EUDEM2

The EU in Humanitarian Demining-State of the Art on HD Technologies, Products, Services and Practices in Europe

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EUDEM2 Technology Survey

Catalogue of Advanced Technologies and Systems for Humanitarian Demining

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Executive Summary and Disclaimer

Executive Summary

In the framework of its Technology Survey, the EUDEM2 project conducted several studies on Humanitarian Demining Technologies. This *Catalogue* summarizes the some of the findings of the project. The *Catalogue* provides state of the art technologies which have been developed for the detection of landmines, both anti-tank and anti-personnel mines. It contains details of technologies which have reached the stage of deployment, as well as those at the prototype or demonstration stage. The benefits which may be obtained from the introduction of new technology to humanitarian demining are highlighted while some of the further development, both technical and operational, which must still be undertaken, is noted.
The technologies considered are evaluated for their state of readiness and given a Technology Readiness Level score; it is however important to note that this is only in the opinion of EUDEM2 team based on its own analysis.

Disclaimer

The information appearing in this Catalogue has been provided predominantly with the analysis of information already made public and also with input from, and co-operation with, the developers of each of the technologies appearing in the Catalogue. EUDEM2 team and the Catalogue authors have prepared this report in good faith with the goals of disseminating results.

Note

In case you notice errors or incoherence's please send comments to K. De Bruyn (kdebruyn@etro.vub.ac.be).

Content

1 Introduction

Since the end of the 1990s considerable funding and effort has been invested worldwide in order to develop new technologies for humanitarian demining. This with the aim of improving the productivity of present humanitarian demining methods while maintaining or increasing deminers´ safety. During this time there has also been considerable investment of military budget in new sensing technologies for demining. The change in the emphasis of the expected operational use of detection technology by military personnel, from e.g. minefield breaching to peace keeping and security building and maintenance, has also seen military detection requirements move to a certain extent towards those expected for humanitarian demining.

There is perhaps a general disappointment that none of these technologies has made quick progress from research and development to field use, though this understandable expectation was to a certain extent unrealistic.

In the very detailed RAND report (2003[1]), which analysed in particular technologies originating in the USA, the authors came to the conclusion that "no single mine detection technology can operate effectively against all mine types in all settings"[2], before recommending that the US Federal government initiate an R&D program to develop a multi-sensor system. They estimated that "initial prototype development would cost approximately $60 million[3]" and that "depending on the amount of resources invested in this research, a prototype multisensor system could be available within seven years", but that "once the prototype is developed, additional allocations totalling approximately $135 million will be needed to fund the engineering and development of an optimal, deployable system.[4]". The need for substantially greater funding to take a functional prototype of humanitarian demining technology to field readiness, than the cost of developing the prototype in the first place, has also been noted at the highest levels in Europe[5].

Nevertheless, a number of technological developments are now coming of age and test results consistently confirm that some of these technologies can indeed increase the productivity of humanitarian demining, while at least maintaining the current high levels of safety. Several development groups have shown this can be the case for the combination of a metal detector with ground penetrating radar (GPR). The first such combined system, the AN/PSS-14, has now been fielded[6] and others are expected to follow in the short-term[7].

In this *Catalogue* information about the most promising developments is presented, with details of: (i) technology which has now reached operational implementation stage, (ii) technology which is close to operational implementation, and (iii) prototype technology where substantial further engineering investment is required before reaching operational readiness.

This *Catalogue* also presents a discussion of how to judge the readiness level of a technology, before going on to consider the working principles in general terms of several of the most important

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[1] J. MacDonald, J. R. Lockwood, J. McFee, T. Altshuler, T. Broach, L. Carin, R. Harmon, C. Rappaport, W. Scott, R. Weaver, Alternatives for Landmine Detection, RAND Science and Technology Policy Institute, Report MR-1608, 2003.

[2] Ibid, p. xvii.

[3] Ibid, p. xvii.

[4] Ibid, p. xxiii.

[5] European Commissioner P. Busquin speaking at the EUDEM2-SCOT 2003 Conference, http://www.eudem.info

[6] We understand that limited fielding of the AN/PSS-14 was authorized for the US 1st Marine Expeditionary Force on 20 January 2004.

[7] See http://www.era.co.uk

technologies: GPR, radiometer, nuclear quadrupole resonance, and vapour / trace detection. Specific systems employing these techniques are then described in terms of the research/development programmes, the developers, the present specifications and available results.

A number of GPR systems presented here are components of multi-sensor systems. In this *Catalogue* we concentrate only on GPR while providing basic information on the other sensor/s used with it. Further information on metal detectors may be found in the Metal Detectors Catalogue published by the Geneva International Centre for Humanitarian Demining (GICHD) in 2003[8].

EUDEM2 considers that the systems featured in this *Catalogue* reflect the most promising technologies for humanitarian mine action programmes in the short, medium and long-term. We also believe that a number or research and development groups should be congratulated for the results that they have achieved with rather limited resources compared to those regarded as necessary by many analysts, including the authoritative RAND report referenced above.

The information appearing in this *Catalogue* has been provided predominantly with the analysis of information already made public and also with input from, and co-operation with, the developers of each of the technologies appearing in the *Catalogue*. For some technologies although input and co-operation was requested it was not forthcoming; in these cases the descriptions are based purely on the information available in the related referenced documents.

The technologies considered are evaluated for their state of readiness and given a Technology Readiness Level score. It is however important to note that this is only in the opinion of EUDEM2 based on its analysis.

EUDEM2 and the *Catalogue* authors have prepared this report in good faith and to the best of their ability with the goals of disseminating results. The details provided on technologies and systems have been collected from material made available by the individual organizations mentioned in this document either directly or in previous publications. EUDEM2 has had no opportunity to verify test results or performance claims provided by the system developers or manufacturers.

[8] Geneva International Centre for Humanitarian Demining (GICHD) Metal Detectors Catalogue, 2003 (http://www.gichd.ch).

2 Technology Readiness Levels[9] [10] [11] [12]

A Technology Readiness Level (TRL) score has been assessed for each system presented in this *Catalogue*.

TRLs have been implemented in space and defence procurement programmes as a systematic scoring method to assess the status of an individual technology and to compare it with other technologies. These scores also provide a basis for risk assessment and risk management.

TRLs range from a score of one which indicates the least ready for use – the basic physical principles have been noted and research can be started – to a score of nine which indicates successful operational deployment. The intermediate levels, two to eight, represent the different research, development and deployment phases as work progresses from research to the final product. Basic research is defined as research into new technologies and concepts which are not specific to a particular system. In defining our TRLs we have stayed close to those we understand to be suggested by the UK Ministry of Defence. An overview of the different TRL phases, as well as references, is presented in the following table.

[9] J. C. Mankins, Advanced Concepts Office, Office of Space Access and Technology, NASA, Technology Readiness Levels, A White Paper, April 6, 1995.

[10] J. C. Mankins, Advanced Projects Office, Office of Space Flight, NASA Headquarters, Research & Development Degree of Difficulty (R&D3) A White Paper March 10, 1998.

[11] M. Bunyan, J. Barratt, AMS Guidance on Technology Readiness Levels (TRLs), 4 February 2002.

[12] D. J. Daniels, ERA Technology, Impact of New Technologies, Presentations Part 1 and 2, EUDEM2 2004 Final Workshop, http://www.eudem.info

Technology Readiness Level	Description
1. Basic principles observed and reported.	Lowest level of technology readiness. Scientific research begins to be evaluated for applications. Examples might include paper studies of a technology's basic properties.
2. Technology concept and/or application formulated.	Invention begins. Once basic principles are observed, practical applications can be postulated. The application is speculative and there is no proof or detailed analysis to support the assumptions. Examples are still limited to paper studies.
3. Analytical and experimental critical function and/or characteristic proof of concept.	Analytical studies and laboratory studies to physically validate analytical predictions of separate elements of the technology are undertaken. Examples include components that are not yet integrated or representative.
4. Technology component and/or basic technology sub-system validation in laboratory environment.	Basic technology components are integrated. This is relatively "low fidelity" compared to the eventual system. Examples include integration of "ad hoc" hardware in a laboratory.
5. Technology component and/or basic sub-system validation in relevant environment.	Fidelity of sub-system representation increases significantly. The basic technological components are integrated with realistic supporting elements so that the technology can be tested in a simulated environment. Examples include "high fidelity" laboratory integration of components.
6. Technology system/subsystem model or prototype demonstration in a relevant environment.	Representative model or prototype system, which is well beyond the representation tested for TRL 5, is tested in a relevant environment. Represents a major step up in a technology's demonstrated readiness. Examples include testing a prototype in a high fidelity laboratory environment or in simulated operational environment.
7. Technology system prototype demonstration in an operational environment.	Prototype near or at planned operational system. Represents a major step up from TRL 6, requiring the demonstration of an actual system prototype in an operational environment, such as in an aircraft or vehicle. Information to allow supportability assessments is obtained. Examples include testing the prototype in a test bed vehicle.
8. Actual technology system completed and qualified through test and demonstration.	Technology has been proven to work in its final form and under expected conditions. In almost all cases, this TRL represents the end of Demonstration. Examples include test and evaluation of the system in its intended detection system to determine if it meets design specifications, including those relating to supportability.
9. Technology System "qualified" through successful mission operations.	Application of the technology in its final form and under mission conditions, such as those encountered in operational test and evaluation and reliability trials. Examples include using the system under operational mission conditions.

Table 2-1 Technology Readiness Table

3 Ground Penetrating Radar Systems

3.1 Sensing Principle

Ground Penetrating Radar (GPR) has come into use over the last 20 years in civil engineering, geology and archaeology, for the detection of buried objects and for soil study. The detection of buried landmines has also been a subject of considerable interest, in particular due to radar's potential for the detection of plastic-cased mines which contain little or no metal. Today, a large number of organizations, in Europe and world-wide, are working on different parts of GPR systems, and amongst all the sensors proposed for humanitarian demining GPR has had by far the greatest research funding and effort dedicated to it.

GPR works by emitting an electromagnetic wave into the ground, rather than into the air as in many radar applications, using an antenna which does not need direct ground contact (in other domains direct contact is often required, e.g. Non-Destructive Testing). GPR systems usually operate in the microwave region, from several hundred MHz to several GHz. Buried objects, as well as the air-ground interface, cause reflections of the emitted energy, which are detected by a receiver antenna and associated circuitry. The antenna is one of the most crucial parts of a GPR system. Most mine-detection GPR systems use very low power and do not present any radiation hazard to the operator.

GPR systems can be subdivided into four categories, depending on their operating principle. The first type is an impulse time domain GPR, where the emitted pulse has a carrier frequency, modulated by a nominally rectangular envelope. This type of device operates in a limited frequency range, and has in most cases a mono-cycle pulse. The second type of time domain GPR is the so-called Chirp Radar, which transmits a pulse-train waveform where the carrier frequency of each pulse is rapidly changed across the pulse width. Frequency domain GPR transmits a signal with a changing carrier frequency over a chosen frequency range. This carrier frequency is changed, either continuously for example in a linear sweep (Frequency Modulated Continuous Wave Radar, or FMCW), or with a fixed step (stepped frequency radar).

The term Ultra Wide Band (UWB) GPR is generally used for a system having a fractional bandwidth which is larger than 25%.

What particularly matters for the detection of objects in a background medium, e.g. mines buried in soil, is the difference between the electromagnetic properties of the target (in particular its dielectric constant) and those of the background. The amount of energy reflected, upon which reliable detection is based, also depends on the object's size and form. Spatial resolution depends on the frequency used, and the resolution needed to cope with the smaller anti-personnel landmines, requires the use of high frequency bands (up to a few GHz). These higher frequencies are particularly limited in penetration depth. Microwaves are strongly attenuated by certain types of conductive soils such as clay, and attenuation increases with frequency and the water content of the medium. Wet clay in particular provides an extremely challenging environment (penetration is very poor). GPR systems for landmine detection are either designed to provide detection warnings when a mine-like object is located (e.g. an audio signal as is used in metal detectors), or to produce image data. As yet hand-held radar-only systems have not been brought to market, though the use of radar with metal-detectors in dual-sensor hand-held systems is becoming established with extensive trials of the USA HSTAMIDS equipment and trials of UK equipment. In both cases the GPR is confirmatory after the metal detector has found a target. Vehicle mounted radar systems with a broad sweep have also been developed and field tested, including in the LOTUS multisensor demonstrator[13].

Related Publications

1. **Title**: D.J. Daniels, Ground Penetrating Radar, 2nd Edition, IEE Radar, Sonar, Navigation and Avionics Series, June 2004, ISBN 0 86341 360 9
2. **Title:** J. MacDonald, *et al.*, Alternatives for Landmine Detection, RAND Science and Technology Policy Institute, Report MR-1608, 2003.
3. **Title:** GPR International Conference series (biennial).
4. **Title:** C. Bruschini, K. De Bruyn, H. Sahli, J. Cornelis, EUDEM: The EU in Humanitarian Demining - Final Report, July, 1999, http://www.eudem.info

[13] http://www.pipehawk.com/projects.htm

3.2 *AN/PSS-14 (HSTAMIDS)*[14]

Project Identification

Project name	*US Army Handheld Standoff Mine Detection System (HSTAMIDS) program*
Acronym	HSTAMIDS (AN/PSS-14)
Participation Level	National
Financed by	US Army
Budget	$73 million over 15 years[15]
Start date	1996
End date	2004

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Project Web Link: http://www.cyterracorp.com

Project Description

CyTerra describes the AN/PSS-14 as revolutionizing landmine detection by combining Ground Penetrating Radar (GPR), highly sensitive Metal Detector (MD) technology and advanced data fusion algorithms, and further that this unique combination enables the system to reliably and consistently detect low-metallic Anti-Personnel (AP) and Anti-Tank (AT) mines. The AN/PSS-14 is claimed further by the manufacturer to offer the highest probability of detection (PD) of any handheld system along with an extremely low-level false alarm rate (FAR). This high level of performance is also claimed to be maintained across all soil types, including wet, dry, frozen, laterite (iron-rich), clay and sand.

This performance is described as being achieved by using unique data fusion algorithms, which allow the operator to effectively discriminate between clutter and mines. CyTerra notes that the algorithms are based on terrain modelling using a real-time novelty (RTN) methodology and that as the operator advances, the terrain model is continuously updated, enabling the system to automatically adapt to varying soil conditions. Potential mine detection alerts are provided to the operator via audio alert signals.

Involved Technology Related Activities

Technology type	metal detector, ground penetrating radar
Readiness level	8[16]
Company/Institution	CyTerra Corporation

[14] This description was made in co-operation with Colin Hatchard, CyTerra Corporation.
[15] "time and costs required to create HSTAMIDS" stated by J. MacDonald, *et al.*, in Alternatives for Landmine Detection, RAND Science and Technology Policy Institute, Report MR-1608, 2003, p. xxi.

[16] EUDEM2 Opinion based on its own analysis.

Detailed Description of the prototype/product

Technical Specifications : AN/PSS-14

Picture courtesy of CyTerra Corporation Ltd

A picture of a US soldier practising with the detector may be found at:
http://www.25idl.army.mil/deployment/OIF%20Iraq/PreDeployment/combinedpictures.htm

AN/PSS-14 SPECIFICATIONS	
Type:	Similar to Minelab F3 (metal detector)
Weight (all up)	4 kg
Battery Life	4hrs (lithium-ion 6 hrs)
Head width (x-axis)	21 cm
Head width (y-axis)	21 cm
Sweep speed	0.3m/s to 0.75m/s
Depth range for all targets / all soils	Will detect mines presenting an operational threat
Probability of Detection	Disclosure requires US Export License
Probability of false alarm	Disclosure requires US Export License
Demining environmental conditions	All
Temp, shock, vibration etc	Robust – meets and exceeds all US Army Requirements Detailed disclosure requires US Export License
Waveform	Stepped frequency employing PCA (principal component analysis)
Transmitted power	Disclosure requires US Export License
Power consumption	30W
Supply voltages	12V
Battery Life	4hrs with NiMH standard battery (the BB-390A/U US Army Singcar Radio), 6hrs on BB2590 (lithium-ion version of BB390). Battery is mounted externally on operators hip belt therefore system can be adapted to use other batteries, provided basic V/Ahr ratings are met.
Programmes	Preset algorithms with no user selectable inputs except for system sensitivity level.
Output	Audio
Power line suppression	N/A
Demining environmental conditions	All
Temperature	All

Test & Evaluation

The US Army conducted extensive evaluations of the AN/PSS-14 as part of its type classification process prior to moving to full production. Tests ranged from basic environmental style testing to full operational evaluation including comparison with current industry metal detectors. Metal detectors used were the AN/PSS-12 by Schiebel and the F1A4 by Minelab.

Environmental tests included but were not limited to temperature, vibration, humidity, drop, parachute readiness, night operations (system includes IR illumination system for use with night vision goggles), EMI susceptibility and emissions, compatibility with body armour, EOD suits, cold weather dress, NBC clothing (headphones allow operation in gas mask without compromising seal). System was deemed to meet or exceed the US Army Operational Requirements for all designated tests.

Operational tests were conducted by U.S. Army Operational Test Command, in support of Low Rate Production (Type Classification-LRP) & Milestone C (Type Classification-Standard). Operational test compared performance of AN/PSS-14, AN/PSS-12 (Schiebel and current US Army mine detector) and F1A4 (Minelab) using blind lane testing of new operators. Systems in the evaluation (AN/PSS-14, AN/PSS-12 and F1A4) were assigned to a platoon of combat engineers with operators given the appropriate specified training course. The AN/PSS-14 standard training class is a 40-hour NET course and was provided by Contractor/USAES.

Test environment comprised 106 mine lanes (1.5m x 25m) with a total of 514 missions (1096 encounters) performed. Mine types included AT, AP, and mixed (AT/AP) of both high metal and low metal types.

Probability of Detection (Pd) % of Operational Tests					
System	**AP-LM**	**AP-M**	**AT-LM**	**AT-M**	**ALL**
AN/PSS-14	98	99	94	99	97
F1A4	95	96	79	71	89
AN/PSS-12	80	99	64	99	81

<table>
<tr><th colspan="8">AN/PSS-14 Performance Summary (FAR = FA's per M^2, Scan Rate = M^2 per Minute)</th></tr>
<tr><th rowspan="3">AN/PSS-14 Parameter</th><th colspan="4">Standing</th><th rowspan="3">Kneeling</th><th rowspan="3">Prone</th><th rowspan="3">Night</th></tr>
<tr><th>AP-LM</th><th>AP-M</th><th>AT-LM</th><th>AT-M</th></tr>
<tr><td>97</td><td>99</td><td>99</td><td>100</td></tr>
<tr><td>Pd %</td><td colspan="4">98.7</td><td>100</td><td>96.2</td><td>100</td></tr>
<tr><td>FAR</td><td colspan="4">0.008</td><td>0.009</td><td>0.03</td><td>0.004</td></tr>
<tr><td>Scan Rate</td><td colspan="4">3.2</td><td>1.9</td><td>1.1</td><td>NA</td></tr>
</table>

The AN/PSS-14 has been supplied for evaluation and operational purposes to a number of foreign governments. Systems are available for individual country or organization evaluation (subject to a suitable US Export License being obtained).

