LOTUS field demonstration in Bosnia of an integrated, multi-sensor, mine-detection system for humanitarian de-mining

John Schavemaker[+], Eric den Breejen[+], and Richard Chignell[*]

[+]Electro Optical Systems
TNO Physics and Electronics Laboratory
PO Box 96864, NL-2509 JG, The Hague, The Netherlands
schavemaker@fel.tno.nl, breejen@fel.tno.nl

[*]EMRAD PIPEHAWK PLC
Systems House, Mill Lane, Alton
Hampshire GU34 2QG, England, UK
enquiries@pipehawk.com

Abstract

In this paper we report on the successful field demonstration of the LOTUS landmine detection system for humanitarian de-mining that took place in August 2002 near the village of Vidovice, in the Northeast of Bosnia and Herzegovina.

1. Introduction

LOTUS is a project to develop, integrate and demonstrate the proof-of-concept of a multi-sensor landmine detection system for humanitarian de-mining. The idea is to combine three sensors into a vehicle-mounted system. The system includes a metal detector array, developed by project partner Förster (Germany), an infrared camera system from project partner TNO-FEL (The Netherlands) and a ground-penetrating radar (GPR) developed by project partner EMRAD (UK). This project is partly funded by the European Commission as ESPRIT project LOTUS, number 29812. Another partner in the project is DEMIRA, a German mine-clearance NGO. DEMIRA organized the minefield test held in Bosnia and Herzegovina.

The aim of the field trial in Bosnia was to give a technology demonstration of all three sensors working together on a vehicle. The idea of using three sensors is to reduce the problems caused by false alarms of individual sensors due to "background clutter". (Hand-held) metal detectors are commonly used in de-mining activities, as most mines have sufficient metal content for today's sensitive metal detectors. Unfortunately, many areas contain vast amounts of other small metal objects. The infrared imaging is the most suitable sensor for detecting objects placed on the surface or buried close to the soil surface. The GPR gives signals from the discontinuity between the soil and a buried mine body. In principle, therefore it is possible to reduce the number of "clutter" signals within the sensor suite and also to detect mines that individual sensors miss. As such, the detection rate of the system as a whole is increased while maintaining or lowering the false-alarm rate at the same time. The way that the data from the different sensors are combined (or "fused") is of critical importance to the performance of such a system. TNO-FEL are responsible for the data fusion and system integration in the LOTUS project and apply sensor-fusion algorithms that have been reported before [1-3].

2. LOTUS Sensor Suite

The LOTUS system was mounted on a Land Rover. A large aluminum frame on the vehicle roof was used to mount all the sensors for mine detection, interrogating the ground in front of the vehicle.

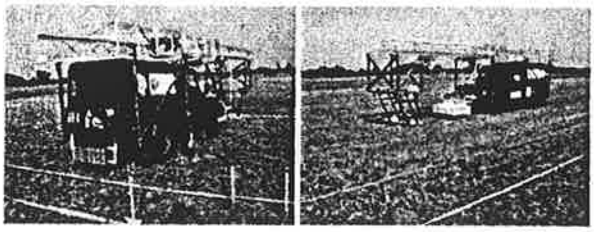

Figure 1: The LOTUS system from different views.

In the front of the vehicle is the Förster metal detector array, which sits in a non-metallic sled that slides along the ground suspended by four swinging arms. Following the metal detector, the infrared cameras are mounted, at 2m above the ground. After the cameras, the GPR antenna is hung from the frame. A tick wheel with shaft encoder is mounted on the side of the vehicle to give a measurement of position. The equipment on the vehicle is controlled by a remote-control (laptop) computer that communicates by wireless LAN with all equipment. The sensor data is transferred over the LAN to the remote-control computer where sensor fusion is performed. Fusion outputs a detection confidence level derived from the combined signal strength and is transmitted back to the vehicle so that its results can be used by the paint marking unit, mounted on the back of the vehicle. The paint-marking unit is used to mark positions at which fusion found a detection and also to mark the lateral limits of the ground covered by the sensors.

