

# ALIS evaluation tests in Croatia

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## ABSTRACT

Tohoku University, Japan is developing a new hand-held land mine detection dual-sensor (ALIS) which is equipped with a metal detector and a GPR. ALIS is equipped with a sensor tracking system, which can record the GPR and Metal detector signal with its location. The Migration processing drastically increases the quality of the imaging of the buried objects. Evaluation test of ALIS has been conducted several test sites. Tests in real mine fields in Croatia has been conducted between December 2007 and April 2008. Under different soil and environment conditions, ALIS worked well. Then ALIS evaluation test started in Cambodia in February 2009 and we could find discrimination capability of ALIS in test lanes, and we are planning to start evaluation test in real mine fields in Cambodia.

**Keywords:** GPR, Landmine detection, Dual Sensor, Hand-held, Sensor tracking, ALIS, Croatia, Cambodia

## 1. INTRODUCTION

Metal detectors are established methodologies for humanitarian demining. However, in order to increase the time and cost efficiency of demining operation, we need a “mine detection sensor”, instead of “metal detector”. Among several candidates of new sensors, we think a hand-held dual sensor is the most practical solution, and it is most close to real deployment. A few dual sensor systems are now available for humanitarian demining in commercial basis. Tohoku university has 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. We have tested ALIS in various conditions, including in test sites in mine affected country such as Afghanistan and Croatia.

The performance and characteristics of dual sensors are quite different from conventional metal detectors. Therefore, new procedures for dual sensors must be established. CEN working group has worked for a document of soil evaluation for dual sensor, which is one of the approaches for standardization of the use of dual-sensors, although at the same time we found so much difficulty to complete this kinds of standards for dual sensors, because too many physical parameters have to be determined, compared to these for metal detectors. At the same time, ITEP is now planning evaluation tests of dual sensors in Germany in 2009. In this paper, we introduce the latest status of ALIS development and its evaluation in Croatia and Cambodia.

## 2. ALIS SYSTEM

### 2.1 ALIS configuration and GPR

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 30×20×8 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 a VNA, which is not easy for an impulse radar system. The calibration data can be stored in the 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.



Fig.1. ALIS system in operation in CMAC test site, Cambodia in 2006. This is a VNA based ALIS, which is to be operated by two deminers. The sensor operator is observing a palmtop PC and the other PC operator is operating a Note PC. ALIS does not require the second operator, but the second operator can observe the operation of the deminer scanning the sensor, and also can advise for the detention by monitoring the visualized image of GPR and a metal detector.

On the other hand, an alternative type of ALIS, namely ALIS-PG is operated by using an impulse GPR system. This impulse GPR system was also developed in the JST project, and can generate a short pulse having approximately 200ps which covers the frequency ranging from DC to a few GHz. Compared to the VNA system, the impulse duration is fixed, and we cannot change the operation frequency dependent on the soil condition. The important advantages of using an impulse GPR system are its light weight and fast data acquisition.

We think, if we operate ALIS-PG in normal conditions, since the impulse GPR system is easier to operate, but if we need to use ALIS in very wet soil condition, ALIS with a VNA GPR is strongly recommended.

The original system of ALIS is shown in Fig. 1. We used two PCs in this type. One palmtop PC is used for monitoring and one note PC is used for data acquiring and signal processing. We think operating by using two PCs still has great advantage for the quality control of the operation. The system can be operated by one deminer, but by using wireless LAN, the second operator can monitor the whole procedure of the operation. All the instruments in this system can work with a rechargeable battery in the system. 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.

In 2007, we developed two new types of ALIS. The new types of ALIS can be operated by single deminer. Fig.2 shows the VNA based ALIS. 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. The control unit of the pulse GPR based ALIS (ALIS-PG) is lighter and smaller than original VNA based ALIS as shown in Fig.3. The both systems use the common

sensor head, and data acquisition and signal processing software. The both systems of ALIS use only one palmtop PC, which is fixed to a flexible arm connected to the control unit. The data acquisition and processing can be done by this PC, and the operator can observe the trace of the metal detector response superimposed on the CCD captured ground surface image on the PC display, which is the same as the original ALIS.



