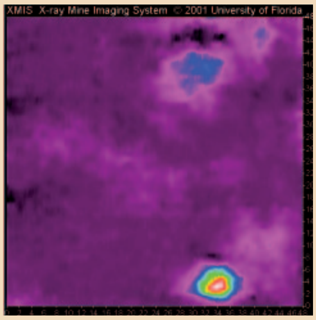
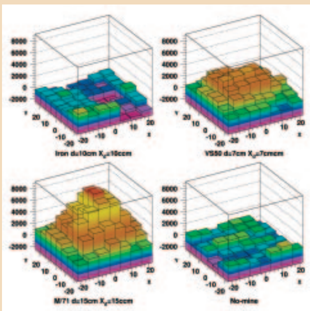
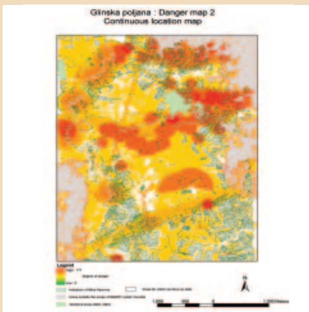
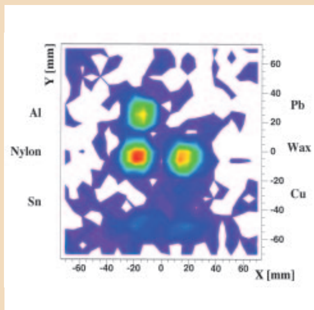
Guidebook on Detection Technologies and Systems for Humanitarian Demining









Geneva International Centre for Humanitarian Demining
Centre International de Déminage Humanitaire - Genève

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The **Geneva International Centre for Humanitarian Demining** (GICHD) supports the efforts of the international community in reducing the impact of mines and unexploded ordnance (UXO). The Centre provides operational assistance, is active in research and supports the implementation of the Anti-Personnel Mine Ban Convention.

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Contents

Acknowledgements

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All individual system descriptions have been drafted in co-operation with the contact persons listed in the Involved organisations annex, or provided by them and reviewed by the editorial team. All images and illustrations have been provided by the respective organisations.

Foreword

The aim of this publication is to provide the mine action community, and those supporting mine action, with a consolidated review and status summary of detection technologies that could be applied to humanitarian demining operations. This *Guidebook* is meant to provide information to a wide variety of readers. For those not familiar with the spectrum of technologies being considered for the detection of landmines and for area reduction, there is a brief overview of the principle of operation for each technology as well as a summary listing of the strengths, limitations, and potential for use of the technology to humanitarian demining. For those with an intermediate level of understanding for detection technologies, there is information regarding some of the more technical details of the system to give an expanded overview of the principles involved and hardware development that has taken place. Where possible, technical specifications for the systems are provided. For those requiring more information for a particular system, relevant publications lists and contact information are also provided.

A significant feature of this *Guidebook* is the assignment of a technology readiness level which is an assessment of how close the system is to actual deployment into mine action operations. How this assessment is determined is explained in Chapter One.

The Geneva International Centre for Humanitarian Demining wishes to acknowledge the valuable assistance provided by the European Union in Humanitarian Demining project (EUDEM2, *www.eudem.info*) in the publication of this *Guidebook*. Much of the background material for this *Guidebook* was derived from the EUDEM2 publication *Catalogue of Advanced Technologies and Systems for Humanitarian Demining* (February 2005). Without the financial support of the Government of Germany, the publication of this *Guidebook* would not have been possible, and their assistance is gratefully acknowledged.

Ambassador Stephan Nellen
Director
Geneva International Centre for
Humanitarian Demining

1. Introduction

Since the mid 1990s considerable funding and effort has been invested worldwide in order to develop new technologies for humanitarian demining — 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 funds in new sensing technologies that in some cases could also be applied to mine action. The change in the emphasis of the expected operational use of detection technology by military personnel — from, for example, combat minefield breaching to peace-keeping and peace-building operations — has also seen military detection requirements move to some extent towards those expected for humanitarian demining.

There is perhaps a general disappointment that only a few of these technologies have progressed quickly from research and development (R&D) to field use, although this understandable expectation was to be somewhat unrealistic. This could be explained by the fact that most of the R&D focused on the technology development and less on the complexity of the environmental and field use conditions. Moreover, the development costs, following the R&D chain from basic research towards prototyping, testing and production, have been underestimated. As an example, the authors of the RAND report [1] (2003), which analysed technologies originating mostly in the US, recommend that the US Federal Government initiate an R&D programme to develop a multi-sensor system, with an initial prototype development cost estimated at approximately US$60 million with a prototype multi-sensor system possibly available within seven years after the start of the aforementioned programme. After this phase, the authors estimate that an additional US$135 million will be needed to fund the engineering and development of an optimal, deployable system. The need for substantially greater funding to take a functional prototype of humanitarian demining technology to field readiness (i.e. beyond the cost of developing the prototype in the first place) has also been noted in Europe.

Although a host of physical principles have been investigated to detect landmines, only electromagnetic-based technologies, in particular enhanced metal detectors and ground penetrating radars, have seen significant advances and are being introduced into the field. 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 is the case for the combination of a metal detector with ground penetrating radar (GPR). The first such combined system, the AN/PSS-14 (the military version), has now been fielded and others are expected to follow in the short term, such as the VMR1-MINEHOUND (see the corresponding descriptions).

1.1 Guidebook structure

This *Guidebook* presents a schematic, non-exhaustive overview of several landmine detection and area reduction sensing technologies and systems for humanitarian demining. These systems have been selected according to their development and test and evaluation status. Moreover, a few systems primarily targeted at defence applications, and which could be applied to humanitarian demining operations, have been also added.

The ***operating principle*** of each technology is presented first, followed by a schematic summary of the possible ***application type***, the ***strengths*** and ***limitations***, the ***potential for humanitarian demining*** *(HD)*, and the ***estimated technology readiness***.

The ***application type*** has been schematically subdivided as: hand-held, vehicle-based and airborne, as well as in close-in versus remote detection systems. Although most of the research carried out so far has focused on the close-in detection of individual mines, wide-area remote sensing methods could be very important for area reduction tasks. The ***potential for HD*** has been mostly evaluated with respect to the mainstream applications within humanitarian demining.

The ***technology readiness*** estimation is a qualitative measure based, as in the EUDEM report [2], on the known state of advancement of R&D, the demonstration of detection capabilities useful for humanitarian demining, as well as the demonstration of building a practical system. The resulting value assigned is undoubtedly subjective. Additional technology readiness estimations can be located in references [1] and [3].

Finally, bibliographic information is provided, listing first the references which are likely to be of greater interest to this *Guidebook*'s audience.

Individual systems

Specific systems employing these techniques are then described in terms of the research/development programmes, the developers, the present specifications and available results. Where possible the *Guidebook* focuses on the most promising developments (high Technology Readiness Level — TRL — value, evaluated for HD applications, and recent systems), complemented by information on a few less mature systems, particularly when this was deemed necessary to illustrate a specific detection approach. The *Guidebook* does therefore contain 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.

Bibliographic information is provided here in reverse chronological order, given that the most recent test and evaluation references are usually the most up-to-date and useful ones.

Most technologies are stand-alone (i.e. they can be used by themselves) but can also be used in combination with others. In some cases comments on cost factors have been added. These have obviously to be weighed against the benefits derived from the use of the corresponding technology.

Notes

A number of GPR systems presented here are components of multi-sensor systems. In this *Guidebook* 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 and PPE Catalogue 2005* published by the GICHD and will not be reproduced here.

The information appearing in this *Guidebook* has been secured predominantly through analysis of information already made public. All individual system descriptions have been drafted in co-operation with the contact persons listed in the *Involved Organisations* annex, or provided by them and reviewed by the editorial team. All images and illustrations have been provided by the respective organisations. For some technologies, although input and cooperation was requested, it was unfortunately not forthcoming.

The *Guidebook* editorial team have prepared this report in good faith and to the best of their ability with the goal of disseminating results. They have had no opportunity to verify test results or performance claims provided by the system developers or manufacturers.

Finally, although the emphasis here is on sensor technologies, it should be noted that a substantial contribution to improving the efficiency of the demining process has come from Information and Communication Technologies (ICT), such as information management (e.g. IMSMA — Information Management System for Mine Action) or positioning systems (global positioning system [GPS], differential GPS [DGPS]). In future we can expect to move towards a coherent framework in which all available information over a given area is integrated and used, with ICT such as integrated geographical information system (GIS) environments, image interpretation methods and decision-support systems playing a prominent role [4].

1.2 Technology Readiness Levels

A Technology Readiness Level (TRL) score, evaluated for HD applications, has been assessed for each system presented in this *Guidebook*. While the initial TRL score was assessed in co-operation with each organisation, the final evaluation was carried out by the editorial team.

TRLs have been implemented in space and defence procurement programmes as a systematic scoring method to assess the development status of an individual technology and to compare it with other technologies [5, 6, 7, 8]. 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.

While an increasing TRL number indicates that the technology is maturing and progressing towards a fieldable system, even a relatively high TRL obviously does not present a guarantee that this will ever happen, nor that the resulting system would be really useful in a humanitarian demining context (for example, because, although effective, it is not sufficiently efficient).

In defining our TRLs we have stayed close to those we understand to be suggested by the UK Ministry of Defence.[1] An overview of the different TRL phases, as well as references, is presented in the following table.

Related publications

1. MacDonald, J., J.R. Lockwood, J. McFee, T. Altshuler, T. Broach, L. Carin, R. Harmon C. Rappaport, W. Scott, R. Weaver (2003)
   Alternatives for Landmine Detection, RAND Science and Technology Policy Institute, Report MR-1608, ISBN 0-8330-3301-8.
2. Bruschini, C., K. De Bruyn, H. Sahli, J. Cornelis (1999)
   EUDEM: The EU in Humanitarian Demining - Final Report, July, *www.eudem.info.*
3. Sahli, H., C. Bruschini, S. Crabbe (2005)
   Catalogue of Advanced Technologies and Systems for Humanitarian Demining, EUDEM2 Technology Survey Report, February, *www.eudem.info.*
4. Cornelis, J., H. Sahli (2004)
   "International Conference Assembles Military Considerations within Mine Action Technology Trends", *Journal of Mine Action*, Issue 8.1, June, p. 63, *maic.jmu.edu/.*
5. Mankins J.C. (1995)
   Technology Readiness Levels, a White Paper, Advanced Concepts Office, Office of Space Access and Technology, NASA, 6 April.
6. Mankins J.C. (1998)
   Research & Development Degree of Difficulty (R&D), a White Paper, Advanced Projects Office, Office of Space Flight, NASA Headquarters, 10 March.
7. Bunyan M., J. Barratt (2002)
   AMS Guidance on Technology Readiness Levels (TRLs), FBG/36/10, UK MOD, 4 February
8. Daniels D.J. (2004)
   Impact of New Technologies, Presentations Part 1 and 2, EUDEM2 2004 Final Workshop: Is Humanitarian Demining Technology a Broken Promise?, Vrije Universiteit Brussel, Brussels, 5-6 October 2004, *www.eudem.info.*

1. Technology Readiness Levels were first introduced to the editorial team by David Daniels, ERA Technology.

Technology readiness table (adapted from (7))	
Technology readiness level	**Description**
1. *Basic principles observed and reported.* ❶●●●●●●●●	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.* ●❷●●●●●●●	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.* ●●❸●●●●●●	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.* ●●●❹●●●●●	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.* ●●●●❺●●●●	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.* ●●●●●❻●●●	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.* ●●●●●●❼●●	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.* ●●●●●●●❽●	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 "accredited" through successful mission operations.* ●●●●●●●●❾	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.

2. Metal Detectors

(electromagnetic induction devices)

Introduction

Metal Detectors (MDs) are a mature technology and are the primary means of detection used in mine action programmes today. Much has been written about the operating principles, characteristics and limitations of the technology and will not be repeated in this publication. A brief summary description of metal detectors is provided below. Readers wishing a more detailed discussion on metal detectors are referred to the related publications listed below, in particular, *The Metal Detector Handbook for Humanitarian Demining* and *Metal Detectors and PPE Catalogue 2005*.

Operating principle

A metal detector's search head is usually composed of a primary coil (transmitter) and one or more secondary coils (receiver), although in some arrangements one coil is actually sufficient. A time-varying current in the transmitter coil generates a low frequency electromagnetic field (kHz to MHz frequency range), which induces electric ("eddy") currents in nearby metallic objects, an effect which can be enhanced in the case of magnetic objects. These eddy currents in turn induce a time-varying current in the receiver coil(s), which is amplified and processed to provide an acoustic signal or other form of warning or signal strength indication as the detector is swept over the ground, typically very close to the soil. A metal detector's search head "illuminates" an area which is roughly as large as the sensor head ("footprint"). Larger sensor heads can therefore be used to search for deeper objects, although they will be less sensitive to small targets close to the surface (this can represent an advantage or disadvantage depending on the operating scenario). The rejection of signals generated by the soil itself is very important in a number of operating scenarios, and in this respect significant advances have been achieved by the manufacturers during the past years.

Application type

Close-in detection: hand-held, vehicle-based (arrays) .

Strengths

- Well-established technology (hand-held; vehicle-based arrays are more recent developments).
- The vast majority of all deployed mines do contain some amount of metal, albeit in some cases only at the level of the detonator capsule or striker pin (minimum-metal mines).
- Indicative detection limits (can also depend on ground conditions): shallow (about 10-15cm for minimum-metal mines, 20-30cm for mines with an

appreciable metallic content, and 50-70cm for UXO and metallic mines). Greater depths are reachable with large loop systems.

Limitations

- Magnetic (e.g. laterite rich) or strongly conductive soils (e.g. sea beaches).
- Ground compensation techniques can reduce detector sensitivity.
- Very small (minimum-metal mines) and/or deep targets, low conductivity metals (e.g. stainless steel).
- Footprint size decreases with depth (conical footprint).
- Electromagnetic interference (e.g. power lines). High false alarm rate caused by metal fragments, etc.

Potential for humanitarian demining

- Well-established technology.
- Metal detectors (MDs) are present in nearly every multi-sensor system being researched.
- Efficiency limited by metallic debris (MDs detect any metal and not just the metal components found in mines).
- Recent improvements in soil signal suppression (fielded systems).
- Appealing but challenging innovations: target identification and parameter estimation (e.g. target depth/size), imaging applications, and sensors other than coils.
- Complemented in humanitarian demining, when a real need exists (UXO only, or deeply buried UXO), by magnetometers, which measure the distortion of the Earth's magnetic field caused by nearby ferromagnetic objects.

Estimated technology readiness (enhanced MDs)

Medium-High.

Related publications

1. Guelle, D., A. Smith, A. Lewis, T. Bloodworth (2003)
Metal Detector Handbook for Humanitarian Demining, European Communities, Publication EUR 20837, 172 pp., ISBN 92-894-6236-1.

2. GICHD (2005)
Metal Detectors and PPE Catalogue 2005, Geneva International Centre for Humanitarian Demining, GICHD, Geneva, 166 pp., ISBN 2-88487-024-5, *www.gichd.ch.*

3. Das Y., J.T. Dean, D. Lewis, J.H.J. Roosenboom, G. Zahaczewsky (Eds) (2001)
A multi-national technical evaluation of performances of commercial off the shelf metal detectors in the context of humanitarian demining, International Pilot Project for Technology Co-operation, Final report, European Commission, Joint Research Centre, Ispra, Italy.

4. Gaudin C., C. Sigrist, C. Bruschini (2003)
Metal Detectors for Humanitarian Demining: a Patent Search and Analysis. EUDEM2 Technology Survey Report, November, v2.0, *www.eudem.info.*

2.1 Other low-frequency electromagnetic systems: Electrical Impedance Tomography Mine Detection System

Project identification

Project name	EIT Confirmatory Detector	**Start date**	April 2005
Acronym	EIT	**End date**	September 2006
Participation level	National (Canada)	**Technology type**	Low frequency electrical currents
Financed by	DRDC Suffield	**Readiness level**	●●●●●⑥●●●
Budget	CAD400,000	**Development status**	Ongoing
Project type	Technology development, Technology demonstration	**Company/institution**	Neptec Design Group

Project description

An evaluation prototype was built and tested in the late 1990s in realistic conditions to assess the potential use of **Electrical Impedance Tomography** (EIT) technology as a confirmatory detection modality. The early evaluations revealed that the EIT technology is particularly efficient in wet, shallow environments such as those found in ocean littorals, marshes and agricultural fields. A second project phase was started to improve the instrument and algorithms, and also extend its field evaluation to wet environments.

Detailed description

EIT is a technology developed to image the electrical conductivity distribution of a conductive medium. The technology is of interest because of its low cost and also because the measurement of the electrical conductivity brings direct information about the composition of the conductive medium. Since the ground is conductive to a certain extent, the technology can also be used to detect buried objects. The application of landmine detection is of particular interest because the object is usually buried at shallow depths and causes a discontinuity in the soil conductivity that can be sensed from the ground surface.

EIT uses low-level electrical currents to probe a conductive medium and produce an image of its electrical conductivity distribution. While a pair of electrodes is stimulated, the electrical voltage is measured on the remaining pairs of electrodes. After all the independent combinations of interest have been stimulated, an algorithm using the measured data reconstructs an image of the electrical conductivity distribution within the volume. In the case of ground probing, an array of electrodes is placed on the surface of the ground to provide an image of the conductivity distribution below the surface. In the case of a shallow underwater application, an electrode array is immersed in the water to probe the sediment layer. The EIT technology will detect mines buried in the ground/sediments by detecting electrical conductivity anomalies. The presence of a metallic or non-conductive mine will disturb the conductivity distribution in the soil. The signal characteristics are based on the size, shape, conductivity and depth of the buried mine.

Figure 1 below shows an EIT detector prototype optimized for the detection of anti-tank landmines. A typical EIT detector has three major components: the electrode array, the data acquisition system and a data processing unit. In this case the electrode array comprises 8 columns and 8 rows of electrodes, for a total of 64 electrodes. The electrodes are spring-loaded and can adjust with terrain variations. The data acquisition system incorporates the electronics and firmware required for the electrical stimulation of the electrodes and the recording of the resulting potentials.

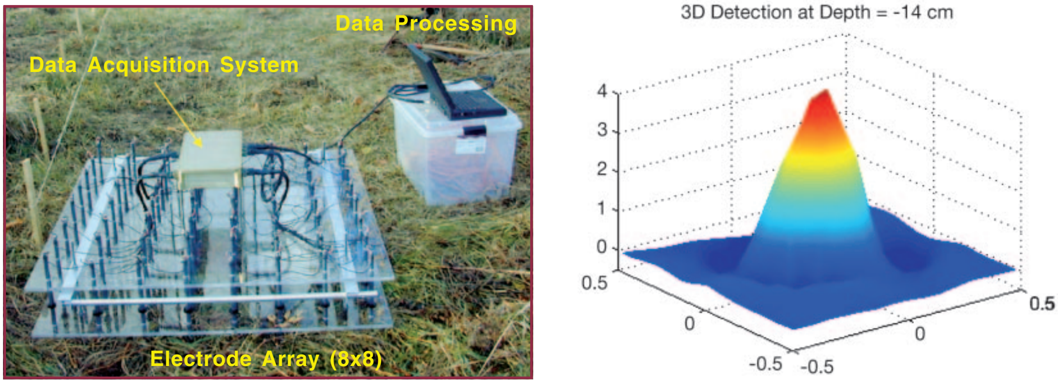


Figure 1. The EIT detector prototype and its response to an anti-tank-mine-like object buried at a depth of 14cm.

