Recent Results Achieved in the 5th FP DEMAND Project

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Abstract

The DEMAND project is sponsored by the European Commission in the Information Society Technologies programme. This paper describes the background which led to the initiation of the DEMAND project and its concept. Technical results are then provided for each of the main sensors in the project; metal detector array, ground penetrating radar and biosensor as well as the data fusion system. The most recent results from the testing of the sensors are presented as is an overview of operational procedure tests. The paper concludes with an overview of how the technology may be further exploited especially for humanitarian demining.

1 Introduction

DEMAND is an acronym for the correct title of the project: "*Enhancement of three existing technologies and data fusion algorithms for the test and DEmonstration of Multi-sensor lANdmine Detection techniques*". It contains seven partners from five European countries, commenced in February 2001 and is scheduled to be completed towards the end of 2003. The project has been able to increase the state of the art for the three sensor technologies in the project: metal detector array, ground penetrating radar and biosensor explosive detector as well as implementing a novel generic data fusion approach. The system is currently taking measurements and undergoing tests in near real field scenarios

2 Background leading up to DEMAND

The DEMAND project was submitted to the European Commission in 2000 as a result of a Call published within the Information Society Technologies thematic area of the European Union's 5th Framework Programme. The call targeted technology for humanitarian demining for the South East Europe Stability Pact Region. The project partners were able to integrate knowledge into the conceptual planning of the project which had been gained from the EUREKA project entitled ANGEL as well as state of the art radar technology, the concept for which had been proved in the previous 4th Framework DEMINE project.

3 DEMAND development concept

The partners initializing the DEMAND project saw the potential of combining three advanced sensor technologies with data fusion to provide a tool for humanitarian demining which could show that advanced technology is able to carry out demining in a safer and more effective way than present demining techniques. The basic idea is that knowledge from three sensors enhanced with data fusion can reduce false alarms. However, as every practical deminer is at pains to point out, the use of technology for safer and effective humanitarian demining is dependent on operational procedures. The work in the project includes a series of tests to assess operational concepts proposed at the beginning of the project. An assessment of the performance of the system in the near real field tests will provide a basis for proposing detailed operational procedures. Extensive evaluation and tests will be required after the end of the project to bridge the gap between research and development and actual operative demining. The system performance assessment will provide a basis to assess the economic effectiveness of an implemented system. This is a key issue with demining organizations reporting costs as low as € 0,1 per sqm in SE Europe.

4 Sensor Technologies

4.1 Metal Detector Array (MD)

The basic metal detector technology which was chosen for the project was the commercially available VAMIDS system developed by Schiebel Elektronische Geraete. Development work in the project has provided for i) increased sensitivity under noise conditions, ii) increased detectability of small targets and iii) support for an arrangement of stacked coils. The signal input of the system has been increased by over 20%, the S/N ratio increased from 7.5 dB to more than 10 dB and low frequency noise is also rejected by the system.

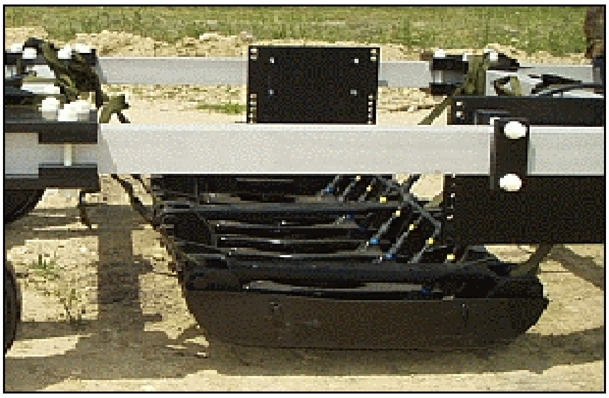

Fig. 1 - The metal detector on the DEMAND test vehicle.

4.2 Ground Penetrating Radar (GPR)

The ground penetrating radar technology which was chosen for the project is based on radar electronics using the M-sequence technique from MEODAT GmbH. IDS S.p.A. provides the antenna (cf. [SEN]) and signal processing solution. These two companies together with the Technical University of Ilmenau have worked together to construct the radar solution. A 15 Tx - 20 Rx full polarimetric linear antenna array has been constructed in the project.