Two different audio signals are provided simultaneous to the operator. The MD signal is provided in the traditional format of a metal detector in which the signal varies in volume and pitch depending on the metal type, size and depth. The other audio signal is the output of the data fusion algorithms, also known as the Aided Target Recognition (ATR) algorithms, and is a sharp beep. This beep is generated only when the ATR processing determines that both the GPR and MD data indicates a "mine like" object. Because the MD and ATR sounds are distinctly different they can be present together without distracting the operator as two continuously varying audio signals might. Situation awareness is therefore maintained while allowing full operation of the GPR and MD sub-systems.

The operator cannot turn off (accidentally or deliberately) either the MD or GPR sub-systems. However, audio muting on a temporary basis to allow the operator to better focus on one of the audio signals is available. This feature is particularly helpful when investigating high metal anti-tank mines where the constant high volume of the MD can be distracting to the operator.

The system is supplied with both a man-portable backpack (53 x 41 x 25 cm, 12 kg) and a hard transport case (66 * 46 * 30 cm, 20 kg) suitable for air, ground and general transport. The system folds compactly to fit within its backpack for easy transport with all accessories. The man portable pack is capable of supporting 8 hours of continuous operation and can be parachuted if required.

The system supports night operations by projecting an infrared (IR) halo of light around the sensor head and the immediate surrounding area. Since the system is an active transmitter of IR light this feature should not considered a covert capability. It should be anticipated that observers with IR sensitive vision equipment would detect this IR source.

The system has been tested with and found suitable for operation with lightweight EOD suits, general body armour and MOPP (NBC) dress. Earphones are designed to be low profile and can be worn under gas masks for use in hostile environments without compromising the mask's integrity. Earphones do not heavily restrict the operator's ability to hear nearby commands and other background noises of importance.

Each AN/PSS-14 system comprises:

Description	Quantity
AN/PSS-14 (HSTAMIDS) Detector	1
Earpiece	2
Battery Pack (for web belt mounting)	1
Battery BB-390A/U	2
Test piece (50mm plastic RTV filled, similar to small AP mines with lo insert representing metal content of low-metal mines)	1
Support Handle	1
Support Strap	1
Man Portable Backpack	1
Hard Transport Case (NBC Case)	1
Technical Manual (TM)	1
Quick Reference Guide (QRG)	1

A commercially orientated variant of the AN/PSS-14 is anticipated in late 2005 with a significantly reduced list price. New system will incorporate same AN/PSS-14 electronics and sensor elements so detection performance will be un-changed.

Cost: 23,500 USD, goal 12,000 USD

Other applications (non demining): civil engineering applications, security applications, weapons cache searches, in wall searches, through wall detection of people (option fielded to US Military but disclosure requires US Export License)

Related Publications

No Public publications made by the company

Details of a verbal presentation made by Colin Hatchard at the Nordic Demining Research Forum may be found in the report by Karin De Bruyn, ETRO-VUB, Revised by C. Bruschini, EPFL, Nordic Demining Research Forum (NDRF) Report on all Sessions, Summer Conference, Bergen, Norway, 27-29 August 2003, http://www.eudem.info

3.3 MINEHOUND[17]

Project Identification

Project name	Handheld Multi-Sensor Mine Detector
Acronym	MINEHOUND
Participation Level (European, National, International)	National
Financed/co-financed by	national, UK
Budget	Contact DFID
Project Type	Applied Research to demonstrator
Start date Phase 1	Apr 2001
End date Phase 1	May 2003
Start date Phase 2	Jan 2004
End date Phase 2	Feb 2006

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Project Web: http://www.era.co.uk

Project Description

MINEHOUND combines a GPR-Sensor and pulsed MD-detector to reduce the false alarm rate. This promises to result in better productivity of mine clearing operations and provides a very practicable acoustic human machine interface.

This multi-sensor system was developed for the detection of AP landmines and hand held operation. It is based on a sophisticated GPR from ERA (UK) and the pulse induction MD-Type VMH3 from VALLON (FRG). The original development (called MINETECT) system was developed under the sponsorship of the UK Department for International Development (DFID).

Test and evaluation:

- Several field tests already passed successfully (ITEP)
- New test series in Cambodia and Angola foreseen for 2005

Involved Technology Related Activities

Technology Type	ground penetrating radar and metal detector
Readiness level	7[18]
Companies/Institutions	ERA Technology Ltd, Vallon GmbH

[17] This description was made and in co-operation with David J. Daniels, ERA Technology Ltd.

[18] Opinion of EUDEM2 based on its own analysis.

Detailed Description of the prototype/product

- **MINEHOUND is a combined metal detector and ground penetrating radar demonstrator system designed specifically for use in humanitarian demining operations using advanced technology. The detector is designed to operate firstly in the metal detection mode, where all metal threats are noted. The output to the operator from both the metal detector and ground probing radar is by means of audio signals. The operator then uses the ground penetrating radar to confirm the presence of a threat. The metal detector audio provides accurate position information and mass of metal indication. The GPR provides accurate position information, depth information and radar cross-section of target information. It is possible to use both detectors together. The manufacturer reports that the GPR responds to even the smallest of flush buried mines but not to small metal fragments. This results in a large amount of metallic clutter such as bullet casings, small arms rounds and shrapnel, which cause false alarms, to be rejected by the system. According to the manufacturer the reduction in PFA lies between a factor of 2 and a factor of 7 compared with an MD, and the GPR also detects zero or minimum metal mines that are difficult for the MD.**
- **MINEHOUND uses a metal detector from Vallon (VHMD3.1) and a custom designed 1 GHz ground probing radar designed by ERA Technology Ltd. The GPR is a time domain radar transmitting 1ns duration impulses at a repetition frequency of 1MHz. The GPR transmitter- receiver and associated control and signal processing is mounted on a compact purpose designed printed circuit board (220mm by 100mm). A dedicated state of the art "Blackfin" DSP processor is used to provide all control and signal processing functions.**
- **MINEHOUND is built to a standard appropriate for use in field trials. It is not yet qualified as an operational system, however, and should not be used as a primary detector in a 'live' minefield situation until approved.**

Note that the GPR will operate in standby mode when not being handled to increase battery lifetime, and this will decrease the power consumption of the GPR in this mode to less than 1 W.

Technical Specifications: MINEHOUND

Photograph courtesy of ERA Ltd

MINEHOUND TARGET SPECIFICATIONS - Production (target)	
Weight (all up)	= 4.75kg
Battery Life (D cells)	> 2 hrs continuous
Head width (x-axis)	< 17 cm
Head width (y-axis)	< 31 cm
Depth range for all targets / all soils	20 cm *
Probability of Detection	> 0.98 **
Probability of false alarm	< 0.25 **
Demining environmental conditions	All world
Temp, shock, vibration etc	TBD
Pulse repetition frequency	1 MHz
Pulse duration	1 ns
Power consumption	24 W @ 12 V
Audio output frequency Max	1500 Hz
Audio output frequency Min	150Hz

* excluding salt water and heavy clay for GPR
** For AP mines with up to 10 cm cover, AT mines with 20 cm cover

MD specification	
Battery Life (D cells)	Up to 25 hrs (program and batteries) 4 D cells or rechargeable
Head width (x-axis)	17 cm
Head width (y-axis)	31 cm
Sweep speed	< 1.5ms^{-1}
Programmes	Normal / soil
Output	Audio / visual
Power line suppression	Yes
Demining environmental conditions	All world
Temperature	-32C to 65C

Test & Evaluation

The following was presented at SPIE 2004 by D.J. Daniels, P. Curtis, R. Amin, J. Dittmer, ERA Technology, An affordable humanitarian mine detector:

The prototype system has demonstrated that the combined sensor approach is a valid method of achieving the goal of a significant reduction in false alarms. The results from a US calibration lane for the MINETECT-B system were, for all mines, blanks, non-metallic clutter and the following categories of metallic clutter:

PD=100% at PFA of 0.03 for small metallic clutter
PD=100% at PFA of 0.28 for all clutter

This performance on the calibration lanes was an improvement (in 2003) over the performance achieved in 2002 and reduced the FAR from 0.07 to 0.03. The GPR function was well able to discriminate against small pieces of metal and in some cases was more effective than the MD in detecting minimum metal AT mines. Mine classification is being further investigated and both template correlation and neural networks are being considered. Initial results on the latter are encouraging but further testing needs to be carried out.

With this aim in mind, it is planned that close-to-production versions of MINETECT (using a Vallon VHM3 detector and a further developed GPR) will be trialled in Cambodia and Southern Africa as part of the next phase of development.

Evaluation units will be available in 2005 and production units end 2005.

- Cost: TBD
- Other applications (non demining): Civil applications such as pipe detection, other security applications, such as through wall radar

Related Publications

1. **Title:** D.J. Daniels, P. Curtis, R. Amin, J. Dittmer, An affordable humanitarian mine detector, SPIE 2004, 12-16 April 2004
   Abstracts: This paper describes the further development of the MINETECT affordable humanitarian mine detector produced by ERA Technology with sponsorship from the UK Department for International Development. Using a radically different patented approach from conventional ground penetrating radar (GPR) designs in terms of the man machine interface, MINETECT offers simplicity of use and affordability, both key factors in humanitarian demining operations. Following trials in 2002 and reported at SPIE 2002, further development work including research on classifying mines, based on data from planned trials in the United Kingdom, is presented. MINETECT has the capability of detecting completely non-metallic mines and offers a considerable improvement in hand-held mine detection.
2. **Title:** D.J. Daniels, ERA Technology, Impact of New Technologies, Presentations Part 1 and 2, EUDEM2 2004 Final Workshop, http://www.eudem.info
3. **Title:** D.J. Daniels, MINETECT Trials, 2003, http://www.itep.ws, http://www.eudem.info
4. **Title:** D.J. Daniels and P. Curtis, MINETECT, EUDEM2-SCOT 2003, International Conference on Requirements and Technologies for the Detection, Removal and Neutralization of Landmines and UXO; H. Sahli, A.M. Bottoms, J. Cornelis (Eds.), Volume II, pp. 542-548.

3.4 PHMD[19]

Project Identification

Project name	Portable Humanitarian Mine Detector
Acronym	PHMD
Participation Level	European
Financed/co-financed	Her Majesty's Treasury Capital Modernisation Fund, UK
Budget	£3.0 M
Project Type	Demonstrator
Start date	1 July 2000
End date	31 October 2002

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Project Web Link: http://www.QinetiQ.com

Project Description

The project was funded from Her Majesty's Treasury Capital Modernisation Fund (CMF). The aim of the project was to develop and test a prototype portable land-mine detector for use in humanitarian demining.

The PHMD project researched the needs of users of hand-held detection equipment in humanitarian demining. The requirement for a detector offering similar detection performance to a current hand-held metal detector but with much reduced false alarm rate from metal clutter was confirmed. Investigation of thousands of "false alarms" from metal clutter makes up a large percentage of the time taken to clear an area. Analysis of the sources of false alarms from two minefields indicated that up to 95% are of the size of a rifle cartridge case or smaller.

The system concept consists of using a GPR array to discriminate between minimum metal anti-personnel mines and small metal clutter, by detecting the dielectric anomaly present around the metal in the mine. Acoustic sensing and a form of passive radiometry sensing were also considered, but could not be sufficiently developed within the timescale of this project. These sensors may still be capable of development to enhance the capability of PHMD and other systems.

The system prototype was developed and tested in the UK, USA and Bosnia using realistic mine targets. The results of some of these tests are published on the ITEP website (www.itep.ws).

Involved Technology Related Activities

Technology Type	Ground penetrating radar, metal detector, Capacitance sensor
Readiness level	5-6[20]
Company/Institution	QinetiQ Ltd, Meodat GmbH, Guartel Technologies Limited, Sensatech Research Ltd

[19] This description was made in co-operation with Dave Allsopp and Ian Dibsdall, QinetiQ Ltd.

[20] Opinion of EUDEM2 based on its own analysis.

Detailed Description of the prototype/product

GPR: previous work by QinetiQ and others suggested that a multiple antenna GPR was most likely to provide acceptable results in a hand-held device. In order to determine shape and size of a target, the system must generate a 3-dimensional image; a single pair of antennas (transmit and receive) can only provide 1-dimensional information and so must either be moved over the target whilst their position is measured (difficult), or combined with further antennas. It was decided that 9 antennas would be used and arranged in a square array. GPR Antennas were developed that could be physically co-located with the metal detector coils without mutual interference, based on a resistive ink technology from previous EU funded research. The Radar itself used a highly integrated correlation based digital chipset from Meodat GmbH. This was interfaced to a central DSP that executed the data extraction, timing calibration, 3D focussing and target detection algorithms.

Metal detector: the metal detector used was based on the Guartel MD8, but with certain modifications. The MD8 uses one transmit coil and one receive coil, but the addition of a second smaller receive coil allows an estimate of the depth of the target to be made. The shape of the large receive coil was also changed, to route it between the GPR antennas and to provide some positional information (e.g. left of head, centre, right of head).

Capacitance sensor: the capacitance sensor consists of four conductive pads embedded in the bottom face of the sensor head, connected to an electronics unit. The capacitance between each pad and the ground surface below is measured, from which the height of each pad above the ground can be determined. By measuring this capacitance at both low and high frequencies, an indication of the resistance of the soil can be obtained, which is dependent on its moisture content. Moisture content greatly affects the penetration of radar waves, and so measuring it facilitates GPR focusing. Due to time constraints, this sensor could not be fully calibrated before the final prototype trials.

The detector consists of three parts: a sensor head, a "top box" mounted on the top of the shaft, and a processing pack. The sensor head houses the 9 GPR antennas whilst the metal detector and capacitance sensor are built in to the bottom of the head. The top-box contains the GPR, Capacitance and Metal detector electronics. The processing pack contains the systems battery packs and the Digital Signal Processing (DSP) boards.
In any next iteration of the PHMD the processing pack will be incorporated into the top box, creating a fully self-contained detector.

Mass: The current total detector mass is approximately 13kg including both the hand-held unit and the processing pack. It was acknowledged that many aspects of the design could be improved with further development that was not possible within the constraints of the project. This particularly applies to size and weight reductions.

These potential improvements led to the design of a space model, as shown in the photo below, intended to represent the realistically achievable size and weight that the detector could be reduced to following additional development and manufacture.

Technical Specifications: PHMD

PHMD prototype during US tests

Bosnian deminer assessing space model

Photographs courtesy of QinetiQ Ltd

GPR Specification		
	Prototype	**Production (target)**
Weight	**13kg**	**<6kg**
Battery Life	**1.5hr**	**~8hr**
Head width (x-axis)	**380mm**	**310mm**
Head width (y-axis)	**380mm**	**310mm**
Height of head (z-axis)	**140mm**	**95mm**
Unambiguous range in air	**11m**	**3m**
Depth range for all targets / all soils	**30cm**	**30cm**
Probability of Detection	**--***	**--**
Probability of false alarm	**--***	**--**
Demining environmental conditions	**IP64 sealed unit**	**IP67 sealed unit**
Temp, shock, vibration etc	**0°C to 35°C**	**-20°C to +40°C**
Waveform	**511bit MLBS**	**127bit MLBS**
Receiver Bandwidth	**3GHz**	**5GHz**
Transmitted power	**1mW ERP**	**1mW ERP**
Power consumption	**20W**	**5W**
Supply Voltages	**-8V, +6V,+15V**	**-6V, +12V**
Resolution	**of the order of 3cm depending on soil properties**	**<2cm**
Acquisition speed	**3 array scans per second**	**>10 per second**
Primary detection algorithm	**proprietary, based on correlation with known targets**	**proprietary, based on correlation with known targets**
Feature extraction	**proprietary, based on deconvolution and focussing of radar data**	**proprietary, based on deconvolution and focussing of radar data**
*** Prototype PD & FAR tested at US test site, but number of targets results in insufficient confidence to quote. Small plastic AP (NR409, PMA2 etc) detected in tests.**		

MD specification **		
	Prototype	**Production (target)**
Head width (x-axis)	**approx 300mm square**	**<280mm square**
Sweep speed	**similar to commercial units when used standalone, but limited by GPR in PHMD system**	**similar to commercial units when used standalone, but limited by GPR in PHMD system**
Programmes	**three sensitivity levels and soil compensation mode**	**three sensitivity levels and soil compensation mode**
Output	**audio tone and LED confirmation of approximate position and depth.**	**audio tone and LED confirmation of approximate position and depth.**
Power line suppression	**proprietary to Guartel**	**proprietary to Guartel**
**** MD specifications are for the metal detector used in PHMD; not for the Guartel unit on which it is based.**		

Test & Evaluation

Following developmental and UK testing, the detector was also tested under the auspices of the International Test and Evaluation Project (ITEP), using facilities available in the United States. The test areas used consisted of several lanes divided into 1m squares, each of which contained an object buried in the centre (some were empty). Thus there was no requirement to locate the target, merely to distinguish between mines, false targets and empty squares. One area had about 200 squares with the ground truth provided, for calibration and checking of the system; the other area had about 1000 squares for blind testing where the ground truth was not provided.

In 2002 data was gathered in all the squares. However, according to the developer, software development delays limited the rate of data transfer between the detector and logging PC. This meant that instead of 'sweeps' over the target as would be the case in a stand-alone device, just one 'snapshot' of each square was obtained. According to the developer this proved to be a major limiting factor in later processing and performance calculations.

QinetiQ reports that the results from the calibration area indicated that it was generally possible to discriminate between most of the mine types and other objects, although this was difficult for the small minimum metal AP mines.
Further testing was carried out in October 2002 in Bosnia. These tests took place at a test site prepared by Norwegian People's Aid, using targets representative of the mines, UXO and clutter found in the area.

The purpose of the Bosnia tests was to evaluate the detector under more realistic conditions, and to give real deminers the opportunity to use the equipment and comment on its design and function. The test areas used were again laid out in prepared ground, but were slightly more demanding than the flat sandy soil used in the USA. Two areas were used, one being coarse gravel over a finer sandy soil, the other being soil with a high clay content with light vegetation (grass cut back).