Fig.2. VNA based ALIS for a single operator. This ALIS can be operated by a single deminer. The deminer can observe the sensor scanned trace on the palmtop PC display in real time, and then the signal processing for 3-dimensional display of GPR data is achieved on the same PC. The deminer will interpret the GPR images to identify the buried mines.



Fig.3. Pulse GPR based ALIS (ALIS-PG) .The system is almost the same as the VNA type ALIS. ALIS-PG is light weight, and scanning for GPR data acquisition can be faster than VNA type.

## 2.2 Sensor head

In the prototype of ALIS, we tested two different antennas including a 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 Figs.1-3. The weight of the sensor head is 2kg. 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.

## 2.3 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.4 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.5 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.

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.

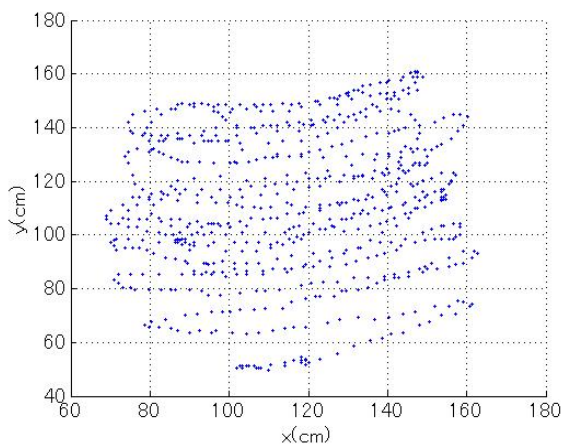


Fig. 4. The locus of the sensor trace and the data sampling points.

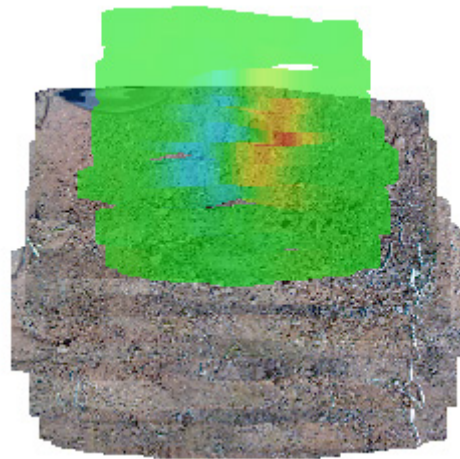


Fig. 5. Visualized metal detector data

## 2.4 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 will be relocated on a regular grid points. Interpolation

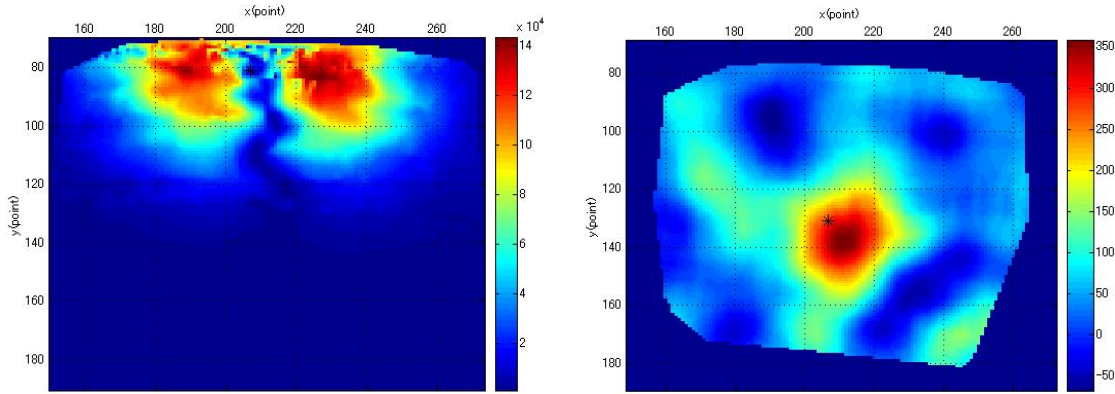
algorithm is used for this process. After the relocation of the data sets, metal detector signal can directly be displayed in a horizontal image as shown in Fig.6.(a).

3-D GPR image is reconstructed by diffraction stacking algorithm. The diffraction stacking 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:

$$P_{out}(x_{out}, y_{out}, z, t) = \frac{1}{2\pi} \iint P_{in}\left(x_{in}, y_{in}, z = 0, t + \frac{r}{v}\right) dx dy \quad (1)$$

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  $(x_{out}, y_{out}, z)$ .

