, JAPAN

[b] Tokyo Gas Co. Ltd., Arakawa-ku, Tokyo 116-0003, JAPAN

ABSTRACT

ALIS (Advanced Landmine Imaging System), which is a novel landmine detection sensor system combined with a metal detector and GPR, was developed. This is a hand-held equipment, which has a sensor position tracking system, and can visualize the sensor output in real time on a head-mounted PC display. In order to achieve the sensor tracking system, ALIS needs only one CCD camera attached on the sensor handle. The new hand-held system ALIS is a very compact and do not require any additional sensor for sensor position tracking. The acquired signal from the metal detector and GPR is displayed on the PC display on real time, and the sensor trace can be checked by the operator. At the same time, the operator can visually recognize the signal on the same display. The CCD captured image is superimposed with the GPR and metal detector signal, therefore the detection and identification of buried targets is quite easy and reliable. Field evaluation test of ALIS was conducted in Afghanistan, and we demonstrated that it can detect buried antipersonnel landmines, and can also discriminate metal fragments from landmines.

Keywords: GPR, Metal detector, Hand-held, Sensor tracking, Landmine detection

1. INTRODUCTION

Humanitarian Demining is gathering interest all over the world. Detection of antipersonnel (AP) landmines, whose casing are made of plastic, is the principle task of humanitarian demining. Even in a plastic AP-landmine, normally very small metallic part is included, and it can be detected by a metal detector (MD). Therefore, MD is widely used for humanitarian demining operation. However, the problem of MD is its very high false alarm rate. Ground Penetrating Radar (GPR) is a useful sensor for detection of buried antipersonnel landmines, and we think it can be used for identification of AP-landmines, if it is used together with MD.

The combination of GPR and MD has been employed in some landmine detection systems. However, the method of combining two sensors must still be developed. We have introduced a novel technique of tracking the sensor position into a combined MD and GPR sensors, in order to use it as a hand-held system. This is Advanced Landmine Imaging System (ALIS) sensor system, which was developed under the grant of JST (Japan Science and Technology Agency).

The Japanese government has carried out efforts for rehabilitation of Afghanistan in various aspects Removal of landmines from Afghan land is an essential factor for every face of development in Afghanistan. The Transitional Administration of Afghanistan has been tackling the problem in collaboration with many actors, such as international organizations, NGOs and donor countries. The Government of Japan has also been supporting the effort to deal with anti-personnel landmine issues through multilateral cooperation and dispatching of experts. The Government of Japan plans to support the anti-personnel mine-clearance activities in Afghanistan through the Japanese Grant Aid for Research, while the Transitional Administration of Afghanistan made a request for the Research Project for Developing Mine Clearance Related Equipment in Afghanistan. This project supported research activities and development of mine detectors which suit the local conditions of Afghanistan.

For the purpose of contributing to the execution of the Project by the Transitional Administration of Afghanistan, the Government of Japan extended a grant to the Transitional Administration of Afghanistan in accordance with the Exchange of Notes signed on November 5th, 2003. On behalf of the Department of Mine Clearance, Department of Disaster Preparedness of the Transitional Administration of Afghanistan, Japan International Cooperation System (JICS), as an implementing agency will invited eligible applicants. Under the support of this project, we tested the Advanced Landmine Imaging System (ALIS) in December 2004, in landmine fields in Afghanistan. In this paper, we introduce the development of ALIS and demonstrate the results in Afghan evaluation tests.

2. ALIS SYSTEM

2.1 ALIS configuration and operation

ALIS is a hand-held landmine detection sensor, which is equipped with a metal detector and GPR. In addition, it can track the sensor position while scanning by a deminer in real time. The sensor signals from the metal detector and GPR are stored in a PC together with the sensor position information. All the system is controlled by the PC, which is inside a daypack on the back of a deminer. WINDOWS based software controls the system, and the operation can be done directly by the PC, but usually we use a handheld PC display which is connected to the PC via wireless LAN.

[*] sato@cneas.tohoku.ac.jp; phone +81 22 795 6075; fax +81 22 795-6075

The deminer usually monitors the metal detector signal displayed on a head-up display.

Fig.1 shows the ALIS system under operation. A deminer is scanning the handheld ALIS sensor, and hanging a daypack which contains the operating PC. The deminer is also wearing a head-up display. The same display that the deminer is monitoring is transmitted to a handheld PC display, and several operators can monitor the operation. Fig.2 shows the ALIS hardware. For the usual operation of ALIS, we need one operator who scans the sensor, and another operator who controls and monitors the sensor signal.