QinetiQ notes that it was important to test the detector with realistic data series from a number of positions over a target, which had not been possible in the USA due to the time pressure to complete all 1000 squares. Hence data was collected from just a few of the targets available, but by conducting a sweep across each target, moving the detector about 5cm each time.
This enabled processing to be performed on the data, to reduce the effects of ground surface reflections and other background features.

QinetiQ reports that the GPR gave significantly better results in the gravel test area than in the grassy soil. This was as expected, as the soil appeared to have a significant clay content and a high moisture content, both known to cause high attenuation of radar signals.

On-going data logging problems again limited the amount of data that could be gathered to assess the performance of the detector (and an RS232 link had to be substituted for the desired 100Mbit/sec Ethernet interface). This made it difficult to assess the ability of the detector to distinguish between mines and clutter. No automatic target detection process was yet incorporated, so manual examination of the data was necessary. However, some results reports QinetiQ were extremely encouraging, particularly in the drier gravel. QinetiQ reports that under certain conditions, it was possible for the GPR to detect a small PMA-2 AP mine buried at 13cm with a high signal to noise ratio – demanding for even the best metal detectors.

The other purpose of the Bosnia tests was to gain some feedback on the equipment from some of the deminers. Two deminers were given the opportunity to use the prototype detector and to comment on the design and layout of the space model. This was particularly useful and led to the repositioning of the handle mounted LEDs onto the top of the sensor head. This allowed them to remain directly in the operator's line of sight making a far more intuitive display.

After implementation of the Ethernet data logging interface, a second trial in the US was carried out during late August/early September 2003. Over 57,000 measurements were captured on both the calibration and blind data grids. The system proved to be reliable in the high temperatures (over 100°F) experienced during this time. A data gathering "trolley" was used to enable gridded data to be captured. This proved to be reasonably successful, but uneven ground, slopes and washout made the data gridding (and hence later processing) less than ideal.

Two new mine types had been added to the grid since the 2002 trial (the M409 and TAB-1). This addition means that detector performance cannot be directly compared between the two trials, as some squares that were blank now contained mines (altering potential Probability of Detection and False Alarm Rates).
Initial results according to QinetiQ indicated that the very small, minimum metal mines (e.g. M-14, M409 etc) are still difficult to image with the current generation PHMD radar, as they are approximately the same scale as one resolution cell. Visibility of some other mine targets (e.g. M-19, PMD-6) had improved since the previous trial, especially with the vastly increased data logging capacity.

The partial removal of metallic clutter from the lanes during this trial also disturbed the well-compacted soil. This appeared as GPR clutter, even though the U.S. trials team made an effort to re-compact the recently disturbed soil.
The initial results are encouraging, with the radar array of great assistance in determining the presence of mine-like objects. Further work is required to reach the full potential of the PHMD sensor.

- Cost: Indications are that the production unit price would be close to £10k.
- Other applications (non demining)

While humanitarian activities form the prime focus of the PHMD requirement, any exploitation plan needs to consider expansion into adjacent markets by offering either whole systems or sensor components. The following three market areas dominate the available market for detector systems similar to PHMD:

- Commercial and Military mine clearance and explosive ordnance disposal
- Location of utilities and underground services
- Science and recreational use: e.g. hobbyists, universities, archaeological and other geophysical service providers.

Related Publications

1. **Title:** D. Allsopp, QinetiQ Ltd, PHMD – QinetiQ portable humanitarian mine detector, 15/3/02, http://www.eudem.info
2. **Title:** D. Allsopp, QinetiQ Ltd, Portable Humanitarian Mine Detector 2003 US Trials, http://www.itep.ws
Abstract: This report describes a trial of the QinetiQ Portable Humanitarian Mine Detector (PHMD) at a US test site in August 2003 under the International Test and Evaluation Project for humanitarian demining (ITEP). An earlier trial of the detector at the U.S. trial site at Fort A.P. Hill was severely limited by a slow laptop data logging link. Since the end of the project, internal investment by QinetiQ has allowed the rate of GPR data logging to be increased by over 20 times. It was therefore agreed to repeat the trials to gather a more comprehensive data set and compare the system to the 2002 baseline.
The main aims of this trial were to:
    - Gather a more comprehensive data set than had been possible in 2002 from an extensive blind test grid
    - Gather a data set from a calibration area with know targets, for use as above
    - Provide feedback to ITEP on trials methods and current detector performance
Full report available on the ITEP website (http://www.itep.ws)

3.5 DEMAND[21]

Project Identification

Project name	Enhancement of three existing technologies and data fusion algorithms for the test and DEmonstration of Multi-sensor lANdmine Detection techniques.
Acronym	DEMAND
Participation Level	European
Financed by	co-financed by EC-IST
Budget	€3.7 M
Project Type	Prototyping
Start date	1 February 2001
End date	29 February 2004

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Project Web: http://www.demand.meodat.com

Project Description

The DEMAND project has built a prototype multi-sensor system composed of a simple trolley-like platform with three state of the art sensors, namely a Metal Detector array, a Ground Penetrating Radar array, and a biological vapour sensor (Biosensor), whose measurement results were strengthened through state of the art Data Fusion. The system performances were evaluated in extended field tests in SE Europe.

Involved Technology Related Activities

Technology Type	GPR, Metal Detector, Vapour detection
Readiness level	6[22]
Company/Institution	Technische Universität Ilmenau, Ingenieria de Sistemas y Software, Messtechnik, Ortung und Datenverarbeitung GmbH, Schiebel Elektronische Geräte GmbH, Ingegneria dei Sistemi SpA, Biosensor Applications Sweden AB, Swedish Rescue Services Agency

[21] This description was made in co-operation with Jürgen Sachs, Technische Universität Ilmenau.

[22] Opinion of EUDEM2 based on its own analysis.

Detailed Description of the prototype/product

Within the DEMAND project a new ultra wideband (UWB) ground penetrating radar (GPR) employing M-sequences, a stacked metal detector array (VAMIDS) and a biosensor system, co-developed within the BIOSENS-project, have been considered for integration with a data fusion platform. The operational concept of the technology was that the biosensor system could be used to target suspect areas and that the combined radar and metal detector could then be used for the detection of alarms, and that further knowledge from the biosensor would then help to further reduce false alarms. Tests were carried out in the project with a simple trolley arrangement whereby the GPR and metal detector were pulled along a line over the test field, whereas in a second stage the biosensor took samples over targets and blanks. These two stages are represented in the pictures below.

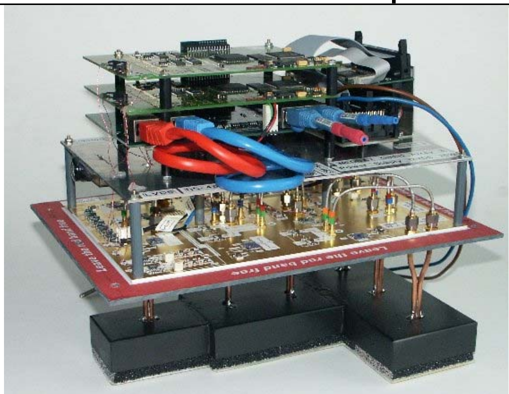
Photographs courtesy of the DEMAND consortium

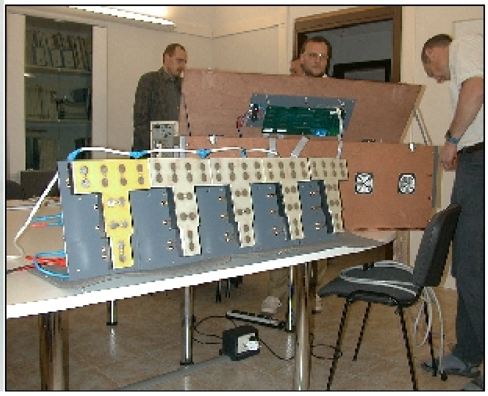
The project has been successful in demonstrating the ability of the radar to reduce false alarms from the metal detector. Further knowledge on the movement of explosive in vapour / particle form is felt necessary before the biosensor system could be used in the planned operational procedure (please see the DEMAND Final Report and BIOSENS Final Report). A direct benefit for demining would seem to be offered through the engineering of the GPR array for combination with the metal detector array.

In what follows we will mainly consider the GPR developed in this project. Details on the VAMIDS technology may be found in the Metal Detectors Catalogue 2003 published by the Geneva International Centre for Humanitarian Demining (GICHD). Details on the Biosensor system are provided in Section 5.2. The ground penetrating radar is based on radar electronics using the M-sequence technique developed by Messtechnik Ortung und Datenverarbeitung GmbH and the Technische Universität Ilmenau. The company IDS, Ingegneria dei Sistemi SpA, provided the antenna and signal processing solution. A 15 TX - 20 RX full polarimetric linear antenna array has been constructed in the project. The figures below provide an impression of one UWB module and a complete array.

The data fusion software architecture used in the project is based on a Blackboard approach, which has the following advantages: supporting both numeric and Artificial Intelligence (AI) techniques; real-time efficiency; distributed (multiprocessor) environment; design flexibility and guaranteed real-time execution for decision aid components. The system represents an Expert Knowledge Base system integrated over a powerful COTS GIS system. In this way, all sensor data is handled in an object-oriented way. The fusion process interprets the global information coming from different sources. Each sensor makes an independent decision based on its own observations and passes these decisions to a central fusion module where a global decision is made. The data fusion system handles uncertainty, widely present in most of the system data, with a fuzzy logic approach. This enables the use of user semantic terms in both the Knowledge Acquisition (KA), as well as the Explanation Facilities of the expert system.

Technical Specifications: DEMAND GPR





Photographs courtesy of the DEMAND consortium

	Prototype	Production (target)
Weight	40kg	<40kg
Battery Life	250 W	TBD
Array width (x-axis)	1000mm	2000mm (arbitrary)
Array width (y-axis)	300mm	300mm
Height of array (z-axis)	400mm	400mm
Unambiguous range in air	8 m	2 … 8 m
Depth range for all targets / all soils	20 cm	20 cm
Probability of Detection	0.94*	> 0.98
Probability of false alarm	0.35*	< 0.25
Demining environmental conditions	Grassy, stony	All world
Temp, shock, vibration etc	0°C to 35°C	-20°C to +40°C
Waveform	511bit MLBS	127 to 511 bit MLBS
Receiver Bandwidth	4 GHz	5 GHz
Transmitted power	1 mW	1 mW
Power consumption	Not available%	Not available %
Supply Voltages	±12V 6A	± 12 V
Resolution	5 cm cross-range, 4.4 cm range.	3 cm
Signal to Clutter Ratio	>20 dB with a processing gain of >20 dB.	>20 dB with a processing gain of >20 dB.
Acquisition speed	The acquisition hardware (ADC and FAP) provides for 68 Msamples/s.	30 cm/s
Primary detection algorithm	Full 3D Kirchhoff migration	TBD
Feature extraction	• Geometrical characterization of putative targets (e.g. reflectivity, size, shape compactness). • Polarimetric characterization (e.g. orientation, elongation factor) • Semi-automatic estimation of propagation speed	TBD
* Best Results obtained during field tests in calibration area.		

Test & Evaluation

Laboratory and field tests were carried out with the prototype; the corresponding results are published in the Final Report.

Field tests showed the ability of the radar to reduce the number of alarms triggered by the metal detector, and also that the metal detector had a high detection probability. In the Bosnian test calibration area, the False Alarm Rate of the metal detector was reduced from 0.81 to 0.35 false alarms per square meter by using the GPR, while maintaining a detection probability of 94%. This corresponds to a reduction in false alarms of 57%.

Other applications (non demining): Sub-systems may be adapted for use in for example: UXO detection, through wall radar, non-destructive testing, complex control solutions (data fusion, e.g. large facility process monitoring, aircraft altitude control)

Related Publications

1. **Title**: DEMAND consortium: DEMAND Final Report, 2004, http://www.eudem.info
   Abstract: Within the DEMAND project three different types of sensors have been combined with the aim of capturing quite different features of a mine:
   a) Metal detector: It refers to the metal content within a mine. In order to be able to combine this characteristic with other features, metal free mines[23] are excluded from the considerations which follow.
   b) Ground Penetrating Radar: It detects all buried objects whose permittivity differs from the one of the soil, and which exceed a minimum size. Thus, its main feature is first of all determined by the permittivity contrast and object size. New GPR techniques connected with a larger bandwidth and large antenna arrays (as the DEMAND system) are potentially able to provide some elementary shape information of the objects, such as linearity/compactness (by polarimetry) or symmetry of the case (by natural frequencies for example). However, these techniques are not yet well developed and are strongly affected by the surrounding soil conditions. Some basic research is still required.
   c) Artificial nose: The goal is to detect the emission of characteristic vapour, i.e. vaporised or dissolved explosive. The corresponding device, called Biosensor, detects TNT molecules with high sensitivity by means of an antigen/antibody reaction.

   The result of the performance evaluation of the system in the project is that we are confident that we are able to provide a detection probability similar to what achieved with present detection techniques, with a considerable reduction in the number of false alarms and at a considerable increase in speed, and this also without the final implementation of the biosensor. We believe this is a basis for increased productivity and safety in humanitarian demining.
2. **Title**: S. Crabbe, J. Sachs, G. Alli, P. Peyerl, L. Eng, M. Khalili, J. Busto and A. Berg: Results of field testing with the multi-sensor DEMAND and BIOSENS technology in Croatia and Bosnia developed in the European Union's 5th Framework Programme, SPIE 2004 12-16 April 2004.
3. **Title**: S. Crabbe, J. Sachs, G. Alli, P. Peyerl, L. Eng, R. Medek, J. Busto and A. Berg: Recent Results achieved in the 5th FP DEMAND Project, EUDEM2-SCOT 2003, International Conference on Requirements and Technologies for the Detection, Removal and Neutralization of Landmines and UXO; H. Sahli, A.M. Bottoms, J. Cornelis (Eds.), Volume II, pp. 617-625.

[23] Demining organisations affirm that metal free mines are rarely faced and that all mines contain at least some metal even if it is of low content.

3.6 LOTUS[24]

Project Identification

Project name	Light ordnance detection by tele-operated unmanned system
Acronym	LOTUS
Participation Level	European
Financed by	EC ESPRIT IV
Budget	
Type	Demonstration
Start date	1 February 1999
End date	31 January 2002

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Project Description

The objective of the LOTUS project was to develop, integrate and demonstrate a proof of concept of a multi sensor APL detection system integrated on a vehicle. The vehicle based multi sensor detection combined with powerful data fusion expected to lead to more productive humanitarian mine detection operations.

Involved Technology Related Activities

Technology Type	Ground penetrating radar, infrared and metal detector
Readiness level	6[25]
Company/Institution	PipeHawk plc, DEMIRA e.V., Institut Dr. Foerster Prüfgerätebau GmbH & Co., Netherlands Organization for Applied Scientific Research - Physics and Electronics Laboratory

[24] This description is made on the basis of the publications in the Related Publications section below.

[25] Opinion of EUDEM2 based on its analysis

Detailed Description of the prototype/product[26]

The consortium reports that the sensors are Multi-Spectral and Multi-Dimensional: Ground Penetrating Radar, Infra Red, Metal detector, and have been studied in the GEODE project and that they were further improved and adapted to a vehicle as was the data fusion and the computer architecture, to handle efficient real time operations.

The technology was tested successful in the Bosnian Mine Detection trial in Vidovice in Aug 2002. The MINEREC GPR array was used with a metal detector array from Foerster GmbH, and an Infra-red camera from TNO-FEL in an integrated real time sensor suite. The data from all three sensors was analysed in real time, fused and used to drive a ground marking system. In the trial in Bosnia, organised by Demira, a German NGO, the vehicle drove along the test lanes and all the mines were marked as the vehicle passed by. By combining the output from different sensors the false alarm rate, the major waste of demining resources, was dramatically reduced.

The major objective, according to the consortium, of the Bosnian trial was to demonstrate the technology on the mine lanes. The trial was not intended as a demonstration of operational capability and for this reason it was felt acceptable to mount the sensors ahead of the vehicle as shown below. The metal detector is at the front, as far away from the vehicle and other metal as possible. The infra-red camera then follows within the framework and the MINEREC GPR array is then immediately in front of the vehicle. Each of the sensors then has its own computer to process their own data before the output is passed to a fusion computer used to drive a simple paint marking system on the back of the vehicle.

Photographs courtesy of the LOTUS consortium

The success of the Bosnian trial in 2002 has enabled PipeHawk plc to carry out a thorough review of both GPR centred detection technology, the operational requirements for effective mine and UXO detection and the system issues. From this plans for an effective operational detection vehicle are emerging that set performance goals significantly higher than those demonstrated in the LOTUS project. The extensive review of all aspects of the GPR system has led to the definition of an advanced system providing full polarimetric capability over an enhanced bandwidth and able to carry out a more detailed search at much higher speed. Interleaved search patterns also allow a much deeper GPR search for UXO to be carried out in the same pass as that for mine detection. The GPR sensor will form part of a multi-sensor suite that is likely to include a metal detector and polarised video. The deployment conditions demanded by the sensors place particular requirements on the vehicle. If the system is operated off the side of the vehicle as allowed in many humanitarian situations the vehicle tracks may stay in the save lane. For cost effective route clearance, a specialist vehicle with a very low ground pressure is required that may overpass mines. PipeHawk plc has established proposals for these options and is currently finalising plans for the build of such vehicles.

[26] Please refer to R.J. Chignell, LOTUS – A Major technology Milestone for De-mining, pages 5-6

Technical Specifications: GPR LOTUS		
	Prototype	**Production (target)**
Weight	**Vehicle carried**	**Vehicle carried**
Battery Life	**Vehicle powered**	**Vehicle powered**
Array width (x-axis cross track)	**0.75m**	**Options of 2m, 3m &4m**
Array width (y-axis along track)	**4m**	**>6m**
Height of array (z-axis)	**Cameras specify highest mounting point required ~2m**	
Unambiguous range in air	**N/A**	**N/A**
Depth range for all targets / all soils	**A/P mines 12cm A/T mines 30cm**	**A/P mines 20cm A/T mines 30cm (plastic) UXO 1m (metal)**
Probability of Detection	**All mines detected in trial. This suggests 100% but statistical analysis in a limited trial indicates that this should not be claimed.**	**>99.6%**
Probability of false alarm	**The false alarm rate was negligible. No false alarms occurred. Some detections were distorted tending towards false alarms, but in all cases the deminers wished this to be reported.**	**Compatible with the requirements of productive vehicle based operation.**
Demining environmental conditions	**Warm European summer conditions.**	**To be set by local conditions.**
Temp, shock, vibration etc	**Laboratory prototypes.**	**Close to a full military environmental specification.**
Waveform	**Pulsed GPR**	**Pulsed GPR**
Receiver Bandwidth	**300MHz to 3GHz with some roll off at high frequency.**	**200MHz to 3.3GHz with no roll off.**
Transmitted power	**~44dBm peak**	**>44dBm (tbc)**
Power consumption	**Generator**	**Generator**
Supply Voltages	**Various**	**Various**
Resolution	**Measurement spacing 50mm cross track 25mm along track.**	**15mm square.**
Signal to Clutter Ratio	**Scenario dependent, high signal to noise ratio.**	**Scenario dependent, high signal to noise ratio.**
Acquisition speed	**1.8km/hr**	**Through progressive development planned to rise from 3km/hr, through 8km/hrto 20km/hr.**
Primary detection algorithm	**Various**	**Various**
Feature extraction	**None**	**To be developed**

Test & Evaluation

Demonstration trials were carried out in Bosnia in 2001 and the following was reported[27] by the consortium. Five test lanes were designated from the easiest (Lane 1) to the most difficult (Lane 5). The detection performance of each sensor and of the ensemble of sensors post fusion was analysed in detail to give a series of Receiver Operating Curves (ROC). These allowed conclusions about the state of development and limiting performance of each sensor.

