ALIS : GPR System for Humanitarian Demining and Its Deployment in Cambodia

Motoyuki Sato · Yuya Yokota · Kazunori Takahashi

Abstract

Humanitarian demining is a very important issue not only in mine affected countries but also for the countries which are technically, politically and financially supporting the mine affected countries. In order to achieve higher efficiency of the mine clearance operation, new technologies can significantly contribute to the societies. Since 2002, Tohoku University, Japan has developed a sensor system “ALIS” for humanitarian demining. ALIS is a hand-held dual sensor, which combines an electromagnetic induction sensor (EMI) and a Ground Penetrating Radar (GPR). ALIS has a real-time sensor tracking system based on a CCD camera and which enables the image reconstruction. We have tested ALIS in Cambodia and found that it can eliminate more than 70% metal fragments. Since 2009, 2 sets of ALIS have detected more than 80 anti-personnel mines, and cleared more than 137,000 m² in Cambodia.

Key words: Humanitarian Demining, GPR, Dual Sensor, Sensor Tracking, Signal Processing.

I. Introduction

More than 10 years has passed since the Ottawa Treaty or the Anti-personnel Mine Ban Treaty became effective in 1997. However, more than 100,000,000 anti-personnel mines have been still left buried in more than 60 regions in the world, where conflicts have occurred, and after many years, the land has to be returned to the local people. Demilitarized Zone (DMZ) in Korea is also known as a remaining huge mine field. Humanitarian demining is a very important and urgent issue not only in mine affected countries, but all over the world. The process for humanitarian demining has been established, and standard protocol is now being used. The primary sensor is a metal detector, which is an Electro Magnetic Induction (EMI) sensor, and can detect all the small metal objects buried in shallow soil. If any signal caused by a metal object is detected, a deminer will plod the buried object by hand. If the deminer understands the mechanism of explosion of the mine, this operation is not so dangerous. However, it must be done very carefully, therefore time for plodding is very long and it causes the operation cost very expensive.

In order to improve the efficiency of the demining operations, discrimination of landmines and metal fragments by Ground Penetration Radar (GPR) is believed to be one of the most promising techniques. It can decrease the False Alarm Rate (FAR) in detection of landmines, and can directly reduce the cost of humanitarian demining.

A sensor combining the EMI sensor and GPR is called “Dual Sensor” in humanitarian demining. Our research group at Tohoku University, Japan has been developing this dual sensor system, namely, Advanced Landmine Imaging System (ALIS) since 2002 and deployment in real mine fields started in 2009. After many trials, ALIS is now being used in real mine fields in Cambodia. In this paper, we will introduce the ALIS system, and then we will show our recent achievements in Cambodia.

II. Conventional Mine Detection Method

A metal detector, which is an Electro Magnetic Induction (EMI) sensor, operating at around 10~50 kHz has been widely used for humanitarian demining. The current metal detectors for humanitarian demining can detect metal pieces which weight less than 10 mg contained in plastic anti-personnel mines buried at shallower than 20 cm. It should be noted that, by the regulation by United Nation, all the mines buried at shallower than 20 cm must be cleared by humanitarian demining. However, deeper mines do not have to be removed, because they have quite low possibilities to explode by agricultural activities. Therefore, these metal detectors can detect almost 100% of buried mines, which can explode...
by the pressure on the ground surface. However, even in a former battle fields, statistically, only one out of 1,000 metal objects detected by a metal detector is a buried landmine, and this large number of metal fragments increase the cost of humanitarian demining operations.

## III. Dual Sensor for Humanitarian Demining

For a hand held system, a sensor has to be compact. However, due to very strong clutter from the ground surface and inhomogeneous soil makes it very difficult to identify anti-personnel mines in GPR images, combined use of GPR with metal detector is more common approach. This is the advantage of using Dual sensors for humanitarian demining. However, only a few dual sensor systems including Mine Hounds (UK and Germany) [1], HSTAMIDS (USA) [2] and ALIS (Japan) [3] ~[9] as shown in Fig. 1, (http://www.alis.jp/, Sato, 2005, http://www.jst.go.jp/kisoken/jirai/EN/index-e.html) are now available for humanitarian demining in commercial basis as of 2011. Our research group at Tohoku University, Japan has been developing this dual sensor system, namely, Advanced Landmine Imaging System (ALIS) since 2002 and deployment in real mine fields started in 2009.

## IV. Development of New Sensors for Humanitarian Demining at Tohoku University

On the request of the Japanese government, Tohoku University has started the development of new sensors for humanitarian demining in 2002. The initial principle purpose of the research development was technical contribution to the rehabilitation of Afghanistan. For this purpose, we developed two different sensors, namely an unmanned vehicle mounted sensor and a hand held sensor. SAR-GPR, which is an unmanned vehicle mounted system is a sensor system composed of a GPR and a metal detector for landmine detection. The GPR employs an array antenna for advanced signal processing for better subsurface imaging. This system combined with synthetic aperture radar algorithm, can suppress clutter and can image buried objects in strongly inhomogeneous material. SAR-GPR is a stepped frequency radar system, whose RF component is a newly developed compact vector network analyzer (VNA), which is shown in Fig. 2. This is a on-board VNA which is very small, and can acquire the data much faster than other VNAs of this size.