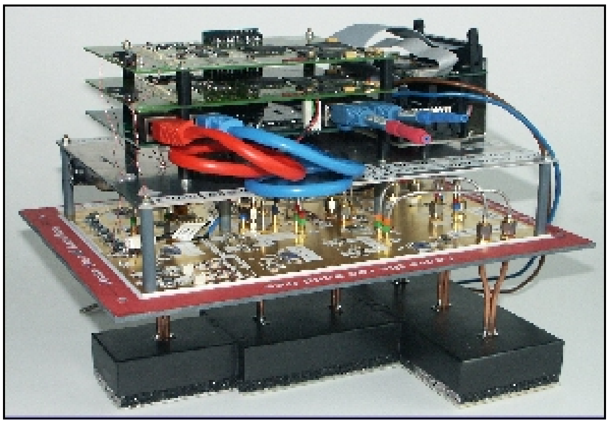

Fig. 2 - One DEMAND radar module. Five such modules are used in the radar array.

The bandwidth of the electronics and the antenna together is 2.5 GHz.

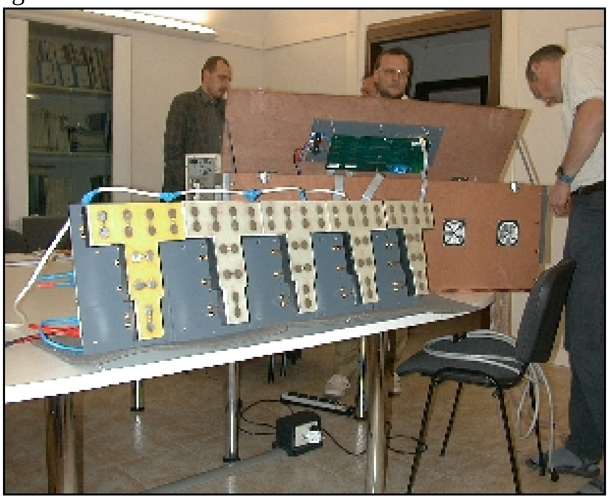

Fig. 3 - Underside of the polarimetric antenna array with its all five modules in the foreground. The radar demonstrator packaging is in the background.

4.3 Biosensor

The biosensor technology chosen for the project is developed by Biosensor Applications AB. This technology is based on a novel Quartz Crystal Microbalance (QCM) weight loss technology and advanced surface chemistry. The biosensor system has two main components, the sample collection system and the analysis unit. The collector runs at a speed of 150 liters/min. Single use filters are used both for sample acquisition and standard control of the analysis unit. The analysis unit holds 4 cells equipped with crystals for TNT, and optionally other explosives. Data analysis is performed by the internal CPU of the analysis unit but during the development phase an external computer is connected to allow for visual inspection of the signals from the cells. The analysis time for a filter is 90 seconds.

Fig. 4 - Main unit of the Biosensor sample collection system which may be carried in a similar manner to a backpack and the use of a sampling probe.

Fig. 5 - Prototype biosensor analysis system used in DEMAND

The sensitivity of the QCM sensor technology is at present 2-10 pg TNT/µl. The volume of the sample plug that passes the cells is in the order of 50 µl. When filters are analyzed the practical sensitivity is about 1-5 ng TNT. Following development of the biosensor is improving the sensitivity of the system.

The biosensor system used in DEMAND is a TNT detection system. Its sister project BIOSENS also partly funded through the European Commission has the goal of improving the DEMAND biosensor analysis system to also be able to detect the explosives RDX and PETN. Traces for TNT, RDX and PETN may be analyzed simultaneously by the technology.

5 Data fusion (DF)

GTD is the partner responsible for developing the data fusion system in the project, the concept for which was one of the results from the EUREKA ANGEL project mentioned earlier. The DF system represents a generic and flexible solution for the fusion of heterogeneous data (spatial and non spatial) coming from the sensors on the platforms, and also from human knowledge available from domain experts. The Data Fusion system as a knowledge based expert system consists in the following parts: Knowledge Base (KB); Inference Engine (IE); Knowledge Acquisition (KA) facilities; and Explanation facilities (EF).