The first conclusion was that the trial was well designed; the results showed that Lane 5 was most demanding. The second conclusion was that all the targets could be detected. Every mine was found. The detection of the smallest mine at the deepest depth required the most sensitive settings for the sensors and led to the generation of the most false alarms. It is essential in discussing the results obtained to relate them to the scenarios considered and current mine detection performance.

According to the consortium, in discussing detection issues it is tempting to concentrate upon small anti-personnel mines with no metal content. Some mines of this type were included in the Bosnian trial, and as expected were detected by the GPR. With such heavy reliance upon this one sensor, fusion only reduced the false alarm rate by around 5%.

With small targets, with some metal, laid close to the maximum detection depth of the metal detector, in the higher numbered Bosnian test lanes, the fused output from the sensor suite produced a false alarm rate of between 17% and 25% of what it would have been if only the metal detector had been used, and all the mines detected. Sensor fusion produces the most dramatic improvements when all the sensors must operate at their most sensitive settings to detect the targets.

In Lane 2, which was typical of many mine detection scenarios, it was not necessary to operate each sensor at its maximum sensitivity. The false alarm rate from all the individual sensors was lower. Fusion reduced the false alarm rate to 69% of what it would have been if the metal detector had been used alone. This is still significant. The false alarm rate was then 0.9 per square metre, below the figure of one per square metre identified by the LOTUS system's investigation as the entry point for a vehicle based detection product into use. On-going development would progressively improve this figure.

The infra-red camera was externally noise or clutter limited. This indicates that there is no point in further developing the sensitivity of the camera. Further improvements in sensitivity will simply capture more noise. The unit used in the trial, which is a commercial off-the-shelf unit (COTS), is adequate.

Both the metal detector and GPR were internally noise limited, and performance enhancements would directly improve detection margins, by reducing the sensor's noise floor. The metal detector was a modern unit operated close to the ground and it is unlikely that significant improvements could be made.

The choice of operating band for GPRs is a compromise between achieving depth and resolution. The majority of applications operate below 1GHz in order to achieve depth penetration of a few metres. The 1998/9 MINEREC array used as the GPR in this trial is now dated. Further on-going developments of key components have subsequently been completed. Simple mine detection tests, not part of LOTUS, have been carried out and show detection performance improvements.

It is concluded by the consortium that if these enhancements were included in a future GPR array, with a modern metal detector and the COTS camera used in this trial, the noise performance of the sensor suite would be highly appropriate for the requirements of mine detection. Similarly fusion enhancements could be envisaged with a closer alignment of the fusion to the specific field scenario of relevance to the user.

It is further concluded by the consortium that if an operational system with these parameters is implemented it will be highly suitable for the detection of objects with the dimensions of mines. The system will be an "object detector", not a "mine detector", but it is the best that is likely to be achieved as a detector. The second step is to be able to distinguish between mines and other objects. This is regarded as mine recognition, not mine detection.

[27] Please refer to R.J. Chignell, LOTUS–A Major Technology Milestone for De-mining, pp.7-9, http://www.eudem.info

Related Publications

1. **Title**: J. Schavemaker, E. den Breejen and R. Chignell, LOTUS Field Demonstration in Bosnia of an integrated Multi-Sensor, Mine Detection system for Humanitarian demining, EUDEM2-SCOT 2003, International Conference on Requirements and Technologies for the Detection, Removal and Neutralization of Landmines and UXO; H. Sahli, A.M. Bottoms, J. Cornelis (Eds.), Volume II, pp. 613-617.
2. **Title**: R.J. Chignell, LOTUS – A Major technology Milestone for De-mining, http://www.eudem.info

Abstract: The LOTUS project was a major success, providing a real-time demonstration of the detection and marking of mines by a vehicle in a heavily mined area of Bosnia. Based upon this success a path to the initial field introduction of vehicle based technology into mine detection, and its progressive safe development has been defined. This is a major technology milestone. It has bought the whole de-mining programme to a major crossroads, because the barriers to deployment are now related to funding and organization, not technology. Is there the political will amongst politicians, administrators and NGOs to address these issues? It is essential if the technology resulting from LOTUS is to be put in place to raise productivity and make the goals of the Land Mine Ban Treaty look achievable in the long term. Time is short, the partners must operate in the real world. Although the project team is still committed to take forward the technology, as time goes on the team will disperse and the advances made in LOTUS will be lost. Dedicated engineers can only provide the solutions that society wants; it is up to society to decide if the Land Mine Ban Treaty was an emotional response or a real commitment.

3.7 DEMINE[28]

Project Identification

Project name	Improved cost-efficient surface penetrating radar detector with system-on-chip solution for humanitarian demining
Acronym	DEMINE
Participation Level	European
Financed by	co-financed by EC-IST
Budget	€1.3 M
Project Type	Prototyping
Start date	1 February 1999
End date	31 July 2001

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Project Web: http://www.tu-ilmenau.de

Project Description

A fundamental aspect of the research within the DEMINE project is to be seen in the creation of an ultra-wideband sensor array. The application of SPR arrays has two aspects. The first one is connected with a quicker survey speed since a larger area is under investigation. The second point is that the gathered data provides more information content as targets may be "seen from different aspect angles". It should be noted that the last point is connected with very complicated data processing. Current processing techniques (e.g. SAR processing) of gathered data do usually assume small point-like targets which do not show a scattering dependent on the aspect angle.
At this point it should be explicitly drawn to the reader's attention that several highly sophisticated techniques are required to build such an SPR-array and to provide appropriate data processing. One should as such always consider that such devices will be High-Tech systems, which means that a contradiction has to be solved between sophisticated hard- and software and application in hard environments by less skilled operators. In the DEMINE project (a relatively short RTD project) the main emphasis was on technical and scientific questions in order to first solve the fundamental problems. We have however been able to solve the technical questions in a manner which may be implemented in practice by an appropriate re-design. The following were the main results from the project:

- System prototype with off-line processing
- Radar on Chip correlation/PRC solution based on high speed digital technology
- Antenna Array for multi-static and multi-polarisation
- Dynamic positioning measurement system
- Multi-dimensional signal processing and classification which exploits the novel features of the radar

Photographs courtesy of the DEMINE consortium (testing of prototype in Angola)

[28] This description was prepared in co-operation with Jürgen Sachs, Technische Universität Ilmenau.

Involved Technology Related Activities

Technology Type GPR

Readiness level 5[29]

Company/Institution Technische Universität Ilmenau; Messtechnik, Ortung und Datenverarbeitung GmbH; Ingegneria dei Sistemi SpA; QinetiQ Ltd, following reorganization of Defence Evaluation and Research Agency (DERA); Menschen gegen Minen; Vrije Universiteit Brussel; Applied Electromagnetics FGE Ltd

Detailed Description of the prototype/product

Technical Specifications: DEMINE GPR	
	Prototype
Weight	**12 kg**
Battery Life	**220 V mains**
Array width (x-axis)	**650 mm**
Array width (y-axis)	**350 mm**
Height of array (z-axis)	**230 mm**
Unambiguous range in air	**8m**
Depth range for all targets / all soils	**2 – 15 cm**
Probability of Detection	**0.7***
Probability of false alarm	**Too few results to comment**
Demining environmental conditions	**Sand Gravel up to 1 cm Sandy soil up to 15% clay Loam (37% sand, 53% silt and 10% clay)**
Temp, shock, vibration etc	**Not tested but temperatures over 40°C experienced**
Waveform	**511 bit MLBS**
Receiver Bandwidth	**4,5 GHz**
Transmitted power	**3 dBm /13 dBm (chip output/amplifier output)**
Power consumption	**55 W**
Supply Voltages	**220 V**
Resolution	**3 cm in air**
Acquisition speed	**10 cm/s (with 2048 averages per scan)**
Primary detection algorithm	**1D, 2D and 3D - Data re-sampling, - Background removal, - Deconvolution, - Adaptive clutter removal, - 2D SAR - 3D SAR - Volume reduction - Image filtering/processing - Permittivity**
Feature extraction	**- Time features - Spectral features - Time/frequency features - Shape features**
*** This value is based on the first ever tests / measurement gathering with the first field demonstrator/prototype in Angola. The measurements at the test sites are also a basis on which to further develop the detector. Safe statistics may only be provided with a great deal more tests and evaluation.**	

[29] Opinion of EUDEM2 based on its own analysis.

Test & Evaluation

The DEMINE system was tested by the consortium during in-house tests, at the JRC in Ispra and in Angola. Details of the tests are provided in the Final Report.

The relatively few tests made it difficult for the consortium to provide results with any statistical significance. They were however able to demonstrate that the new MLBS radar method worked and that metallic and non-metallic APL and ATMs could be detected and clutter discriminated.

Other applications (non demining): Sub-systems may be adapted for use in for example: UXO detection, through wall radar, non-destructive testing, complex control solutions (data fusion, e.g. large facility process monitoring, aircraft altitude control)

Related Publications

1. **Title**: DEMINE consortium: DEMINE Final Report, 2001, http://www.eudem.info

3.8 Hand-held Stepped Frequency Modulated Continuous-Wave Radar[30]

Project Identification

Project name	Hand-Held Stepped Frequency Modulated Continuous-Wave Radar
Acronym	not applicable
Participation Level	international
Financed	International Science and Technology Centre (ISTC); APSTEC Ltd.
Budget	$240,000
Start date	2000
End date	2003

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Project Web: not available

Project Description

A prototype hand-held GPR for detection of subsurface metals and dielectrics has been designed and produced. The radar is based on continuous ultra-high (2-8 GHz) frequency EM waves (microwaves) with stepped frequency change. The radar allows one to determine:

- Dimensions of the concealed object;
- Its dielectric characteristics.

Identification of the detected object can be achieved by comparing its dielectric constant with those of known objects.

Involved Technology Related Activities

Technology Type	Ground penetrating radar
Readiness level	5[31]
Company/Institution	Applied Physics Laboratory, V.G. Khlopin Radium Institute, St. Petersburg

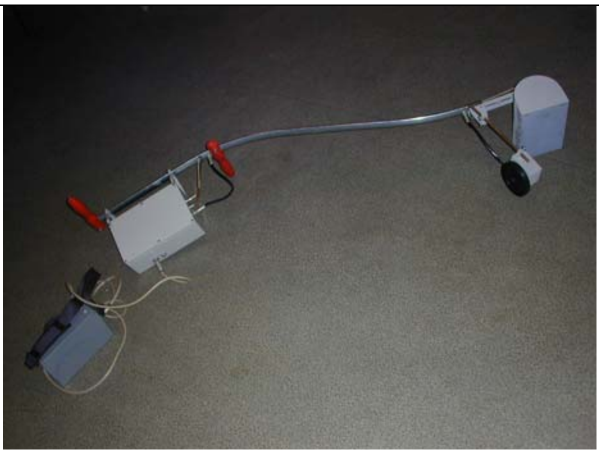
[30] This description was prepared with the co-operation of Andrey Kuznetsov, Applied Physics Laboratory, V.G. Khlopin Radium Institute, St. Petersburg.

[31] Opinion of EUDEM2 based on its own analysis.

Detailed Description of the prototype/product

The method for the localisation of suspicious anomalies is provided by a modulated continuous wave radar, which analyses scattered continuous electromagnetic radiation. This enables the characterisation of objects within an inspected volume in terms of their shape and dielectric characteristic. The present prototype device can detect objects with dimensions larger than 5 cm in soil (with spatial resolution of 5 cm in-plane and 2.5 cm in-depth). The device measures amplitude and phase of the reflected electromagnetic wave and plots these data as functions of the amplitude on the coordinate along the line of scanning (X or Y axis) and on the distance to the object (Z axis). Unlike pulsed systems, this prototype uses stepped-frequency change in the range 2-8 GHz, which allows one to perform the analysis of dielectric properties of the object, and greatly simplifies the antennae array. In a commercial version the frequency range can be selected according to the required resolution.

Technical Specifications: Hand-Held Modulated Continuous-Wave Radar



Photograph courtesy of Applied Physics Laboratory V.G. Khlopin Radium Institute

	Prototype	Production (target)
Weight	5 kg	5 kg
Battery Life	8 hours	8 hours
Dimensions of the antennae block, cm	25×15×15	depending on the task
Frequency sweeping range, GHz	2-8	depending on the task
Minimal frequency sweeping step, MHz	1.5	depending on the task
Minimal measurement and analysis time of one sweeping cycle at sweeping step 200 MHz, millisecond	100	depending on the task
Receiver sensitivity, dB/W	-120	depending on the task
Dynamic range, dB	50	depending on the task
Unambiguous range in air	100 cm	depending on the task
Depth range for all targets / all soils	at soil humidity 16 %: 8-10 cm.	at soil humidity 16 %: 8-10 cm.
Spatial resolution in air, cm in-depth longitudinal transversal	2.5 5 4	down to 1 cm, depending on the chosen frequency range
Can distinguish between metallic (conductors) and dielectric objects	YES	YES
Can determine dielectric constants and geometrical sizes of detected objects	YES	YES
Probability of detection	n/a	n/a
Probability of false alarm	n/a	n/a
Demining environmental conditions	Humidity of soil < 16 %	Humidity of soil < 16 %
Temp, shock, vibration etc	Laboratory environment	resistant
Waveform	Modulated Continuous Wave Radar	Modulated Continuous Wave Radar
Receiver Bandwidth	6 GHz	depending on the task
Transmitted power	1 mW	
Power consumption	10 Watt	less than 10 Watt
Supply Voltages	12V / ~220V	depending on the task

Test and Evaluation

The Applied Physics Laboratory also proposes a multi-sensor based on a localization sensor (stepped-frequency continuous-wave radar (GPR) working in 2-8 GHz range) and an Identification sensor: “neutron in, gamma out” sensor based on Nanosecond Neutron Analysis/ Associated Particles Technique (NNA/APT).

a) Test & Evaluation: Laboratory tests completed
b) Cost: $7,000-10,000 (estimated for commercial version)
c) Other applications (non demining): detection of thin metallic foils in passenger luggage; human body inspection.

Related Publications

1. **Title**: V.P. Averianov, I.Yu. Gorshkov, A.V. Kuznetsov, A.S. Vishnevetski, Detection of explosives using continuous microwaves, Proc. of the NATO ARW #979920 “Detection of bulk explosives: advanced techniques against terrorism”, St.-Petersburg, Russia, Kluwer Academic Publishers, NATO Science Series, Series II: Mathematics, Physics and Chemistry – Vol.138, 2004.
   Abstract: The continuous microwave technique is based on irradiation of an object or inspected area with low-power, broadband electromagnetic continuous microwave radiation and measurement of interference of the probing radiation with that scattered from objects located in the area. The on-line analysis yields both position of reflecting surfaces within the irradiated volume and dielectric properties of substances comprising the volume. The method is very fast and allows continuous scanning of large areas. It is capable of locating “suspicious” objects and their preliminary identification by their dielectric properties.

4 Radiometer Systems

4.1 Sensing Principle

Passive radiometers working in the microwave range of the electromagnetic spectrum have been suggested as suitable for the detection of mines placed on the surface of the ground (but covered with light vegetation for example) or shallow buried mines (to a depth of a few cm). The maximum detection depth is a strong function of the frequency used, soil humidity and conductivity, mine case material type (metal or plastic) and mine size (large antitank mines are much easier to detect than small anti-personnel mines). Increasing the detection frequency results in better spatial resolution, but soil penetration can be rapidly and significantly reduced (especially for wet soils); the trend has been therefore towards lower operating frequencies, typically below 10 GHz. In addition to close-in detection, distant detection (remote sensing) of larger objects on the surface also appears to be possible using millimetre wave devices working at higher frequencies, for example 94 GHz.

Metallic targets have a low emissivity and strong reflectivity (acting like a mirror) in the microwave band, whereas soil has a high emissivity and low reflectivity. Soil microwave radiation depends therefore almost entirely on its physical temperature, whereas metal radiation depends mostly on the reflection of the very low-level background radiation from the "cold" sky which "illuminates" it. It is possible to measure the contrast between the "warm" ground and a "cold" mine (both temperatures as seen in the microwave band) using a passive radiometer. This is essentially a tuned directional receiving antenna and associated circuitry which measures the microwave radiation coming from an object - it functions as a microwave band power meter. The detection of plastic targets is also possible but more difficult, given that they produce a much smaller microwave ΔT (apparent temperature difference) than metal objects as they have much lower reflectivity and greater transparency to background radiation from below them.

Passive microwave radiometers are simpler devices than Ground Penetrating Radars and should suffer less from clutter problems. In principle it should be possible to build human portable systems at relatively low cost. Like many other sensors, they can be scanned over the ground to generate two dimensional images. Best results are likely to be obtained in dry soils, for large metallic targets. The maximum depth of detection is, however, unlikely to be sufficient for microwave radiometers to be used as a stand-alone device except for surface objects. In this they complement GPR which has difficulty detecting an object close to the air-ground interface.

Active systems, where some form of target "illumination" in the microwave range is applied, have also been proposed and studied by some organizations. The enhanced contrast they offer may justify the increased cost and complexity.