Fig.1 ALIS system under test at the CDS site in Afghanistan.

The scanning by ALIS follows the exactly same procedure that normal hand-held metal detector is using. A deminer stands in front of the boundary of a safe zone, and scan the area about 1m by 1m using the hand-held sensor. We recommend scanning continuously, even the deminer detect anomalous signal from the metal detector. After scanning the area, we process the acquired data sets using the same PC. Normally, the processing requires one to a few minutes until all the data sets are displayed. Finally ALIS provides a horizontal visualized image of the metal detector signal, and 3-D GPR information. The information of 3-D GPR is usually too much for interpretation on the site, so ALIS displays horizontal slices (C-scan) of the GPR signal. An operator can move the depth of GPR slice images, and can detect the buried landmine image.

Fig.2 ALIS system.

Another unique feature of ALIS is its compatibility to the conventional landmine detection operation. Landmine detection by metal detectors are quite common demining operation in many courtiers. The procedure of the demining is well established, and many deminers have been trained and they are exactly following the procedure to avoid any accident. Any new sensor for landmine detection requires a change of the procedure of operation. However, ALIS requires minimum modification of the procedure, as we have described. The ALIS is a add-on system which can be attached to an existing commercial metal detector. The performance of the metal detector does not change by adding ALIS system. The operator still hears the audio tone signal from the metal detector, and can detect anomalies using their own experience. ALIS adds visualized image of metal detector sensor, and GPR images. Therefore, the operator can obtain additional valuable information, although the operation of the sensor does not have to be so much changed.

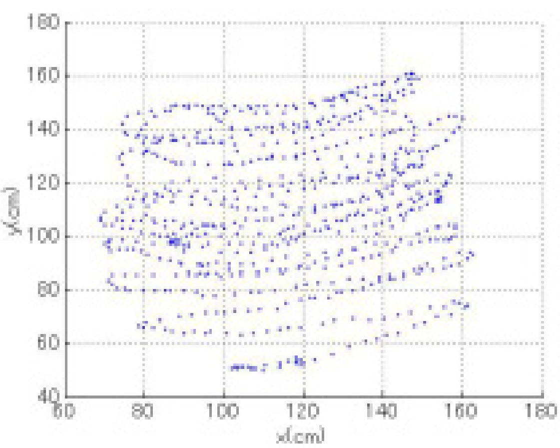


Fig.3 Data sampling points.

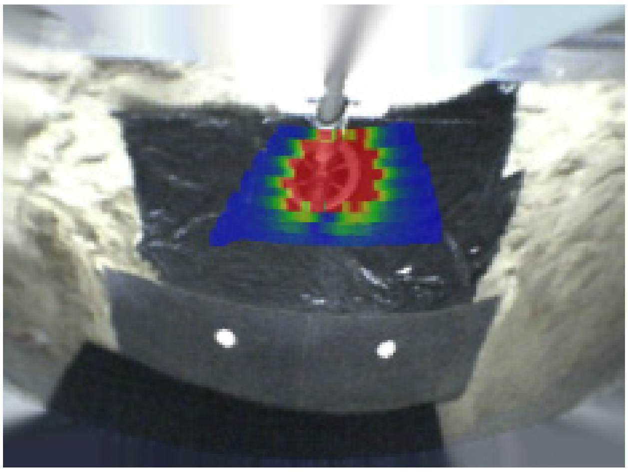


Fig.4 Visualized metal detector data.

2.2 Sensor tracking system

A conventional MD sensor outputs audio signal and an operator has to estimate the position of the buried objects only from the sound. If the sensor signal can be visualized, detection of objects can be much easier. Visualization of the sensor is possible, if we can obtain the sensor position together with the sensor signal. However, most of the conventional hand-held sensor could not provide the sensor position. In order to obtain the senor position, we can use a stereo-vision system, which needs at least two camera set around the sensing position. Sensors mounted on a robotic arm can track the sensor position, but the size of the senor becomes larger and is not suitable for a hand-held sensor.