The architecture is designed with a multi-agent and blackboard pattern, the Data Fusion Engine (DFE) handles a dynamic catalogue of Automatic Target Recognition (ATR) agents, which interact with the registered geographical feature objects in the Virtual Scene Blackboard (i.e. the GIS database).

The implementation of the system is based on the integration of a number of commercial-off-the-shelf components and proprietary developments. The GIS system is based on ESRI´s products ArcGIS and ArcSDE, which provide a powerful platform for the integration of the spatial data coming from the sensors. The combination of the DFE with this GIS system results in an advanced spatial decision support system (or intelligent GIS). The knowledge representation capabilities combine spatio-temporal relations and fuzzy rules. All of this enables the system expert to calibrate the data fusion performance in a flexible way with advanced qualitative spatial reasoning capabilities.

6 Performance Evaluation of the system

This section describes the planned and so far executed tests of the Demand sensors and system. We describe in particular: the tests of the GPR MD arrays and Data Fusion at the European Commission Joint Research Center (JRC) Test Site and separate tests of the Biosensor in Croatia.

6.1 JRC Tests

The joint GPR + MD + Data Fusion system was tested in May 2003 on the European Commission Joint Research Center Test Site. The site includes 7 6×6 m plots of different soils each containing the same variety of mine and clutter simulates with identical layout. It is therefore possible to compare sensor and system performance as a function of soil variation. Although the number of targets per plots is insufficient for a highly reliable statistical determination of the performances in terms of Probability of Detection and False Alarm Rate for each of the soils, analyzing the performances on the whole site, these parameters can still be estimated with a reasonable confidence (± 14%).

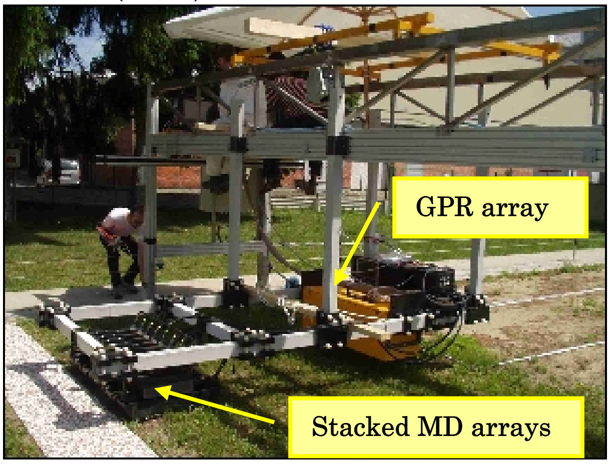

Fig. 6 - GPR and MD arrays acquisition setup at the JRC tests in May 2003

6.1.1 MD data processing

Typical data collected on the site by one of the 2 stacked MD is presented in Fig. 7.

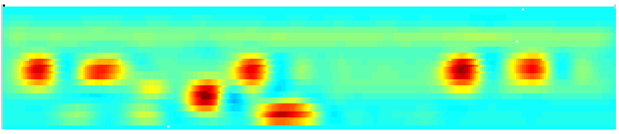

Fig. 7 - MD array 1 data for the JRC plot 3 (sandy soil), lane 8. Axis not to scale

A first conversion is needed in order to filter impulse noise. A filter is applied in order to eliminate noise and an interpolation is made in the Y axis (in the direction of the coil array) for smoothing the signal and enhancing the resolution. The stopband used is related to the distance between two coils in the MD array. Afterwards, the signal is windowed using a window size multiple of distance between coils because it determines the resolution of the system. Then, the peaks are detected within each window. Peak detection is a very relevant way of extracting metal information since each peak is an indicator of possible presence of target.

Size of the peaks are proportional to the value of the signal for the peak. Metal values are normalized and equalized for using the full range of values and for making the peak values of each scan independent.

Fig. 8 shows results of the peak detection algorithm. Each dot is a detected peak, brighter dots are small peaks, and darker dots are large peaks (i.e. peaks with higher signal values).