Related Publications

1. **Title**: HOPE consortium: Public HOPE Final Report, 2002, http://www.eudem.info
2. **Title:** D.J. Daniels, Ground Penetrating Radar, 2nd Edition, IEE Radar, Sonar, Navigation and Avionics Series, June 2004, ISBN 0 86341 360 9
3. **Title:** D.J. Daniels, An Overview of RF sensors for mine detection: Part 1 Radiometry, MINE'99 Conf. Proceedings, pp. 31-36, Oct. 1-3, 1999, Florence, Italy

4.2 HOPE[32]

Project Identification

Project name	Hand-held Operational Demining System
Acronym	HOPE
Participation Level	European
Financed by	EC ESPRIT IV
Budget	2.8 MEUR (EC funding)
Start date	1 January 1999
End date	30 June 2001

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Project Web: not available

Project Description

During the HOPE project a sensor head combining an improved pulse metal detector and an array of antennas for Ground Penetrating Radar and Micro Wave Radiometer has been developed. Furthermore an Optical Position Monitoring System has been developed providing position data as a basis for 2D and 3D processing of the data collected. Software for visualizing the bulk data to make it interpretable has been written. In a number of tests several stages of the project progress have been tested in lab, company test fields, in Ispra and in test fields of NPA in Bosnia. The demonstrators built for the Bosnia tests and the other test prototypes were comprised of light weight sensor heads (Metal detector coils, a common set of antennas for GPR and MWR, camera for OPMS) and a electronic back pack with specific electronics and off the shelf computers. The prototypes had limited real time capabilities and mainly were used to collect data for offline data processing[33].

The consortium views the results as follows[34]:
The results obtained are quite encouraging. To the best knowledge of the consortium, this was the first time high-resolution registered images could be obtained from a manual scanning using a multi-sensor system.
Only raw images were computed but even so some of the images exhibited characteristics that could be used for object discrimination. Focusing was possible for the GPR and for the MD but was not performed in the scope of this project mainly due to lack of time but also due to some hardware problems that limited the position accuracy which would need to be solved first. Solutions are known but were not implemented at that point in time. Results of the GPR were poor in Bosnia and could not be used because the scanning height was too low.
However, even the raw images showed quite interesting discriminating features. Fusion was possible and showed quite promising results, especially for the radiometer. This showed that registration is possible. Taking into account the relative position of the various sensors on the head, it was possible to create images in a common reference view. With focusing and higher level feature extraction, we expect that a lot of additional discriminative characteristics could be used. Therefore there is room for significant improvement, for instance any mechanical support to achieve a more regular sampling is desirable. Furthermore the suppression of artificial transmitters interfering with the radiometer receiver should be reduced by an automatic adjustment of the receivers' center frequencies.

Involved Technology Related Activities:

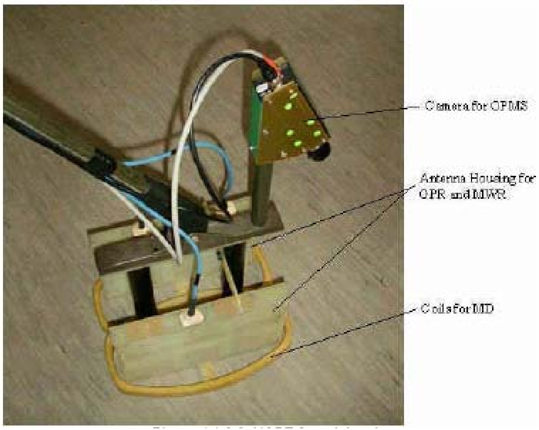
Technology Type	metal detector, ground penetrating radar, micro wave radiometer
Readiness level	4[35]
Company/Institution	Deutsches Zentrum für Luft- und Raumfahrt e.V.; Vallon GmbH ; Institut Franco-Allemand de Recherches de Saint-Louis); Norwegian People's Aid; Office National d`Etudes et de Recherches Aerospatiales - Centre d`Etudes et de Recherches de Toulouse; Radar Systemtechnik AG); Royal Military Academy - Signal & Image Centre); Ruhr-Universitat Bochum), SPACEBEL S.A.; Universität Karlsruhe (TH) - Institut für Höchstfrequenztechnik und Elektronik)

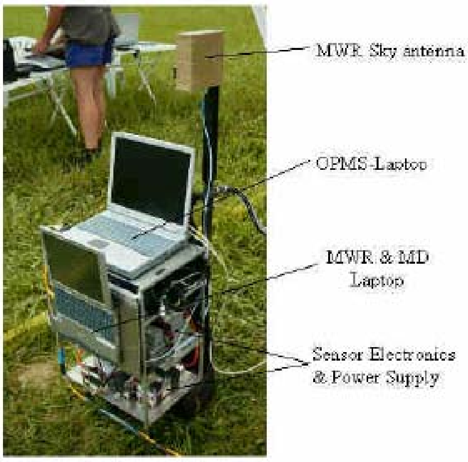
[32] This description was prepared with the co-operation of Helmut Suess and Markus Peichl, Deutsches Zentrum für Luft- und Raumfahrt e.V.
[33] HOPE consortium: Public HOPE Final Report, 2002, page 7
[34] HOPE consortium: Public HOPE Final Report, 2002, page 159

Detailed Description of the prototype/product

The radiation usually is composed of three contributions: the objects'self emission, the reflection of elsewhere similar generated radiation on the objects' surface, and the transmission through the object in the case of a partial microwave transparency[36]. All parts of the radiometer receiver, except the synthesizer, are housed in a robust case of cast aluminium. The synthesizer has a similar own case. The control computer is a standard laptop and the DSP board is ingrained in synthetics. The power supplies are several modules each one housed in a steel case[37]. The following table is based on information provided by the project consortium summarizing the physical characteristics achieved in the project and the detector performance elaborated and defined in the project. Most numbers under detector performance need to be understood as a point of reference which allows for slight deviations for technical reasons in the prototype constructed[38].

Technical Specifications : HOPE microwave radiometer





Photograph courtesy of HOPE

Physical Characteristics - microwave radiometer

Size:	**Receiver without synthesizer: ~19x12x6 cms** **Synthesizer: ~12x10x3 cms** **Power supply*: ~20x 17x 6 ** .cms** **DSP board*: ~13x 7x 7 ***cms** **Control computer*: ~25x 23x 3 cms**
Weight:	**Receiver without synthesizer: 1260g** **Synthesizer: 260g** **Power supply: 1700g** **DSP board: 250g** **Control computer: 1600g**
Power consumption	**8.58W**

***Dimensions and weights of the radiometer receiver and accessories.**
**** Several blocks without battery, *** including optocoupler box.**

Detector Parameter - microwave radiometer

Estimated system temperature range	**300K – 800K**
Center frequency range, tunable	**1.5GHz – 7GHz**
Instantaneous receiver bandwidth	**50MHz**
Overall system gain at HF	**64dB**
Estimated average ground resolution (in operational configuration)	**5cm – 10cm**
Required sensitivity	**< 1.5K**
Maximum tolerable integration time	**< 6ms**
Number of center frequencies to be measured	**8**
Required maximum scan speed of the sensor head	**20cm/s**
Number of receiver inputs	**3**

[35] Opinion of EUDEM2 based on its analysis

[36] HOPE consortium: Public HOPE Final Report, 2002, page 60

[37] HOPE consortium: Public HOPE Final Report, 2002, page 69

[38] HOPE consortium: Public HOPE Final Report, 2002, page 66

Test & Evaluation

According to the consortium, a multitude of experiments were performed to optimise the receiver development and operational strategies. In brief they have supported the following main investigations: the influence of antenna distance and tilt angle relative to the ground concerning resolution and shadowing effects, the required density of the sampling grid on the ground for proper imaging, the influence of the antenna patterns, the determination of the required sensitivity and ground resolution, the frequency dependence of typical scenes concerning a suitable number of frequencies, the examination of the depth of the objects and the penetration depth, the dependence of surface variations, and finally the general detection and discrimination capabilities for mine surrogates, reference objects, and false targets[39].

In order to acquire more information about the sensor performance and how to optimise it in future, additional field tests have been carried out. For that the radiometer was combined with the metal detector as foreseen for a typical operation. This means that the two antennas were mounted in-between the two coils of the MD in a common head and both electronic devices together with power supplies were integrated on a common platform. Two suitable test areas were used for the experiments: a test site at JRC in Ispra, Italy, and a second one at the NPA installations in Sarajevo, Bosnia. Both are artificial mine fields equipped with mines or mine surrogates and false targets[40].

From the experiments carried out at the test site of JRC in Ispra, Italy, the following key conclusions were drawn:

- Many of the mine simulants could be detected by the MWR, although a lot of them were also hard or not possible to extract from the background clutter. Up to now only target detection was considered with the HOPE MWR system. Target discrimination will require more frequencies and deeper signature analysis for a future system.
- Several interference problems were observed: RF interference by artificial transmitters as communications, broadcast, radars, and switched high currents in the vicinity of the MWR sensor. For a future MWR system those have to be detected automatically and reduced or removed by an automatic centre-frequency adjustment. In general, interference can reduce the contrast or, in excess, makes the MWR system completely blind[41].

From the experiments carried out at the NPA test site in Sarajevo, Bosnia, it pointed out that the present version of the overall hand-held system is not in a suitable status to be the basis for an industrial instrument. There are several improvements to be addressed in addition to those already mentioned within the Ispra conclusions:

- A main problem of the hand-held operation is the irregular scanning. This can produce artefacts and a significant contrast reduction due to a bad scan pattern in all of the three dimensions. The possibility of touching the ground or approaching it to close should be avoided automatically in a future development. A tool to assist the deminer in performing a proper more regular scanning would be quite helpful and would increase the data quality significantly. The head has to be reduced in weight considerably to allow an easier operation and a more regular scanning.
- A suited image processing software is required to perform the operations of pattern and feature recognition automatically to assist for the detection process from the images. Only visible investigations are subjective and unsatisfactory.
- Some of the insight acquired already at Ispra have shown a stronger impact in Sarajevo. These are the RF interference problems which require definitely an automatical adjustment. Furthermore improvements of the antenna‘s directivity and the reduction of sidelobes is a major demand.
- It should be avoided in general to locate equipment in the close vicinity of the MWR antenna to avoid any shadowing and additional interference[42].

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[39] HOPE consortium: Public HOPE Final Report, 2002, page 71

[40] HOPE consortium: Public HOPE Final Report, 2002, page 75

[41] HOPE consortium: Public HOPE Final Report, 2002, page 78

[42] HOPE consortium: Public HOPE Final Report, 2002, page 80

Related Publications

1. **Title**: M. Peichl, H. Süß, M. Zeiler, S. Dill, DLR, Oberpfaffenhofen, Germany; Recent advances in the detection and identification of landmines by microwave radiometry, JRC, Ispra, Italy, 12-14 July 2000 Joint Workshop Research on Demining Technologies, www.jrc.it
2. **Title**: HOPE consortium: Public HOPE Final Report, 2002, http://www.eudem.info

   Abstract: *The objectives of the HOPE-Project is to develop and build an efficient handheld demining tool as a remarkable contribution to the European and world wide Humanitarian Demining Programs particularly in countries facing the danger caused by millions of anti-personnel mines left behind from former wars.*

   At the end of the project after extensive tests on test sites and in (test-) minefields in Bosnia we can say:

   a) The project has confirmed that we are on the right way using the technologies of the HOPE sensors to improve demining significantly. At least two partners have indicated that they are willing to continue the HOPE approach and to develop a commercial product based on the results of HOPE.

   b) Searching mines with the HOPE sensor starts in conventional manner using the metal detector or the GPR if non metal mines are expected. In a second step of operation metal detector alarms can be qualified by GPR and / or MWR data, i. e. the number of false alarms can be reduced by processing the data available on computers. In a third level of enhancement additional information can be provided (e. g. size and depth of the suspicious object, position of the metal fuse) allowing the deminer to continue much more systematically / efficiently instead of prodding in a completely unknown volume.

   Using complex sensor technology yields an enormous amount of raw data which cannot be directly interpreted by human senses and brain any more. But processing the data by all means of modern data processing technology may not output the simple binary information mine/no mine (at least as long as we haven't passed through a several years lasting successful and reliable operation). The responsibility for the decision to step ahead or not must be left to the deminer himself. So the job of the equipment is to deliver sufficient and easily understandable, clear information enabling the deminer to choose an adequate way of progressing. This results in Man Machine Interfaces which are either much more complex than those one-dimensional beeps of a metal detector or must go through an evolutionary process before they are satisfying. So as a consequence of using high tech in the field, demining procedures as well as qualification requirements of deminers will have to be adapted to the new generation of tools.
3. **Title**: Peichl M., Dill S., Süß H., Advanced detection of anti-personnel landmines using multi-spectral low-frequency microwave radiometry techniques, Proc. of the Progress in Electromagnetic Research Symposium PIERS 2001, Osaka, Japan, 18-22 July 2001.
4. **Title**: Peichl M., Dill S., Süß H., Detection of anti-personnel landmines using microwave radiometry techniques, NATO Advanced Workshop on „Detection of Explosives and Landmines", St. Petersburg, Russia, 9th-14 September 2001.
5. **Title**: Dill S., Peichl M., Schulteis S., Süß H., Microwave radiometry techniques for buried landmine detection, Progress in Elecromagnetic Research Symposium PIERSS 2002, Cambridge, Massachusetts, USA, 1-5 July 2002.
6. **Title**: Peichl M., Dill S., Süß H., A microwave radiometer for buried landmine detection, Progress in Elecromagnetic Research Symposium PIERSS 2003, Singapore, 7-10 January 2003.
7. **Title**: Peichl M., Dill S., Süß H., Application of microwave radiometry for buried landmine detection, 2nd International Workshop on Advanced Ground Penetrating Radar, TU Delft, Delft, The Netherlands, 14-16 May 2003.
8. **Title**: Peichl M., Dill S., Süß H., Buried landmine detection using microwave radiometry, Progress in Elecromagnetic Research Symposium PIERSS 2004, Pisa, Italy, 28-31 March 2004.

5 Trace Explosive Detection Systems

5.1 Sensing Principle

Trace explosive detection consists in the chemical identification of microscopic residues of the explosive compound, either in vapour or in particulate form (or both).

- **Vapour** refers to the gas-phase molecules emitted from the explosive's surface (solid or liquid) because of its finite vapour pressure, and
- **Particulate** refers to microscopic particles of solid material (typically down to sub-picogram size - 1 picogram of TNT contains about 2.6 billion molecules) that adhere to and contaminate surfaces that have, directly or indirectly, come into contact with an explosive material.

A sample has to be acquired in the field and either used directly in a portable detector, or transported to the analytical device (a contrast to bulk detection in particular). Trace particle detection can potentially detect samples of explosive material of a few picograms at the detector, equivalent to ppt (parts per trillion, $1:10^{12}$) concentrations. Even greater sensitivities are certainly achievable (chromatography can already achieve this in laboratory systems), and perhaps necessary, but whether this can be done for field portable systems remains to be seen. In practice, the need for a field system depends on the application and working methods. Some users, most notably Mechem in S. Africa, have preferred to focus on REST (Remote Explosive Scent Tracing) systems. In the Mechem MEDDS (Mechem Explosive and Drug Detection System) the sample is brought to the detector – dogs in this case! This permits the dogs to work under more closely controlled conditions with fewer distractions, and allows the sample to be sniffed by a larger number of dogs. Cross contamination and handling issues are of great importance when dealing with picogram level samples.

Trace and vapour explosive detection is increasingly seen as a method for Area Reduction and not for locating individual mines. The use of a consistent negative result to declare a defined area free from contamination (Area Reduction) offers such significant benefits that it is already used by some operators under certain circumstances. Currently the most common method is to use dogs to scan the area.

Several automated trace detection technologies have been in use for quite some time, for example in the aviation security sector and for the detection of drugs. Their application to landmine detection has, however, to take into account the effects of explosive transport in soil, which are complex and strongly dependent on any water flow and other parameters. Concentrations of vapour in a mined area may be several orders of magnitude lower than in a screening portal in an airport. There is also some evidence that weather and soil conditions lead to samples not being repeatable.

Studies and measurements on **environmental fate and transport of explosives** have been carried out, for example, at the Sandia National Labs, CRREL (USACE Engineer Research and Development Center, Cold Regions Research and Engineering Laboratory), FOI (Swedish Defence Research Establishment), DRES (Defence Research Establishment Suffield, Canada). Mechem (South Africa) for example has accumulated practical field experience on the subject, as have the partners in the EC-IST BIOSENS project. In general these studies confirm that there is a large influence of environmental parameters, target history, and other factors, on the variables of interest (explosive vapour and particle concentration), and that the quantity of explosive substance available for detection can be very small. The presence of traces of explosive- and/or mine-related substances, and the possibility of detecting them, might also well be worth considering.

Sensor systems for field application need to have an appropriate **sampling system** (of the air, vegetation or the soil), possibly including filtering to increase concentration. Suitable operational procedures also have to be defined. Up to now it seems that sensors either have insufficient sensitivity, are too slow or too large to be used in routine field applications, and the nature of explosive movement from mines - particularly microscopic particles - has made defining procedures very challenging. Some evidence is emerging that sampling is now the key problem.

Significant further work remains to be done on understanding how to obtain samples reliably and with statistical confidence, on vapour and particulate transport mechanisms and other aspects of vapour and particulate detection, as well as on the detectors themselves. There is not even any general agreement yet on how dogs manage to find mines and what they are actually sniffing. The huge challenge that the physical environment (particularly the soil) presents for vapour / trace detection is perhaps highlighted by the decision of a US programme, which will provide €58M over an eight year period for demining technology[43], to target 60% of this funding towards soil and environment research.

[43] Russell S. Harmon, US Army Research Office, presentation at EUDEM2-SCOT 2003 Conference, 15-18 September 2003, http://www.eudem.info

Related Publications

1. **Title:** I.G. McLean (Ed.), Mine Detection Dogs: Training, Operations and Odour Detection, Geneva International Centre for Humanitarian Demining, 2003, http://www.gichd.ch/
2. **Title:** J. MacDonald, *et al.*, Alternatives for Landmine Detection, RAND Science and Technology Policy Institute, Report MR-1608, 2003.
3. **Title:** J. Yinon, Forensic and Environmental Detection of Explosives, 1999, John Wiley and Sons, ISBN 0-471-98371-0.
4. **Title:** C. Bruschini, Commercial Systems for the Direct Detection of Explosives (for Explosive Ordnance Disposal Tasks), ExploStudy, Final Report, Feb. 2001, http://diwww.epfl.ch/lami/detec/explostudy.html, http://www.eudem.info

5.2 BIOSENS[44]

Project Identification

Project name	Vapour Detection - area reduction in demining
Acronym	BIOSENS
Participation Level	European
Financed by	co-financed by EC-IST
Budget	€3.924.947
Type	Prototyping
Start date	01 January 2001
End date	30 September 2004

Contact Person

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Project Description

The project aimed at explosive detection technology employing unique weight loss quartz crystal microbalance (QCM) with antibodies and antigens technology, suitable for deployment in the field by non-technical staff. The present Biosensor system consists of two units:

- A sample collector
- An analysis system (which itself comprises the analysis unit, the sensor cell and the operating software) for detection of explosives

This technology has demonstrated high levels of selectivity and sensitivity.