Test and evaluation

On the ground

The EIT detector prototype was evaluated at Defence R&D Canada Suffield, using anti-tank mine surrogates. Evaluations have assessed the maximum detection depth, spatial resolution and response to various anti-tank mine types.

Using the 1m² footprint detector, typical anti-tank-mine-like objects can be detected at depths of the order of 20cm. The detector has shown a capability to resolve the presence of more than one anti-tank-mine-like object down to depths of about 14cm.

Tests were conducted at the Defence R&D Canada (DRDC) Suffield Mine Pen facility. The first set of experiments was performed on a hard-packed gravel road containing various buried landmines. The EIT detector was used to image several inert anti-tank mines buried at depths ranging from 6 to 16cm. Examples are shown below. Tests conducted with anti-tank mine surrogates in a different part of the field were inconclusive due to factors that are not yet fully understood. There are currently not enough statistical data to define the detection and false alarm characteristics of the detector.

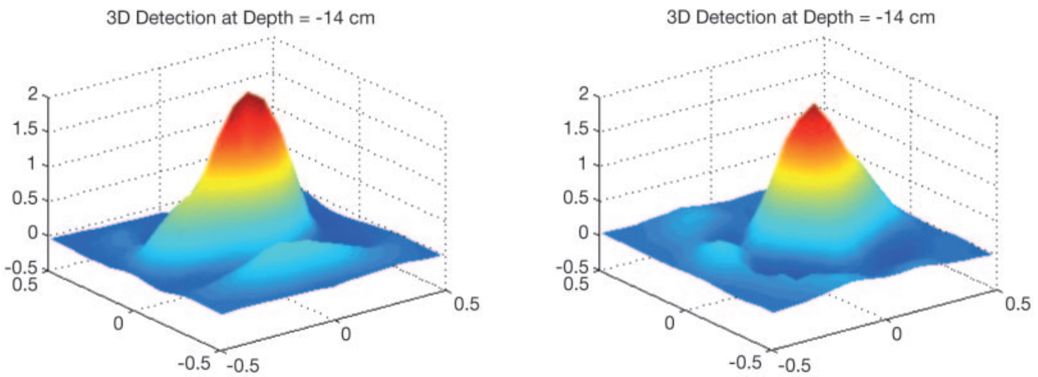


Figure 2. (Left) Detector response for a TMA3, buried at a depth of 6.4cm and (right) detector response for a M15, buried at a depth of 16.5cm.

Under water

The EIT technology has been evaluated under water in a laboratory environment. Figure 3 illustrates an experimental underwater electrode array detecting anti-personnel-mine-like objects buried under water in a layer of sand. The early results have shown it is possible to detect and discriminate mine-like objects buried in sediments such as sand, under a layer of water. Further research is being conducted with DRDC Suffield to develop additional algorithms, build an underwater electrode array, and perform field tests.

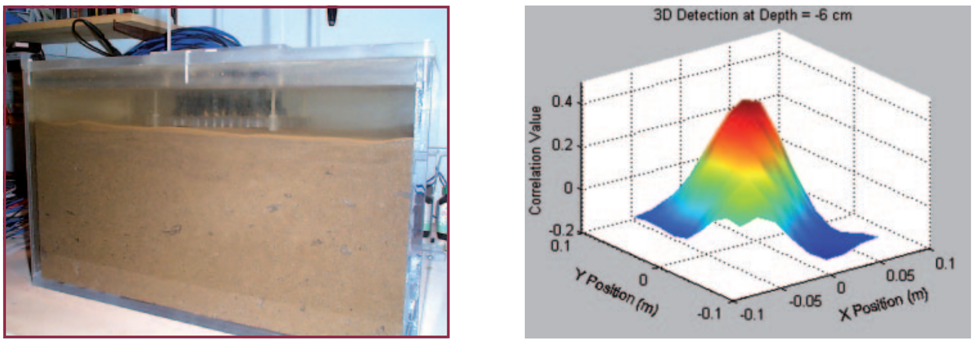


Figure 3. Laboratory evaluation of an underwater electrode array with corresponding detector response for an anti-personnel-mine-like object buried 6cm in the sand layer.

Other applications (non-demining)

EIT can be used for other geophysical-related applications, such as detection of a pollution plume seeping in the ground or detection of man-made tunnels.

Related publications

1. Church P., J. McFee (2004)
   "Laboratory Evaluation of the EIT Technology Capability to Detect Mines Buried in an Underwater Sediment Layer", *Proceedings of SPIE Conference on Detection and Remediation Technologies for Mines and Mine-like Targets IX*, Vol. 5415, pp. 342-350, Orlando, US.
2. Church P. (2003)
   "Electrical Impedance Tomography", in *Alternatives for Landmine Detection*, MacDonald et al, pp. 161-168, RAND.
3. Church P., P. Wort, S. Gagnon, J. McFee (2001)
   "Performance Assessment of an Electrical Impedance Tomography Detector for Mine-Like Objects", *Proceedings of SPIE Conference on Detection and Remediation Technologies for Mines and Mine-like Targets VI*, Vol. 4394, pp. 120-131, Orlando, US.
4. Wort P., P. Church, S. Gagnon (1999)
   "Preliminary Assessment of Electrical Impedance Tomography Technology to Detect Mine-like Objects", *Proceedings of SPIE Conference on Detection and Remediation Technologies for Mines and Mine-like Targets IV*, Vol. 3710, pp. 895-905, Orlando, US.

Technical specifications	*Neptec Design Group, Electrical Impedance Tomography Mine Detection System*
1. Used detection technology:	Low frequency electrical currents
2. Mobility:	Man portable
3. Mine property the detector responds to:	Size, shape and conductivity
4. Detectors/systems in use/tested to date:	Experimental system
5. Working length:	—
6. Search head:	
➢ size:	1m^2
➢ weight:	47kg (experimental unit)
➢ shape:	square
7. Weight, hand-held unit, carrying (operational detection set):	47kg
Total weight, vehicle-based unit:	50kg
8. Environmental limitations (temperature, humidity, shock/vibration, etc.):	Very dry soil
9. Detection sensitivity:	TBD[a)]
10. Claimed detection performance:	
➢ low-metal-content mines:	Yes
➢ anti-vehicle mines:	Yes
➢ UXO:	TBD
11. Measuring time per position (dwell time):	< 10 s
Optimal sweep speed:	—
12. Output indicator:	Laptop
13. Soil limitations and soil compensation capability:	Very dry conditions
14. Other limitations:	—
15. Power consumption:	1.5W
16. Power supply/source:	Battery
17. Projected price:	TBD
18. Active/Passive:	Active
19. Transmitter characteristics:	—
20. Receiver characteristics:	TBD
21. Safety issues:	None
22. Other sensor specifications:	—

a) To be defined.

3. Ground Penetrating Radar Systems

3.1 Sensing principle

Operating 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 organisations are working on different parts of GPR systems, and — among 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.[2] 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. GPR can produce a fuzzy depth "image" by scanning the suspected area, and/or using an antenna array. The antenna is one of the most crucial parts of a GPR system.

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 GPR works as a target-soil electrical contrast sensor). The amount of energy reflected, upon which reliable detection is based, also depends on the object's size and form. Spatial resolution[3] 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, however, particularly limited in penetration depth.

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

2. The upper frequency band corresponds roughly to that of cellular phones/microwave ovens.
3. The capability to distinguish two closely spaced objects and/or to define the shape of an object. Increased spatial resolution leads to sharper "pictures", whether real ones in the case of an imaging sensor, or "virtual" ones in the case where an operator interprets a sensor's output — in demining, typically an acoustic signal — and builds a mental map of it.

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 systems operating over a very wide frequency range (in relation to their central operating frequency).

Application type

Close-in: hand-held, vehicle-based (arrays)

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, although the use of radar with metal-detectors in dual-sensor hand-held systems is becoming established with extensive trials of prototype equipment. Vehicle-mounted radar systems with a broad sweep have also been developed and field tested, mostly for military applications.

Strengths

- Capable of detecting entirely non-metallic objects (e.g. minimum-metal mines).
- Well established for a number of applications (see above).
- Can provide target depth information.
- Could be very useful in stand-alone mode for selected applications (e.g. deep minimum-metal anti-tank mines).
- Rather insensitive to small metallic debris therefore good potential to reduce false alarm rate (FAR) by discriminating clutter from mine-like objects.
- Most mine detection GPR systems use very low power and do not present any radiation hazard.

Limitations

- 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).
- Soil inhomogeneities (roots, rocks, water pockets), very uneven ground surfaces, soil moisture profile fluctuations.
- Very dry soils have a reduced electrical contrast when looking for plastic objects and therefore plastic objects may not be detected.
- Small anti-personnel mines present a considerable challenge.
- Need to balance resolution (better at higher frequencies) with depth penetration (better at lower frequencies).

Potential for humanitarian demining

- Most mature of all alternative technologies, subject of extensive studies and trials.
- Preferred combination is with a metal detector.
- Advanced hand-held prototypes now available for extensive testing.
- Depending on the configuration, the GPR can be confirmatory after the MD, to reduce its false alarm rate.
- Vehicle-based systems mostly developed and tested for military applications (especially route clearance).

Estimated technology readiness:

Medium-High.

Related publications

1. Daniels D.J. (2004)
   Ground Penetrating Radar, 2nd Edition, IEE Radar, Sonar, Navigation and Avionics Series, June, ISBN 0 86341 360 9.
2. MacDonald J. et al. (2003)
   Alternatives for Landmine Detection, RAND Science and Technology Policy Institute, Report MR-1608.
3. *GPR International Conference* series (biennial).
4. *Evaluation of Hand-Held GPR System for AP Landmine Detection - Final Report* (2003) (for DRDC Suffield, Canada), Project R111, Sensors & Software Inc., 31 March, 148 pp.
5. Bruschini C., K. De Bruyn, H. Sahli, J. Cornelis (1999)
   EUDEM: The EU in Humanitarian Demining - Final Report, July, *www.eudem.info.*

3.2 The AN/PSS-14 (HSTAMIDS)/AMD-14

Project identification

Project name	US Army Hand-held Standoff Mine Detection System (HSTAMIDS) program	**Start date**	1996
Acronym	HSTAMIDS (AN/PSS-14)	**End date**	2004
Participation level	National	**Technology type**	Metal detector, ground penetrating radar
Financed by	US Army	**Readiness level**	AN/PSS-14: ●●●●●●●●9 AMD-14: ●●●●●●●8●
Budget	US$73 million over 15 years[4]	**Development status**	Ongoing
Project type	*AN/PSS-14:* Technology development, Technology demonstration, System/subsystem development, System test & in-field operations *AMD-14*: System/subsystem development	**Company/Institution**	CyTerra Corporation

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 in a unique manner that 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 hand-held 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.

The data fusion algorithms 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.

Detailed description

The system combines a GPR and a highly sensitive MD. The AN/PSS-14 is shown in Figure 1.

4. "Time and costs required to create HSTAMIDS" stated by J. MacDonald et al. (2003), in *Alternatives for Landmine Detection*, RAND Science and Technology Policy Institute, Report MR-1608, p. xxi.

Figure 1. AN/PSS-14 (HSTAMIDS).

Two different audio signals are provided simultaneously 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.

A variant of the AN/PSS-14 oriented to humanitarian demining, the **AMD-14**, is anticipated in 2006 with a significantly reduced list price. The new system will incorporate the same AN/PSS-14 electronics and sensor elements so detection performance will be unchanged (see Figures 2 to 4).

Figures 2 and 3. AMD-14.

Figure 4. Detail of AMD-14 control handle.

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. System was deemed to meet or exceed the US Army Operational Requirements for all designated tests.

Operational tests were conducted by US Army Operational Test Command. They compared performance of AN/PSS-14, AN/PSS-12 (Schiebel AN-19 and the current US Army mine detector) and F1A4 (Minelab) using blind lane testing of new operators. Systems in the evaluation 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 course and was provided by Contractor/US Army Engineer School.

Test environment comprised 106 mine lanes (1.5m x 25m) with a total of 514 missions (1,096 encounters) performed. Mine types included AT, AP and mixed (AT/AP) of both high metal (M) and low metal (LM) types. Developmental testing results are as follows:

Table 1. Comparative probability of detection (PD) between three detectors

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	91	89
AN/PSS-12	80	99	64	99	81

Initial operational test results are described as follows:

Table 2. Initial operational test results

AN/PSS-14 performance summary
(FAR = FA's per m², Scan Rate = m² per minute)

AN/PSS-14 Parameter	Standing				Kneeling	Prone	Night
	AP-LM	AP-M	AT-LM	AT-M			
	97	99	99	100			
PD %	98.7				100	96.2	100
FAR	0.008				0.009	0.03	0.004
Scan Rate	3.2				1.9	1.1	NA

Systems are available for individual country or organisation evaluation (subject to a suitable US Export License being obtained).

HSTAMIDS has also been undergoing the following operational field trials and demonstration under the ITEP banner, supported by local Mine Action Centres and/or NGOs:

- Thailand, September/December 2004, finalised,
- Namibia, March 2005, finalised,
- Afghanistan, late 2005, finalised.

The Thailand trials are fully detailed in [2] and can be summarised as follows. Participants included the US Humanitarian Demining Team of NVESD (Night Vision and Electronic Sensors Directorate), ITEP personnel, Thailand Mine Action Centre (TMAC), HALO Trust from Cambodia and CyTerra Corporation. The evaluation was conducted near the minefields at the TMAC Humanitarian Demining Action Unit (HMAU) #1.

The test target set was composed of mines that are found in the area of HMAU #1 and mines that are typically used for US Army testing. All mines, detonators, and fuzes were free from explosive. The main charges were replaced with RTV Silicone Rubber 3110. The metal components and characteristics of the mines remained intact. To get statistically significant results, the test was designed so that most mine types were encountered 36 times.

Site setup: brush and vegetation were removed and the ground was levelled to facilitate water drainage. A vehicle-borne magnet was used to remove significant amounts of surface metallic clutter. The test area consisted of ten 1mx25m blind lanes and one 1mx30m calibration lane. All anti-personnel mines were buried 5cm deep, and all anti-tank mines were buried 10cm deep.

Metal detectors were used to locate all indigenous metallic clutter in the lanes. The test targets were then arranged throughout the lane so that they had sufficient separation between them and the clutter. No indigenous clutter was removed from the lanes after being located by the metal detectors. Operators were credited with a detection if they marked a detection within 15cm of the edge of a target, as in all US Army testing of the HSTAMIDS.

According to the authors, the resulting overall detection probability (PD) and False Alarm Rate (FAR) show a reduction in FAR by a factor of five, with increased detection probability with respect to the locally used metal detector. Up to 77 per cent of false alarms have been rejected, with up to an estimated improvement of five times in clearance time.

Table 3. Potential reduction of effort

	Metal detector (Vallon) operators	HSTAMIDS experienced operators	HSTAMIDS trainee operators
PD (%)	76	94	86
FAR (m^{-2})	1.02	0.201	0.254
Total clutter marked	956	806	713
Clutter called mine	956	183	232
Clutter rejected	0 (0%)	623 (77%)	481 (67%)
Time scanning	17 hrs @ 1.01 min/m^2	21 hrs @ 1.25 min/m^2	38 hrs @ 2.29 min/m^2
Time digging clutter called mine (hours)	319	61	77
Time saved [a)]	0	254	221

a) Average time saved based on 20 minutes per investigation, using TMAC data for operations in the same area.

Other applications (non-demining)

Civil engineering, security, weapons cache searches, in wall searches, through wall detection of people (option fielded to US Military but disclosure requires US Export License).

Related publications

1. Hatchard C. (2005)
   Dual Technology Detectors – A New System and ITEP Results, NDRF 2005, Stockholm, 24-26 August 2005, *www.ndrf.dk.*

2. Doheny R.C., S. Burke, R. Cresci, P. Ngan, R. Walls (2005),
   "Handheld Standoff Mine Detection System (HSTAMIDS) Field Evaluation in Thailand", *Proceedings of SPIE Conference on Detection and Remediation Technologies for Mines and Mine-like Targets X,* Vol. 5794, pp. 889-900, Orlando, US.

3. Hatchard C. (2003)
   AN/PSS-14 (HSTAMIDS), NDRF 2003, Bergen, Norway, 27-29 August 2003, *www.ndrf.dk.*

Technical specifications	*CyTerra HSTAMIDS / AMD-14*
Detector	
1. Brand:	CyTerra
2. Model:	AN/PSS-14 (HSTAMIDS) / AMD-14 (humanitarian demining model). MD: similar to Minelab F3.
3. Version:	—
4. Detection technology:	MD, GPR
5. Mobility:	Hand-held
6. Mine property the detector responds to:	Restricted
Development status	
7. Status:	Continuous improvement process
8. Detectors/systems in use/tested to date:	AN/PSS-14 > 2000
9. Location of use/test:	US and non-US military
10. Other types of detectors/systems:	—
Dimensional data	
11. Working length:	
➢ min. length:	AN/PSS-14: 96cm, AMD-14: 93cm.
➢ max. length:	AN/PSS-14: 147cm, AMD-14: 166cm.
12. Search head:	
➢ size:	AN/PSS-14: Width: 21cm, AMD-14: Width: 21cm, Height: 10cm
➢ weight:	—
➢ shape:	Circular, closed style
13. Transport case:	
➢ weight:	AN/PSS-14: 20kg, AMD-14: 20kg
➢ dimensions:	AN/PSS-14: Hardcase 64x53x36cm, AMD-14: Hardcase 95x45x25cm
➢ hard/soft case (material):	—
14. Weight, hand-held	AN/PSS-14: 4.9 kg (excluding battery), AMD-14: 4.3 kg (excluding battery)
15. Weight, hand-held unit, carrying (operational detection set):	AN/PSS-14: 4kg, AMD-14: 4.3kg.
Total weight, vehicle-based unit:	—
16. Weight, additional equipment:	AMD-14: batteries, 0.6 kg
17. Weight distribution/balance:	System counterbalanced for easy use
18. Other dimensional specifications:	
Environmental influence	
19. Humidity (limitations):	AN/PSS-14: meets and exceeds all US Army Requirements[a] overall -32°C to +49°C, 0 – 100% humidity. AMD-14: STANAG 2895 A1 (dry desert), B1 (tropical), C1 (cold) and B3 (hot and humid) overall -32°C to +49°C, 0 – 100% humidity.
20. Temperature (limitations)	
➢ storage:	AN/PSS-14:-46°C to +73°C, AMD-14: -46°C to +73°C
➢ operational	AN/PSS-14:-32°C to +49°C, AMD-14: -32°C to +49°C.
21. Water resistant:	HSTAMIDS:[a] AMD-14: 1m.
22. Shock/vibration resistant:	HSTAMIDS:[a]
23. Environmental compensation:	—
24. Operational hours/operating endurance:	—
Detection and detection performance specifications	
25. Control of working depth:	—
26. Calibration/set-up	—
➢ auto/manual:	
➢ duration:	—

27. Detection sensitivity:	—
28. Claimed detection performance:	
➢ low-metal-content mines:	AN/PSS-14 & AMD-14: Will detect mines presenting an operational threat (PD, PFA:[a]).
➢ anti-vehicle mines:	AN/PSS-14 & AMD-14: Will detect mines presenting an operational threat (PD, PFA:[a]).
➢ UXO:	—
29. Measuring time per position (dwell time):	—
Optimal sweep speed:	0.3 to 0.75m/s
30. Output indicator:	AN/PSS-14 & AMD-14: Audio, external speaker or headphones.
31. Pinpointing feature:	Combination of MD and ATR signals
32. Search head/antenna type:	—
33. Adjustment of search head angle:	—
34. Soil compensation capability:	All soils
35. Soil limitations:	None
36. Interference with other detectors as well as from the environment:	5m separation
37. Other limitations:	Power line suppression: Not available.
38. Other specifications:	Test piece: 50mm plastic RTV filled, similar to small AP mines with Io insert representing metal content of low-metal mines.