The size of the SAR-GPR system is 30 cm×30 cm×30 cm, composed of 6 Vivaldi antennas and 3 vector network analyzers, which is equipped in a blue and white box mounted on a robotic arm shown in Fig. 3. The weight of the system is less than 30 kg. In the signal processing of the SAR-GPR has a unique future. It is equipped with 3 pairs of transmitter and receiver, having the same center position and different separations. 3 sets of acquired radar signal is processed and create CMP stacked image. This algorithm is very effective for clutter suppression [10].

The sensor has about 10cm offset from the ground surface, and can even image the ground surface topography. It will be implemented for more advanced imaging algorithm, which can be used for the ground surface with a large roughness. Field tests of SAR-GPR were carried out in March 2005 in Japan. Then after, it was also evaluated in the Netherlands and Croatia. One of the GPR results of this evaluation test is shown in Fig. 4.
Fig. 3. SAR-GPR mounted on Mine Hunter Vehicle.

Fig. 4. SAR-GPR horizontal image. Three figures shows horizontal slice of GPR images at 135, 180 and 185 mm. We can find the images of mines at different depths.

We think we could demonstrate the high performance of SAR-GPR for humanitarian demining in these evaluation tests. However, we have to understand that in the humanitarian demining, the conditions where this kind of unmanned vehicle can be used are limited by some reasons. For example, the vehicle must be transported, and we have to prepare a good road. The operation in wide area is good for unmanned vehicle, but it is not effective of the area is small.

V. Hand-Held Dual Sensor ALIS

Compared to unmanned vehicle based sensor system, a handheld dual sensor can more easily replace the conventional metal detectors, because the operation procedure is very similar to each other. ALIS is a hand-held dual sensor, which we have developed since 2002 [11]. The sensor antenna of ALIS is scanned by a hand of an operator (deminer). In order to reconstruct the buried land mine image by GPR, we need a synthetic aperture radar (SAR) processing, which is equivalent to migration processing. In order to achieve this signal processing, we need the sensor position information, while the data is acquired. ALIS is quite unique among some dual sensors, because it is only one duals sensor which has a visualization function of GPR image.

5-1 GPR

Anti-personnel mines are normally buried at very shallow depth, i.e., typically 5~10 cm from the ground surface. However, after many years, landmines can move and many of them moved deeper, mainly due to heavy rain. Deep mines are not dangerous, because it may not explode, and by UN regulation, we normally have to detect land mines buried up to 20 cm. This is relative shallow, and the anti-personnel mines have a diameter of less than 10 cm, we need high resolution.

We developed two GPR systems for ALIS. One is the VNA based step frequency continuous wave (SF-CW) system, and the other is the impulse radar system. The VNA system uses the VNA board which was developed for SAR-GPR shown in Fig. 2, and can operate at 10 MHz ~ 6 GHz. We think this VNA system can operate in any frequency range, and has high performance as a GPR system.

However, considering the depth and the required resolution for humanitarian demining, we employed an impulse radar, which operates in the frequency range of 1~3 GHz. The specifications and features of these two GPR systems are summarized in Table 1.

ALIS uses a sensor head which is a combination of a coil for metal detector and cavity-back spiral antennas for GPR. The cavity-backed spiral antennas transmit and receive GPR signals. The impulse radar operates in the frequency range of 1~3 GHz and has high resolution. The specifications and features of these two GPR systems are summarized in Table 1.

Table 1. Specifications of ALIS systems.

<table>
<thead>
<tr>
<th>Radar system</th>
<th>ALIS-VNA</th>
<th>ALIS-PG</th>
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<tbody>
<tr>
<td>Operation frequency</td>
<td>10 MHz ~ 6 GHz</td>
<td>DC-3 GHz</td>
</tr>
<tr>
<td>Frequency selection</td>
<td>Variable</td>
<td>fixed</td>
</tr>
<tr>
<td>Control unit</td>
<td>Backpack</td>
<td>Combined to the Sensor Head</td>
</tr>
<tr>
<td>Data acquisition rate</td>
<td>5 Hz</td>
<td>30 Hz</td>
</tr>
<tr>
<td>Applications</td>
<td>Wet soil Deep targets (&gt;20 cm)</td>
<td>Normal soil Shallow targets (&lt;15 cm)</td>
</tr>
<tr>
<td>Feature</td>
<td>High performance</td>
<td>Compact</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Less expensive</td>
</tr>
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receive circular polarized wave, which is quite adaptive to any targets, and antenna isolation is very good. The frequency response of this antenna above 500 MHz is quite flat and suitable for wide-frequency range operation.