Involved Technology Related Activities

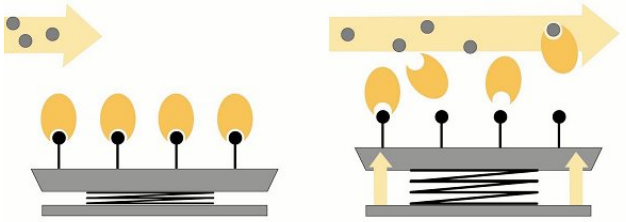
Technology Type	Vapour/trace detection
Readiness level	6-7[45]
Company/Institution	Biosensor Applications Sweden AB; Swedish Rescue Services Agency; Norwegian People's Aid; The Weizmann Institute of Science

[44] This description was prepared with the co-operation of Lars Eng, Biosensor Applications Sweden AB.

[45] Opinion of EUDEM2 based on its own analysis.

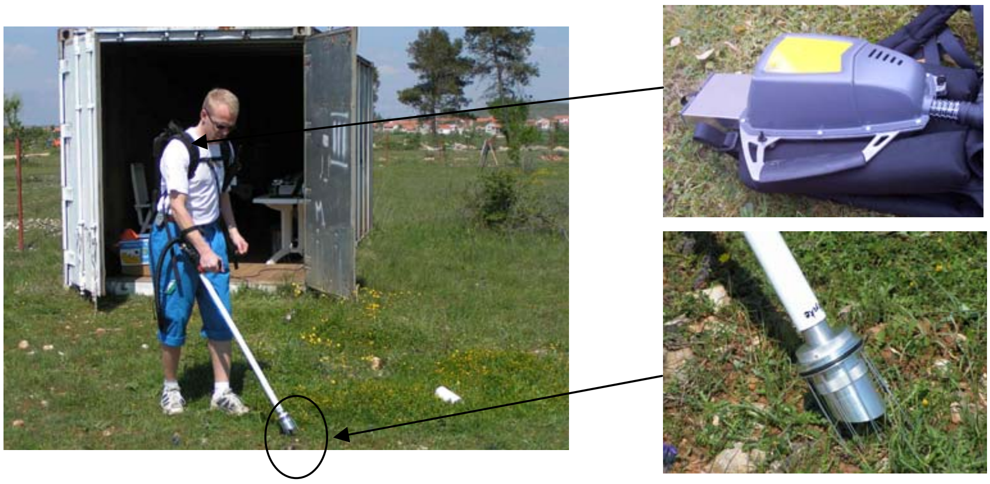
Detailed Description of the prototype/product

The biosensor system itself is composed of two main units: a collection system and an analysis system. The collections system is able to collect TNT/DNT, RDX, PETN and tetryl. The analysis system flowing out of the project is able to detect TNT/DNT, PETN, and tetryl simultaneously. The system detects the emission of characteristic vapour, i.e. vaporised or dissolved explosive, by means of an antigen/antibody reaction with high sensitivity provided by an innovative and unique weight loss Quartz Crystal Microbalance (QCM) technology. The sample collector draws air and vapours through a filter. The various substances adsorbed onto the filter are then prepared and pumped through the Biosensor detectors (BioCells). The BioCell comprises a quartz crystal microbalance (QCM) sensor and its support. A change in mass will change the frequency of the crystal. This change in frequency can be measured and will correspond to the amount of material on the crystal. The QCM sensor uses antigens bonded to a gold plated piezoelectric crystal to which, in turn, antibodies are bonded. The antibodies are designed in such a way that although they will naturally attach to the antigen, they will release when they react with antigen- molecules in the analyte. The process is shown schematically in the following drawing:



In the first image the analyte is flowing into the BioCell where the antibodies (yellow) are attached to the QCM surface. In the second image the target molecules (violet) in the analyte react with the antibodies causing the antibody molecule to release from the surface, giving a mass reduction on the QCM. This in turn causes the QCM frequency to change and this change is monitored.

The following figures illustrate the sweeping collection system provided at the end of this project.



Technical Specifications: Biosensor system	
Physical Characteristics	
Size:	Sample collection back pack: 30x25x12 cm Analysis system: 50x45x25 cm
Weight:	Sample collection system 5-6 kg Analysis system: 17 kg
Power supply:	Sample collection system: rechargeable battery for 3 hours operational time. Analysis system: 220 V AC or 24 V DC.
Detection Performance:	
No. of simultaneously detectable substances	4
Detectable explosive substances	TNT, 2,4-DNT, Tetryl, PETN
Probability of detection (on filter)	TNT, 2,4-DNT: >95% at 2 ng PETN: >95% at 10 ng Tetryl: >95% at 10 ng
Sensitivity in BioCell	TNT, 2,4 DNT: 10 pg in cell PETN and Tetryl: ca 50 pg in cell
Analysis time	< 2 minutes
Collection efficiency (%)	75 % for TNT vapour >20% for particles
Climatic conditions:	15 to 30 °C

Test & Evaluation

Thirteen methodology tests were carried out in the project's test field in Croatia between 2001 and 2004, as well as 10+ other area tests and comparisons with soil samples and mine detection dogs. These tests showed that collection of particles could be promising for area reduction in demining, but that further knowledge and tests are required for the development of optimal operational procedures.

Evaluation tests carried out in and near to a number of real minefields showed that the collection and analysis system worked stably and reliably for extended periods. The probability of detection figures are based on spiked filters provided to the analysis system.

a) Readiness level: Prototypes available for further field testing. Engineered product foreseen for 2005
b) Cost: ca. €50K for one analysis system and collection system
c) Other applications (non demining): Aviation and general security; drug detection with different BioCells

Related Publications

1. **Title**: BIOSENS consortium: <u>BIOSENS Final Report</u>, 2004 (awaiting release at time of writing) http://www.eudem.info
   Abstract: The main idea behind the BIOSENS project was to develop a Biosensor system, a vapour and particle detector, which would be able to find the smallest quantities of explosives from mines. The concept of such a sensor has sometimes been described as an artificial dog's nose" and it was with this in mind that the project was formed. The developments in the project were targeted to producing a sensor which could be used to replace or compliment dogs. Dogs, while undoubtedly being a very effective demining tool, have a number of characteristics which it was felt could be improved upon by "an artificial dog's nose". Dogs are relatively expensive, in terms of purchase, training, feeding, boarding and illness. It is also recognised that dogs become tired and also bored. In addition, although dogs are an accepted demining tool the demining and scientific community still does not know how they exactly function. It was felt that the "artificial dog's nose" could offer improvements in terms of cost, productivity and reliability and that knowledge gained would help contribute to the understanding, training and operational procedure of use of dogs.
   The project has been very successful in developing a prototype system which works stably and also reliably. The collection and analysis systems have been extensively tested in Bosnia Herzegovina and Croatia in a series of tests including in mined locations. It is a major success to be able to develop a QCM system with Ag/Ab technology which may be applied in environments a great deal harsher than the "lab top".
2. **Title**: S. Crabbe, J. Sachs, G. Alli, P. Peyerl, L. Eng, M. Khalili, J. Busto and A. Berg: <u>Results of field testing with the multi-sensor DEMAND and BIOSENS technology in Croatia and Bosnia developed in the European Union's 5th Framework Programme</u>, SPIE 2004 12-16 April 2004.

5.3 NOMADICS (FIDO)

Project Identification

Project name	NOMADICS FIDO
Acronym	FIDO
Participation Level	National
Financed	Defense Advanced Research Projects Agency (USA)
Project Type	Product
Start date	1990s
End date	on running for demining

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Project Web: http://www.nomadics.com/

Project Description

Nomadics develops landmine detectors based on the principle of Trace/Vapour Detection. The Nomadics landmine detector includes an extremely sensitive and highly selective chemosensor that uses novel amplifying fluorescent polymers (AFPs) synthesized by research partners at MIT. When vapours of nitroaromatic compounds such as TNT bind to thin films of the polymers, the fluorescence of the films decreases. A single molecular binding event quenches the fluorescence of many polymer repeat units, resulting in an amplification of the quenching. Analyte binding to the films is reversible, so the films can be reused.

Involved Technology Related Activities

Technology Type	Vapour/trace detection
Readiness level	8[46]
Company/Institution	Nomadics Inc.

[46] Opinion of EUDEM2 based on its own analysis.

Detailed Description of the prototype/product

Nomadics states that the new range of Fido portable explosives detectors from Nomadics are the smallest, most sensitive explosives sensors available. Inspired by dogs, Fido screens packages, shipping containers, vehicles, and people for traces of nitroaromatic explosives. Fido is based on a unique chemical sensing material known as Amplifying Fluorescent Polymer (AFP). In the absence of explosive compounds, the polymer fluoresces when exposed to light of the correct wavelength. When molecules of interest are present, the brightness of the fluorescence is dramatically reduced. The drop in fluorescence intensity is then detected by a sensitive photodetector and processed by the instrument. According to the manufacturers in side-by-side field operations, the performance of Fido is comparable to dogs and it can detect explosive vapour at levels as low as a few femtograms. Fido is available in two models. The Fido X offers an integrated head which allows for easy portability, storage, and usage on bench tops and in storage and mail rooms. The Fido XT model with tethered head and pistol grip can be easily adapted for use on remote vehicles for standoff applications such as IED detection. Other uses include manual searches and direct screening[47].

Technical Specifications: FIDO™[48]

Pictures courtesy of Nomadics Inc

Specifications	
Size:	**9.8" x 4.8" x 2" Fido XT sensor head (w/out grip): 3.5" x 3.5" x 1.5" Fido XT tether lengths: 3´, 6´and custom Fido X sensor head 3.5" x 1.5" x 1.5"**
Weight:	**700 g including battery**
Power:	**Battery: Lithium Ion (included) Batter life: 4 hours**
Adapters	**Power supply 100 – 250V, 50-60 Hz AC adapter 100 – 120V, 50-60Hz 12V connector (supplied)**
Com Ports:	**USB Infrared (low power bi-directional) RS 232**
Memory	**256 MB (10 days continuous data logging**
Presentation of results	**Bar chart display Audio signal Connection to external computer**
Detectable explosive substances	**Nitroaromatic compounds**
Sensitivity	**1 femtogram (1 x10^{-15} g) for TNT (based on laboratory tests)**
Analysis time	**~ 5 seconds**

[47] http://www.nomadics.com/products/fido/index.html

[48] Nomadics Inc., Size Matters and Technical Overview Fido™ Explosives Detector (Information sheets), http://www.nomadics.com/

Test & Evaluation

M. Fisher, C. Cumming, Nomadics, Inc. Detection of Trace Concentrations of Vapor Phase Nitroaromatic Explosives by Fluorescence Quenching of Novel Polymer Materials:

Blind field testing of FIDO against buried landmines has also been conducted at the DARPA test facility at Ft. Leonard Wood. Blind test lanes were established by marking potential target positions in the test field. At each test position, two flags were planted, approximately 50 centimeters apart. Some of the test locations were mined with the mine centered between the flags. The landmines used for the test were authentic TMA5 or PMA1A landmines with the fuzes and detonators removed and with shipping plugs capping the detonator well. FIDO was used to sample between the flags at each test location. The sensor responses were recorded and submitted to DARPA for scoring. In a lane consisting of TMA5 AT mines (plastic cased, containing TNT), the best sensor performance recorded was a probability of detection (Pd) of 0.89, with a probability of false alarm (Pfa) of 0.27.
Although the Nomadics ERC sensors are highly sensitive, it remains that the explosives being detected have been released and hence, are not necessarily tightly associated with the land mine. Environmental factors that propagate explosive chemical flux from the land mine also contribute to the diffusion of the chemical away from the buried land mine, making precise location of a buried target challenging. It may be more beneficial to the user community for near-term payoff to reinvestigate their employment to detect general areas of explosives contamination, such as for mine field area reduction, portal or perimeter security. The use of the Nomadics ERC sensors to specifically locate a buried land mine has potential but will require additional time for research and development and may involve probing of soils near the target.

Related Publications

1. **Title**: M. Fisher, M. laGrone, C. Cumming, E. Towers, Nomadics, Inc., Utilization of Chemical Vapor Detection of Explosives as a Means of Rapid Minefield Area Reduction, http://www.nomadics.com/
2. **Title**: M.E. Fisher, M. Prather and J.E. Sikes, Serial Amplifying Fluorescent Polymer arrays for Enhanced Chemical Vapor Sensing of Landmines, EUDEM2-SCOT 2003, International Conference on Requirements and Technologies for the Detection, Removal and Neutralization of Landmines and UXO; H. Sahli, A.M. Bottoms, J. Cornelis (Eds.), Volume I, pp.174-181
3. **Title**: Nomadics Inc., Explosive-related Chemical Sensors for the Detection of Gunpowders in Improvised Explosive Devices, http://www.nomadics/com
4. **Title**: M. Fisher, J. Sikes and K. Schultz, Nomadics, Inc., REST Sampling: Landmine Detection Using a Fido Device, Issue 7.3, December 2003 Journal of Mine Action.
Abstract: Once a landmine is deployed, a complex process begins in which the environment near the mine becomes contaminated with explosives and explosive-related compounds (ERCs) derived from the charge contained in the mine. It has been known for decades that mine detection dogs can detect the chemical vapor signature of explosives emanating from landmines[49]. More recently, detection of landmines by vapor-phase sensing of key chemical signature compounds using ultra-sensitive chemical sensors has been demonstrated. As part of the Defense Advanced Research Projects Agency's (DARPA's) Dog's Nose Program, Nomadics Inc., first demonstrated chemical vapor detection of landmines using an electronic vapor sensor in 1998. This sensor, known as Fido, utilizes novel fluorescent polymers to detect ultra-trace concentrations of explosives (TNT) and other nitro-aromatic compounds emanating from landmines. The sensor has recently been adapted to enable analysis of modified REST filters. Using the REST methodology, Nomadics and Mechem Division of Denel (Pty), Ltd., participated in testing of the Fido sensor and the Mechem Explosive and Drug Detection System (MEDDS) system as a tool for minefield area reduction. This work, funded by the U.S. Army Night Vision and Electronic Sensors Directorate (NVESD) Humanitarian Demining (HD) Program, enabled comparison of the Fido sensor with canines as a tool for minefield area reduction. While more testing is needed, the initial results were promising. From July 2001 to August 2003, Nomadics and Mechem performed a series of trials at a test minefield in Europe. This effort tested the ability of both the Nomadics and Mechem trace chemical vapor collection and analysis systems in detecting the presence of mined areas within a larger area clear of landmines.

[49] R.V. Nolan and D.L. Gravitte, "Mine Detecting Canines." Report 2217, U.S. Army Mobility Research and Development Command, 1977.

6 Bulk Explosive Detection Systems: Nuclear Quadrupole Resonance

6.1 Sensing Principle

Nuclear Quadrupole Resonance (NQR), a derivative of NMR, is a bulk inspection technology which can be used to detect certain chemical elements which have an electric quadrupole moment. Amongst these is nitrogen-14 (^{14}N) and nitrogen is a constituent of explosives used in landmines, such as RDX and TNT. NQR has been described as "an electromagnetic resonance screening technique with the specificity of chemical spectroscopy", as it not only detects, but can be used to identify the exact chemical used. Unlike NMR where a powerful external magnetic field is needed, quadrupole resonance takes advantage of the material's natural electric field gradient, i.e. the electrical gradients available within the asymmetrical molecule itself. These gradients are due to the distribution of the electrical charge and do therefore strongly depend on the chemical structure (they will be different for RDX, for TNT, etc.). When a low-intensity RF signal of the correct frequency is applied to the material, usually in the range 0.5 to 6 MHz, the alignment of the ^{14}N nuclei can be altered. After the RF stimulation is removed, the nuclei can return to their original state, producing a characteristic radio signal. The signal can be detected using a radio receiver and be measured for analysis of the compounds present. Detecting the presence of explosives becomes similar to tuning a radio to a particular station and detecting the signal, and the uniqueness of a molecule's electric field allows NQR technology to be highly compound specific. This high selectivity is partly a disadvantage, as it is not straightforward to build a highly specific multichannel system necessary to cover a wide range of target substances, and the precise frequencies drift with temperature.

The impossibility of detecting substances fully screened by metallic enclosures (also foils, depending on their thickness) is an issue for NQR. However, the presence of such metallic objects can be detected by the detuning effect on the NQR probe. It may also still be possible to detect explosives in imperfectly shielded objects, e.g. within metallic containers having holes or slots or other regions where there are poor electrical connections (possibly even some UXO!), but this will result in a correspondingly weaker NQR signal. Practical applicability is therefore likely to be an issue which requires extensive testing. Detection times are likely to be higher than a few (tens of) seconds, depending on type and quantity of the target substance (especially on its T_1 relaxation time), and on its distance for one-sided applications, such as buried mine detection, where the suspected mine cannot be put inside a coil. In addition, the signal to noise ratio increases with frequency as $\omega^{3/2}$, which implies that detection becomes much easier with increasing frequency and hence *detection of (low-frequency) TNT is much harder than detection of RDX* - for which NQR has already been confirmed as very promising. Signals are in general rather weak, so that some form of signal averaging is usually necessary - as well as shielding and active cancellation of interference, because the detector will work, in the case of TNT, within the AM (medium wave) broadcasting band! Spurious signals have also been reported due to "*acoustic ringing*" effects (due to certain metals and metal coatings), as well as due to *piezoelectric responses* from silica in the soil (for applications such as landmine detection). All these effects are being tackled using appropriate pulsing sequences and detection software, as well as specific hardware. Care will have also to be taken of the temperature dependency of the spectral lines, selecting for example those NQR transitions which are least affected by temperature changes (e.g. 3.410 MHz line instead of 5.192 MHz for RDX). TNT also presents further problems due to TNT cast in mines usually being a solid solution of different crystalline forms, which can affect the characteristic frequency response.

Blind tests in the USA have demonstrated that NQR is close to readiness for field testing, for use as a confirmation detector for shallow-buried plastic-cased anti-tank mines containing kilograms of explosive. Application for buried anti-personnel mines with only 100g of explosive, or less, still appears to be extremely elusive for TNT, though research is continuing in several countries. As electronic systems become cheaper and more powerful it may be possible to substantially improve performance in the future. In the RAND report, referring to NQR it is stated that "Detectability of RDX and tetryl is rather good by NQR, but for TNT the NQR relaxation times are less favourable, and the possible presence[50] of two crystalline polymorphs (monoclinic and orthorhombic) lead to weaker TNT signals. Finding small (50 g) anti-personnel TNT mines by NQR will be difficult, but is not ruled out. RDX and tetryl mines are much easier to find"[51].