Power

39. Power consumption:	30W
40. Power supply/source:	12V, Battery
41. Operating time:	AN/PSS-14: 4h (Nickel Metal Hydride); AMD-14: 4h (NP-Fx70 series Li-ion)
42. Power supply:	
➢ weight:	AMD-14: 0.6kg (Li-ion pair) rechargeable
➢ no. of batteries/size/type:	AN/PSS-14: NiMH rechargeable battery .
➢ rechargeable:	—
➢ other:	AN/PSS-14 Battery is mounted externally on operators' hip belt, therefore system can be adapted to use other batteries, provided basic V/Ahr ratings are met. AMD-14: battery pack mounted on handheld system or on belt with optional cable.

Price and availability

43. Price:	
➢ for low volume:	AN/PSS-14: 23.500 USD; AMD-14: 12,000 USD (estimate)
➢ operating costs:	—
44. Availability for hire:	None

Sensor specifications

45. Active/Passive:	Active
46. Transmitter characteristics:	GPR: Stepped frequency, 1-3GHz.
47. Receiver characteristics:	—
48. Transmitted power:	+7 dBm (typical)
49. Spatial resolution:	—
50. Signal to Noise ratio:	—
51. Detection algorithm:	Aided Target Recognition (ATR) employing Principal Component Analysis (PCA) to automatically generate terrain model.
52. Feature extraction:	Background/terrain rather than target modelling, with the GPR looking for objects against a clutter background.
53. Safety issues:	None
54. Other:	Detection algorithms: preset, with no user selectable inputs except for system sensitivity level. GPR: three antennae mounted in a triangular configuration inside the MD coil.

a) Detailed disclosure requires US Export License.

Remarks

Metal detector specifications are similar to those of the commercially available Minelab F3.

3.3 VMR1-MINEHOUND

Project identification	
Project name	Handheld Multi-Sensor Mine Detector
Acronym	VMR1-MINEHOUND
Participation level	National
Financed/co-financed by	National, UK, Vallon GmbH
Budget	DFID contract
Project type	Technology demonstration, System/subsystem development
Start date Phase 1	April 2001
End date Phase 1	May 2003
Start date Phase 2	January 2004
End date Phase 2	February 2006
Technology type	Metal detector, ground penetrating radar
Readiness level	8
Development status	Completed
Company/institution	ERA Technology Ltd; Vallon GmbH

Project description

The **MINEHOUND** dual sensor detector combines ground penetrating radar (GPR) and a pulsed metal detector to reduce the false alarm rate normally encountered by metal detectors. This results in improved productivity of mine clearing operations. MINEHOUND was developed for the detection of anti-personnel landmines and hand-held humanitarian operations. It is based on a custom-designed GPR from ERA (UK) and the pulse induction MD-Type VMH3 from Vallon (Germany). The original development (called **MINETECT**) was developed under the sponsorship of the UK Department for International Development (DFID) and MINEHOUND was additionally supported by the German Foreign Ministry.

Detailed description

MINEHOUND is a combined metal detector (MD) and GPR system designed specifically for use in humanitarian and military demining operations using advanced technology. The output to the operator from both the metal detector and GPR is by means of audio signals. The metal detector audio provides accurate information on position and mass of metal indication. The GPR provides accurate position information, depth information and radar cross-section[5] of target information. Both detectors can be used together or independently. The manufacturer reports that trials show 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. Production systems

5. The radar cross-section describes how well an object reflects the radar's incoming electromagnetic waves, and therefore how much "visible" the object is to the radar.

will offer a combined mode to further reduce the time taken to scan the ground and autocalibration for the GPR soil conditions and mineralised soil for the MD.

According to the manufacturer, trials in live minefields show that the FAR can be reduced by a factor of between two and seven times with respect to a standalone MD, and the GPR also detects zero or minimum metal mines that are difficult for the MD. Following initial encouraging results, mine classification is also being further investigated.

The manufacturer also notes that experienced deminers soon gain full performance level with MINEHOUND. Effective training is an important requirement, although this does not require more than one day for experienced deminers.

Figure 1. NPA deminer checking the detector on the calibration grid during trials in Bosnia.

Figure 2. Deminers practicing with the detector in Cambodia.

MINEHOUND uses a state-of-the-art metal detector from Vallon and a custom-designed 1GHz ground penetrating radar designed by ERA Technology Ltd. The GPR is a time domain radar operating at a centre frequency of 1GHz and compliant with international licensing requirements. The GPR transmitter-receiver and associated control and signal processing is mounted on a compact, purpose-designed printed circuit board. A dedicated state-of-the-art digital signal processor (DSP) is used to provide all control and signal processing functions. The operator can select MD *or* GPR or MD *and* GPR functions. The GPR will operate in standby mode when not being handled to increase battery lifetime.

Test & evaluation

A number of trials have been completed, in particular in the UK (ERA) in July-August 2002, in country trials in Bosnia (NPA) in August 2002, at a US Army site in September-October 2002, real trials in Lebanon (BACTEC) in November-December 2002, again at the same US Army site in September-October 2003, and in the UK (Hurn) in December 2004-February 2005. Further trials were carried out in live minefields in Cambodia, Bosnia and Angola during 2005 (see below).

Figure 3. Cambodia, trials in the rainy season.

MINETECT tests

***US tests*:**
The manufacturer believes that 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 original development MINETECT-B system were, for all mines, blanks, non-metallic clutter and the following categories of metallic clutter [4]:

- PD=100 per cent at PFA of 0.03 for small metallic clutter;
- PD=100 per cent at PFA of 0.28 for all clutter.

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 anti-tank mines.

***Bosnia 2002*:**
Three test sites were used, with the results summarised in full in [6].

Lebanon 2002:
Typical FAR rates for an MD and the MINETECT GPR at Lebanese sites, as well as the corresponding false alarm rate reduction, were reported as follows [7]:

Table 4. False alarm rate reduction

Site location	MD FAR (m^{-2})	GPR FAR (m^{-2})	Reduction in FAR
Baraachit 1	2	0.375	5.3:1
Baraachit 2	1.75	0.5	3.5:1
Training 1 (BLU)	0.875	0.125	7:1
Training 1 (BLU)	0.94	0.125	7:1

The typical depth range performance for the GPR in Southern Lebanese soil was also assessed [8] at three different test sites:

Table 5. Detection depth, Lebanon

Mine type	Israeli AP No. 4 (fuze)	Israeli AP No. 4 (no fuze)	VS50	French AP Model 1951	French AT Model 1947	PMA3	BLU15	TM46
Maximum depth in cm at each of the three test sites[a)]	20/–/15	10/–/5[b)]	15/5/–	13/5/10	20/–/–	–/–/10	15/–/10	30/–/–

a) Training site, Baraachit site and Naquora site, respectively.
b) Not tested deeper because of ground conditions.
– Not available.

MINEHOUND tests

Recent field trials:
A pre-production version has undergone field trials in real minefields, alongside the currently used MD and under ITEP invigilation. These trials were conducted in Cambodia (September 2005), in Angola with the assistance of Mines Advisory Group (MAG) [1], and in Bosnia (September 2005) with Norwegian People's Aid (NPA). The Bosnia and Cambodia results should be available in 2006. Additional trials are planned in Angola in 2006.

During these trials the detector was used to follow up an indication from the existing metal detector. MINEHOUND was then used to investigate that alarm and the results recorded. The alarm was then investigated according to the standing operating procedures (SOPs) of the demining organisation. Approximately 1,000 data records (mine or fragment encounters) were collected for each country and for Cambodia and Bosnia the potential reduction in false alarms ranged from 5:1 to 7.5:1 with 100 per cent detection of mines. In Angola, tests are continuing at additional locations where mines are expected.

Other applications (non-demining)

Civil applications such as pipe detection, and other security applications, such as through wall radar.

Related publications

1. Dibsdall I. (2005)
   MINEHOUND tests underway in Cambodia and Bosnia, September, *www.itep.ws.*
2. Daniels D.J. (2005)
   MINEHOUND Trials, NDRF 2005, Stockholm, Sweden, 24-26 August.
3. Daniels D.J., P. Curtis, R. Amin, N. Hunt (2005)
   "MINEHOUND production development ", *Proceedings of SPIE Conference on Detection and Remediation Technologies for Mines and Mine-like Targets X*, Vol. 5794, pp. 488-494, Orlando, US.
4. Daniels D.J., P. Curtis, R. Amin, J. Dittmer (2004)
   "An affordable humanitarian mine detector ", *Proceedings of SPIE Conference on Detection and Remediation Technologies for Mines and Mine-like Targets IX*, Vol. 5415, pp. 1185-1193, Orlando, US, 12-16 April.
5. Daniels D.J. (2004)
   Impact of New Technologies, Presentations Part 1 and 2, EUDEM2 2004, Final Workshop: Is Humanitarian Demining Technology a Broken Promise?, Vrije Universiteit Brussel, Brussels, 5-6 October 2004, *www.eudem.info.*
6. Daniels D.J. (2003)
   MINETECT Trials, 2003, *www.itep.ws, www.eudem.info.*
7. Daniels D.J., P. Curtis (2003)
   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, Vrije Universiteit Brussel, Brussels, September 2003, *www.eudem.info.*
8. Daniels D.J., P. Curtis (2003)
   "MINETECT", *Proceedings of SPIE Conference on Detection and Remediation Technologies for Mines and Mine-like Targets VIII*, Vol. 5089, pp. 203-213, Orlando, US.

Technical specifications *Vallon/ERA VMR1-MINEHOUND®*

Detector

1. Brand:	Vallon / ERA
2. Model:	VMR1-MINEHOUND®
3. Version:	—
4. Detection technology:	MD, GPR
5. Mobility:	Hand-held
6. Mine property the detector responds to:	Dielectric characteristics (see *GPR Operating Principles*) and metal content.

Development status

7. Status:	Production ready late 2006
8. Detectors/systems in use/tested to date:	—
9. Location of use/test:	Angola, Bosnia, Cambodia, Lebanon
10. Other types of detectors/systems:	—

Dimensional data

11. Working length:	
➢ min. length:	66cm from handgrip nominal
➢ max. length:	106cm from handgrip nominal
12. Search head:	
➢ size:	Width: 17cm (x axis), 30.5cm (y axis)
➢ weight:	1.5kg
➢ shape:	Oval
13. Transport case:	
➢ weight:	3.5kg
➢ with equipment (full):	8.75kg
➢ dimensions:	103cm x 34cm x 25cm
➢ hard/soft case (material):	Case with foam insert
14. Weight, hand-held unit:	4.1kg
Weight, vehicle-based sensor unit:	—
15. Weight, hand-held unit, carrying (operational detection set):	4.75kg
Total weight, vehicle-based unit:	—
16. Weight, additional equipment:	—
17. Weight distribution/balance:	Batteries are housed in a compartment opposite the search head to provide a counterbalance, but can be removed and the detector connected to a belt battery (weight reduction by nearly 1kg).
18. Other dimensional specifications:	—

Environmental influence

19. Humidity (limitations):	—
20. Temperature (limitations)	
➢ storage:	MD: -55°C to +75°C
➢ operational:	-10°C to +45°C. MD: -32°C to +65°C.
21. Water resistant:	Up to 1.5m
22. Shock/vibration resistant:	MD: according to MIL STD 810 F 514.5 C1
23. Environmental compensation:	MD: all soil conditions
24. Operational hours/operating endurance:	5 hours

Detection and detection performance specifications

25. Control of working depth:	Audio
26. Calibration/set-up	
➢ auto/manual:	MD: auto; GPR: auto
➢ duration:	A few seconds
27. Detection sensitivity:	—

28. Claimed detection performance:	
➢ low-metal-content mines:	Max depth range: 20cm.[a] PD>0.98, PFA<0.25 for all clutter and PFA<0.08 for small metal fragments.[b]
➢ anti-vehicle mines:	Max depth range: 40cm.[a] PD>0.98, PFA<0.25 for all clutter and PFA<0.08 for small metal fragments.[b]
➢ UXO:	—
29. Measuring time per position (dwell time):	—
Optimal sweep speed:	<1.5m/s
30. Output indicator:	Audio (min/max output frequency: 150/1500Hz) and visual (LED bar showing MD detected signal level).
31. Pinpointing feature:	Maximum signal over centre of target
32. Search head/antenna type:	Oval MD head containing one transmit and one receive GPR antenna.
33. Adjustment of search head angle:	Freely adjustable
34. Soil compensation capability:	MD: normal/conductive soil.
35. Soil limitations:	GPR: salt water and heavy clay.
36. Interference with other detectors	MD: min distance 2m
as well as from the environment:	No problem
37. Other limitations:	None
38. Other specifications:	Demining environmental conditions: all world. Supervisor can control additional settings (target type, sensitivity mode, time/depth range control).

Power

39. Power consumption:	—
40. Power supply/source:	Batteries
41. Operating time:	>4hrs continuous, >4hrs at 20min on and 20 min off. MD: up to 25 hrs.
42. Power supply:	
➢ weight:	650 g
➢ no. of batteries/size/type:	4x1.5 V rechargeable 8 Ahrs D cells
➢ rechargeable:	Yes
➢ other:	Alkaline D-Cells

Price and availability

43. Price:	
➢ for one detector:	—
➢ operating costs:	—
44. Availability for hire:	Yes

Sensor specifications

45. Active/Passive:	Active
46. Transmitter characteristics:	GPR: centre frequency: 1GHz
47. Receiver characteristics:	Automatic gain set-up.
48. Transmitted power:	—
49. Spatial resolution:	—
50. Signal to Noise ratio:	—
51. Detection algorithm:	—
52. Feature Extraction:	—
53. Safety issues:	None
54. Other:	MD operating programmes: Normal/Conductive soil. MD: power line suppression: Yes. GPR: type selectable (AP/AT), sets the value of average removal.

a) Excluding salt water and heavy clay for GPR.
b) For anti-personnel mines of diameter >5cm with up to 10cm cover, anti-tank mines of diameter >15cm with up to 20cm cover.

Remarks
Supervisor can set up and optimise the GPR settings for a specific operational scenario.

3.4 NIITEK Mine Stalker for Humanitarian Demining

Project identification

Project name	Mine Stalker	**Technology type**	Ultra-wideband ground penetrating radar (WGPR)
Acronym	—	**Readiness level**	●●●●●●⑦●●
Participation level	National	**Development status**	Ongoing with completed Angola field test in fall 2005
Financed by	US DoD HD R&D Program	**Company/institution**	NIITEK, Inc.
Budget	US$2.6 million over 3 years		
Project type	Technology development, System/subsystem development[6]		
Start date	2003		
End date	2006		

Project description

Figures 1 and 2. NIITEK's Remotely Controlled MineStalker in Angola (October 2005).

The **Mine Stalker** is a remote controlled system designed to detect and mark anti-tank mines. It has a specially designed ground penetrating radar (GPR) that was leveraged from the US Army for use in humanitarian demining. The GPR is capable of producing very clear and precise radar imaging of targets. The Mine Stalker was developed in response to a requirement from the 2004 US Department of Defense Humanitarian Demining R&D Requirements Workshop. The system consists of a relatively lightweight, remote controlled vehicle outfitted with the NIITEK GPR, real-time detection algorithm, and a marking subsystem. The system completed a successful test and field evaluation in southern Africa during 2005. Additional features and system improvements are currently being incorporated.

6. Field-ready prototype development and testing in real-world humanitarian demining conditions.

Detailed description

System

- Remote controlled.
- Very low ground pressure in the configuration shown in Figure 1 (anti-tank overpass, not anti-personnel overpass).
- Visible marking system.
- Flashing light, horn and auto-halt for detections.

Radar

- Ultra-wideband ground penetrating radar developed specifically for vehicle-mounted mine detection.
- Can be mounted on various platforms.
- Remote subsurface visualisation.

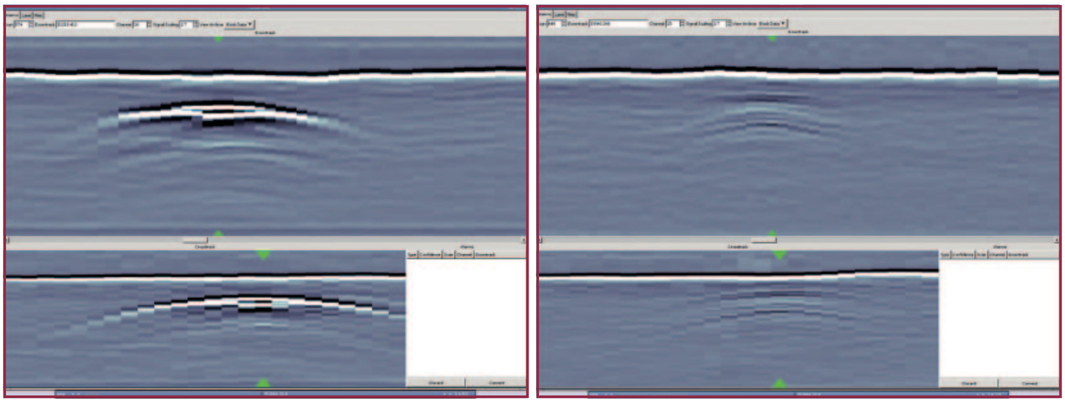
Algorithm

- Automatic target recognition algorithms.
- Detects all anti-tank mines including hard to detect plastic mines such as the South African #8, VS1.6, and VS2.2.
- Detects large AP mines such as PMN and PPM-2.

Test & evaluation

During US Army testing from 2002 to 2005, the NIITEK GPR performance far exceeded expectations. It demonstrated a higher probability of detection and lower false alarm rate against metal and plastic cased anti-tank mines than any other vehicle-based GPR evaluated to date.

Recently, in October 2005, the Mine Stalker was tested at a US built test site in Namibia and then completed a field evaluation in Angola. A real-time, non-discriminating, pre-screener algorithm processed the GPR data to automatically detect targets. At the Namibia test site, 42 individual AT mines were buried in 10 test lanes. Nineteen per cent of the targets were metal AT mines and eighty-one per cent were low-metal AT mines. The Mine Stalker encountered a total of 252 AT mines and covered 1,800m^2. The pre-screener algorithm achieved a probability of detection of 0.996 with a false alarm rate of 0.079 per square metre.



Figures 3 and 4. Mine Stalker GPR imagery taken during Namibia testing(a) metal AT mine and (b) plastic-cased, low-metal AT mine.

The field evaluation in Angola was conducted in cooperation with the German NGO Menschen gegen Minen (MgM). MgM deminers operated the Mine Stalker throughout the evaluation. Four previously cleared areas were selected for the field evaluation. The primary objective of the evaluation was to evaluate the effectiveness and reliability of the Mine Stalker under field conditions. Data collection in realistic minefield conditions was the second objective. The Mine Stalker was extremely reliable during the evaluation with no significant maintenance issues. All AT mines used to verify GPR performance were detected, even when buried to depths as deep as 25-33cm.

Other applications (non-demining)

Subsurface visualisation, non-intrusive inspection, buried object detection and counterdrug.

Related publications

1. Walls, R., J. Clodfelter, S. Laudato, S. Lauziere, M. Price (2005) "Ground penetrating radar field evaluation in Angola", *Detection and Remediation Technologies for Mines and Mine-like Targets XI*, edited by R.S. Harmon, J.T. Broach, and J.H. Holloway, Vol. 6217, SPIE, Bellingham, WA.
2. Scientific publications by third parties on data processing aspects are available in the SPIE Proceedings series (search the SPIE Publications starting from *www.spie.org*).