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.



(a) Metal detector image

(b) GPR image

Fig.5. ALIS output image acquired at CDS test site (Afghanistan, 2004).

## 2.5 ALIS operation

When ALIS is used as a primary sensor in demining operation, the procedure of detection of landmines by ALIS is not the same as that by conventional metal detectors. However, after several fields evaluation test, we found that it can be very similar to the conventional one, so that the local deminers can use ALIS more efficiently.

The current suggested standard operation procedure (SOP) of ALIS is as follows:

- (1) A deminer stands on a fixed position.
- (2) The deminer concentrates on the audio output of the metal detector and operates ALIS as a metal detector. The deminer will scan the ALIS in the area about 1m by 1m. The deminer will pinpoint the location of the buried metal objects, if there is any in the area. The operation time for this process is exactly the same as conventional metal detectors.



- (3) If there is any metal object, the deminer will scan ALIS again on the area around the detected anomaly. The scanning area should be now about 40cm by 40cm, which is required for migration processing of GPR for better imaging. The scanning speed should be slightly slower than normal metal detector operation, which also improves the quality of the final images. The second scanning takes a few minutes. The deminer should scan the sensor head regularly, so that there will be no blank area.
- (4) Process the data after the data acquisition. The data processing takes typically 5-10 seconds.
- (5) Observe the metal detector image as shown in Fig.6 (a). Since the shape of the anomaly and the intensity of the anomaly are visualized, identification of the metal objects is much easier than the conventional audio signal information.
- (6) Observe the GPR image and identify the buried object. The operator will move the depth of horizontal slice images and observe the GPR image and discriminate the metal fragments from landmines. Typical small metal fragments do not appear as an image of a certain shape in GPR image, but AP and AT mines and large size metal objects including UXO will be visualized.

We are continuously developing a semi-automatic mine detection algorithm using ALIS in order to reduce the task and operation of deminers.



Fig.6 Interpretation of ALIS data. The deminer is observing GPR horizontal slice images on the palmtop PC display, after processing the acquired data sets. The signal processing for 3-dimentional GPR imaging takes about 10second.

### 3. EVALUATION TEST OF ALIS

#### 3.1 ALIS evaluation until 2006

After laboratory tests, we have conducted field evaluation tests of ALIS in several different locations. The first field trial test was carried out 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. Afghanistan has relatively dry soil, even though we had frequent shower during the test, the soil moisture was about 10%. Under this soil condition, 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 a 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.

We then tested ALIS at the TNO test facility in the Hague, the Netherlands, in October 2005. This is a joint collaboration with TNO and Tohoku University. ALIS is designed as a hand-held sensor, which has a sensor tracking system. Normally, one data set is acquired within 1m by 1m square area by hand scanning. However, in the test site of TNO, we mounted ALIS sensor on a mechanical antenna positioner, in order to evaluate the characteristics of the sensor by avoiding operation skill by the operators. However, due to the difference of the scanning method, we had to change the signal processing methods, too. Processing includes IFFT, 2D interpolation, and migration. We use diffraction stacking with the relative permittivity of 4 (i.e., the velocity is 0.15 m/ns) for migration.

Under the joint research work of JST and CROMAC, we carried out evaluation test of SAR-GPR 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 and one hand-held sensor were evaluated. Fig.8 shows one example of ALIS output in Croatia. The soil was wet condition, occasionally we had strong rain during the test.