[50] G. R. Miller and A. N. Garroway, A Review of the Crystal Structures of Common Explosives, Part I: RDX, HMX, TNT, PETN, and Tetryl, NRL Memorandum Report NRL/MR/6120-01-8585, October 15, 2001.
[51] J. MacDonald, *et al.*, Alternatives for Landmine Detection, RAND Science and Technology Policy Institute, Report MR-1608, 2003, A.N. Garroway, Appendix K. Nuclear Quadrupole Resonance (Paper II), p. 186.

Related Publications

1. **Title:** J. MacDonald, *et al.*, Alternatives for Landmine Detection, RAND Science and Technology Policy Institute, Report MR-1608, 2003.
2. **Title:** C. Bruschini, Commercial Systems for the Direct Detection of Explosives (for Explosive Ordnance Disposal Tasks), ExploStudy, Final Report, Feb. 2001, http://diwww.epfl.ch/lami/detec/explostudy.html, http://www.eudem.info
3. **Title:** Proceedings, Expert Workshop on Explosive Detection Techniques for Use in Mine Clearance and Security Related Applications, 2-4 June 2003, Bled Lake, Slovenia, European Commission, Directorate General Joint Research Centre; International Trust Fund for Demining and Mine Victim Assistance, http://demining.jrc.it/aris/events/slovenia/PROCEEDINGS.pdf
4. **Title:** C. Bruschini, K. De Bruyn, H. Sahli, J. Cornelis, EUDEM: The EU in Humanitarian Demining - Final Report, July, 1999, http://www.eudem.info
5. **Title:** J. Yinon, Forensic and Environmental Detection of Explosives, 1999, John Wiley and Sons, ISBN 0-471-98371-0.

6.2 Quantum Magnetics QRCS[52]

Project Identification

Project name	Quadrupole resonance confirmation sensor – vehicle based
Acronym	QRCS
Participation Level	National
Financed	U.S. Army and U.S. Navy (for the Marine Corps), with additional support from DARPA
Budget	
Project Type	Basic and Applied Research, Prototyping
Start date	1997
End date	on-going

Contact Person

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Project Web: http://www.qm.com

Project Description

Quantum Magnetics asserts that on-going development efforts will lead to products for both military and humanitarian demining applications. Quantum Magnetics' efforts have been supported by the U.S. Army and U.S. Navy (for the Marine Corps), with additional support from the Defense Advanced Research Projects Agency (DARPA). At this point, QM does not have any landmine detection systems that have reached a prototype stage comparable to the MINEHOUND (ERA), AN/PSS-14 (CYTERRA) or FIDO (Nomadics). It does however have on-going programs to develop mine detection sensors that incorporate QR detection. Efforts to date have focused on military countermine systems as opposed to humanitarian demining. Projects include a vehicle mounted system and a handheld QR/GPR/MD system. In what follows we describe the system developed for the detection of anti-tank and anti-vehicle landmines.

Involved Technology Related Activities

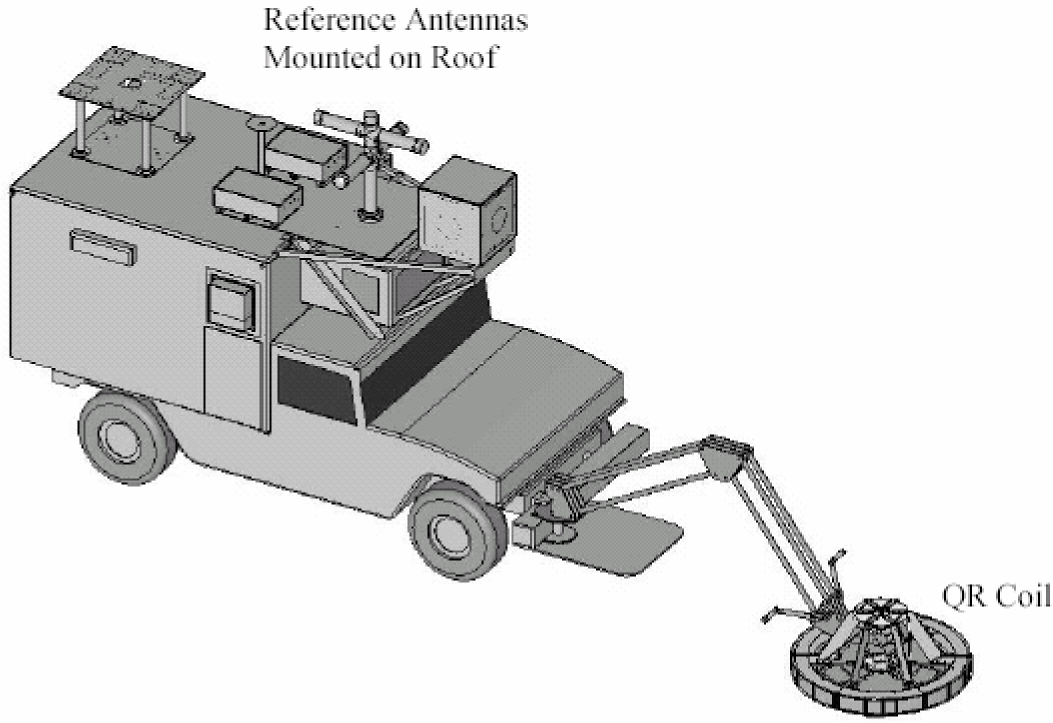
Name Type	NQR
Readiness level	6[53]
Company/Institution	Quantum Magnetics, Inc.

[52] This description was prepared with the co-operation of Geoffrey A Barrall, Quantum Magnetics, Inc.

[53] Opinion of EUDEM2 based on its own analysis.

Detailed Description of the prototype/product

Technical Specifications: QRCS vehicle based



Picture courtesy of Quantum Magnetics Inc.

QR target specification

Weight	**90 kg**
Head x-axis	**120 cm**
Head y-axis	**120 cm**
Head z-axis (height)	**10 cm**
Depth range	**Nominally up to 20 cm overburden**
Environmental conditions	**Typical military requirements**
Probability of detection	**>95%**
Probability of false alarm	**<5%**
Reduction of number of site neutralizations	**factor of 20-25**
Transmitted power	**45 kW**
Power consumption	**200 watts during 24 hrs continuous operation**
Supply voltages	**Compatible with all vehicle electrical/charging systems**
QR System Weight	**< 65 kg**

Note: These specifications refer to the low size, power and weight system currently under development at Quantum Magnetics

Test & Evaluation

Following results have been published by Quantum Magnetics[54]: "During 2002, the QRCS performed in two government supervised blind tests. The first test was conducted in an arid environment and the second in a temperate environment. In both tests, locations were marked on the ground over blank sites and sites with a buried mine. The halo or offset from the mark to the edge of the mine was up to 25 cm in order to simulate inaccuracy in the location provided by the primary sensor. The distribution of offsets was Gaussian with a 13 cm standard deviation and a 0 cm bias. The maximum distance to the center of the mine was ~40 cm assuming a typical AT mine diameter of ~30 cm.

The actual halo of the primary sensor may ultimately prove to be smaller than 25 cm. The depths of the mines in the arid test were varied with a soil overburden (shortest distance from the soil surface to any part of the mine) ranging from 2.5 cm to 12.5 cm. In the temperate test, the soil overburden was fixed at 7.5 cm. Mines buried at both sites contained either a Comp B (an explosive consisting of ~60% RDX and 40% TNT by weight) or TNT main charge. The mass of the Comp B charges ranged from 2 to 10 kg and the TNT charges ranged from 5 to 8 kg. The total scan time at each marker was ~25 s. Reduction in the scan time by ~5 s is immediately possible by interleaving the RDX and TNT scans. The TNT scans are composed of multiple applications of a short pulse sequence or echo train. The duration of each echo train is of order 100 ms with ~5 s between echo trains. Both durations are dependent upon the estimated temperature of the explosive. The current system performs the entire 20 s TNT scans (~4 echo trains with 5 s separation between each) followed by a 3-6 s RDX scan. Simple modification to the system will allow for implementing the RDX between the individual TNT echo trains."

The results from these tests are presented later in the same article as follows:

Test Location	PD [90% Confidence Limit]	PFA [90% Confidence Limit]	# of Markers
Arid Test Site	0.98 [0.95, 1.00]	0.04 [0.02, 0.07]	312 Temperate Test Site
Temperate Test Site	0.98 [0.90, 1.00]	0.04 [0.02, 0.10]	134

Since the tests in 2002 Quantum Magnetics reported that it has implemented methods to improve RFI immunity due to the presence of large radio frequency interference in the frequency bands of interest, as well as to cancel piezoelectric ringing generated in the very near field of the QR coil. Further tests were carried out in 2003 at the same test site as in 2002, under largely similar conditions although temperatures were slightly higher and the scan time was approximately 29 s.

In the same articles as above (pp.11-12) Quantum Magnetics reports that: "RDX performance is exceptional, overall performance is nearly identical night or day, but TNT performance (in 2003) is well below that demonstrated in 2002......The improvements in ringing rejection and RFI immunity acted to reduce the TNT sensitivity in the 2003 blind tests. Reversing this effect is achieved most simply by increasing the scan time to compensate for losses incurred by individual system modifications." During 2004, substantial sensitivity improvements were made to restore the TNT performance. This work is to be presented at the SPIE Defense and Security Symposium, Florida, in March 2005.

a) Cost: TBD
b) Other applications (non demining): security applications e.g. baggage screening

Related Publications

1. **Title**: C. Williams, P. V. Czipott and L. J. Burnett, Quantum Magnetics Targets Landmine Explosives Using Quadrupole Resonance, http://maic.jmu.edu/journal/5.2/features/quantum.htm
2. **Title**: G. A. Barrall, L. J. Burnett*, K. A. Derby, A. J. Drew, K. V. Ermolaev, S. Huo, D. K. Lathrop, T. R. Petrov, M. J. Steiger, S. H. Stewart, and P. J. Turner, Nuclear Quadrupole Resonance for Landmine Detection, 2004, Military Sensors Symposium in Dresden, Germany

   Abstract: Quantum Magnetics has developed a Quadrupole Resonance (QR) system for the detection of anti-tank and anti-vehicle landmines. The QR confirmation sensor (QRCS) is a part of the U.S. Army GSTAMIDS Block 1 Program and is designed to confirm the presence of landmines initially flagged by a primary sensor system. The ultimate goal is to significantly reduce the number of sites that require neutralization or other time consuming investigation into the presence of a landmine. Government tests in 2002 and 2003 demonstrated the performance of the system in a wide variety of conditions including high radio frequency interference (RFI) and piezoelectric ringing (PER) environments. Field test results are presented, along with an overall description of the system design and methods used to solve prior issues with RFI and PER.

[54] G. A. Barrall, L. J. Burnett*, K. A. Derby, A. J. Drew, K. V. Ermolaev, S. Huo, D. K. Lathrop, T. R. Petrov, M. J. Steiger, S. H. Stewart, and P. J. Turner, Nuclear Quadrupole Resonance for Landmine Detection, Military Sensors Symposium in Dresden, Germany 2004, p. 3.

7 Bulk Explosive Detection Systems: Fast Neutron Methods

7.1 Sensing Principle

Fast neutron systems offer **bulk detection methods** capable of identifying a wide range of explosives and also chemical weapons. For field deployment there are significant difficulties relating to cost, power consumption, the size and weight of dense shielding required, safety, sensitivity and the practicalities of deployment. For adequate sensitivity expensive detectors and high intensity neutron generators must be used. Such generators may fall into the category of equipment subject to restriction under the International Nuclear Non-proliferation Agreements.

Fast Neutron Analysis (FNA) is based on the interaction of fast neutrons, mostly by inelastic neutron scattering, with the elements of interest, principally carbon, nitrogen and oxygen of explosives and soils, and chlorine in some chemical weapons. During irradiation, the high energy neutrons can put nuclei of these elements in excited, short lived states. The nuclei return to their initial state by emitting radiation, often gamma radiation whose wavelength (and hence, energy), or spectrum, reflects the chemical characteristics of each nucleus. By detecting and measuring a range of the outgoing gamma rays it is possible to calculate the elemental proportions – how much of each element (C, N, O) is present with respect to the others – and this permits the determination of the type of substance under analysis. All military explosives used in mines are composed of Carbon, Nitrogen, Oxygen and Hydrogen (which is not detectable by pure FNA) in known proportions. Usually in FNA, the radiation detected is the "prompt" gamma radiation, a direct result of the neutron irradiation and occurs immediately or very soon after irradiation FNA has therefore the potential of delivering better results than TNA (Thermal Neutron Analysis), because it is *sensitive to nearly all elements in explosives* and opens the possibility of identifying the substance under analysis, but is usually far more complex and expensive. *The resulting γ-ray spectra can indeed be quite complex* as numerous nuclear levels are often excited, and in the case of buried objects there is also a complex spectral background due to soil.

Pulsed Fast Neutron Analysis (PFNA): Pulsed operations allow the use of timing information which can be useful for reducing the influence of background radiation from neutron interactions with the soil. Pulsed operations are particularly interesting when using *very short fast neutron pulses* (typically nanosecond wide, 10^{-9} sec) - which is short compared to the flight time across the object to be analysed. In this case the neutrons have to be as monoenergetic as possible since they have to travel at the same speed. Given these conditions, **Time-Of-Flight (TOF)** techniques can be used to determine the location of the detected material; the measurement start time is given when the neutron pulse is created, and the stop time when the γ-rays are recorded (the γ-rays travel at the speed of light, much faster than the neutrons). Thus the distance from the neutron source to the point where the gamma rays are emitted can be calculated from the time of flight, and conversely gamma radiation from objects not at the point of interest can be ignored. Up to now this technique has required rather large installations to produce a neutron beam of the required characteristics, combined with the need for fast electronics and very sensitive and discriminating detectors.

Pulsed Fast-Thermal Neutron Analysis (PFTNA) represents yet another form of neutron based explosive detection system. In a typical PFTNA setup a neutron generator produces microsecond wide fast neutron pulses, e.g. 14 MeV neutrons from a D-T generator. During these pulses, and possibly also shortly thereafter, prompt γ-rays resulting from fast neutron inelastic scattering reactions (and nuclear reactions) are measured, in particular to identify carbon and oxygen. The accelerator is then kept off for a time of about 100 microseconds, and during this interval the neutrons which have been thermalised by water in the soil, and by low atomic mass elements in the mine case and the explosive itself, can interact with the soil and buried objects. Prompt γ-rays resulting from neutron capture reactions can be measured as in TNA (q.v.), in particular for the detection of nitrogen. The cycle then starts again. A longer pause can also be exploited (a few msec).

Other neutron based techniques, such as Associated (Alpha) Particle - Time-of-Flight Neutron Analysis (API-TOF), are covered in more detail in the specialist literature. Fast (Pulsed) Neutron systems represent a **bulk explosive detection technique**, allowing the direct detection of a macroscopic mass of explosive material.

System Configuration: Neutron analysis systems could typically be combined with other sensors, and used in a confirmatory role. Amongst the drawbacks of pulsed neutron systems are, as noted above, system complexity and cost, radiation hazard and other safety issues, system weight (especially due to heavy shielding), power requirements and potential misuse of stolen intense neutron generators by nuclear terrorists. Depth of penetration also has to be carefully assessed, as well as minimum amount of detectable explosive. It remains to be established if such a system will be practical and fieldable, and if the added performance will be sufficient to justify the extra costs even in specialist applications.

Related Publications

1. **Title:** J. MacDonald, *et al.*, Alternatives for Landmine Detection, RAND Science and Technology Policy Institute, Report MR-1608, 2003.
2. **Title:** C. Bruschini, Commercial Systems for the Direct Detection of Explosives (for Explosive Ordnance Disposal Tasks), ExploStudy, Final Report, Feb. 2001, http://diwww.epfl.ch/lami/detec/explostudy.html, http://www.eudem.info
3. **Title:** Proceedings, Expert Workshop on Explosive Detection Techniques for Use in Mine Clearance and Security Related Applications, 2-4 June 2003, Bled Lake, Slovenia, European Commission, Directorate General Joint Research Centre; International Trust Fund for Demining and Mine Victim Assistance, http://demining.jrc.it/aris/events/slovenia/PROCEEDINGS.pdf
4. **Title:** C. Bruschini, K. De Bruyn, H. Sahli, J. Cornelis, EUDEM: The EU in Humanitarian Demining - Final Report, July, 1999, http://www.eudem.info
5. **Title:** J. Yinon, Forensic and Environmental Detection of Explosives, 1999, John Wiley and Sons, ISBN 0-471-98371-0.

7.2 Nanosecond Neutron Analysis System[55]

Project Identification

Project name	Portable device for detection of explosives and other hazardous substances, based on nanosecond neutron analysis (NNA).
Acronym	not applicable
Participation Level	International
Financed	U.S. Civilian Research & Development Foundation (CRDF), Virginia, The Foundation for Assistance to Small Innovative Enterprises (FASIE), Moscow, APSTEC Ltd., St. Petersburg
Budget	$400,000
Type	Full-size prototype
Start date	2003
End date	2005

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Project Web: not available

Project Description

The objective of this project is to develop and manufacture a prototype portable device for non-intrusive detection of explosives and other hazardous substances. The key idea of the project is to modify the well-established “neutron-in – gamma-out” technique to achieve more than an order of magnitude reduction of the identification time compared to the existing analogues. Unlike these analogues, the proposed device uses a neutron source based on a portable neutron generator with a new type of a built-in position-sensitive detector of alpha particles that accompany neutron emission in the t(d,n) reaction. The main idea of the method – Nanosecond Neutron Analysis (NNA) – is to suppress the background that is unrelated to the inspected area by imposing several conditions on the data acquisition system. NNA is a further development of the Associated Particle Technique (APT). It works as follows:

A) Secondary gamma rays born in the (n,n’γ) reactions of primary 14 MeV neutrons with the material of the inspected object are detected within a very narrow (few nanoseconds wide) time window, which is counted from the moment of emission of each neutron from the neutron generator. This moment is in turn determined by detecting alpha particles that accompany neutron emission in the D+T reaction. Neutrons from the D+T reaction have energy of about 14 MeV and velocity of about 5 cm/ns, and it takes them some time to reach the inspected area. There they produce prompt gamma rays, which travel at the speed of light to the gamma detector (BGO- or NaI-based). Any gamma rays that are detected before the “tagged” neutron can reach the object, or after it leaves the inspected area, are unrelated to the physical process of interest, and are rejected by the data acquisition system.