Fig. 8 - MD processed data for the JRC plot 3 (sandy soil), lane 8. Figure Axis not to scale

6.1.2 GPR data processing

Data collected by the GPR array is pre processed for improving the signal to noise & clutter ratio, compensating for the soil loss, equalizing the gain of each channel and aligning the polarimetric channel triplets on the basis of previously acquired laboratory calibration experiments. During such steps some global environmental and acquisition parameters are automatically extracted from the data; in particular: the array trajectory over the soil in terms of its baricenter trajectory plus pitch and roll evolution, the soil surface average reflectivity, the soil attenuation and propagation speed[1].

Pre processed data from the 24 co-polar channels composing the array are then focalized in 3D by taking into account the estimated array trajectory over the soil surface. Fig. 9 presents a C-scan example of the GPR focalized data collected over the same area of Fig. 7.

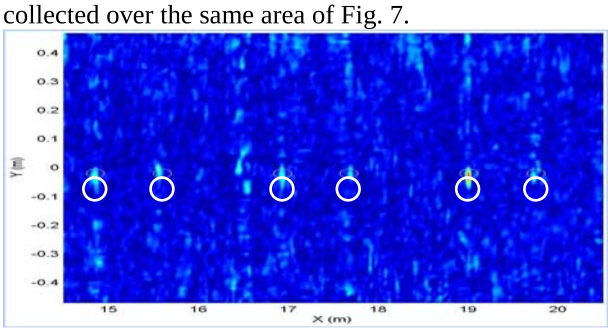

Fig. 9 - Horizontal slice of GPR focalized data (Integration Gain) at 3 cm depth for the JRC plot 3 (sandy soil), lane 8. (Figure axis not to scale: x-span = 6m, y-span = 0.8 m, nominal ground truth as white circles)

One of the products of focalization is the so called Integration Gain that represents, for each of the voxels on the 3D focalization volume, a normalized measure of how the data conforms to a quasi point-like object (e.g. a mine). The Integration Gain is used as the basis of a first level detection on GPR data only. This detection step is performed in order to provide Data Fusion with higher level features on a reduced set of points of the scanned volume rather than raster data for the whole volume. Clearly it is important that such Data Reduction step is performed with very high PD even at the cost of a high PFA. This first detection is achieved by a suitable threshold

[1] Only semi automatically at the time of writing.

followed by morphological operations in order to cluster the detection voxels in 3D. Such clusters along with their spatial and statistical characteristics in terms of both the Integration Gain and the corresponding Reflectivity values, form the first set of features of GPR target characterization.

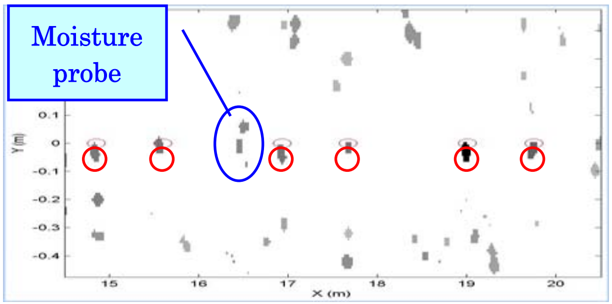

Fig. 10 – GPR detection clusters (slice at 3 cm depth) for the JRC plot 3 (sandy soil), lane 8. (Figure axis not in scale: x-span = 6m, y-span = 0.8 m, nominal ground truth as hollow regular circles)

Fig. 10 shows on a gray scale a slice through clusters appearing at 3 cm depth; intensity values represent the maximum of the Integration Gain for each cluster (cf. Fig. 9). All targets are detected along with a number of further alarms some of which, though, are known to be valid GPR targets as indicated in the figure.

The typical performances of this processing on a single scan over one of the JRC boxes are 400 detected clusters over a surface of 6 m² by data focalization down a depth of approximately 30 cm . In terms of data reduction the very mild threshold only reduces the data by 1/3, i.e. from ~10^6 original focalization voxels to ~3×10^5 detected voxels. The morphological and clustering steps further reduce the detected voxels to 400 detection objects some of which can in principle be eliminated on the basis of their geometrical characteristics (e.g. their extension in depth is incompatible with the size and shape of a mine, etc.). Our approach, however, is to extract further characterization parameters (i.e. polarimetric and spectral features) from the GPR data but only in the region surrounding the detected objects[2]; in this sense, the first level detection reduces the computational burden by a factor of 2-3×10^3.