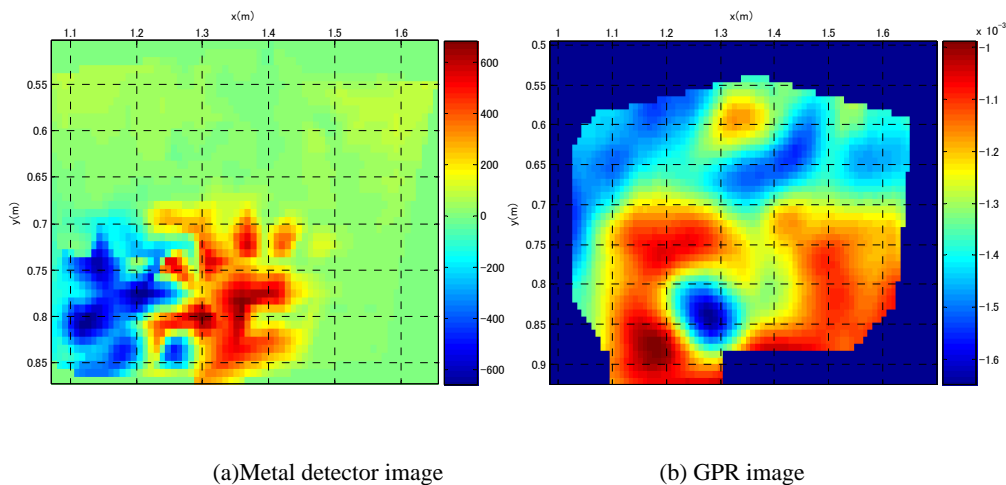


Fig.7. ALIS visualization output in CROMAC test site, Croatia. Lane 3 area40

Then, a 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 the two-month 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.

### 3.2 ALIS evaluation test in Croatia 2007

Systematic evaluation test of ALIS was conducted in September-October 2007 in Croatia. This test was originally planned as ITEP dual sensor test, but due to cancellation of other sensors, only ALIS was evaluated in this test. Therefore, it is not ITEP test, but ITEP send observers in this test. The test was sponsored by JST (Japan Science and Technology Agency), and conducted by CROMAC (Croatian Mine Action Center)-CTDT, and the test lanes were designed by BAM. In this test, we used ALIS-PG. We trained the operation of ALIS-PG to Croatian deminers for two weeks. It included tutorial of fundamental principle of sensors, and signal acquisition, processing and interpretation. Then, we conducted training operations in calibration lanes. We think two-week training is sufficient, however, longer experience of operation of ALIS improves the skill of the operators.



Fig.8. Training of the operation of ALIS-PG in Croatia, October 2007.

## 4. ALIS QC TEST IN CROATIA

### 4.1 QC operation

After the evaluation test carried out in the test site of CROMAC-CTDT, we agreed with CROMAC-CTDT to start evaluation tests of ALIS-PG in mine fields in Croatia. In this test, ALIS-PG were tested in QC(Quality Control) operation.

CROMAC (Croatian Mine Action Center) is a demining organization within the Croatian government but the actual demining activity is consigned to demining specialized companies. CROMAC main operation is to assign demining areas to demining companies to execute the demining activities efficiently. More than 90% of the demining work in Croatia is conducted by the demining companies, and metal detectors have been used. IN the demining operation, all detected metallic objects must be removed in principle. Demining companies must submit a Daily Log to CROMAC everyday and CROMAC supervises the demining activity and conducts a Final QC after completion of the demining work.

The supervision and QC is conducted by a QA (Quality Assurance) Officer. The Final QC is conducted directly by CROMAC-CTDT. The QC is conducted at the area where the demining company has done demining work and based on the location where mines or unexploded ordnance (UXO) had been detected and reported, they will carefully search for mines in selective areas where they believe there is a high concentration of mines, buried with high possibilities, buried in a line, etc. Therefore, there is a high possibility of detecting buried mines that were missed during the demining work. When a mine or UXO is detected in an assigned area, the demining company must conduct the demining work again in the entire area free of charge. Normally, the demining work in a single assigned area takes about 1 week.

### 4.2 Normal QC operation

The following is the normal QC operation procedure in Croatia.

QC is conducted at areas against all demining methods (machine demining, metal detector, demining dogs).

- The QC rules can be confirmed at CTDT's website.
- QC is conducted at about 1% to 3% of the area where demining work had been completed.
- Currently, most of the detection is done by metal detectors (Vallon) and is dug out one by one by hand.



- If two or more metallic object larger than 3cm<sup>2</sup> is found in 1m<sup>2</sup> or if a part/particle of a mine is found, it means the demining company has failed the QC and they must conduct demining work all over again in the assigned area.
- There were 10 cases this year that failed QC. Parts of a mine or larger metal objects were found.
- CTDT's initial objective was reducing time of QC by using ALIS.
- If ALIS can be used to estimate the size of the metallic object, it can eliminate the work of digging out the metallic object.