B) A position-sensitive alpha detector that is built into the portable neutron generator provides information about the position at which each neutron, “tagged” by the associated alpha particle, has interacted with the material of the inspected object. The direction of the alpha particles correlates with that of the neutrons, since they are products of a binary D+T reaction. If a gamma ray arrives at the gamma detector, but no alpha particle is detected, then this gamma ray is produced somewhere outside the area of interest, and is rejected. Such filtering of events allows one to improve effect-to-background (signal-to-noise) ratio by about two orders of magnitude compared to traditional “neutron in, gamma-out“ methods.

Involved Technology Related Activities:

Technology Type	nanosecond neutron analysis
Readiness level	7[56]
Company/Institution	Applied Physics Laboratory, V.G. Khlopin Radium Institute, St. Petersburg; APSTEC Ltd., N.L. Dukhov All-Russian Research Institute of Automatic (VNIIA)

[55] This description was prepared with the co-operation of Andrey Kuznetsov, Applied Physics Laboratory, V.G. Khlopin Radium Institute, St. Petersburg.

[56] Opinion of EUDEM2 based on its own analysis.

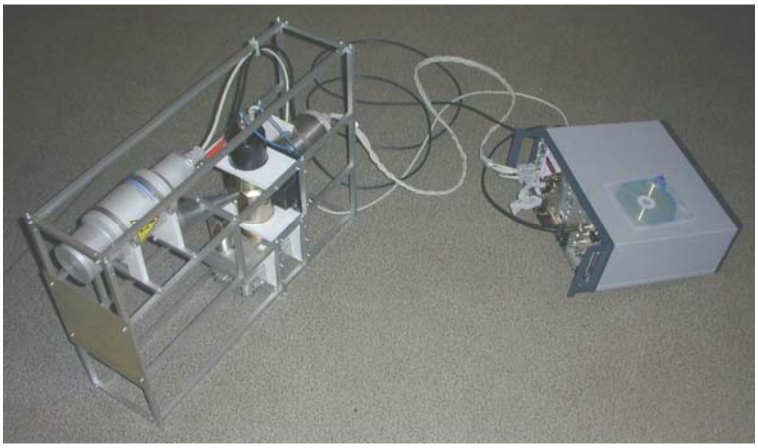
Detailed Description of the prototype/product

The device is based on the Nanosecond Neutron Analysis (NNA) and the Associated Particle Technique (APT), which provide a 3D imaging of the elemental composition of the inspected volume. NNA/APT rely on measuring secondary radiation (gamma or neutron) induced in the inspected volume by fast neutrons. The secondary radiation is measured in very narrow (nanosecond-range) time "windows" counted from the time of emission of each primary neutron from the neutron source – a portable neutron generator with built-in position-sensitive detector of associated alpha particles. The emission time and direction of each emitted neutron are determined by detecting the associated alpha particle, which originated from the same d+t-->n+α reaction and flies in a direction opposite to that of the neutron. NNA/APT allows one to obtain the distribution of partial densities of different chemical elements in the inspected volume. Knowing the elemental composition of the inspected object, one can compare the measured ratios of light elements with those of known threat materials. For example, certain ratios, such as C/O and O/N, are specific for high explosives. The proposed NNA/APT approach for a mobile device can also serve as a basis for the creation of a stationary installation for the inspection of sea containers and other cargo.

In the present version the prototype NNA device consists of the following components:

1. **Measurement module:**
   a. **a portable neutron generator with built-in nine-segment semiconductor detector of associated alpha particles**
   b. **BGO-based detector of gamma rays;**
2. **Electronics:**
   a. **ultra-fast data acquisition system based on digital signal processing**
   b. **control and data analysis electronics**
   c. **power supplies and batteries.**

In the commercial version both components will be combined in a single unit. The prototype is shown in the figure below.



Technical Specifications: Nanosecond Neutron Analysis device		
	Prototype	Production (target)
Measurement module		
▪ Weight ▪ Dimensions	18 kg 80 x 52 x 31 cm	< 25 kg to be determined
Electronics		
• Weight • Dimensions	12 kg 63×50×22 cm^3	will be combined with the measurement module
Max. generator intensity	3x10^7 14 MeV neutrons per sec. into 4π	10^8 14 MeV neutrons per sec. into 4π
Secondary characteristic gamma rays detector	Scintillation detector based on BGO crystal (dimensions: ∅6.1×6.1 cm^3)	One or several BGO- or NaI-based detectors
Detectable explosive	100g in 60-120 seconds	100g in 60 seconds
Simultaneously inspected area	30×30×30 cm^3	to be determined
Spatial resolution	10 cm in-plane, 10-15 cm in-depth	better than 10×10×10 cm^3
Battery power	3 hours of autonomous work	according to user requirements
Radio controls	Bluetooth	at distances up to 200 m
Vacuum tube lifetime	over 10,000 measurement cycles	over 30,000 measurement cycles
Radiation safety	safe when switched-off	safe when switched-off
Operator operational safety distance	7m	according to user requirements

Test & Evaluation

- Test & Evaluation: laboratory tests completed, field tests planned
- Cost: $300,000 (planned for commercial version)
- Other applications (non demining): general security, antiterrorism.

Related Publications

1. **Title**: A.V. Evsenin, A.V. Kuznetsov, O.I. Osetrov, D.N. Vakhtin, Detection of Hidden Explosives by Nanosecond Neutron Analysis Technique. H. Schubert, A. Kuznetsov (Eds.), Proc. of the NATO ARW #979920 “Detection of bulk explosives: advanced techniques against terrorism”, St.-Petersburg, Russia, 16 – 21 June 2003. Kluwer Academic Publishers, NATO Science Series, Series II: Mathematics, Physics and Chemistry – Vol.138, 2004.
   Abstract: The main idea of the nanosecond neutron analysis (NNA) technique is to irradiate an unknown object or “suspicious” area with neutrons from isotopic sources or portable neutron generators, and to simultaneously measure secondary gamma-radiation induced by neutrons in the object and charged particles that accompany neutron emission from the source. The latter allows one to use “marked” neutrons and to carry out detection of secondary gamma radiation in narrow (nanosecond) time intervals, thus considerably reducing the identification time. By using position-sensitive detectors of the accompanying alpha particles one can obtain a 3D elemental image of the inspected volume and identify explosives (by elemental content) hidden inside large volumes of metallic, organic or other material. Existing prototypes of portable devices for bulk explosive detection, based on a portable neutron generator with a built-in 9-segment position-sensitive detector of the accompanying α-particles, are described.

8 Involved Organizations

This section includes the contact details and short descriptions of most of the organizations appearing in this *Catalogue*.

AEL (Applied Electromagnetics) FGE Ltd

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Organization Web: http://www.fges.demon.co.uk

Organization Details: AEL is a working division of Fluid Gravity Engineering Ltd. (FGE) and as such conforms to the QA standards (ISO 9001) of FGE. The main business of AEL/FGE is computational physics and the modelling of complex wave propagation and scattering effects. The company has extensive experience in the development and use of numerical techniques for electromagnetic scattering and antenna calculations, particularly in broad-band frequency environments.

Applied Physics Laboratory, V.G. Khlopin Radium Institute

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Applied Physics Laboratory
V.G. Khlopin Radium Institute
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Contact Person

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Organization Web: not available

Organization Details: Developer of the GPR and NNA devices appearing in this *Catalogue.*

APSTEC Ltd

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Organization Web: not available

Organization Details: Producer of multi-pixel detector of associated particles for work in static vacuum, used with the NNA device developed by the Applied Physics Laboratory, V.G. Khlopin Radium Institute.

Biosensor Applications Sweden AB (publ)

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Contact Person

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Organization Web: http://www.biosensor.se

Organization Details: Biosensor Applications AB has identified and developed a biotechnology solution which analyses vapour and particle trace chemicals with high accuracy, with simplicity of operation and acceptable operational speed. The solution is based on a quartz crystal microbalance sensor with antibody/antigen weight loss technology.

CyTerra Corporation

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Organization Web: http://www.cyterracorp.com

Organization Details: CyTerra describes itself as creating innovative security solutions by capitalizing on its team's decades of experience and by applying cutting-edge technology, and further that its scientists and engineers have been at the forefront of critical areas such as explosives and land mine detection, trace detection, and counter-terrorism technology for more than 20 years. The CyTerra team of seasoned engineers and scientists are trained in physics, chemistry, ultra-trace detection, thermodynamics, Radio Frequency (RF) design, radar, electronics, software and materials science.

DEMIRA e.V. (NGO)

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Organization Web: http://www.demira.org

Organization Details: Demining organization.

DLR - Deutsches Zentrum für Luft- und Raumfahrt e.V. (Research Centre)

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Project Web: http://www.dlr.de

Organization Details: The DLR Microwaves and Radar Institute is engaged in the concept and realisation of innovative passive and active microwave systems and performs theoretical, experimental and practical research work in the field of microwave technology, wave propagation and radar backscattering modelling.

ERA Technology Ltd

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Organization Details: ERA Technology works at the leading edge of many advanced technologies. The business was founded in 1920 and today provides specialist, high value-added, technology-based services including design and development, testing, assessment and expert advice. The company has built an international reputation for technical expertise through constant innovation at the leading edge of technology. ERA's services reduce technical and commercial risk, improve the operational performance of engineering infrastructure assets, and enhance the competitiveness of products and systems. ERA is organised into business units working across industries such as communications, aerospace, defence, IT, manufacturing, transport, electronics and energy. ERA Technology is a Chelton Group company, part of Cobham plc.

GTD, Ingenieria de Sistemas y Software Industrial S.A.

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Organization Details: Since its foundation in 1987, GTD has consolidated its position as a leading, private Spanish provider of System and Software Engineering for both the national and international markets. GTD operates in the roles of main contractor or sub-contractor or essential services provider in high value and profile projects and programs related with industry, science, aerospace, defence and telecommunications.

Guartel Technologies Limited

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Organization Web: http://www.guartel.com

Organization Details: Guartel Technologies Ltd designs, develops and manufactures metal mine detectors and a range of security and protection equipment. The company's products are currently in-service with police forces, security services, NGOs, the UK MoD and other military forces world-wide. The company employs both military (EOD) and technical staff within the company and has considerable operational and technical expertise in all areas of mine detection, specialist electronics and security & protection[57].

[57] http://www.guartel.com

IDS, Ingegneria dei Sistemi SpA

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Organization Details: IDS aims to provide high technology services in civil and defence areas as well as SW-HW system solutions aimed at specific agency needs (Aeronautical, Space, Telecom, etc.). IDS produces and sells a family of GPR products specifically made for a wide number of applications ranging from mapping of underground utilities, structural analysis for civil engineering, to geology and archaeology.

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Organization Web: http://www.foerstergroup.de

Organization Details: Metal detector manufacturer, the MINEX 2FD (two-frequency differential continuous wave system). Detection, localisation and mapping of unexploded ammunition, explosives and chemical pollutants in ferromagnetic containers or with ferromagnetic constituents with the FEREX magnetometers.

MEODAT, Messtechnik, Ortung und Datenverarbeitung GmbH

Address

MEODAT, Messtechnik, Ortung und Datenverarbeitung GmbH
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Organization Web: http://www.meodat.com

Organization Details: MEODAT is specialised in three technology fields:

- High frequency sensors (Ultra Wideband Radar, UWB, M-Sequence),
- Digital Signal Processing with special processors, and
- Automatic position measurement, preferably using the Global Positioning System (GPS).

Its strategy is to develop and produce adapted sensors for special applications with focus on ultra wideband applications. The M-Sequence technique can be optimised without modifications on the RF chip for parameters such as: cost, power consumption, dynamic range and acquisition rate. In contrast to existing SPR systems the sensor allows the construction of large sensor arrays with low costs.

MgM - Menschen gegen Minen (NGO)

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Organization Web: http://www.MgM.org

Organization Details: MgM is an NGO carrying out humanitarian demining and active in supporting the development of new technology and methods for humanitarian demining.

NPA - Norwegian People's Aid

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Organization Web: http://www.npaid.org

Organization Details: Norwegian People's Aid (NPA) has been involved in mine action since 1992. NPA is presently working in ten different mine affected countries and has altogether been operational in 16 countries in Africa, Asia, the Middle East, and Europe. NPA is participating to several research projects.

Nomadics Inc.

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Organization Web: http://www.nomadics.com/

Organization Details: Nomadics, Inc. develops advanced sensors, instrumentation, and mobile technology products. Its target markets include defense and security, medical, environmental, chemical analysis, and general industry. Using novel amplifying fluorescent polymers engineered by Nomadics´ research partners at MIT, sensors are developed that are very sensitive and selective for chemical detection applications. First implemented to help solve the extremely difficult task of detecting trace vapors that emanate from landmines, the sensors form a technology platform capable of detecting part per quadrillion levels of explosives, herbicides, pesticides, chemical/biological agents, illicit drugs and other chemicals of interest[58].

[58] http://www.nomadics.com

N.L. Dukhov All-Russian Research Institute of Automatic (VNIIA)

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Organization Web: not available

Organization Details: Commercial producer of the portable neutron generator used by the NNA device developed by the Applied Physics Laboratory, V.G. Khlopin Radium Institute.

PipeHawk plc

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Organization Web: http://www.pipehawk.com

Organization Details: PipeHawk plc was formed and floated on the AIM market of the London Stock Exchange in 2000. from Its predecessor EMRAD Ltd. The company provides a centre for GPR commercial developments, with the parent company providing the technology. The two successful commercial developments established are Adien Ltd and SUMO, both working in the utility sector. Adien Ltd provides high level underground mapping services to planners of street works. SUMO is a franchise operation, jointly owned with Franchise Concepts. They provide "mark out" services to utility contractors often immediately ahead of excavation. The concept is a man, a van and a radar and the franchise is targeted upon providing geographically coverage for the service. Currently there are ten franchises in the UK. In recent years the company's technical activities have been focused on the development of high performance vehicle systems for various applications including mine detection and the development of a hand held radar product for utility detection.

QinetiQ Ltd

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Organization Web: http://www.qinetiq.com

Organization Details: QinetiQ has been structured to facilitate involvement by the private sector. It comprises the greater part of DERA, the British Government's "Defence Evaluation and Research Agency". Until July 2001, DERA was an agency of the UK Ministry of Defence, incorporating the bulk of the MoD's non-nuclear research, technology and test and evaluation establishments. It then split into two organizations, DSTL and QinetiQ Group plc. DSTL remains part of the MOD and continues to handle the most sensitive areas of research.
Competence areas are divided between the four following main groups:

- Sensors and Electronics
- Future Systems & Technology
- Knowledge & Information Systems
- Integrated Services

Quantum Magnetics, Inc.

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Organization Web: http://www.qm.com/home/index_body.htm

Organization Details: Quantum Magnetics conducts applications-oriented research and development for the commercialization of products based on its quadrupole resonance (QR), magnetic resonance (MR) and electromagnetic sensing technologies. There are four main research and development areas of expertise:

- Detection Technology (Weapons Detection and Explosives Detection);
- Development of Landmine Detection Systems;
- Non-Destructive Sensing Technology;
- Industrial Process Monitoring Applications.

Sensatech Research Ltd

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Organization Web: http://www.sensatech.com

Organization Details: Sensatech Research develops, produces and supplies custom electronic non-contact sensing solutions primarily based on capacitive and electric field sensing techniques[59].

Swedish Rescue Services Agency

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Organization Web: http://www.srv.se

Organization Details: The Swedish Rescue Services Agency is the central Swedish supervisory government authority for the rescue services. Its tasks include examining co-ordination between the various branches of the national rescue services, as well as contingency planning by the county administrative boards for the rescue services in the event of a release of radioactive substances. The agency also collates observations and lessons learned from serious emergencies that have occurred at home and abroad. The Swedish Rescue Services Agency also maintains a state of emergency preparedness to assist other countries with rescue and humanitarian aid operations. It also provides support in the form of Mine Action; part of this work is to support new technology developments for safer and more cost effective demining.

[59] http://www.sensatech.com

Technische Universität Ilmenau

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Organization Web: http://www.tu-ilmeanu.de

Organization Details: The Department of Electrical Engineering and Information Technology at the Technical University of Ilmenau is well known within the community of electrical engineers. The most important emphasis of the sub-department's expertise lies in its wide spectrum of methods for signal processing and signal identification with applications in the area of HF and radio technology as well as acoustics and vibration analysis. Projects including project co-ordination are undertaken at the national and European level. In the search for applications for a new type of broad band measuring head (M-Sequence), interesting discoveries have been made with surface penetrating radar and general purpose ultra wideband radar. The University has been working on these measuring technology problems since 1995, including device technology on printed and integrated circuit level as well as algorithmic problems.

TNO FEL - Netherlands Organization for Applied Scientific Research

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Organization Web: http://www.tno.nl/instit/fel/

Organization Details: TNO-FEL’s mission is to be a corporate laboratory for the Ministry of Defence and the Armed Forces, a strategic partner for other task-oriented organizations and a technological partner for commercial organizations. The two groups involved in electro-optics (electro-optical systems and electro-optical propagation and signature management) support both government and industrial customers in applying electro optical, infrared and laser equipment.

Vallon GmbH

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Organization Web: http//:www.vallon.de

Organization Details: Vallon GmbH is an international operating manufacturer of Metal Detectors (Mine Detectors) and Ferrous Locators (Bomb Locators) for civilian and military applications. A further field of activities based on magnetics is the product range of powerful degaussing systems[60].

Vrije Universiteit Brussel VUB-ETRO

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Organization Web: http://www.etro.vub.ac.be

Organization Details: ETRO (Electronics and Information processing) focuses on three major topics: devices and electronic technology (LAMI), the processing of information through electronic means in fields related to digital images and video (IRIS) and speech (DSSP). The three subunits within ETRO cover a wide range of generic technologies in the field of Information Technology, which cannot be dealt with separately when the real world applications of the "Information society" are envisaged.

[60] http://www.vallon.de

The Weizmann Institute of Science

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Organization Details: The Weizmann Institute is located in Rehovot Israel. It is focused on basic research in the accurate sciences, including Chemistry, Mathematics, Life Sciences, and Physics, and has a Graduate School of 700 students at the graduate level. The faculty and research staff – highly respected internationally – is composed of 1400 scientists and technical members. The Department of Immunology at the Weizmann Institute is a modern, well-equipped research laboratory with access to all the facilities which modern science requires, including the inter-departmental service units of the Faculties of Life Sciences. Prof. Eshhar's laboratory has published over 80 peer-reviewed articles in the field of antibody generation and design over the last 20 years. Its laboratory has broad experience in the generation of monoclonal and recombinant antibodies, their chemical and genetic manipulation.

9 References and Bibliography

Apart from the references cited in the footnotes and sections titled 'related publications' of Sections 3.2 to 7.2, we add hereafter extra references used for producing this document.

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