Technical specifications	*NIITEK HD Mine Stalker*
1. Used detection technology:	WGPR, ultra-wideband GPR
2. Mobility:	Vehicle-based
3. Mine property the detector responds to:	Shape, size, and internal structure
4. Detectors/systems in use/tested to date:	Many in US Army field tests and one in Africa.
5. Working length:	Not applicable
6. Search head:	
➢ Size:	1.2m x 1.5m x 0.25m, as shown in Fig. 1
➢ Weight:	45kg (100lbs) for detection and marking subsystem
➢ Shape:	See Fig. 1
7. Weight, hand-held unit, carrying (operational detection set):	—
Total weight, vehicle-based unit:	295kg (650lbs) as shown in Fig. 1
8. Environmental limitations (temperature, humidity, shock/vibration, etc.):	NIITEK GPR has temperature compensation features. No other environmental limitations have been identified to date.
9. Detection sensitivity:	—
10. Claimed detection performance:	
➢ Low-metal-content mines:	Performance depends more on size
➢ Anti-vehicle mines:	Nearly 100% in all tests to date
➢ UXO:	100% in limited test to date
11. Measuring time per position (dwell time):	—
Optimal sweep speed:	1-15 km per hour (depending on application)
12. Output indicator:	LED lights, audible tones/voice, visible mark on ground
13. Soil limitations and soil compensation capability:	—
14. Other limitations:	—
15. Power consumption:	Fully functional from vehicle power
16. Power supply/source:	Onboard vehicle power
17. Projected price:	Undetermined
18. Active/Passive:	Active
19. Transmitter characteristics:	Ultra-wideband GPR
20. Receiver characteristics:	Ultra-wideband GPR
21. Safety issues:	—
22. Other sensor specifications:	—

3.5 Advanced Landmine Imaging System (ALIS)

Project identification			
Project name	Advanced Landmine Imaging System	**Start date**	September 2002
Acronym	ALIS	**End date**	March 2006
Participation level	National (Japan)	**Technology type**	Metal detector, ground penetrating radar
Financed by	JST (Japan Science and Technology Agency)	**Readiness level**	●●●●●6●●●
Budget	n/a	**Development status**	Completed
Project type	System/subsystem development	**Company/institution**	Tohoku University

Project description

ALIS, the **Advanced Landmine Detection System**, is a hand-held dual sensor for anti-personnel landmine detection, which can visualize the metal detector (MD) and ground penetrating radar (GPR) signals for the benefit of deminers. The visualized metal detector signal image provides a direct information about the location of metallic objects, and then the GPR gives the radar image of the buried objects, which can be used to detect landmines. According to the developer, the visualisation system increases the reliability of operation. The locus (position in space) of the sensor head scanned by the deminer can also be recorded in real time. This record can be used for the quality control of the operation, and also for the training of operators.

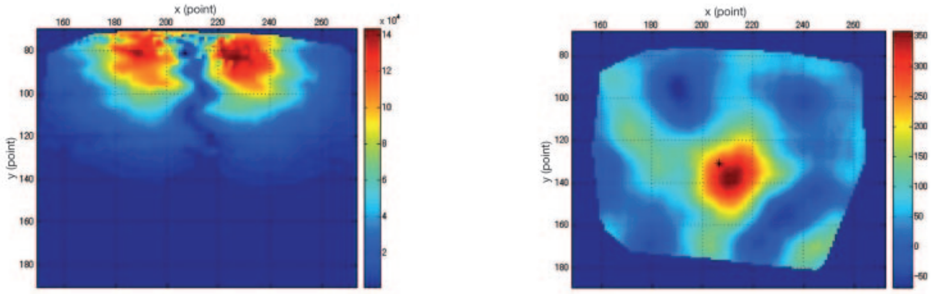
Detailed description

ALIS combines a MD and a GPR. The sensor signals from the metal detector and GPR are stored in a PC, which provides both detection and sensor position information. The entire system is controlled by a PC which is carried inside a backpack worn by the deminer. The deminer monitors the metal detector signal displayed on a hand-held display or PDA and scans the ALIS sensor as shown in Figure 1. The same image which the deminer is looking at is transmitted by wireless LAN to a handheld PC display, allowing several operators to also monitor the operation. For the normal operation of ALIS, one operator scans the sensor and another operator controls and monitors the sensor signals.

Figure 1. ALIS and details of the search head.

The scanning by ALIS follows a procedure that is similar to the normal hand-held metal detector. A deminer stands at the front of the boundary of a safe zone, and scans an area of about 1m x 1m. Continuous scanning is recommended, even if the deminer detects an anomalous signal from the metal detector. One set of data acquisition by ALIS takes several minutes, which is almost equivalent to the time required for normal scanning operation of a conventional MD.

After scanning the area, the acquired data sets are processed using the PC. First, all acquired data sets are transformed to a regular grid of points. An interpolation algorithm is used for this process. The full processing usually requires one to a few minutes until all the data sets are displayed. Subsequently, ALIS provides a horizontal (plan) visual image of the metal detector signal (Fig. 2a) and 3-D GPR information. The 3-D GPR information is, however, usually too detailed and cluttered for interpretation on site, so the displays of horizontal time slices (C-scans) of the GPR signal (Fig. 2b) are preferred instead. In the developer's experience, the detection of buried landmines with the horizontal time slice image is the most reliable.



(a) Metal detector image

(b) GPR image

Figure 2. Typical ALIS output image of buried AP landmine. (PMN-2, 10cm depth).

After processing and generating the signal images, one can locate/designate the suspect position on the display. Currently, the data is interpreted manually. First, anomalies appearing in the metal detector image are detected. Normally this is quite easy, but it includes many signals due to metal fragments and other objects (i.e. false alarms). After marking the location of these anomalous points on the GPR horizontal slice image, the operator can move the depth of the horizontal slice images trying to find a continuous image that can correspond to a GPR image of buried landmines. A semi-automatic detection algorithm can be used to get advice during the manual interpretation procedure.

Another unique feature of ALIS is its compatibility with conventional landmine detection operations, as it requires, according to the developer, minimum modification of the operational procedures. The ALIS is an add-on system that can be attached to an existing commercial metal detector (e.g., CEIA MIL-D1). The performance of the metal detector is not altered by adding the ALIS system[7]: the operator still hears the audio tone signal from the metal detector, and can detect anomalies using its own experience.

Test & evaluation

ALIS was evaluated at several locations, including tests in Kabul City, Afghanistan, in December 2004. The field tests were conducted at two locations: the first site (CDS: Central Demolition Site) was a controlled flat test site, prepared for the evaluation of

7. Note: *a priori* this does not apply to all metal detectors.

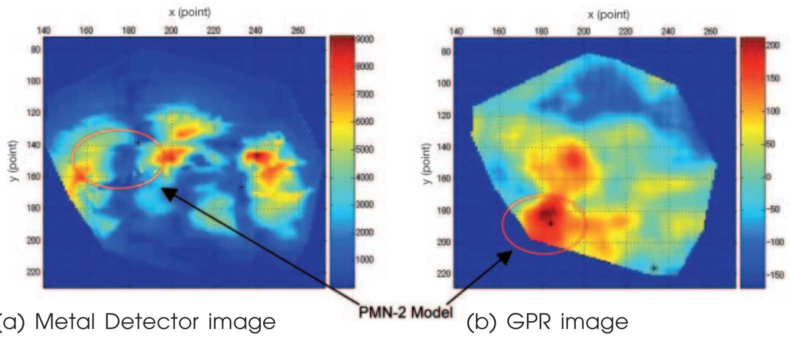
landmine sensors; the second site (Bibi Mahro Hill) is a small hill inside Kabul City, which is a real minefield where a demining operation was being carried out.

Figure 3. ALIS tests at the Central Demolition Site near Kabul.

Figure 4. ALIS tests at Bibi Mahro Hill, Kabul.

At the CDS site, the operation of the ALIS for known targets could be validated under various conditions. The soil in the CDS site was relatively homogeneous, although much clutter was found in the raw GPR profile. Metal fragments had basically been removed from the soil before the evaluation was carried out. After migration processing[8] of the GPR data, in most cases clear images of buried landmines could be found. The climatic conditions during the field tests were partly rainy, and water content of the soil at the CDS site was about 10 per cent, corresponding to a dielectric constant of 5.3. Real PMN-2 and Type 72 landmines without boosters were buried at the CDS site at different depths between 0 and 20 cm. The metal detector could only detect landmines buried shallower than 15 cm, whereas GPR could show clear images of landmines which were buried up to a depth of 20 cm. Metal fragments do not show clearly on the GPR images, and could therefore be discriminated from landmines using ALIS. Figure 2 shows an example of the ALIS output for an inert PMN-2 mine, which was buried at 10 cm. Both MD and GPR images are clear in this case.

Bibi Mahro Hill is a small hill near the Kabul airport. The soil in this site is very non-homogeneous, and contains many small objects such as gravel, pieces of wood and metal fragments. At the calibration site in Bibi Mahro Hill, a PMN-2 plastic shell model filled with TNT explosive was buried; it also contained a small metal pin imitating the metallic part of a booster in a real landmine. In addition, a small metal fragment was added at about 15 cm from the landmine model. Figure 5 shows the corresponding ALIS visualisation output. Figure 5(a) is the MD image, which features two separated metal objects.[9] Figure 5(b) shows the GPR image, in which only one clear image could be found that corresponds to the landmine model. (The images in Figure 2 and Figure 5 have a 20cm offset between MD and GPR.)



(a) Metal Detector image (b) GPR image

Figure 5. ALIS output at Bibi Mahro Hill in Kabul, Afghanistan.

8. Software refocusing of the GPR data after data acquisition.
9. The CEIA MIL-D1 has a differential signal output. A single metal object shows therefore a symmetric response with a null point at the centre, right above the object.

Other applications (non-demining)

The ALIS stepped-frequency GPR is capable of operating in the 100MHz-4GHz frequency range. The operational frequency range can be adaptively selected as a function of the soil conditions, mainly its moisture. This unique feature is useful not only for landmine detection, but also for other applications. Especially, its capability in the lower frequency range allows using ALIS for environmental studies including ground water monitoring and detection of buried utilities, e.g. pipes.

The sensor head of the ALIS is small, and is also suitable also as a sensor unit for a robot arm mounted on a vehicle as shown in Figure 6. In this case the scanning speed can be increased due to higher accuracy of the sensor positioning.

Figure 6. ALIS mounted on a vehicle during field tests in Croatia.

Related publications

1. Sato M, J. Fujiwara, X. Feng, T. Kobayashi (2005)
   "Dual Sensor ALIS evaluation in Afghanistan", *IEEE Geoscience and Remote Sensing Society Newsletter*, pp. 22-27, September.
2. Feng X. and M. Sato (2004)
   "Pre-stack migration applied to GPR for landmine detection", *Inverse Problems*, 20, pp. 1-17.
3. Feng X., J. Fujiwara, Z. Zhou, T. Kobayashi and M. Sato (2005)
   "Imaging algorithm of a Hand-held GPR MD sensor (ALIS)", *Proceedings of SPIE Conference on Detection and Remediation Technologies for Mines and Mine-like Targets X*, Vol. 5794, Orlando, US.
4. Final Report (Summary) for Humanitarian Mine Clearance Equipment in Afghanistan (2005)
   Japan International Cooperation System, 31 March, *www.mineaction.org/doc.asp?d=452.*

Technical specifications	Tohoku University ALIS
1. Used detection technology:	Metal Detector and GPR Visualisation
2. Mobility:	Hand-held (vehicle-based possible)
3. Mine property the detector responds to:	Dielectric characteristics (see *GPR Operating Principles*) and metal content.
4. Detectors/systems in use/tested to date:	Two prototypes
5. Working length:	—
6. Search head:	
➢ size:	30cm diameter, 20cm height
➢ weight:	ca. 2kg
➢ shape:	Round (CEIA MIL-D1)
7. Weight, hand-held unit, carrying (operational detection set):	ca. 6kg
Total weight, vehicle-based unit:	—
8. Environmental limitations (temperature, humidity, shock/vibration, etc.):	—
9. Detection sensitivity:	—
10. Claimed detection performance:	
➢ low-metal-content mines:	Max 20cm depth (PMN-2)
➢ anti-vehicle mines:	Not applicable
➢ UXO:	Not applicable
11. Measuring time per position (dwell time):	2-3 min/m^2
Optimal sweep speed:	30cm/s
12. Output indicator:	PDA Display
13. Soil limitations and soil compensation capability:	Equivalent to CEIA MIL-D1
14. Other limitations:	—
15. Power consumption:	—
16. Power supply/source:	DC12V car battery
17. Projected price:	—
18. Active/Passive:	Active
19. Transmitter characteristics:	100MHz-4GHz Stepped Frequency
20. Receiver characteristics:	Synchronized to Transmitter
21. Safety issues:	—
22. Other sensor specifications:	—

4. Other Ground Penetrating Radar Systems

4.1 Portable Humanitarian Mine Detector (PHMD)

Project identification

Project name	Portable Humanitarian Mine Detector
Acronym	PHMD
Participation level	European
Financed by	UK Treasury Capital Modernisation Fund
Budget	£3,000,000
Project type	Technology development, Technology demonstration, System/Subsystem Development
Start date	1 July 2000

End date	31 October 2002
Technology type	Ground penetrating radar, metal detector, capacitance sensor
Readiness level	6
Development status	Completed
Company/institution	QinetiQ Ltd, Meodat GmbH, Guartel Technologies Ltd., Sensatech Research Ltd

Project description

The aim of the **Portable Humaniarian Mine Detector** project was to develop and test a prototype portable land-mine detector for use in humanitarian demining. The project first 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 per cent 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. The system prototype was developed and tested in the UK, US and Bosnia using realistic mine targets. The results of some of these tests are published on the ITEP website (*www.itep.ws*).

Detailed description

The PHMD system is composed of the following units:

Ground Penetrating Radar (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 three-dimensional image; a single pair of antennae (transmit and receive) can only provide one-dimensional information and so must either be moved over the target while their position is measured (difficult), or combined with further antennae. It was decided that nine antennae would be used and arranged in a square array. GPR antennae 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 digital signal processor (DSP) that executed the data extraction, timing calibration, 3D focusing and target detection algorithms.

***Metal detector (MD)*:** The MD 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 antennae 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 nine GPR antennae while 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 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 Figure 2, intended to represent the realistically achievable size and weight to which the detector could be reduced following additional development and manufacture.

Figure 1. PHMD prototype during US tests.

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.

In 2002 data was gathered in all the squares. However, software development delays limited the rate of data transfer between the detector and logging PC. This meant that instead of "sweeps" over the target, just one "snapshot" of each square was obtained. 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. A second trial in the US was carried out during late August/early September 2003 (see references below for details).

Further testing was carried out in October 2002 in Bosnia. These tests took place at a test site prepared by Norwegian People's Aid. 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 US.

Figure 2. Bosnian deminer assessing space model.

In this case, data were 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.

Ongoing data logging problems again limited the amount of data that could be gathered to assess the performance of the detector. 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 reported by 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.

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 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.

Other applications (non-demining)

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. Allsopp D. (2002)
   PHMD – QinetiQ portable humanitarian mine detector, QinetiQ Ltd, 15 March. *www.eudem.info*
2. Dibsdall I. M., S. M. Bowen, D. J. Allsopp (2003)
   Portable Humanitarian Mine Detector 2003 US Trials, QinetiQ Ltd, September. *www.itep.ws*

Technical specifications	*QinetiQ PHMD*[a)]
1. Used detection technology:	MD, GPR, Capacitance Sensor
2. Mobility:	Hand-held
3. Mine property the detector responds to:	Dielectric characteristics (see *GPR Operating Principles*), metal content.
4. Detectors/systems in use/tested to date:	Prototype
5. Working length:	
6. Search head:	
➢ size:	Width: 380mm (310mm), Height: 140mm (95mm).
➢ weight:	—
➢ shape:	—
7. Weight, hand-held unit, carrying (operational detection set):	13kg (<6kg)
Total weight, vehicle-based unit:	—
8. Environmental limitations (temperature, humidity, shock/vibration, etc.):	IP64 sealed unit, 0°C to 35°C (IP67 sealed unit, -20°C to +40°C).
9. Detection sensitivity:	—
10. Claimed detection performance:	
➢ low-metal-content mines:	b)
➢ anti-vehicle mines:	b)
➢ UXO:	—
11. Measuring time per position (dwell time):	—
Optimal sweep speed:	MD: Similar to commercial units, but limited by GPR in PHMD system.
12. Output indicator:	MD: Audio tone and LED confirmation of approximate position and depth.
13. Soil limitations and soil compensation capability:	MD features soil compensation mode.
14. Other limitations:	MD: power line suppression, proprietary to Guartel.
15. Power consumption:	20W (5W)
16. Power supply/source:	Battery. Lifetime: 1.5 hrs (~8hrs)
17. Projected price:	~£10k
18. Active/Passive:	Active
19. Transmitter characteristics:	GPR: transmitted power: 1mW ERP (effective radiated power)
20. Receiver characteristics:	GPR bandwidth: 3GHz (5GHz); 3 array scans/s (>10/s).
21. Safety issues:	None
22. Other sensor specifications:	GPR resolution: ~3cm depending on soil properties (<2cm). Primary detection algorithm (GPR): proprietary, based on correlation with known targets. Feature extraction: proprietary, based on deconvolution and focussing of radar data.

a) Main figures are for the prototype: figures in square brackets are target production specifications.
b) Prototype PD and FAR tested at US test site, but number of targets results was with insufficient confidence to quote. Small plastic AP (NR409, PMA2 etc) detected in tests.

Remarks

MD specifications are for the metal detector used in PHMD, not for the Guartel unit on which it is based.

Target depth range: 30cm.

4.2 Hand-held Stepped Frequency Modulated Continuous-wave Radar

Project identification

Project name	Hand-held Stepped Frequency Modulated Continuous-wave Radar	**Start date**	2000
Acronym	—	**End date**	2003
Participation level	International	**Technology type**	Ground penetrating radar
Financed by	International Science and Technology Centre (ISTC); APSTEC Ltd.	**Readiness level**	●●●●5●●●● (5)
Budget	US$240,000	**Development status**	Completed
Project type	Technology development, Technology demonstration	**Company/institution**	Applied Physics Laboratory; V.G. Khlopin Radium Institute, St. Petersburg

Project description

The proposed method for the localisation of suspicious anomalies is based on a **modulated continuous-wave radar**, which analyses the continuously scattered electromagnetic radiation. This enables the characterisation of objects within an inspected volume in terms of their shape and dielectric characteristic. According to the manufacturer, the radar allows one to determine:

- dimensions of the concealed object;
- its dielectric characteristics; and
- distinctions between metallic (conductors) and dielectric objects.

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

Detailed description

A prototype hand-held Ground Penetrating Radar (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 electromagnetic waves (microwaves) with stepped frequency change.[10] The manufacturer states that the present prototype device can detect objects with dimensions larger than 5cm in soil (with spatial resolution of 5cm in-plane and 2.5cm 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

10. Note that this high frequency range is very likely to result in limited penetration in most soils.

range 2-8 GHz, which allows 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.