The development of polarimetric and spectral features extraction is still ongoing and at the time of writing it has not yet been implemented into the DEMAND processing SW. One of the most critical factors for polarimetric analysis by a GPR is the calibration of the instrument in terms of common time alignment and gain equalization of the HH, HV and VV channels composing the full polarimetric measurement. These problems have been resolved by a careful calibration procedure based on an experiment in air with a thin metal pipe.

Preliminary tests of the algorithm were made with a lower frequency impulse radar over pipes and led to encouraging results whereas the orientation of even small dielectric pipes at 1-2 m depth were automatically estimated within an error of 2.5 deg. The algorithms used are based on a modified version of those developed by Chen [CHE].

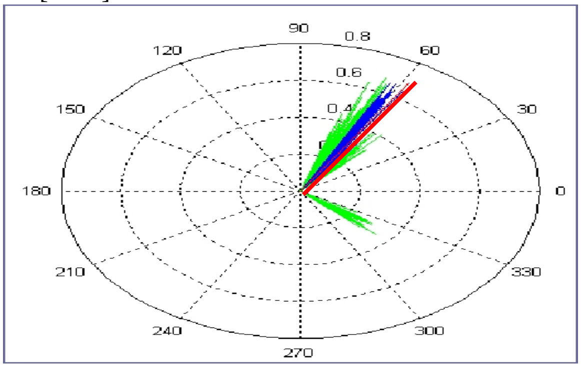

Fig. 11 – Estimated orientation (red vector) of a skew pipe based on statistical analysis of polarimetric features (green vectors) along the hyperbolic detection pattern.

6.1.3 Fusion of GPR and MD data

This section illustrates the process of data fusion of GPR and MD objects. The figures are based on the real data gathered at the system integration tests performed in April 2003 at Schiebel´s facilities in Vienna. At each scenario of 2x1 meters, 10 mine-like objects were deployed in 2 rows, with 40cm of separation between each object. The objects were made with a dielectric material plastic case with a metal screw inside as a fuse substitute.

The aim of data fusion is to have all objects found by the sensors integrated in the GIS database and then to process the information for target detection. For data integration, all objects must be co-registered (they must contain the coordinates where they were extracted). Uncertainty in the co-registering of objects is taken into account in the GIS applying fuzzy logic to the spatial relations and extending objects with defined “halos”. Fig. 12 shows the importation of metal detector objects and GPR objects in the GIS system.

[2] I.e. areas of the original B-scan data along a portion of the 3D focalization integration patterns.

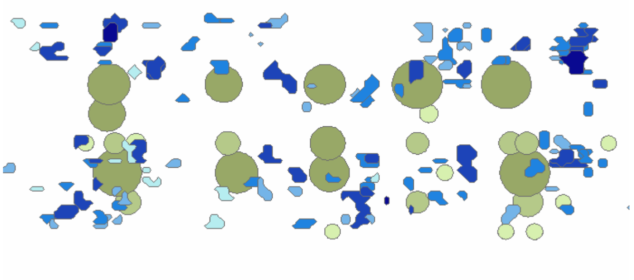

Fig. 12 2-D representation of GPR and MD objects. Green are MD objects, Blue are GPR objects.

Once the GPR and MD are imported into the GIS, the data fusion models can be trained for target detection. As introduced in Section 5, there are two main types of fusion models available: a contextual spatial reasoning model, and a feature space fuzzy-rule-based classifier. The first one is based on manual learning from expert´s knowledge, and the second one provides an automated supervised learning capability based on the Fuzzy-ARTMAP neural network algorithm. There are several training strategies possible. First, a training area containing several targets must be defined, this area is used to train a feature space based classifier which will be used in the test area. Using the contextual reasoning capabilities of the system it is possible to focus the attention of the training process on different criteria. In other words, it is possible to model the training points of the area according to the sensory feature objects present in the GIS. For example, we can concentrate the training on the zones where there is presence of both GPR and MD objects. This model is introduced with the graph based Knowledge Acquisition tool as shown in the diagram:

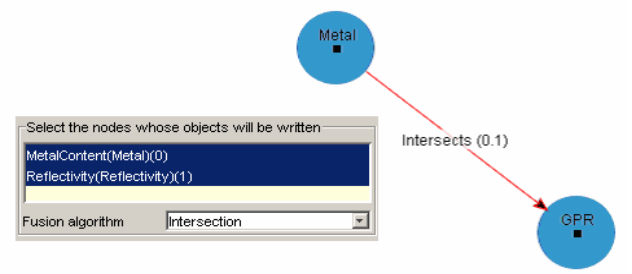

Fig. 13 Graph algorithm, showing the intersection between MD and GPR objects.

Afterwards, the rule based classifier model is trained on the defined area and with the define object oriented attentional strategy. The rules (learnt by the NN algorithm) can be expressed in a user understandable way as shown:

1. **If (IntegrationGain *is* [0.0,0.32]**
and Reflectivity *is* [0.0, 0.23]
and MetalContent is [0.0,025])
then (Object_point *is* BACKGROUND)

2. **If (IntegrationGain *is* [0.52,0.55]**
and Reflectivity *is* [0.35,0.39]
and MetalContent is [0.36,0.73])
then (Object_point *is* TARGET)

Fig. 14 Rule set example. IntegrationGain and Reflectivity are GPR objects.

After training, the algorithm is able to predict targets in test areas. Another attentional model can be defined and applied to the test area. So far, a quadtree algorithm is applied to focus the test points according to the present density of sensory feature objects. Fig. 15 shows a train and test example area and the predictions made by the classifier (small red dots). Targets are shown using red and transparent big polygons. In this example, all targets are detected however there is some deviations (of a few centimeters) in their detections due to misalignment in object geo-registering and sensor processing.

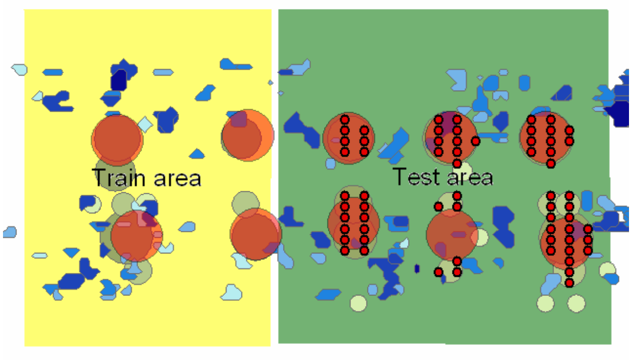

Fig. 15 Predicted objects are marked using small regular dots.

6.2 Biosensor Tests in Croatia in May 2003

After several improvements of the instrument design and cell chemistry performance the second field tests of the instrument were undertaken at the end of May 2003 in Croatia.

In some collections a double-filter holder was used. This permitted analysis by both the biosensor analysis unit and by a GC-μECD system. The GC-μECD system has higher sensitivity than the biosensor system at this stage. It also permits quantitative analysis of TNT on filters but requires more elaborate and time consuming sample preparation and cannot be used in the field.

Initial performance of the analysis unit was tested at a hotel just outside of Zadar with filters previously prepared with TNT and 2,4-DNT. The results showed that the biosensor analysis unit was performing satisfactorily at the 10 ng level with a PD of 100%.

Collections above a mine (anti tank; TMA5) were performed using a double-filter holder. A collection time of 6 minutes was used. A total of 9 collections at positions above and around the mine was performed covering a surface of 60x60 cm. A collection was also performed at a position with no mine. During the analysis with the biosensor analysis unit back at the hotel the biosensor sensitivity was checked by also analyzing a total of 5 filters to which 10 ng of TNT had been previously added. Also a filter containing no TNT was analyzed. None of the filters collected on and around the mine position nor the filter collected above a no-mine position gave rise to a TNT/DNT indication when analyzed on the biosensor analysis unit. All 5 filters to which 10 ng of TNT had been previously added gave rise to positive indications. The absence of TNT indications above the mine when filters were analyzed by the biosensor analysis unit is not unexpected. Previous tests with the collection system at the test field has indicated the presence of very low levels of TNT above mines when filters were analyzed by GC-µECD. At best 5 ng of TNT has been discovered. We are awaiting the analysis of the accompanying filters by GC-µECD to see the actual amount of TNT on the collected filters. Until this analysis has been achieved it is difficult to draw detailed conclusions about this test.