2.1: The Metal Detector

The MD array employed in the LOTUS project is a Förster MINEX 2FD Array. It is a simultaneous two-frequency continuous-wave metal detector. The sensor array has one transmitter and seven receiver coils covering a width of 1.15m. The receiver coils are phase and frequency synchronized. Each receiver channel has a high precision phase (<0.001°) and amplitude regulation circuit, which is activated for each system frequency (2.4 kHz and 19.2 kHz) 300 times per second.

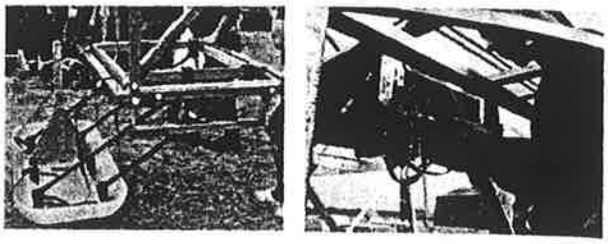

Figure 2: The MD Array with its Ground Adaptation System during Demonstration Trials in Bosnia.

The two-frequency detection system is supported by an advanced real-time filter function, which eliminates uncertain object signals and noise in order to reduce the false-alarm rate of the MINEX 2FD array. An object calculation function defines the object position based on the filtered signals. Filter settings are adjustable and can be set according to scenario requirements. The output of the MD array is real-time data containing the positions and the characteristics of metal detections, like signal strength and size of the detected objects. This data is converted by TNO-FEL processing to produce an area map, containing real-valued, confidence numbers between 0 and 1 indicating the confidence or belief in a mine detection on a certain position, that is used in the subsequent sensor-fusion process.

2.2. The Ground-Penetrating Radar

The MINEREC GPR Array was built as part of an earlier Framework 4, EC project and contains many EMRAD proprietary items. The design is based upon the requirement to detect small anti-personnel mines.

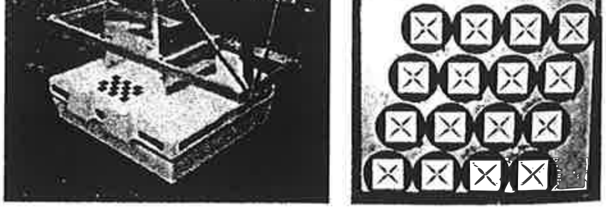

Figure 3: The GPR array with and without cover.

The data generated by the MINEREC array is subject to significant processing before an output is obtained in the form of a "confidence" map that is used as input to the fusion process. The first step in the processing is to remove the effects of antenna breakthrough and reflections from the ground. For the real-time software used in LOTUS a moving average is subtracted from the signal to remove these effects. The second step generates a smoothed local energy map. The conversion to a confidence value requires the calibration of the system. In LOTUS this was done by scanning a "clean" area of ground approximately 3m x 1m with one mine present of the type sought.

2.3. The Infrared Camera

The IR detection system consists of a commercial off-the-shelf (COTS) camera, an associated processor board and a PC. The processor board is housed within the PC. The camera specified for LOTUS was the Radiance HS also known as Galileo. The camera is operated using a Matrox Genesis board. This acts as a frame grabber, digitizing the camera output and carrying out the pre-processing based upon the use of DSP.

The real-time infrared processing method relies on the principle that the mines have a different (apparent) temperature than their surrounding. Furthermore, the method applies local contrast enhancement to make it invariant for the local background intensity and performs false-alarm reduction by selecting blobs on morphological and size attributes by using a priori domain knowledge.

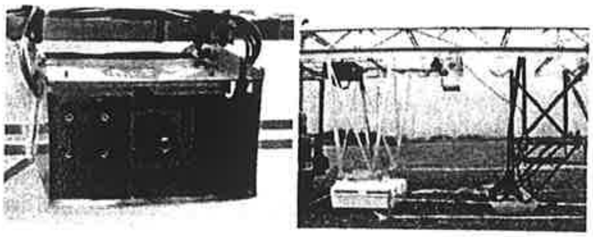

Figure 4: IR looks down between GPR and MD.