CTDT does not conduct demining work. Therefore, their primary interest is in QC and not for adopting ALIS as the demining primary sensor/equipment. However, they seem to have interest in instructing demining companies to evaluate the ALIS and also to sell the ALIS to them.

### 4.3 Examples of ALIS operations in QC

During December 2007 and April 2008, in more than 15 locations in Croatia, ALIS has been used and evaluated in QC operation. We show some examples of these evaluation tests.



Fig.9. Mine fields in Croatia.

#### December 19:

Site Test (North of Sibenik City, near Drnis)

The area was a mild hilly terrain a few hundred meters away from a village with grass and trees. It is an area where sheep are pastured but is specified as a mine suspected area/dangerous zone. During the 2 hours of operation on Dec. 19, the following objects were detected. Each operator worked about an area of 5m x 10m.

- Hirvoje (soil where machine demining was conducted)
  - 6 locations of metal detection:
    - 2 places were confirmed by GPR image. One was a dug out hole and another one was a metallic wire underneath a rock of about 20cm size.
- Stjepan (soil where manual (MD) demining was conducted)
  - 9 locations of metal detection:
    - 1 location was confirmed by GPR image. Confirmed that it was a dug out hole.

The area where machine demining was conducted had no grass so it was easier to use ALIS compared to the manual (MD) search area. The soil is plowed by the machine but seems not to effect the performance of ALIS.



Fig.10. Hirvoje Stipetic and Nikola Gambiroza (CROMAC technical manager) QC after machine demining. The soil is plowed and many small rocks appear on the surface.

Figure 12 shows one of the buried objects which was detected by ALIS in this site. It is a stone, and a piece of metal located close to the stone. Figure 13 shows the ALIS image for this object. We can see clear response to the metal detector shown in Fig.13(a) and also can see round shape in GPR image shown in Fig.13(b). Therefore, the deminer has judged it as a possible landmine.



Fig.11. Metal fragments detected by ALIS.



Fig.12 A stone detected by ALIS.

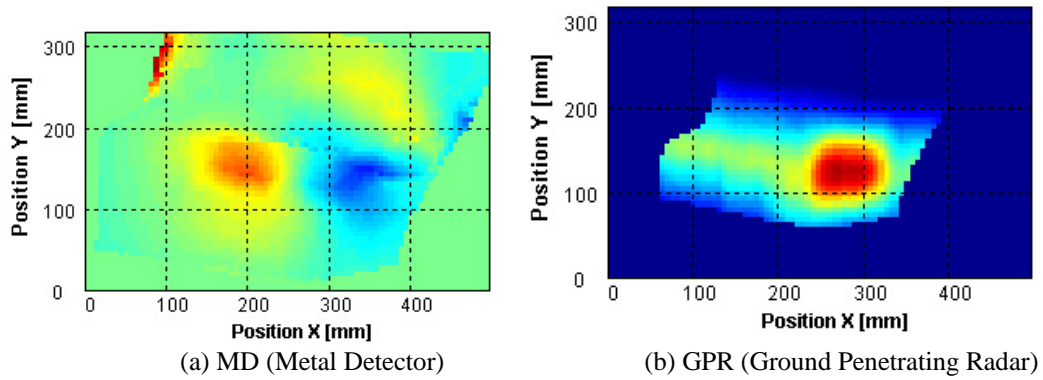


Fig.13 . ALIS image of a piece of metal wire under a rock

**11 March, 2008**

Near Karlovac city, about 50km south of Zagreb.  
 The demining area is former Yugoslavian army facility.  
 The clearance area was very narrow near a fence, therefore, only manual demining was carried out.  
 One AP mine case was found in this area, and many buried metal wires were detected.



Fig.13 Mine field near Karlovac city.

**12 March, 2008**

Near Josidol village, about 100km south of Zagreb.  
 This is a moderate hill, and was machine demined.



Fig.14 Mine field near Josidol village

**13 March, 2008**

Near Islam village, about 10km north of Zadar.

This is machine demined area.

3 of 10mx10m areas were determined by a QA officer of CRIOMAC.

Several small metal fragments were detected in each area.

## **5. 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, and it will be available by the end of 2009. ALIS is now under evaluation by CMAC in Cambodia. ALIS will be tested in two international evaluation tests, namely Defuse and ITEP test in Germany in 2009.

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