In order to solve these problems, we developed a sensor tracking system by using a CCD camera mounted on the sensor itself and attached it o the MD and GPR sensors. In Fig.2, two white disks placed near the scanning area are standard positions of the sensor tracking system, and its position is traced in the CCD captured image. Compared to the location of the plastic discs, the sensor position can be tracked in real time. The output signals of MD and GPR are stored in a PC together with the sensor position information. The MD signal is visualized on the CCD captured image and they are projected on a head-mounted PC display of the operator. Three types of information, i.e., CCD image, GPR and metal detector are continuously acquired. However, due to the time required for data acquisition, the sampling data interval is several points per second. Fig.3 shows an example of the trace of the sensor head scanned manually. Each dot indicates the points where the data was acquired. We can find that the data acquisition points are quite random. Fig.4 shows the visualized metal detector signal superimposed on the CCD image.

2.3 GPR

ALIS uses an impulse GPR system which operates at the frequency range of 1GHz-3GHz. Two orthogonal polarization cavity back spiral antennas are used, and they are mounted in from of the MD coil as shown in Fig.5(a). This system uses an impulse radar system. We are also developing a stepped frequency GPR system, which uses a Vivalidi-type antenna as shown in Fig.5(b)[1]. This type of antenna will be used combined with a compact vector network analyzer. The system is now under evaluation. Interferences between MD and GPR can be minimized by sensor calibration.

2.4 Metal detector

We use a commercial metal detector (CEIA MIL-D1) for ALIS system. More than 200 sets of this type of metal detector have been operated, and we believe it is one of the most reliable sensors, for landmine detection in Afghan soil condition. The interference of the two sensors, namely GPR and metal detector has been studies. MIL-D1 has a calibration function, and even metal objects are located near the metal detector sensor, the output signal can be compensated by this calibration procedure. We found that, if the antenna is firmly fixed against the metal detector sensor position, the influence of the existence of GPR antennas can be completely canceled. And the sensitivity of the metal detector to buried objects does not change. However, the influence of the metal detector sensor to the GPR signal is hard to compensate. Therefore, the GPR antennas are mounted in front of the metal detector sensor.

2.5 Data processing and display

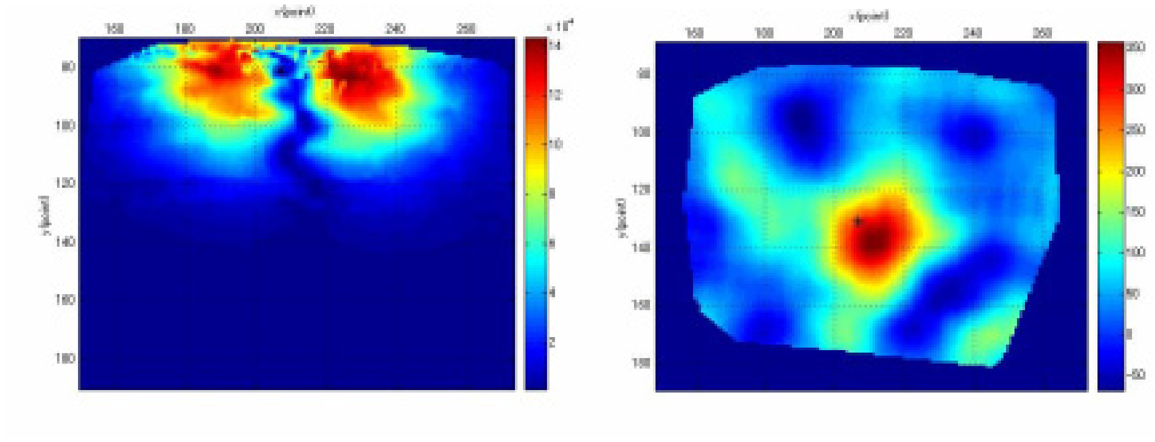
The GPR data acquired with the sensor position information is processed after the scanning the ALIS sensor over the area of about 1m by 1m. At first, all the acquired data set was relocated on a regular grid points. Interpolation algorithm is used for this process. After the relocation of the data sets, 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

(a) Cavity back spiral antenna (b) Vivaldi antenna

Fig.5 GPR antennas and metal detector sensor

$P_{in}(x_{in}, y_{in}, z=0, t)$, which is measured at the surface (z=0). The integral solution used in migration is



(a) Metal detector image (b) GPR image

Fig.6 ALIS output image acquired at CDS test site.

given by:

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

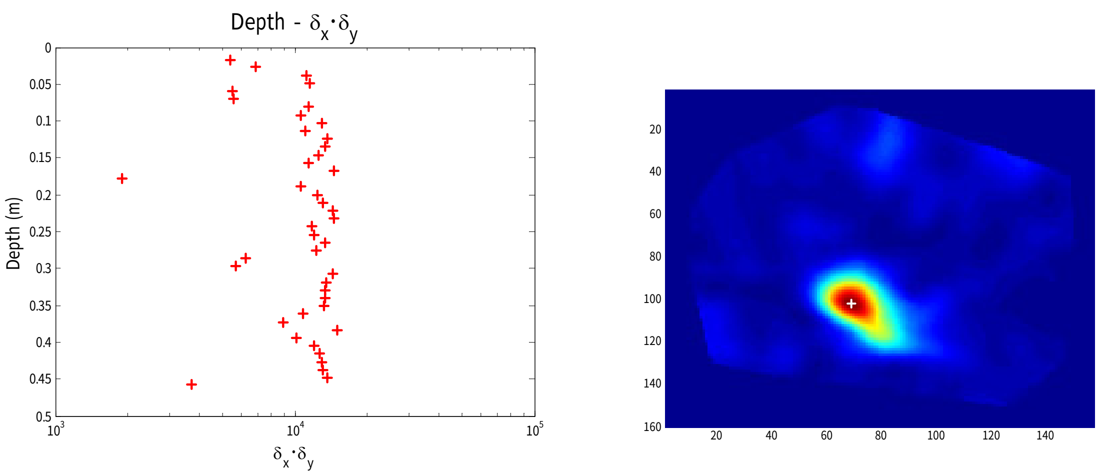
$$\left.+\frac{\cos\theta}{vr}\frac{\partial}{\partial t}P_{in}\left(x_{in}, y_{in}, z=0, t+\frac{r}{v}\right)\right]dxdy$$

(4)

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.6(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.

Data acquisition takes about several minutes, which is almost equivalent to the time required for normal scanning operation of a conventional MD, and the signal processing needs about two minutes after the data acquisition. Wireless LAN sends sensor data to a handheld PC display for judging the image by multiple operators.



(a) Similarity function. (b) Detected landmine in a horizontal slice.

(b) Fig. 7 Automatic detection algorithm and an example.

2.6 Detection of landmine

After all the data processing was finished, we use the metal detector and GPR signals for detection of buried landmine. Currently, we are interpreting the data manually. At first, we find anomaly appears in the metal detector image. Normally, it is quite obvious, but it includes many signals due to metal fragments and other objects. After marking the location of these anomalous points, we observe the GPR image. We move the depth of the horizontal slice images and try to find a continuous image, which can be a GPR image of buried landmines.

This detection algorithm was now implemented in a semi-automatic software. In this algorithm, we calculate the similarity between the adjusting two horizontal slices and detect the location of buried land mine. Fig.7 shows an example of the output of the buried land mine detection algorithm, and in Fig.7(a) we can find the indicator shows the minimum at 0.17m in depth, and corresponding horizontal GPR slice image shown in Fig.7(b) shows the location of the detected buried landmine.

3. EVALUATION TEST IN AFGHANISTAN

After laboratory tests, we have conducted field evaluation test of ALIS in Kabul city, Afghanistan in December 2004. Field test was conducted at two locations. The first site (CDS site) was a controlled flat test site, prepared for the evaluation of landmine sensors. The second site (Bibi Mahro Hill) is a small hill inside Kabul city, which is a real landmine field, where demining operation was being carried out.

At the CDS site, we could validate the operation of the ALIS for known targets in various conditions. The climate when we conducted the field tests was partly rainy, and water content of the soil at CDS site was about 10% , correspond to the dielectric constant of 5.3. Real PMN-2 and Type 72 landmines without booster were buried at the CDS site at different depths between 0 and 20cm, and we could find that the metal detector can detect landmines buried shallower than 15cm, and GPR can show clear images of landmines, which are buried up to 20cm in depth. We also found that the metal fragments, which are included in the soil does dot show clear GPR image, therefore we could discriminate metal fragments from landmines by ALIS.

Bibi Mahro Hill is a real landmine field, and we buried a PMN-2 plastic shell model filled with TNT explosive and put a small metal pin in it imitating the metallic part of a booster of the real landmine. In addition, we buried a small metal fragment about 15cm apart from the landmine model. Fig.9 shows the ALIS visualization output at Bibi Mahro Hill. Fig.9(a) is the MD image, and we can find two separated metal objects in the figure. CEIA MIL-D1 has a differential signal output, and a single metal object shows symmetric response, having a null point at the center. Fig.9(b) shows the GPR image, and we can find only one clear image, which correspond to the landmine model. Note that the center of the two sensors differs by 20cm, then the images in Fig4 has 20cm offset.