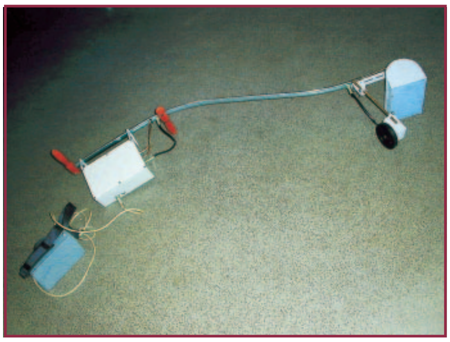


Figure 1. Hand-held prototype GPR.

Test & evaluation

Test and evaluation has been completed at the laboratory level.

The Applied Physics Laboratory also proposes a multi-sensor based on a localisation sensor (the stepped-frequency continuous wave radar detailed here) and a "neutron in, gamma out" identification sensor, based on Nanosecond Neutron Analysis/ Associated Particles Technique (NNA/APT) and detailed later on.

Other applications (non-demining)

Detection of thin metallic foils in passenger luggage; human body inspection.

Related publications

1. Averianov V.P., I.Yu. Gorshkov, A.V. Kuznetsov, A.S. Vishnevetski (2004)
   Detection of explosives using continuous microwaves, Proceedings 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.

   Extracted from the *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.*"

2. Kuznetsov A. (2003)
   Portable multi-sensor for detection and identification of explosives substances, Proceedings of Expert Workshop on Explosive Detection Techniques for Use in Mine Clearance and Security Related Requirements, Lake Bled, Slovenia, 2-4 June 2003, pp. 64-69.

Technical specifications	APL Hand-held GPR[a)]
1. Used detection technology:	GPR
2. Mobility:	Hand-held
3. Mine property the detector responds to:	Dielectric characteristics (see *GPR Operating Principles*).
4. Detectors/systems in use/tested to date:	—
5. Working length:	—
6. Search head:	
➢ size:	25x15x15cm ([b)])
➢ weight:	—
➢ shape:	—
7. Weight, hand-held unit, carrying (operational detection set):	5kg
Total weight, vehicle-based unit:	—
8. Environmental limitations (temperature, humidity, shock/vibration, etc.):	Prototype : laboratory environment (resistant).
9. Detection sensitivity:	—
10. Claimed detection performance:	
➢ low-metal-content mines:	Depth range @ 16% soil humidity: 8-10cm. PD, PFA: Not available.
➢ anti-vehicle mines:	Depth range @ 16% soil humidity: 8-10cm. PD, PFA: Not available.
➢ UXO:	—
11. Measuring time per position (dwell time):	[c)]
Optimal sweep speed:	—
12. Output indicator:	—
13. Soil limitations and soil compensation capability:	Soil humidity <16%
14. Other limitations:	—
15. Power consumption:	10W (<10W)
16. Power supply/source:	Battery, 8hrs autonomy
17. Projected price:	7,000-10,000 US$
18. Active/Passive:	Active
19. Transmitter characteristics:	2-8GHz([b)]), minimal frequency sweeping step of 1.5MHz([b)]) (modulated continuous wave radar). Transmitted power: 1mW.
20. Receiver characteristics:	Sensitivity: –120dB/W([b)]), bandwidth: 6GHz ([b)])
21. Safety issues:	None
22. Other sensor specifications:	Dynamic range: 50dB([b)]). Spatial resolution in air: in-depth: 2.5cm, transversal: 5cm, longitudinal: 4cm (down to 1cm, depending on chosen frequency range).

a) Main figures are for the prototype: figures in square brackets are target production specifications.
b) = "Task dependent".
c) Minimal measurement and analysis time of one sweeping cycle at a sweeping step of 200 MHz: 100ms.

4.3 Surface-penetrating Radar Detector with system-on-chip, DEMINE

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 million
Project type	Technology development, Technology demonstration
Start date	1 February 1999
End date	31 July 2001
Technology type	Ground penetrating radar array
Readiness level	●●●●⑤○○○○
Development status	Completed
Company/institution	Technische Universität Ilmenau; Meodat GmbH; Ingegneria dei Sistemi SpA; QinetiQ Ltd; Menschen gegen Minen; Vrije Universiteit Brussel; Applied Electro-magnetics FGE Ltd

Project description

The fundamental research aspect within the **DEMINE** project has been the development of an ultra-wideband sensor array considering two main characteristics:

- A quicker survey speed is achievable, since a larger area is under investigation.
- The gathered data provides more information content as targets may be "seen from different aspect angles". It should be noted, however, that the last point is connected with very complicated data processing.[11]

In the DEMINE project, which took place in a relatively short research and technical development timeframe, the main emphasis was on technical and scientific questions in order to first solve the fundamental problems of detecting buried non-metallic mines. These technical questions have been solved, according to the DEMINE Consortium, in a manner which may be implemented in practice by an appropriate re-design of the developed system.

Detailed description

The DEMINE system consisted in a hand-held ground penetrating radar (GPR) array with the following characteristics:

- GPR System prototype with off-line processing,
- Radar on Chip correlation/pseudo random code (PRC) solution based on high speed digital technology,
- Antenna array for multi-static and multi-polarisation,

11. Current data processing techniques (e.g. SAR processing) do usually assume small point-like targets which do not show a scattering dependent on the aspect angle.

- Dynamic positioning measurement system,
- Multi-dimensional signal processing and classification which exploits the novel features of the radar.

Figure 1. Testing of the DEMINE prototype in Angola.

Test & evaluation

The DEMINE system was tested by the consortium during in-house tests, at the Joint Research Centre in Ispra and in Angola. Details of the tests are provided in the *DEMINE Final Report*. The relatively few tests made it difficult for the consortium to provide results with any statistical significance. The consortium was, however, able to demonstrate that the new maximum length binary sequence (MLBS) radar method worked and that metallic and non-metallic APs and ATs 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 publication

1. DEMINE Consortium (2001)
DEMINE Final Report, 2001, www.eudem.info.

Technical specifications	***DEMINE GPR***
1. Used detection technology:	Ultra wide band GPR array
2. Mobility:	Hand-held based
3. Mine property the detector responds to:	Dielectric characteristics (see *GPR Operating Principles*).
4. Detectors/systems in use/tested to date:	Prototype
5. Working length:	Not applicable
6. Search head:	
➢ size:	Array width: x axis: 650mm, y axis: 350mm, height: 230mm.
➢ weight:	12kg
➢ shape:	—
7. Weight, hand-held unit, carrying (operational detection set):	—
Total weight, vehicle-based unit:	—
8. Environmental limitations (temperature, humidity, shock/vibration, etc.):	Temperatures over 40°C experienced.
9. Detection sensitivity:	—
10. Claimed detection performance:	
➢ low-metal-content mines:	Max depth range: 2-15cm. PD: 0.7[a], PFA: too few results to comment.
➢ anti-vehicle mines:	—
➢ UXO:	—
11. Measuring time per position (dwell time):	—
Optimal sweep speed:	10cm/s (with 2048 averages per scan)
12. Output indicator:	—
13. Soil limitations and soil compensation capability:	—
14. Other limitations:	—
15. Power consumption:	55W
16. Power supply/source:	20V mains
17. Projected price:	—
18. Active/Passive:	Active
19. Transmitter characteristics:	Transmitted power: 3dBm/13dBm (chip output/ amplifier output)
20. Receiver characteristics:	Bandwidth: 4.5 GHz
21. Safety issues:	—
22. Other sensor specifications:	Resolution: 3cm in air. Primary detection algorithms and feature extraction methods: see full details in the DEMINE Final Report.

a) This value is based on the first tests/measurement gathering with the first field demonstrator/ prototype in Angola. The test measurements are a basis for further development of the detector: reliable statistics will only be available after more tests and evaluation.

Remarks

Technical specifications are those of the prototype system.

Tested environmental conditions: sand, gravel up to 1cm, sandy soil up to 15 per cent clay, loam (37 per cent sand, 53 per cent silt, 10 per cent clay).

5. Radiometer Systems

5.1 Sensing principle

Operating 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 centimetres). 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 anti-tank 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 therefore been 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 (similar frequency range as GPR-GHz range). 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.

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

Application type

Close-in detection: hand-held, vehicle-based.

Remote detection: possible for large surface laid objects.

Strengths

- Surface or shallowly buried objects, e.g. as a complement to GPR which has difficulty detecting an object close to the air-ground interface.
- Detection depth depends strongly on operating frequency, soil humidity and conductivity, mine case (metal or plastic) and size (large anti-tank mines are much easier to detect than small anti-personnel mines).
- Best results likely for large metallic objects in dry soils.
- In principle simpler than GPR and should suffer less from clutter problems.
- Can be scanned over the ground to generate two dimensional images.

Limitations

- Less effective in wet soils.
- Clear depth limitations. Unlikely to be used as a stand-alone device except for surface objects.
- Need to balance resolution (better at higher frequencies) with depth penetration (better at lower frequencies).
- Has to be protected from radio frequency interference.

Potential for humanitarian demining

- Integration with GPR possible (can use same antenna).
- Should be possible to build human portable systems at relatively low cost.
- Overall potential for humanitarian demining seems, however, limited.
- Active systems possible ("illuminate" target with microwaves) and may offer enhanced contrast.

Estimated technology readiness

Medium.

Related publications

1. HOPE consortium (2002)
   Public HOPE Final Report, 2002, www.eudem.info.
2. Daniels D.J. (2004)
   Ground Penetrating Radar, 2nd edition, IEE Radar, Sonar, Navigation and Avionics Series, June, ISBN 0 86341 360 9.
3. Daniels D.J. (1999)
   An Overview of RF sensors for mine detection: Part 1 Radiometry, MINE'99 Conf. Proceedings, pp. 31-36, 1-3 October 1999, Florence, Italy *(http://demining.jrc.it/aris/events/mine99/program/P31-36/MINE-RAD.htm).*

5.2 HOPE Microwave Radiometer

Project identification (* = Radiometer specific)

Project name	Hand-held Operational Demining System
Acronym	HOPE
Participation level	European
Financed by	Co-financed by EC ESPRIT FP IV
Budget	€ 2,800,000
Project type*	Basic technology research, Research to prove feasibility, Technology development, Technology demonstration
Start date	1 January 1999
End date	30 June 2001
Technology type	Metal detector, ground penetrating radar, microwave radiometer
Readiness level*	●●●●5○○○○
Development status*	Completed
Company/institution	Deutsches Zentrum für Luft- und Raumfahrt e.V.; Vallon GmbH; Institut Franco-Allemand de Recherches de Saint-Louis; Norwegian People's Aid; ONERA - Toulouse; Radar Systemtechnik AG; Royal Military Academy; Ruhr-Universität Bochum; SPACEBEL S.A.; Universität Karlsruhe (TH)

Project description

The **HOPE** project [1] consisted in developing a sensor head combining an improved pulse metal detector, a ground penetrating radar (GPR) and microwave radiometer — as well as an optical position monitoring system to provide position data as a basis for 2D and 3D data processing. Software for data visualisation and interpretation was also provided. In a number of tests, several stages of the project progress have been tested in the lab, in company test fields, at the Joint Research Centre (JRC) in Ispra (Italy) and in Norwegian People's Aid (NPA) test fields in Bosnia. The demonstrators built for the Bosnia tests and the other test prototypes comprised lightweight sensor heads and an electronic backpack with specific electronics and off-the-shelf computers. Due to time constraints two separate systems have actually been built: one combining a metal detector and the radar, the other with a metal detector and the radiometer. The prototypes had limited real time capabilities and were mainly used to collect data for offline data processing.

The consortium views the results of the HOPE project as quite encouraging [1, p. 159]. To the best knowledge of the consortium, this was the first time that high-resolution registered images could be obtained from 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 metal detector (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 position accuracy. 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 interesting discriminating features. Fusion was possible and showed quite promising results, especially for the radiometer. This showed that registration is possible (creation of images in a common reference view). With focusing and higher level feature extraction, the consortium expected that a lot of additional discriminative characteristics could be used in the future.

Detailed description

The HOPE sensor head combines an improved pulse metal detector, a GPR and a microwave radiometer (MWR). Searching mines with the HOPE sensor starts conventionally, using the metal detector or the GPR if non-metallic mines are expected. In a second step, 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 fuze), allowing the deminer to continue much more systematically and efficiently instead of prodding in a completely unknown volume.

NOTE: The following description and discussion concentrates mainly on the microwave radiometer, rather than on the whole HOPE system.

The microwave radiation is usually composed of three contributions: (1) the object's self emission, (2) reflection of similar radiation, generated elsewhere, on the object's surface, and (3) transmission through the object in the case of a partial microwave transparency [1, p. 60]. All parts of the radiometer receiver, except the synthesiser, are housed in a robust case of cast aluminium. The synthesiser has a similar case. The control computer is a standard laptop and the digital signal processing board is ingrained in synthetics. The power supply has several modules, each housed in a steel case.

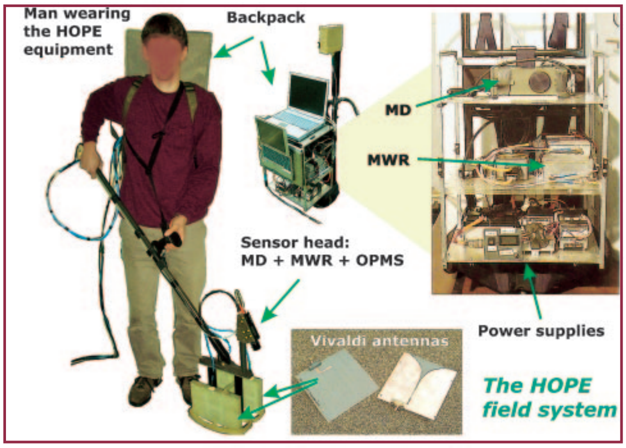


Figure 1. Essential elements of the HOPE multi-sensor system as it is to be operated in the field. Shown is the experimental equipment for the microwave radiometer (MWR), metal detector (MD) and optical position monitoring system (OPMS) demonstrator.

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 [1]. For these investigations a laboratory type of the MWR (similar to the field type) was used in conjunction with a computer-controlled positioning system located in a tent, in order to achieve a more controlled environment.

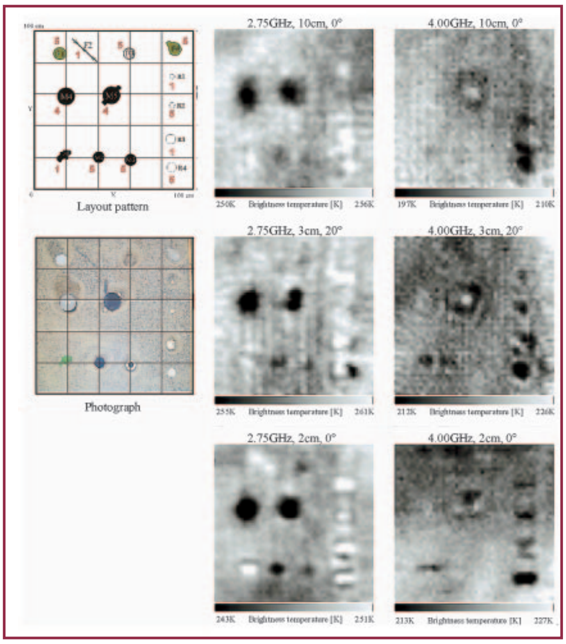


Figure 2. Photograph, layout pattern, and brightness temperature images of the measurement of scene S1 (laboratory experiments). Results for two centre frequencies, two tilt angles and various ground distances of the antenna are shown.

Field tests: The radiometer was combined with the metal detector as foreseen for a typical operation. The two antennae were mounted 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, as shown in Figure 1. One antenna was actually used for the MWR, since the other was only required when the radar was added to the system as intended for the final HOPE device.

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 impossible to extract from the background clutter. It has to be noted that very moist or wet soil conditions due to rain were encountered during the measurement. Only target detection was considered with the HOPE MWR system. Target discrimination will require more frequencies and deeper signature analysis.
- Several interference problems were observed: radio frequency interference by artificial transmitters such as communications, broadcast, radars, and switched high currents in the vicinity of the MWR sensor. For a future MWR system these need to be detected automatically and reduced or removed by an automatic centre-frequency adjustment. In general, interference can reduce the contrast or, in excess, make the MWR system completely blind.

The experiments carried out at the NPA test site in Sarajevo, Bosnia, underlined that the prototype was not yet sufficiently mature to be used as the basis for an industrial instrument. There are several improvements to be addressed in addition to those already mentioned:

- A main problem of the hand-held operation is the irregular scanning pattern. This can produce artefacts and a significant contrast reduction due to a bad scan pattern in all three dimensions. The possibility of touching the ground or approaching it too closely should be avoided automatically in a future development. A tool to assist the deminer in performing more regular scanning would be helpful and would increase the data quality significantly, as was observed under more controlled laboratory experiments. The head has to be reduced in weight considerably to allow easier operation and more regular scanning.

- Appropriate image processing software is required to perform the pattern and feature recognition operations automatically so as to assist the image-based detection process. Visible investigations alone are subjective and unsatisfactory.
- Improvements to the antenna's directivity and the reduction of sidelobes is a major need.
- Equipment should not be located near the MWR antenna to avoid shadowing and additional interference.

After the HOPE project some DLR internal work continued to investigate more deeply the benefits of frequency profiling instead of imaging. For this purpose the sensor head has to be located for a few seconds in one position directly above the suspicious area. If a frequency profile consisting of a sufficient number of single frequency lines is obtained, some kind of fingerprint analysis can help to discriminate the observed signature from a false target. Depth estimation can also be supported using the measured frequency profile.

Other applications (non-demining)

The multi-spectral principle of the HOPE radiometer system can be used for hidden object detection in general.

Related publications

1. HOPE Consortium (2002)
   Public HOPE Final Report, www.eudem.info

   Extracted from the *Abstract*: "*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.*"

2. Peichl M., S. Dill, H. Süß, (2003)
   Application of microwave radiometry for buried landmine detection, 2nd International Workshop on Advanced Ground Penetrating Radar, 14-16 May 2003, TU Delft, Delft.

3. Peichl M., S. Schulteis, S. Dill, H. Süß (2002)
   Application of microwave radiometry for buried landmine detection, German Radar Symposium GRS 2002, 3-5 September 2002, Bonn.

4. Peichl M., S. Dill, H. Süß (2001)
   Detection of anti-personnel landmines using microwave radiometry techniques, NATO Advanced Workshop on "Detection of Explosives and Landmines", 9-14 September 2001, St. Petersburg.

5. Christophe F., P. Borderies, P. Millot, M. Peichl, H. Süß, M. Zeiler, S. Dill, F Reinwaldt (2000)
   Electromagnetic technologies for improved detection of anti-personnel landmines, Proceedings of 2nd ONERA-DLR Aerospace Symposium, 15-16 June 2000, Berlin.