A series of filters were also analyzed at the test field site at Skabrnje. The biosensor analysis unit was set up inside a container at the site and a total of 10 filters to which 10 ng of TNT previously added were analyzed. The 10 filters analyzed all gave rise to positive indications on the biosensor analysis unit. This shows that the biosensor analysis unit basically performs also under test field conditions.

7 Operational Procedures

The system could be potentially used in a number of demining operations, including supporting mechanical demining and for quality assurance. In what follows we describe two possible procedures.

7.1 Procedure 1: Close in detection

This procedure would be used at areas confirmed to be mined. The borders of the minefields would be known by technical surveys and the whole area would have to be cleared. The procedures would be the same whether it is a low-density or a high-density minefield.

1. The ground will first be controlled by MD and GPR.
2. All alarms must be evaluated if the GPR and MD can not discriminate the alarm as false, the Biosensor must verify existence of TNT or classify the object as a false alarm.
3. If the alarm is verified as a mine, it must be marked out. Before going further on that lane, the mine must be destroyed or removed. If the mine is destroyed in situ, one must be aware that the biosensor will not be useful in the surrounding area.
4. Each lane must be well marked so that the operators know exactly where the borders are between the safe area (cleared) and minefield.
5. When the next lane is started there must be an overlap.

7.2 Procedure 2: Area reduction

This procedure will be used at areas which are suspected but not confirmed minefields or to find the borders of minefields.

1. The same procedure as in “close in detection” point 1-4 is used except that the mine must not be destroyed or carried away. This provides safety for the operators of the DEMAND-equipment.
2. If no mines are found the Biosensor collects air samples in steps of x m per filter.
3. If a filter proves to contain TNT this lane will be closed at the point where the sample was taken.
4. A new lane will be cleared x m away from the last.

Today it is unknown how far from a mine Biosensor will be able to detect a mine. It should be noted that the greatest benefit that a DEMAND system is believed to offer is a reduction in false alarms. If the system is used as primary detection method this benefit will only be obtainable if a demining operation is not required to remove all metal from the ground.

8 “Real Field” Test Plan in Bosnia

During the second half of 2003 system tests will be carried out at Norwegian People’s Aid test and training facilities at Raljevo near to Sarajevo in Bosnia. The “Real Field” Test Plan has been designed to evaluate technical progress made and to give the project input for further system iteration. The campaign will be set up as a mine localization/ identification probability test. In the test area there will be both AP/AT-mines containing explosives but disabled and also false alarms clutter objects. The ground conditions in the test field are most similar to grassland.

9 Exploitation of the results

The technical work in the project has resulted in a prototype system composed of a simple trolley like platform with three enhanced sensors whose measurement results are strengthened through Data Fusion. The main tasks of integration have been those connected to Data

Fusion, survey strategy development and performance evaluation parameters. Good test results in terms of both detection performance and potential cost effectiveness will enable the project partners to press ahead with engineering of a DEMAND system for humanitarian demining. Knowledge which has already been achieved in the project is in the process of successful exploitation by a number of individual or groups of partners.

10 Summary and Conclusions

The conceptual reasoning for the DEMAND project was presented. The key sensors, data fusion system and present results were described. Recent results from JRC tests have provided qualitative indications that the system will be able to reduce false alarms. The results of tests with the biosensor have also shown its TNT detection capability. An overview of an operational concept was described and our Bosnia test intentions. Exploitation opportunities were also described.

11 Disclaimer

The information appearing in this document has been prepared in good faith and represents the opinions of the authors. The authors are solely responsible for this publication and it does not represent the opinion of the European Community. Neither the authors nor the European Community are responsible for any use that might be made of data appearing herein.

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