Fig. 8 Bibi Mahro Hill in Kabul, Afghanistan.

4. BUGGY MOUNTED SYSTEM

A remote metal detection buggy system can range over a large area, and improves work efficiency based on conventional metal detection. The robot arm uses conventional metal detection technology that allows users to remotely confirm the presence of mines. ALIS was equipped on a robot of a buggy system developed by the group of Prof. Hirose at Tokyo institute of technology. All the same signal processing algorithm of ALIS was used, and the data acquisition rate can be improved by the scanning by a robot arm.

Fig.10 shows on example of ALIS GPR image acquired by a buggy mounted system.

Fig.9 ALIS mounted on a buggy

5. CONCLUSIONS

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. ALIS was evaluated in real mine field in Afghanistan and we could demonstrate its high ability. We are planning to replace the GPR by stepped frequency system, and it will increase the flexibility of the system, because we can select operation frequency range on site.

ACKNOWLEDGEMENTS

Part of this work was supported by JSPS Grant-in-Aid for Scientific Research (S)14102024 and by JST (Japan Science and Technology Agency). We thank Mr. Tatsuki Yagi for his contribution in the experiment. The field evaluation test was supported by the research project for developing mine clearance related equipment in Afghanistan of JICS (Japan International Cooperation System). We acknowledge META, UNMACA and other Afghan colleagues, who gave us useful suggestions for ALIS.

REFERENCES:

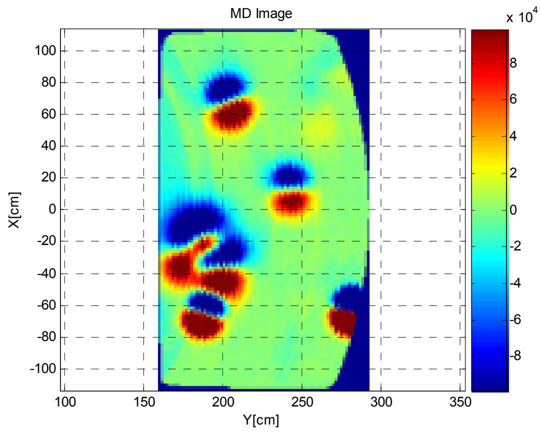
[1] M.Sato, Y.Hamada, X. Feng, F.Kong,Z.Zeng, G. Fang,"GPR using an array antenna for landmine detection," Near Surface Geophysics, 2, pp3-9,2004.

[2] X. Feng and M. Sato, "Pre-stack migration applied to GPR for landmine detection," Inverse problems, 20, pp1-17, 2004.

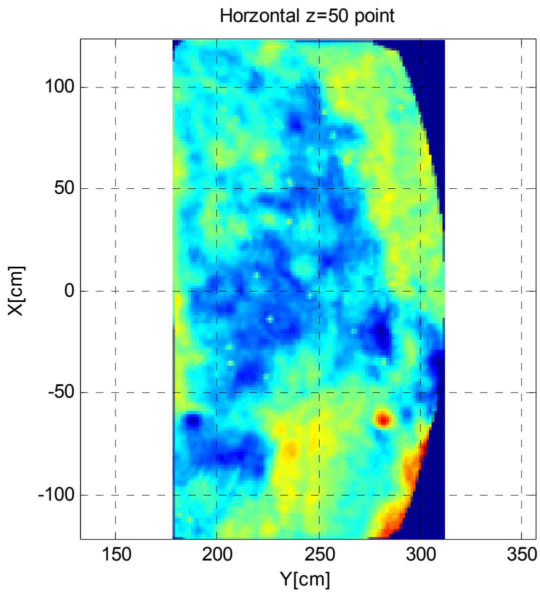
[3] X. Feng,, J. Fujiwara , Z. Zhou., T. Kobayashi and M. Sato, Imaging algorithm of a Hand-held GPR MD sensor (ALIS), Proc. Detection and remediation technologies for mines and minelike targets X, March 2005.

[4] X. Feng,, Z. Zhou., T. Kobayashi, T. Savelyev, J. Fujiwara and M. Sato, Estimation of ground surface topography and velocity models by SAR-GPR and its application to landmine detection, Proc. Detection and remediation technologies for mines and minelike targets X, March 2005.

[5] http://www.jst.go.jp/kisoken/jirai/EN/index-e.html



(a) Metal detector image



(b) GPR image

Fig.10 GPR image acquired by a buggy mounted ALIS