5-2 Sensor Positioning System and Signal Processing

Sensor position information is essential for the image reconstruction. We use a CCD camera attached close to the antenna, which captures the images of the ground surface continuously. The arrangement of the CCD camera can be seen in Fig. 5. The relative position movement of the sensor is estimated from the differences of the captured images. This is a very simple system, but we found it works effectively. The positioning accuracy is about 10%, and it is quite enough for this purpose. While the sensor head containing a coil for EMI sensor and antennas for GPR is scanned by a hand, and the EMI sensor signal and GPR signal are acquired simultaneously with the sensor position information. Fig. 6 shows an example of ALIS signal visualization. Fig. 6 (a) is an EMI sensor signal and we can see the locus of the sensor head movement. Red and Blue colors indicate the sense of the signal. Fig. 6(b) is the reconstructed image of GPR, which was obtained by signal processing after the data acquisition.

We use Synthetic Aperture Radar processing (SAR), or migration processing. In ALIS, we reconstruct a 3-D GPR image by Kirchhoff migration algorithm [3]. The Kirchhoff migration gives the output wave field \( P_{\text{out}}(x_{\text{out}},y_{\text{out}},z,t) \) at a 3-D subsurface scattering point \( (x_{\text{out}},y_{\text{out}},z) \) from the input wave field \( P_{\text{in}}(x_{\text{in}},y_{\text{in}},z=0,t) \), which is measured at the 2-D surface \((z=0)\) positions. The integral solution used in migration is given by:

\[
P_{\text{out}}(x_{\text{out}},y_{\text{out}},z,t) = \frac{1}{2\pi} \int \int \frac{\cos \theta}{r^2} \frac{\partial}{\partial t} P_{\text{in}}(x_{\text{in}},y_{\text{in}},z=0,t + \frac{r}{v}) + \frac{\cos \theta}{vr^2} \frac{\partial}{\partial t} P_{\text{in}}(x_{\text{in}},y_{\text{in}},z=0,t + \frac{r}{v}) \, dx \, dy
\]

where \( v \) is the RMS velocity at the scatter point \( (x_{\text{out}},y_{\text{out}},z) \) and \( r = r\sqrt{(x_{\text{out}} - x_{\text{in}})^2 + (y_{\text{out}} - y_{\text{in}})^2 + z^2} \), which is the distance between the input point \( (x_{\text{in}},y_{\text{in}},z=0) \) and scatter point \( (x_{\text{out}},y_{\text{out}},z) \).

We found that the migration processing is effective not only for image reconstruction, but also clutter reduction. ALIS GPR does not have very high resolution, however, the migration process has an effect of spatial averaging, and we found that the clutter caused by inhomogeneous soil moisture or small grains can be reduced by this processing. At the same time, this is very robust processing, and the error of the velocity of electromagnetic wave in migration processing does not affect to the image.

5-3 ALIS on an Unmanned Small Vehicle

An unmanned buggy system can survey over a large area, and improves the work efficiency based on conventional metal detection. The robot arm uses ALIS that allows users to remotely confirm the presence of mines.
ALIS was equipped on a robot of a buggy system Gryphon shown in Fig. 8 developed by the research group at Tokyo Institute of Technology. All the same hardware and software of ALIS were used, and the data acquisition rate can be improved by the scanning with a robot arm. The buggy mounted ALIS uses a VNA based GPR with a Vivaldi antenna, which gives the best GPR performance.

VI. Field Evaluation of ALIS in Cambodia

We have tested ALIS in mine effected couriers including Afghanistan (2004), Egypt (2005), Croatia (2006) and Cambodia (2006). We need the experience of the operation by professional deminers in real mine fields to improve the sensor performance. However, governmental organizations do not allow sensors which are not proven well. After many trials in test lanes in these mine affected couriers, in 2009, we could obtain the permission of the use of ALIS in real mine field in Cambodia by Cambodian Mine Action Center (CMAC). We rented two sets of ALIS systems to CMAC, and CMAC organized a ALIS team with 6 deminers. We instructed the operation of ALIS to them and after several months, they are very well trained and started operation of ALIS in real mine fields.

For example during one month in July 2009, ALIS cleared 4,192 m² area, and detected 9 mines, which are all PMN-2 type. Fig. 11 shows the structure of PMN-2. We can find that it includes metal part in it. Metal det-
Fig. 11. Anti-personnel Mine PMN-2.

Fig. 12. Monthly correct discrimination ratio of mine and metal fragments by ALIS (Mar. 2009 ~ Oct. 2010).

Fig. 13. One of the Mine cleared sites in Cambodia.

VII. Conclusion

ALIS, a dual sensor for humanitarian demining has been developed at Tohoku University, Japan since 2002. It is quite unique sensor, with a strong visualization function by a sensor tracking system combined with GPR and EMI sensor. GPR is working at the frequency range of 500 MHz ~ 3 GHz, and can detect mined buried up to 20 cm in real mine fields. The performance of ALIS has been tested in Cambodia since 2009. More than 80 anti-personnel mines have been detected and removed from local agricultural area. ALIS has cleared more than 70,000 m² area and returned it to local farmers. We are still working for deployment of ALIS in more mine affected courtiers.

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References


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