The IR processing strategy is appropriate for mine detection. It ensures that high level signals arising in even small areas are not ignored and that a consistent signal level is generated and supplied to the sensor fusion [4].

3. The Bosnian Field Trial

The Bosnian field trial provided the focus for the conclusion of the LOTUS phase in the development of a vehicle-based mine detection capability. The trial took place on farmland next to the village of Vidovice, near the town of Orašje. This location is in the Northeast of Bosnia and Herzegovina, close to the border with Croatia (the Sava river) and not far from the border with Yugoslavia (Serbia). The area was the scene of very heavy fighting in the war.

The LOTUS trial site was within a suspected mined area of flat farmland, but it had been cleared by DEMIRA for reasons of safety. The area surrounding the trial field was uncleared land. The soil of the test field appeared to be fairly heavy clay, on which the grass had been cut short. When the field was cleared, a large amount of metallic debris was removed. A lot of this debris was from ordnance fired in the war. Despite the removal of this, it was conceded that there remained some metallic clutter.

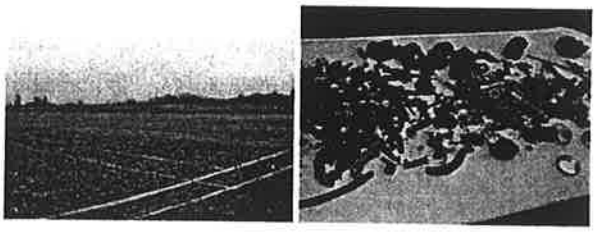

Figure 5: The trial site and removed metal debris.

The focus of the trial was upon the five 50m test lanes that were carefully prepared by DEMIRA. The choice of targets and layout was designed by DEMIRA to being representative of Bosnian mine detection issues and problems. In general the first three lanes numbers one to three were laid to reflect current field issues and lanes 4 and 5 were laid with a view to establishing the limitations of the LOTUS system. In lanes 4 and 5 targets were buried at depths of up to 200mm which is deeper than required but could be required if the area had been flailed.

4. Bosnian Field Trial Results

The objective of the LOTUS system is to detect and mark mines in real-time. The on-line real-time results for the system are of relevance to de-miners and therefore the most important. All the results presented were recorded during a demonstration day. During that day data from all five lanes was analyzed in real-time during the demonstration runs. No hardware or software failure occurred. The weather conditions for the measurements were good: warm, sunny with some occasional clouds.

During the demonstration day some different sensor-fusion algorithms and settings were implemented and tested. The demonstration sensor-fusion algorithm can be described as follows:

- mark all MD signals with one color (yellow);
- mark all MD signals with significant support from at least one other sensor (IR, GPR) with another, second color (white).

Examination and evaluation of all sensor-fusion detection results took place by visual inspection of the marking results by a number of attending people (including the EC reviewer). Inspection was relatively easy because all objects placed by DEMIRA were either directly visible or identified with a small flag with an identification number at the same horizontal position, 1m away. After collection and re-checking of some of the results, real-time detection performance of the system achieved is presented in table 1.

Lane	Detection result (all objects)	Detection result (metal objects)
1	95%	100%
2	100%	100%
3	96%	100%
4	93%	93%
5	69%	69%

Table 1: The Detection Results achieved in the Real-time Demonstration on the Bosnian Mine Lanes.

The detection results apply to all classes of object without distinction including anti-personnel mines, anti-tank mines, UXO and remnants of objects. The number of false alarms was negligible. This arose for two reasons. Each of the sensors was operated at their calibrated operating points, severely limiting the number of sensor generated false alarms. The second reason was that DEMIRA had cleared the land of metal detritus.

5. Summary and Conclusions

The conclusion from the real-time operation is that the sensor suite may be used to detect minimum metal anti-personnel mines down to a depth of 8cm, with no false alarms caused by the system. False alarms caused by fragments in the ground may be present but not system-generated false alarms. This limitation is a direct reflection of the limitations of the metal detector. At a greater depth the GPR takes over as the most important sensor and the strategy for combining sensor outputs may need to be different as also put forward in [2].

6. References

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H. Sahli
A. M. Bottoms
J. Cornelis (Eds.)

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