Technical specifications	*DLR HOPE Microwave Radiometer[a)]*
1. Used detection technology:	Microwave radiometer
2. Mobility:	Hand-held
3. Mine property the detector responds to:	Local changes in the permittivity of the ground
4. Detectors/systems in use/tested to date:	Only the demonstrator during the HOPE project
5. Working length:	Not applicable
6. Search head:	
➢ contains:	2 antennae with cases, 2 coils, 1 optical camera
➢ size:	about 30cm x 30cm x 50cm (L x W x H)
➢ weight:	about 5kg
➢ shape:	see Fig. 1
7. Weight, hand-held unit, carrying (operational detection set):	~6kg (Receiver without synthesizer: 1,260g, Synthesizer: 260g, Power supply: 1,700g, DSP board: 250g, Control computer: 1,600g.[a)])
Total weight, vehicle-based unit:	—
8. Environmental limitations (temperature, humidity, shock/vibration, etc.):	Estimated but not proven (and not optimized for): -10 to +40°C, 80%. Shock/vibration not known.
9. Detection sensitivity:	<1.5K. Estimated system temperature range: 300-800K.
10. Claimed detection performance:	
➢ low-metal-content mines:	In general no limitation depending on metal content, since the variation of permittivity is detected.
➢ anti-vehicle mines:	Should be high if not buried to deep and the soil is not too humid
➢ UXO:	Not tested
11. Measuring time per position (dwell time):	—
Optimal sweep speed:	Max 20cm/s
12. Output indicator:	Image
13. Soil limitations and soil compensation capability:	Wet and too humid soils (>50%) for buried mines decrease detection probability, soil type rather uncritical.
14. Other limitations:	Only outdoor operation possible (cold sky required).
15. Power consumption:	8.58W (radiometer receiver)
16. Power supply/source:	24V battery
17. Projected price:	Not estimated
18. Active/Passive:	Passive
19. Transmitter characteristics:	—
20. Receiver characteristics:	# of receiver inputs: 3. Centre frequency range (tunable): 1.5-7GHz. Instantaneous receiver bandwidth: 50MHz. # of centre frequencies to be measured: 8 (HOPE demonstrator).
21. Safety issues:	None
22. Other sensor specifications:	Estimate average ground resolution (in operational configuration): 5-10cm.

a) Based on information provided by the project Consortium summarising 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 (1).

6. Trace Explosive Detection Systems

6.1 Sensing principle

Operating principle

Trace explosive detection consists of the chemical identification of microscopic residues of 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 (in contrast to bulk detection devices). In practice, the need for a field system depends on the application and working methods. Some users, most notably Mechem in South 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.

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.

Studies and measurements on **environmental fate and transport of explosives** have been carried out, for example, at the Sandia National Labs, the Cold Regions Research and Engineering Laboratory (CRREL) (US), the Defence Research Agency (FOI) (Sweden) and the Defence Research Establishment Suffield (DRES) (Canada). Mechem has accumulated practical field experience on the subject, as have Nomadics and the partners of the EC-IST BIOSENS project.

Sensor systems for field application need to have an appropriate **sampling system**. Suitable operational procedures also have to be defined. Up to now it seems that sensors either have insufficient sensitivity or 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. 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 (providing €58 million over an eight-year period for demining technology[12]) to target 60 per cent of this funding towards soil and environment research.

Application type

Close-in detection or remote detection.

Strengths

- Can potentially detect picogram ($1{:}10^{12}$ grams) level samples of explosive material at the detector, or ppt (parts per trillion, $1{:}10^{12}$) concentrations. At least in one case (Nomadics Fido *see 6.2 below*) even greater sensitivities have been achieved in the field for TNT, possibly comparable to those of dogs.
- Comparisons are often carried out with dogs (e.g. Nomadics Fido) — but there does not yet seem to be general agreement on how dogs manage to find mines and what they are actually sniffing.
- Filtering to increase concentration is possible.
- Trace detection is in routine use in other applications (e.g. aviation security, drug detection).

Limitations

- Even greater sensitivities than those quoted above are certainly achievable, and perhaps necessary, but whether this can be done for field portable systems remains to be seen.
- Sample acquisition — of the air, vegetation or soil — is crucial.
- Trace quantities available for detection might very largely vary in quantity and quality (substance types) in similar situations, and can be very small.
- Explosive fate and transport in soil: complex effects, strongly dependent on any water flow and other parameters. Large influence of environmental parameters, target history, etc., on the variables of interest (explosive vapour and particle concentration[13]).
- Weather and soil conditions can lead to samples not being reproducible. Direct vapour detection seems to be more difficult in arid areas.
- Cross-contamination and handling issues are of great importance — experimental conditions can be hard to control/reproduce.
- Possible problems due to interfering chemicals, and explosive residues due to devices which have detonated.

12. Russell S. Harmon, US Army Research Office, presentation at EUDEM2-SCOT 2003 Conference, 15-18 September 2003, *www.eudem.info*
13. Concentrations of vapour in a mined area may be several orders of magnitude lower than, for example, in a screening portal in an airport.

Potential for humanitarian demining

- Aims at replacing, or at least complementing, mine detection dogs (an artificial "dog's nose").
- Strong potential for area reduction (declaring an area free of contamination) and verification, rather than detection of individual mines.
- REST methodology is already used by some organisations with dogs, e.g. for road verification.
- Up to now most sensors either have insufficient sensitivity or are too slow/too large to be used in routine field applications.
- Even if sufficient sensitivities are achieved, extensive field trials are necessary to establish an appropriate methodology.
- The possibility of detecting traces of explosive- and/or mine-related substances, as well as surface or soil sampling, might also be well worth considering in the future.

Estimated technology readiness:

Medium-High.

Related publications

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

6.2 Nomadics Fido

Project identification

Project name	Nomadics Fido	**Start date**	1990s
Acronym	Fido	**End date**	Ongoing for demining
Participation level	National	**Technology type**	Vapour/trace detection
Financed by	Defense Advanced Research Projects Agency (DARPA, US)	**Readiness level**	●●●●●●●⑧●
Budget	—	**Development status**	In production, but continuing R&D efforts
Project type	Technology development, Technology demonstration, System/subsystem development	**Company/institution**	Nomadics Inc.

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 chemo-sensor that uses novel amplifying fluorescent polymers (AFPs) synthesised by research partners at the Massachusetts Institute of Technology (MIT). In the absence of explosive compounds, the polymer fluoresces when exposed to light of the correct wavelength. When vapours of nitro-aromatic 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. The drop in fluorescence intensity is then detected by a sensitive photodetector and processed by the instrument. Analyte binding to the films is reversible and, immediately after analysing a sample, a new sample can be introduced without replacement of the sensing element.

For demining applications, the **Fido** sensor is most effective as an area reduction tool when combined with a high volume sampling technique (e.g., REST, MEDDS or RasCargO). In this methodology, air from suspected areas is drawn across a filter cartridge and presented to the sensor. The extreme sensitivity and selectivity of Fido provides a high degree of confidence that an area is or is not contaminated with explosives.

Detailed description

The Nomadics Fido detector includes an extremely sensitive and highly selective chemo-sensor that uses novel AFPs. According to the manufacturer, the performance of the

Nomadics Fido detector, evaluated in side-by-side field operations, is comparable to dogs and can detect explosive vapour at levels as low as a few femtograms. Fido is available in two models. The Fido X is best suited for analysing the aforementioned air filters. The Fido XT has a tethered head and pistol grip and is better suited as a general purpose explosives detector. This model has recently entered service with US military agencies, primarily in the fight against improvised explosive devices.

Figure 1. Fido X (left) and Fido XT (right).

Figure 2. Analysing a high-volume sample collection filter using the Fido X.

Test & evaluation

US field trials: Blind field testing of Fido against buried landmines was conducted at the DARPA (Defense Advanced Research Projects Agency) test facility at Fort Leonard Wood [7]. Blind test lanes were established by marking potential target positions in the test field. At each test position, two flags were planted, approximately 50cm 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. In a lane consisting of TMA5 anti-tank mines (plastic cased, containing TNT), the best sensor performance recorded was a PD of 0.89, with a PFA of 0.27.

Nomadics notes that, although its ERC (explosive related compounds) sensors are highly sensitive, it remains that the explosives being detected have been released — and hence are not necessarily tightly associated with the landmine — making precise location of a buried target challenging. Nomadics therefore suggests that it may be more beneficial to the user community to reinvestigate the employment of ERC sensors to detect general areas of explosives contamination, such as for area reduction (see below) or portal or perimeter security. The use of the Nomadics ERC sensors to specifically locate a buried landmine has potential but will require additional research and development, and may involve probing of soils near the target.

Figure 3. High-volume sampling in a test minefield using a Nomadics battery-powered pump.

Croatian field trials: Additional tests were therefore carried out adapting the sensor to enable analysis of modified REST filters [1,2]. Using the Remote Explosive Scent Tracing (REST) methodology, Nomadics and Mechem Division of Denel (Pty) Ltd., participated in testing the Fido sensor and the Mechem Explosive and Drug Detection System (MEDDS) system as a tool for minefield area reduction, with sponsorship from the US Army NVESD Humanitarian Demining (HD) Program. From July 2001 to August 2003, a series of trials were performed at a test minefield in Croatia. This effort tested the ability of both the Nomadics and Mechem trace chemical vapour collection and analysis systems in detecting the presence of mined areas within a larger area clear of landmines.

In detail the test field[14] consisted of two segments:

- A 40,000 square metre "blind area" laid out in a grid pattern and containing eight to 15 mines with locations, type and burial depth unknown to the team; and
- A "proximity area", which contained three each of four different mine types (12 mines total) at known positions separated by 30m; the purpose of this area was to determine how far explosive contamination could be detected from a mine.

Figure 4. Field testing of Fido and MEDDS systems near Sisak, Croatia.

Over the life of the project, five samplings were taken after burial of the mines, in environmental conditions ranging from hot and dry to moderately cold and damp.

- *In every sampling both systems detected the presence of explosive contamination.*
- Surprisingly, even three days after burial of the mines, both systems detected the presence of mines in the blind test area.
- In general, *there was an increase in contamination of the area with time*, with more positive samples being obtained as the time the mines were in the ground increased.

In the proximity area, samples were taken along and two metres to each side of three-, seven- and 11-metre radii marked around each mine during each sampling event. *Fido and the Mechem canines routinely detected contamination up to 11m from the mine centres.* Because of the layout of the test field (the mines were only 30m apart), it was impossible to determine if contamination spread past 11m from the mines. Results

14. The following is a slightly edited version of the *Field Test Results* section in [1].

from the blind test area suggest that contamination spread more than 11m, but it was not possible to determine on average how far the contamination spread from a given mine location. *Based on the test results, it was determined that both systems could detect mined areas*. In retrospect, the blind test area probably contained too many mines and did not contain a large area that was free of mines. Because of the large number of mines in the area, *contamination of the test area was widespread*. Hence, in these tests, it was not possible to delineate a mined area from a non-mined area. (Both systems had found the area to be free of contamination prior to emplacement of the mines.)

Certain results from the field tests were somewhat surprising:

- *The locations of positive samples as determined by Fido and the dogs were largely uncorrelated.* One possible explanation for this is that the dogs were trained to detect TNT while the Fido sensor detects TNT as well as other nitroaromatic compounds derived from TNT. Hence, Fido and the dogs may not have been detecting the same scent compounds in all samples.
- *A portion of the test area that was positive in one sampling was not necessarily positive in other samplings.* This suggests that the contamination in a minefield is dynamic, changing along with changes in environmental conditions. Ultimately, it was concluded that the systems detected contamination of the test field with mines, but that there is still much to be learned about the spread of explosive contamination.

Full details of the results are available in [2].

Related publications

1. Fisher M., J. Sikes and K. Schultz (2003)
   "REST Sampling: Landmine Detection Using a Fido Device", *Journal of Mine Action*, Issue 7.3, December, *www.maic.jmu.edu/journal/7.3/focus/fisher/fisher.htm.*
2. Williams A. (2003)
   Trace Chemical Mine Detection Data Collection – Final Scientific and Technical Report (Comparative testing of MECHEM's MEDDS System and Nomadics's Fido System in Croatia), Contract # DAAB15-01-C-0017, September, *www.humanitarian-demining.org.*
3. Fisher M.E., M. Prather and J.E. Sikes (2003)
   "Serial Amplifying Fluorescent Polymer arrays for Enhanced Chemical Vapor Sensing of Landmines, EUDEM2-SCOT 2003", in H. Sahli, A.M. Bottoms, J. Cornelis (Eds.), *International Conference on Requirements and Technologies for the Detection, Removal and Neutralization of Landmines and UXO*; Volume I, pp.174-181, Vrije Universiteit Brussel, Brussels, September, *www.eudem.info.*
4. Fisher M. E., J. Sikes (2003)
   "Minefield edge detection using a novel chemical vapor sensing technique", *Proceedings of SPIE Conference on Detection and Remediation Technologies for Mines and Mine-like Targets VIII*, Vol. 5089, pp. 1078-1087, Orlando, US.
5. la Grone M. J., M. E. Fisher, C. J. Cumming, E. Towers (2002)
   "Investigation of an area reduction method for suspected minefields using an ultrasensitive chemical vapor detector", *Proceedings of SPIE Conference on Detection and Remediation Technologies for Mines and Mine-like Targets VII,* Vol. 4742, pp. 550-561, Orlando, US.
6. Fisher M., M. la Grone, C. Cumming, E. Towers
   Utilization of Chemical Vapor Detection of Explosives as a Means of Rapid Minefield Area Reduction, Nomadics, Inc.
7. Fisher M., C. Cumming
   Detection of Trace Concentrations of Vapor Phase Nitroaromatic Explosives by Fluorescence Quenching of Novel Polymer Materials, Nomadics, Inc.

Technical specifications	*Nomadics Fido*[a)]
1. Used detection technology:	Trace explosive detection (nitroaromatic compounds and plastic explosives)
2. Mobility:	Hand-held
3. Mine property the detector responds to:	Explosive compounds
4. Detectors/systems in use/tested to date:	Currently in-service with US military for IED detection
5. Working length:	Fido XT tether lengths: 3´, 6´and custom
6. Search head:	
➢ size:	Fido X: 3.5" x 1.5" x 1.5", Fido XT: (w/out grip): 3.5" x 3.5" x 1.5"
➢ weight:	700g including battery (Fido X)
➢ shape:	Hand-held
7. Weight, hand-held unit, carrying (operational detection set):	—
Total weight, vehicle-based unit:	—
8. Environmental limitations (temperature, humidity, shock/vibration, etc.):	—
9. Detection sensitivity:	1 femtogram (1×10^{-15} g) for TNT (based on laboratory tests)
10. Claimed detection performance:	
➢ low-metal-content mines:	—
➢ anti-vehicle mines:	—
➢ UXO:	—
11. Measuring time per position (dwell time):	Analysis time: 5 seconds
Optimal sweep speed:	—
12. Output indicator:	Bar chart display; Audio signal; Connection to external computer.
13. Soil limitations and soil compensation capability:	—
14. Other limitations:	—
15. Power consumption:	Battery life: 4 hours
16. Power supply/source:	Lithium Ion battery (included); see remarks
17. Projected price:	US$24,750
18. Active/Passive:	Passive
19. Transmitter characteristics:	N/A
20. Receiver characteristics:	N/A
21. Safety issues:	Moderately hot tip (90°C)
22. Other sensor specifications:	Base unit size: 9.8" x 4.8" x 2"

a) Nomadics Inc., *Size Matters* and *Technical Overview Fido Explosives Detector* (Information sheets), *www.nomadics.com*

Remarks

Adapters: Power supply 100–250V, 50-60 Hz; 12V connector (supplied).
Memory: 256 MB (10 days continuous data logging).

6.3 Biosensor Applications – BIOSENS

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
Project type	Technology development, Technology demonstration, System/subsystem development
Start date	1 January 2001
End date	30 September 2004

Technology type	Vapour/trace detection
Readiness level	●●●●●⑥●●●
Development status	Completed
Company/institution	Biosensor Applications Sweden AB; Swedish Rescue Services Agency; Norwegian People's Aid; The Weizmann Institute of Science

Project description

The **BIOSENS** project aimed at using trace explosive detection technology to find the smallest quantities of explosives from mines, employing an innovative weight loss quartz crystal microbalance (QCM) together with antibody (Ab) and antigen (Ag) technology, and suitable for field deployment by non-technical staff. The trialled biosensor system consisted of two units:

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

According to the manufacturer this technology demonstrated high levels of selectivity and sensitivity.

Detailed description

The biosensor system is composed of two main units: a collection system and an analysis system. The collection system is able to collect TNT/DNT, RDX, PETN and tetryl. The analysis system, developed within the project, is able to detect TNT/DNT, PETN and tetryl simultaneously. The system detects the emission of characteristic vapour, i.e. vapourised or dissolved explosive, by means of an Ag/Ab reaction with high sensitivity provided by an innovative (and unique, according to the consortium) weight loss QCM technology. The sample collector draws air and vapours through a filter. The various substances adsorbed and particles collected onto the filter are then prepared and pumped through the biosensor detectors (biocells). The biocell comprises a 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:

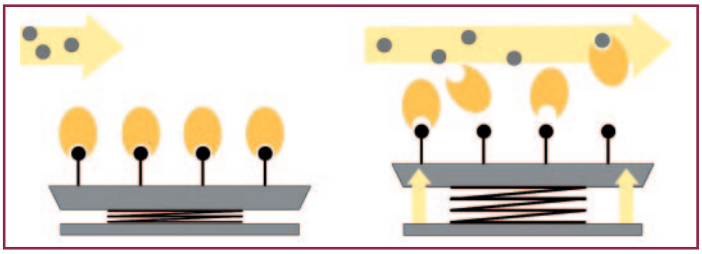


Figure 1. Left: the analyte is flowing into the biocell where the antibodies (orange) are attached to the QCM surface. Right: the target molecules (grey) in the analyte react with the antibodies causing the antibody molecule to release from the surface, giving a mass reduction on the QCM. This in turn 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.

Figure 2. Sweeping collector in test field, with detail (Figure 3).

Test & evaluation

According to the project consortium the project has been very successful in developing a prototype system which works stably and also reliably in environments a great deal harsher than the "lab top". The collection and analysis systems have been extensively tested in Bosnia & Herzegovina and Croatia in a series of tests including in and near to a number of real minefields — and they worked stably and reliably for extended periods [*BIOSENS Final Report*]. Thirteen methodology tests were carried out in the project's test field in Croatia between 2001 and 2004, as well as more than 10 other area tests and comparisons with soil samples and mine detection dogs. (For full details see the literature referenced below; public test reports are available at *www.g2ing.com/rapp.htm*.)

The test results 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. Indeed, at the beginning of the project, the consortium felt that if a sensor were able to detect picogram quantities of explosives in minefields then it would be possible to detect mines. The test results suggest, however, that the detection problem is not as simple as this.

The consortium has been able to confirm the following *key findings:*

Figure 4. Air pump.

1. Explosive vapour/particles seem to be spread out in test and minefields.
2. It is not always possible to detect explosive vapour/particles directly above mines (with limit of detection of 50pg).
3. It is possible to detect explosive vapour/particles between mines.
4. Areas that can be positive during one sampling may not necessarily be positive during another, suggesting that explosive contamination changes with environmental conditions.
5. Dogs are able to pinpoint mines.
6. There is still a great deal to be learned about the spread of explosive contamination from mines.

In addition, the following findings are felt to be of particular relevance for further work targeted towards vapour/trace detection for demining:

1. Concentrations of explosive detected may not necessarily be higher close to mines.
2. Explosive may be detected (which the consortium believes emanated from mines in their test field) more than 11m away from individual mines; in their results, explosive was detected more than 100m away from the area containing mines.
3. It is possible to detect explosive vapour/particles in expected "clean areas" in mine-affected countries (in their example, at the hotel).
4. Dogs are able to pinpoint mines even if there is a high amount of background explosive contamination.

According to the consortium, this leads to a number of *conclusions and hypotheses*, the most important of which are that:

1. Dogs are using a combination of molecules and perhaps ratios to pinpoint mines; this probably includes explosives and their by-products, but may well also include plastic and rubber (Norwegian People's Aid reports that on occasions dogs have marked false alarms at rubber tyres).
2. Although it is difficult to draw a distinction between systems that rely purely on vapour for detection of explosives and those which rely on particles as well, operational procedures for demining are potentially very different depending on the type of sample collected.
3. A system which is even more sensitive (and real-time) and able to detect continuous leakage of the low flow of TNT/DNT (as opposed to a temporary deposit) could offer improvements in terms of detection but it is perhaps also necessary to look for other substances.
4. Saturated sampling of suspect areas — which relies purely on the detection of explosive by a technology as a marker of mines — could be a method to reduce suspect areas if no explosive is found, but operational procedures require development. It may, for example, be necessary to carry out sampling on a number of occasions.

Other applications (non-demining)

Aviation and general security; drug detection with different biocells.

Related publications

1. Crabbe S., L. Eng, P. Gårdhagen, A. Berg (2005)
   "Detection of explosive as an indicator of landmines – BIOSENS project methodology and field tests in South East Europe ", *Proceedings of SPIE Conference on Detection and Remediation Technologies for Mines and Mine-like Targets X*, Vol. 5794, pp. 762-773, Orlando, US.
2. BIOSENS consortium (2004)
   BIOSENS Final Report, *www.eudem.info*
3. Crabbe S., J. Sachs, G. Alli, P. Peyerl, L. Eng, M. Khalili, J. Busto and A. Berg (2004)
   "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", Proceedings of SPIE Conference on Detection and Remediation Technologies for Mines and Mine-like Targets IX, Vol. 5415, 12-16 April.

Technical specifications	*BIOSENS*
1. Used detection technology:	Trace explosive detection
2. Mobility:	Sampling system: hand-held. Analysis unit: vehicle-based.
3. Mine property the detector responds to:	(Emission of) Explosive compounds in trace form
4. Detectors/systems in use/tested to date:	—
5. Working length:	—
6. Search head:	
➢ size:	—
➢ weight:	Sample collection system: 5-6kg
➢ shape:	—
7. Weight, hand-held unit, carrying (operational detection set): Total weight, vehicle-based unit:	— Analysis system: 17kg (vehicle-based).
8. Environmental limitations (temperature, humidity, shock/vibration, etc.):	15-30°C
9. Detection sensitivity:	On filter: TNT, 2,4-DNT: PD>95% @ 2 ng, PETN: PD>95% @ 10 ng, Tetryl: PD>95% @ 10 ng. In BioCell: TNT, 2,4 DNT: 10 pg in cell, PETN and Tetryl: ca 50 pg in cell.
10. Claimed detection performance:	
➢ low-metal-content mines:	—
➢ anti-vehicle mines:	—
➢ UXO:	—
11. Measuring time per position (dwell time): Optimal sweep speed:	Analysis time: <2min —
12. Output indicator:	—
13. Soil limitations and soil compensation capability:	—
14. Other limitations:	—
15. Power consumption:	—
16. Power supply/source:	Sample collection system: rechargeable battery for 3 hours operational time. Analysis system: 220V AC or 24V DC.
17. Projected price:	~€ 50,000 for one analysis & collection system.
18. Active/Passive:	Passive
19. Transmitter characteristics:	—
20. Receiver characteristics:	# of simultaneously detectable substances: 4 (BIOSENS prototype: TNT, 2.4-DNT, Tetryl, PETN).
21. Safety issues:	None
22. Other sensor specifications:	Collection efficiency: 75% for TNT vapour, >20% for particles. Size: Sample collection back-pack: 30 x 25 x 12cm, Analysis system: 50 x 45 x 25cm.

Remarks

The probability of detection figures are based on spiked filters provided to the analysis system.
Prototypes are available for further field testing.
RDX can now be detected.

7. Bulk Explosive Detection Systems:[15] Nuclear Quadrupole Resonance

7.1 Sensing principle

Operating principle

Nuclear quadrupole resonance (NQR), a derivative of nuclear magnetic resonance (NMR), is a bulk inspection technology which can be used to detect certain chemical elements which have an electric quadrupole moment. Among 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 also 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; they do therefore strongly depend on the chemical structure and will be different for RDX, for TNT, etc.

When a low-intensity radio frequency (RF) signal of the correct frequency is applied to the material, usually in the range 0.5 to 6 MHz (i.e. slightly higher than metal detectors), 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 multi-channel system necessary to cover a wide range of target substances, and the precise frequencies drift with temperature. Coils similar to those of metal detectors are used.

In addition, the signal-to-noise ratio increases with the operating frequency f as $f^{3/2}$, 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. Care will have also to be taken with the temperature dependency of the spectral lines, selecting for example those

15. Bulk explosive detection techniques allow the direct detection of a macroscopic mass of explosive material.

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 US 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, although research is continuing in several countries.

Application type

Close-in: hand-held (power issues), vehicle-based (especially for anti-tank mines on roads).

Strengths

- NQR is a derivative of nuclear magnetic resonance, which is routinely used, for example, in medical diagnostics, without the need for an external magnetic field.
- NQR technology can be highly compound specific (each explosive has a unique signature).
- NQR has potentially a very low false alarm rate.
- The presence of metallic objects (in particular those containing explosives) can be detected by the detuning effect on the NQR probe.
- NQR is being investigated for other security related applications (e.g. aviation security).
- No nuclear radiation is involved.

Limitations

- Detection times are of a few seconds to tens of seconds, depending on type (in particular relaxation time), quantity and depth of the target substance.[15]
- Impossible to detect substances fully screened by metallic enclosures[16] (also foils, depending on their thickness), e.g. within metal cased mines or UXO. Practical applicability is therefore likely to be an issue which requires extensive testing.
- Detecting TNT is much harder than RDX (because of the frequency dependence of the SNR [signal to noise ratio] and possible presence of two crystalline polymorphs — monoclinic and orthorhombic — which affects the characteristic frequency response and leads to weaker TNT signals).
- Weak signals: signal averaging, shielding and active cancellation of interference, including radio frequency interference, are necessary (the detector must work, in the case of TNT, within the medium wave (AM) radio broadcasting band).

15. Buried mine detection is a typical one-sided application (the target object can obviously not be put inside a coil as in other applications). The resulting SNR can therefore depend considerably on the target distance, i.e. its depth.
16. It may 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.

The received TNT signal is so weak that it is often masked by AM radio interference. It is important to know that the TNT response can be recognised even in the presence of high power AM signals. One can obviously not switch off neighbouring AM radio transmitters.

- Spurious signals due to piezoelectric responses from silica in the soil (quartz) and "acoustic ringing" effects (due to certain metals and metal coatings) might require appropriate pulsing sequences and detection software, as well as specific hardware.

Potential for humanitarian demining

- For "confirmation" type of applications.
- Very promising for RDX and tetryl, and/or confirmation of shallow buried plastic-cased anti-tank mines.
- Power requirements are considerable and complicate the design of hand-held equipment.
- Application for small buried anti-personnel mines still appears to be extremely elusive for TNT (unfortunately TNT is much more common than RDX in landmines).
- As electronic systems become cheaper and more powerful it may be possible to substantially improve performance in the future.

Estimated technology readiness

Medium.

Related publications

1. MacDonald J., et al. (2003)
   Alternatives for Landmine Detection, RAND Science and Technology Policy Institute, Report MR-1608.
2. Garroway A.N., M.L. Buess, J. B. Miller, B. H. Suits, A. D. Hibbs, G. A. Barrall, R. Matthews, and L. J. Burnett (2001)
   " Remote Sensing by Nuclear Quadrupole Resonance", *IEEE Transactions on Geoscience and Remote Sensing,* Vol. 39, No. 6, June, pp. 1108-1118.
3. Bruschini C. (2001)
   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* and *www.eudem.info.*
4. *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.*
5. Bruschini C., K. De Bruyn, H. Sahli, J. Cornelis (1999)
   EUDEM: The EU in Humanitarian Demining - Final Report, July, *www.eudem.info.*
6. Yinon J. (1999)
   Forensic and Environmental Detection of Explosives, John Wiley and Sons, 1999, ISBN 0-471-98371-0.

7.2 Quadrupole Resonance Confirmation Sensor: QRCS

Project identification

Project name	Quadrupole Resonance Confirmation Sensor – vehicle-based
Acronym	QRCS
Participation level	National
Financed by	US Army and US Navy (for the Marine Corps) with additional support from DARPA
Budget	Not available
Project type	Technology development Technology demonstration, System/subsystem development

Start date	1997
End date	Ongoing
Technology type	NQR
Readiness level	6
Development status	Ongoing
Company/institution	GE Security (formerly Quantum Magnetics Inc.)

Project description

GE Security asserts that ongoing development efforts will lead to products for both military and humanitarian demining applications. At this point, the manufacturer does not have any landmine detection systems that have reached a prototype stage comparable to the VMR1-MINEHOUND (Vallon/ERA), AN/PSS-14 (CyTerra) or Fido (Nomadics). It does, however, have ongoing programmes to develop mine detection sensors that incorporate quadrupole resonance (QR) detection. Efforts to date have focused on military countermine systems as opposed to humanitarian demining. Projects include a vehicle-mounted system and a hand-held QR/ground penetrating radar (GPR)/metal detector (MD) system. In what follows, the system developed for the detection of anti-tank and anti-vehicle landmines is described.

Detailed description

GE's **Quadrupole Resonance Confirmation Sensor (QRCS)** is meant to confirm or refute the presence of explosives at a candidate location first identified by some other primary sensing device, typically a combination of MD and GPR, thereby providing a considerable reduction in probability of false alarm (>20x) but at a reduced speed to the primary sensor.

The QR coil first acts as a transmitter, irradiating the explosives with a radio frequency (RF) pulse sequence of precise frequency and timing. Then, special circuits remove energy from the QR coil so that it can be used as a low noise receiver. However, the QR coil is unable to discriminate completely between the small signal from the explosive and other interfering signals. The latter are largely cancelled by careful construction of the pulse sequence and minimization of electric fields. The operator of the QRCS receives a simple “clear” signal if no explosive is present, or a warning indicating that either TNT or RDX or a combination of both has been detected [1].

As RDX QR sensitivity is much higher than that of TNT, the key performance limitation is TNT detection. (The nominal signal to noise ratio [SNR] for RDX is 50 times greater than for TNT.) One way of improving the TNT SNR is to increase the scan time, as this increases the relative amplitude of the QR response to the instrument noise. The most successful method is, however, to increase the amplitude of the RF magnetic field used to excite the TNT resonance. Full details are provided in the referenced documents.

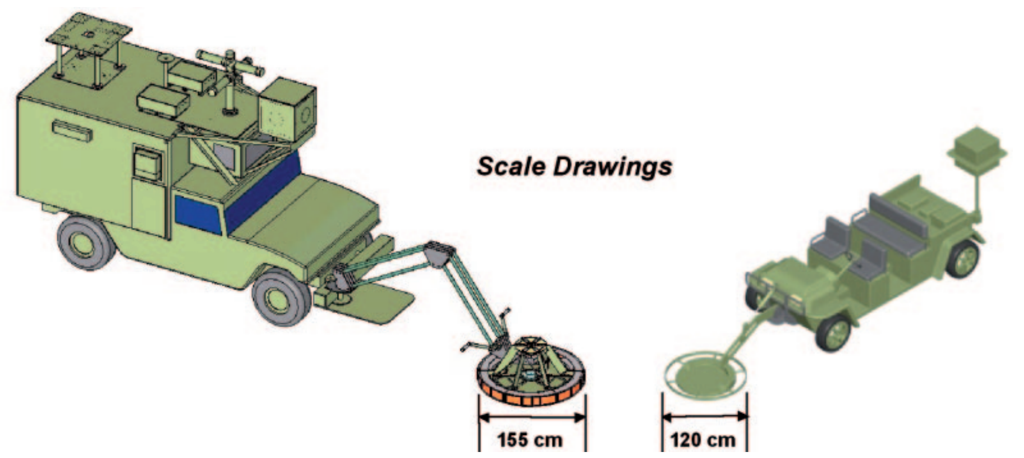


Figure 1. Scale comparison of (left) the original QRCS as tested in 2003 and (right) the next generation QRCS based on developments described in (1).

Test & evaluation

The manufacturer reports [2,3] that during 2002 the QRCS performed in two US 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 25cm in order to simulate inaccuracy in the location provided by the primary sensor. The distribution of offsets was Gaussian with a 13cm standard deviation and a 0cm bias. The maximum distance to the centre of the mine was ~40cm, assuming a typical anti-tank mine diameter of ~30cm.

The actual halo of the primary sensor may ultimately prove to be smaller than 25cm. 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 2.5cm to 12.5cm. In the temperate test, the soil overburden was fixed at 7.5cm. Mines buried at both sites contained either a Comp B (an explosive consisting of ~60 per cent RDX and 40 per cent TNT by weight) or TNT main charge. The mass of the Comp B charges ranged from 2 to 10kg and the TNT charges ranged from 5 to 8kg.

The total scan time at each marker was ~25s. The TNT scans were composed of multiple applications of a short pulse sequence or echo train. The duration of each echo train is of order 100ms with ~5s between echo trains. Both durations are dependent upon the estimated temperature of the explosive. The trialled system performed the entire 20s

TNT scans (~4 echo trains with 5s between each), followed by a 3-6s RDX scan. Simple modifications to the system are possible to implement the RDX scan between the individual TNT echo trains.

The 2002 blind test results were presented as follows [2,3]:

Table 6 . QRCS System-2002 blind test results

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	0.98 (0.90, 1.00)	0.04 (0.02, 0.10)	134

The manufacturer reports that since then it has implemented methods to improve radio frequency interference (RFI) immunity due to the presence of large RF 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 29s.

The 2003 blind test results were reported as confirming "exceptional RDX performance", with an overall performance which was nearly identical night or day, but with a TNT performance well below that demonstrated in 2002 [1]. This was due to the improvements in ringing rejection and RFI immunity, which reduced the TNT sensitivity per unit time. Reversing this effect is achieved most simply by increasing the scan time. It is reported that further technical improvements during 2004, such as the increase in the peak excitation field for TNT, which resulted in an approximately twofold increase in TNT SNR per complete scan, restored the TNT sensitivity [1].

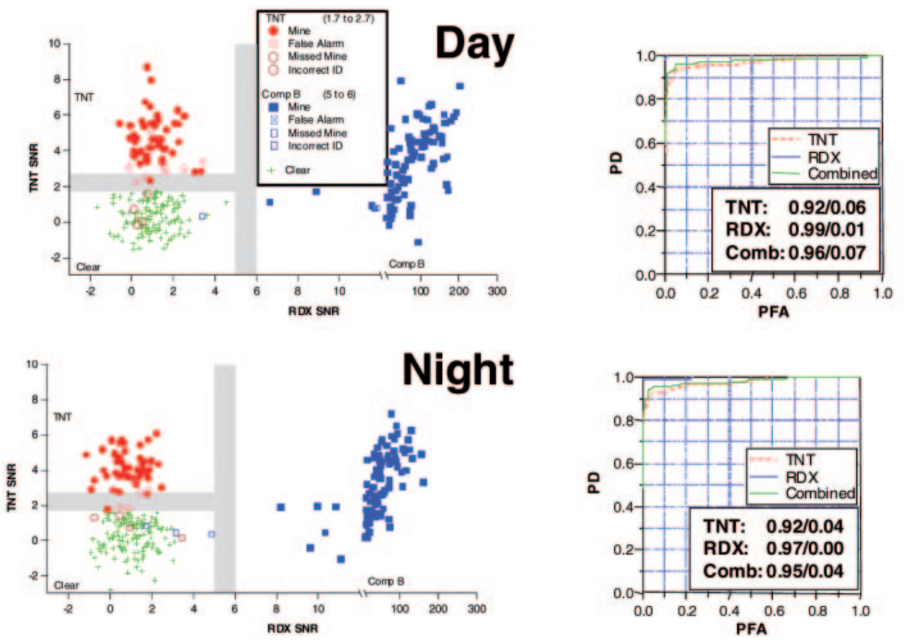


Figure 2. Arid test site results in 2003 (1). (Left) TNT and RDX signal amplitudes for blanks, Comp B mines and TNT only mines. (Right) Associated ROC curves with sample PDs and PFAs listed for TNT, RDX and Combined detection. (Top) Daytime results. (Bottom) Night-time results. The gray bars on the left plots indicate the rescan threshold range.

Other applications (non-demining)

Security applications, e.g. baggage screening.

Related publications

1. Barrall G.A. et al. (2005)
   "Advances in the Engineering of Quadrupole Resonance Landmine Detection Systems", *Proceedings of SPIE Conference on Detection and Remediation Technologies for Mines and Mine-like Targets X,* Vol. 5794, pp. 774-785, Orlando, US.
2. Barrall G.A. et al. (2004)
   "Development of a Quadrupole Resonance Confirmation System", *Proceedings of SPIE Conference on Detection and Remediation Technologies for Mines and Mine-like Targets IX*, Vol. 5415, pp. 1256-1267, Orlando, US,.
3. Barrall G.A. et al. (2004)
   Nuclear Quadrupole Resonance for Landmine Detection, Military Sensors Symposium in Dresden, Germany.
4. Williams C., P. V. Czipott and L. J. Burnett (2001)
   "Quantum Magnetics Targets Landmine Explosives Using Quadrupole Resonance", *Journal of Mine Action*, Issue 5.2, August 2001, *http://maic.jmu.edu/journal/5.2/features/quantum.htm.*
5. Garroway A.N., M.L. Buess, J.B. Miller, B.H. Suits, A.D. Hibbs, G.A. Barrall, R. Matthews, and L.J. Burnett (2001)
   "Remote Sensing by Nuclear Quadrupole Resonance", *IEEE Transactions on Geoscience and Remote Sensing*, Vol. 39, No. 6, June 2001, pp. 1108-1118.

Technical specifications	GE Infrastructure QRCS
1. Used detection technology:	NQR
2. Mobility:	Vehicle-based
3. Mine property the detector responds to:	Explosive content in bulk form
4. Detectors/systems in use/tested to date:	—
5. Working length:	Not applicable
6. Search head:	
➢ size:	Diameter: 120cm, height: 10cm.
➢ weight:	QR coil: 13kg
➢ shape:	Circular
7. Weight, hand-held unit, carrying (operational detection set):	—
Total weight, vehicle-based unit:	63kg
8. Environmental limitations (temperature, humidity, shock/vibration, etc.):	Typical military requirements.
9. Detection sensitivity:	Targeted at kg quantities of explosives with up to 20cm overburden.
10. Claimed detection performance:	—
➢ low-metal-content mines:	N/A
➢ anti-vehicle mines:	PD: >95%, PFA: <5%.
➢ UXO:	—
11. Measuring time per position (dwell time):	20-30s
optimal sweep speed:	—
12. Output indicator:	Yes(TNT, RDX or both)/No signal
13. Soil limitations and soil compensation capability:	Induced piezo-electric ringing (esp. from quartz).
Soil compensation:	Employs modified pulse sequences and minimization of electric fields (e.g. use of reference antennae).
14. Other limitations:	Environmental radio frequency interference (power lines, AM transmitters). Residual coil and electronics ringing. Temperature variations (induces changes in resonance frequencies).
15. Power consumption:	<200W during 20s scan, <40W when idle. Average: 120W.
16. Power supply/source:	4 car batteries or 8 NiMH batteries.
17. Projected price:	—
18. Active/Passive:	Active
19. Transmitter characteristics:	Peak transmit field: 16 Gauss, peak transmit power: 21kW (both in TNT mode).
20. Receiver characteristics:	—
21. Safety issues:	None
22. Other sensor specifications:	Overall system volume: ~0.35m^3.

Remarks

These specifications refer to the low size, power and weight system currently under development (next generation QRCS system (1)).

Key performance limitation is TNT detection.

8. Bulk Detection Systems:[17] Neutron-based Methods

8.1 Sensing principle

Operating principle

Neutron analysis systems offer **bulk detection methods**, some of which are also capable of identifying a wide range of explosives and chemical weapons. In general terms they are composed of a *neutron source* to produce the neutrons that have to be directed into the ground, and a *detector* to characterise the outgoing radiation, usually gamma rays (high energy X-rays), resulting from the interaction of the neutrons with the soil and the target.

Thermal neutron analysis (TNA) relies on slow neutrons, which can be produced by slowing down fast neutrons from small radioisotopic sources, or from portable electronic neutron generators. TNA is based on the detection of characteristic gamma rays emitted by the nitrogen nuclei and features high sensitivity to nitrogen concentration. (Explosives are more nitrogen-rich than average soil.)

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 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.

Pulsed fast neutron analysis (PFNA): Pulsed operations are particularly interesting when using *very short fast neutron pulses* (typically nanosecond wide, 10^{-9}s) — 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

17. Bulk detection techniques allow the direct detection of a macroscopic mass of material.

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 (compact) deuterium-tritium neutron 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 milliseconds).

Other neutron-based techniques, such as associated (alpha) particle — TOF neutron analysis, are covered in more detail in the specialist literature.

A simplified variant is represented by **neutron moderation** methods. These rely on the fact that fast neutrons are slowed down, after having been shot into the ground, by collisions with light nuclei — in particular hydrogen — in the soil and in the mine's explosive (and casing, if plastic). Some of the resulting slow neutrons are detected, providing a measure of the hydrogen content of the material, explosives and plastics being more hydrogen-rich than average (dry) soil. Neutron moderation is traditionally — but not exclusively — used in a backscattering configuration, in which both the source and the detector(s) lie above ground and the slowed down neutrons measured are those which "return back" in the direction of the source.

Application type

Close-in detection: hand-held (neutron moderation), vehicle-based.

Strengths

- Fast neutrons can penetrate a few centimetres of steel (e.g. UXO).
- FNA is *sensitive to nearly all elements in explosives* and potentially able to identify the type of substance under analysis. Has the potential to deliver better results than TNA.
- TNA has high sensitivity to nitrogen concentration.
- Pulsed systems allow the use of timing information which can be useful for reducing the influence of background radiation from neutron interactions with the soil.
- Neutron moderation:
  - Probably the simplest neutron-based technique; can use a weak radioactive source.

- Can be integrated with a metal detector in hand-held equipment.
- Similar devices are in use in a number of other fields (e.g. petroleum industry).
- Imaging might be achievable, to reduce the false alarm rate.

Limitations

- Cost, power consumption, the radiation hazard or the size and weight of the dense shielding required, safety, sensitivity and the practicalities of deployment are important issues.
- Expensive detectors and high intensity neutron sources must often be used to assure adequate sensitivity. Depth of penetration has to be carefully assessed, as well as minimum amount of detectable explosive.
- TNA is relatively slow (second or even minute response times).
- FNA is usually far more complex and expensive than TNA. *The resulting γ-ray spectra can be quite complex* as numerous nuclear levels are often excited. In the case of buried objects the complex spectral background due to soil also has to be considered.
- Soil and other background signals can overwhelm the target signal.
- Not specific to explosive molecule (unlike NQR).
- Neutron moderation:
  - As water is nothing but hydrogen and oxygen, this technique will stop working beyond a given soil humidity.
  - Soil non-homogeneities and surface variations can cause false alarms.
  - Limited target burial depth.
  - Shielding is required if the source strength is increased.

Potential for humanitarian demining

- Neutron analysis systems could typically be combined with other sensors and used in a confirmatory role, in particular for the detection of anti-tank mines on roads.
- 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.
- For adequate sensitivity, expensive detectors and high intensity neutron generators must often be used. Such generators may fall into the category of equipment subject to restriction under the International Nuclear Non-proliferation Agreements.
- Neutron moderation:
  - Is adapted to dry or slightly humid environments.
  - Working with radioactive sources, although routine in other applications, requires a certain number of precautions.
  - More likely to be used for confirmation rather than detection.

Estimated technology readiness

(Mostly) Medium.

Related publications

1. MacDonald J., et al. (2003)
   Alternatives for Landmine Detection, RAND Science and Technology Policy Institute, Report MR-1608.

2. Bruschini C. (2001)
   Commercial Systems for the Direct Detection of Explosives (for Explosive Ordnance Disposal Tasks), ExploStudy, Final Report, February, *http://diwww.epfl.ch/lami/detec/explostudy.html* and *www.eudem.info.*

3. *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. Bruschini C., K. De Bruyn, H. Sahli, J. Cornelis (1999)
   EUDEM: The EU in Humanitarian Demining - Final Report, July, *www.eudem.info.*

5. Yinon J. (1999)
   Forensic and Environmental Detection of Explosives, John Wiley and Sons, ISBN 0-471-98371-0.

6. Gasser R. (2000)
   Technology for Humanitarian Landmine Clearance, PhD thesis, Development Technology Unit, School of Engineering, University of Warwick, September, 173 pp., *www.eudem.info.*

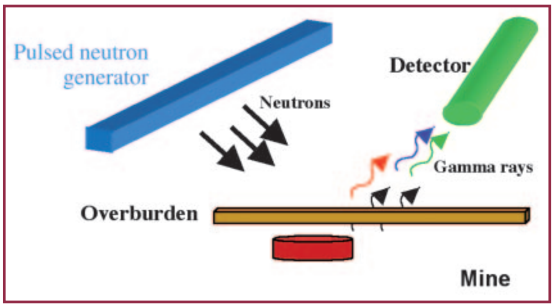
8.2 Pulsed Elemental Analysis with Neutrons (PELAN)

Project identification

Project name	PELAN	**Start date**	—
Acronym	—	**End date**	—
Participation level	National, US	**Technology type**	Fast/Thermal neutron interrogation
Financed by	US DoD/SAIC		
Budget	—	**Readiness level**	●●●●⑤⑥●●●
Project type	Technology development, Technology demonstration, System/subsystem development	**Development status**	Completed
		Company/institution	Science Applications International Corporation (SAIC)

Project description

Neutrons have high penetrability and easily traverse the overburden under which a mine might be buried. The incident neutrons interact with the nuclei of the various chemical elements in the mine, emitting characteristic gamma rays which act as fingerprints of the various chemical elements. The gamma rays are detected by appropriate detector(s), capable of differentiating the gamma rays according to their energy and their quantity.



The chemical elements of interest for the detection of mines require different neutron energies in order to be observed. Elements such as H, Cl (Chlorine), and Fe (Iron) are best observed through nuclear reactions initiated from very low energy neutrons. Other elements such as C and O need neutron energies of several MeV[18] to be observed at all.

18. The electronvolt (eV) is often used to measure (kinetic) energies in particle and nuclear physics, whereby neutrons with energy <0.5eV are usually defined as slow. The behaviour of neutrons in matter — e.g. their probability of colliding in an elastic or inelastic way with nuclei, or to be captured — and the resulting reaction products depend strongly on the neutrons' kinetic energy.

To satisfy this, a neutron source is required that can produce the high energy neutrons for measurement of elements such as C and O, and low energy neutrons (energy <0.025 eV) for elements such as H and Cl. Such a task can be accomplished with the use of a pulsed deuterium-tritium (D-T) neutron generator.

Figure 1. A complete PELAN unit.

Detailed description

Figure 1 shows a complete PELAN unit. The upper cylindrical part contains the pulsed neutron generator. Neutrons are generated only when a high voltage is applied to the neutron generator. The rectangular part contains the control circuits, power supplies and embedded computer for data accumulation, reduction and analysis. The neutrons from the generator impinge on the object on the ground (e.g. the shell shown in the picture), generating characteristic gamma rays which are collected by the gamma ray detector located in the lower section of the rectangular container, facing the interrogated object.

PELAN main features are, according to the manufacturer:

- It identifies high explosives (TNT, RDX, C4, etc.) or improvised explosive devices through their chemical elements;
- It is equally capable of identifying plastic or metal mines;
- Data acquisition and analysis takes five minutes;
- No radiation is emitted with neutron generator OFF;
- It can be operated wireless or with a cable from a distance of 45 metres;
- It is immune to ambient temperature changes; and
- It can operate with its internal battery for up to 6 hours.

Figure 2. The PELAN evaluated in the US as an anti-personnel mine identifier (2003).

Test & evaluation

From 2001 to 2005 there have been numerous evaluations of PELAN's performance as an identifier (or as a confirmation sensor) of landmines (both anti-personnel and anti-tank), improvised explosive devices and high explosives. Full reports of each evaluation has been written for the organisations sponsoring the tests. Their names can be made available on request.

Croatia evaluation

Two separate evaluations were performed at a test minefield at Sisak, Croatia. This test minefield was set up by the Croatian Mine Action Centre (CROMAC) and contained a number of anti-tank and anti-personnel mines buried at various depths. These evaluations were performed for the International Atomic Energy Agency (IAEA), which, on the advice of a group of international experts, evaluated PELAN as a landmine confirmation sensor. The first evaluation took place in October-November 2002, using the 2002 version of PELAN, called PELAN III. This extensive evaluation is available through IAEA and contains the PELAN performance in confirming four types of landmines (three anti-personnel and one anti-tank). The second evaluation (with very small operational success due to component failure) took place in August 2003, with CROMAC personnel operating PELAN in the test minefield. The 2002 blind tests gave an overall probability of detection of 92 per cent with a 22 per cent false alarm rate. More detailed information on the Croatia tests can be found in [1].

Figure 3. An earlier PELAN version evaluated in Croatia (2002), sponsored by the IAEA.

US anti-tank mine evaluation

In 2003, a series of blind tests was performed by the US Department of Defence at a landmine evaluation site, using the latest version of PELAN. Mines were buried at various depths and with different types of overburden. Both types (plastic or metal casing) of mines were used. The cumulative PELAN results were: probability of detection 90 per cent, 14 per cent false alarm rate, and a 98 per cent identification of the casing (plastic or metal) of the landmines.

Other applications (non-demining)

Improvised explosive devices

In 2002, an evaluation of PELAN as a detector of improvised explosive devices (IEDs) took place in the US, supervised by the US Department of Defence. Several packages were prepared and included explosives such as dynamite, black powder, ANFO etc., as well as several innocuous materials. PELAN was operated from a safe distance by a member of a police bomb squad.

High explosives

In 2002, 2004 and 2005, an evaluation of PELAN took place at various US military bases. These tests were sponsored by various agencies of the US Department of Defence. During these tests, PELAN went through an extensive evaluation as a fill identifier for a very large range of shell sizes. The evaluation, other than establishing the performance characteristics of PELAN (probability of detection and false alarm rate), had the following objectives:

- To obtain a library of elemental signatures for a variety of shells as found in ranges and proving grounds,
- To check the reliability of PELAN’s decision making process,
- To determine the range of validity of the decision process,
- To ascertain the repeatability of the PELAN measurements.

Related publications

1. Knapp V. (2004)
   Neutron explosive detector and its perspective in humanitarian demining, International Symposium Humanitarian Demining 2004, 21-23 April 2004, Sibenik, Croatia, *www.itep.ws/pdf/PELANsibenikpublication.pdf.*

2. Vourvopoulos G., R.A. Sullivan, V. Knapp and D. Hrupec (2003)
   "Evaluation of PELAN as Confirmation Sensor", EUDEM2-SCOT 2003, in H. Sahli, A.M. Bottoms, J. Cornelis (Eds.), *International Conference on Requirements and Technologies for the Detection, Removal and Neutralization of Landmines and UXO* , Vrije Universiteit Brussel, Brussels, September 2003, *www.eudem.info.*

3. Knapp V., D. Hrupec (2002)
   "Evaluation of PELAN for landmine confirmation, Croatia, 21 October- 1 November 2002", in *IAEA Technical Cooperation Project RER/1/005 Field Testing and Demonstration of a Pulsed Neutron Generator for Humanitarian Demining*, Report to IAEA, November

4. Womble P.C., G. Vourvopoulos, I. Novikov, J. Paschal (2001)
   "PELAN 2001: Current Status of the PELAN Explosives Detection System", *Proceedings, SPIE conference on Hard X-Ray and Gamma-Ray Detector Physics III*, San Diego, Vol. 4507, pp. 226-231.

5. Womble P.C., C. Campbell, G. Vourvopoulos, J. Paschal, Z. Gácsi, S. Hui (2001)
   Detection of Explosives with the PELAN System, CP576, Application of Accelerators in Research and Industry-Sixteenth International Conference, American Institute of Physics, 0-7354-0015.

6. Vourvopoulos G., P.C. Womble (2001)
   "Pulsed Fast/Thermal Neutron Analysis: A Technique for Explosives Detection"*, TALANTA* 54 (2001) pp. 459-468.

Technical specifications	*SAIC PELAN*
1. Used detection technology:	Pulsed neutrons
2. Mobility:	Man portable or carted (close or over the suspected mine position).
3. Mine property the detector responds to:	Measures and quantifies chemical elements.
4. Detectors/systems in use/tested to date:	Seven systems built and delivered for testing/ evaluation.
5. Working length:	Not applicable
6. Search head:	PELAN is an autonomous, single unit, composed of two interlocked components operated from a laptop or palmtop computer wireless or with a cable from a distance up to 45m.
➢ size:	75cm(H) x 45cm(L) x 15cm(W)
➢ weight:	Total weight: 40kg. Each of the two interlocked components weighs approx. 20 kg.
➢ shape:	One component cylindrical, the other rectangular
7. Weight, hand-held unit, carrying (operational detection set):	—
Total weight, vehicle-based unit:	See above.
8. Environmental limitations (temperature, humidity, shock/vibration, etc.):	No temperature limitation, weather resistant case, can be carted, hand carried or trucked over rough terrain
9. Detection sensitivity:	—
10. Claimed detection performance:	See section on Test & Development
11. Measuring time per position (dwell time):	5 minutes
Optimal sweep speed:	Stationary during the measuring time.
12. Output indicator:	Computer screen or hand held palmtop indication *THREAT* or *NO THREAT*.
13. Soil limitations and soil compensation capability:	No soil limitation. There is limitation on ground moisture content (<25%).
14. Other limitations:	Detector needs to be placed within 15cm from or above the suspected mine position.
15. Power consumption:	130W
16. Power supply/source:	Internal battery (6 hrs), car battery, 110/220V AC.
17. Projected price:	To be determined
18. Active/Passive:	Active interrogation
19. Transmitter characteristics:	—
20. Receiver characteristics:	—
21. Safety issues:	Requires state/national nuclear radiation license. An 8 meter exclusion zone is required around PELAN during the 5 minute measuring time. Redundant hardware and software controls instantaneously interrupt the operation of PELAN if a person inadvertently enters.
22. Other sensor specifications:	—

Remarks

PELAN is a confirmation sensor, to follow a screening device such as a metal detector or other "flagging" device. PELAN identifies a landmine by measuring the chemical elements of the explosive within it. PELAN is equally sensitive to all high explosives (TNT, RDX etc.) and both plastic and metal-encased mines. PELAN's component configuration can be customised to decrease both measuring time and radiation exclusion zone. Either modification will increase PELAN's total weight.

8.3 Hydrogen Density Anomaly Detection (HYDAD)

Project identification

Project name	Detection of landmines by HYdrogen Density Anomaly Detection
Acronym	HYDAD
Participation level	South Africa and Austria, participating in an IAEA-coordinated research programme
Financed by	IAEA
Budget	US$5,000 per annum for five years
Project type	Technology development, Technology demonstration
Start date	2000
End date	2006
Technology type	NEM (neutron energy moderation)
Readiness level	5 (of 9)
Development status	Ongoing
Company/institution	University of Cape Town, South Africa

Project description

Three types of **HYDAD (HYdrogen Density Anomaly Detection)** landmine detector (HYDAD-H, HYDAD-VM and HYDAD-D) have been developed in this project [1-3]. Each consists of an isotopic source of fast neutrons (AmBe or ^{252}Cf), one or more slow neutron detectors and some electronic and/or computer equipment for data processing. The neutron detectors sense the increase in slow neutron intensity that occurs when the source and detector are brought in the vicinity of a hydrogen-rich object such as a landmine. An audio and/or visual output is produced to indicate the presence or absence of a hydrogen-rich object.

Detailed description

HYDAD-H is a hand-held detector that employs a single slow neutron detector and is manually scanned across the area under investigation at a height of 1-2cm above the ground surface. A description of HYDAD-H and a film-clip demonstration of its operation in outdoor conditions can be obtained by visiting the webpage given in reference [1].

HYDAD-VM [2] is a vehicle-mounted detector that employs an array of six identical slow neutron detectors positioned close to the ground surface. The six detectors are symmetrically dispersed about the fast neutron source which is located 15-25cm below the surface. Differences between the count rates of the six detectors indicate the presence and approximate location of a landmine.

HYDAD-D [3] is a differential type of detector that has evolved from HYDAD-H and HYDAD-VM. It consists of a fast neutron source and two identical slow neutron detectors symmetrically positioned relative to the neutron source. This arrangement detects hydrogen-rich objects by monitoring the difference in count rate between the two slow neutron detectors as the source-detector system is scanned across the landmine or other hydrogen-rich object.

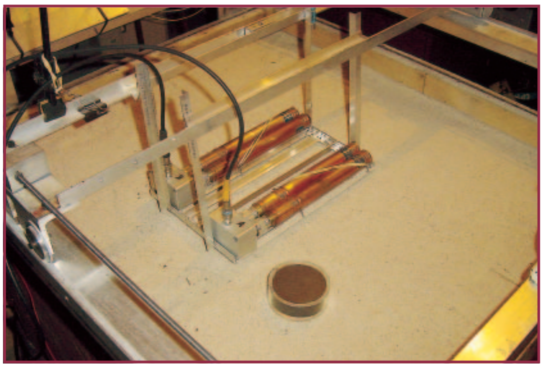


Figure 1. Photograph of the laboratory test model of HYDAD-D. Each slow neutron detector consists of a pair of boron-trifluoride-filled proportional counters. The isotopic neutron source (not shown) is placed symmetrically between the active volumes of the two detectors when used in the above-ground position. The dummy landmine DLM2 (see reference (2)) can be seen in the foreground. DLM2 consists of TNT-simulant (100g) sealed in an acrylic cylinder (100g) of outer dimensions 80mm (diam) x 34mm.

Test & evaluation

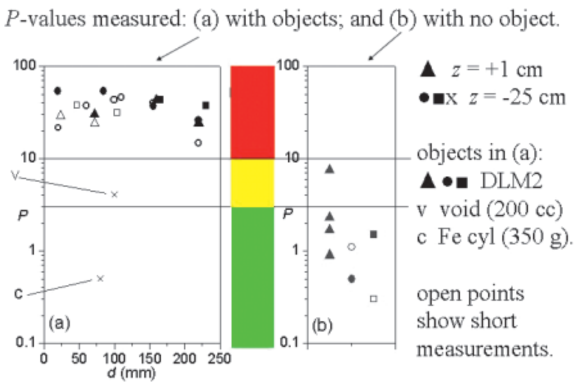


Figure2. Summary of test measurements made using HYDAD-D on a dry-sand laboratory test bed: (a) with test objects present in the sand; and (b) with no test object present. In (a) the test object was the dummy landmine DLM2 (2) for all measurements except those indicated by the two crosses. The plots show the landmine "signature parameter" P (3). In (a) P is plotted against the depth d of the centre of the test object below the ground surface. See reference (3) for further details.

Test and evaluation measurements made using the three HYDAD detectors are presented in references 1-3. Examples of test measurements of the "landmine signature parameter" P for HYDAD-D [3] are shown in Figure 2. P may be described as a measure of the strength in which a hydrogen-rich object is indicated, expressed in units of its own standard deviation. In other words P = 3 indicates that such an object is found to be present at the "3-sigma" level. From Figure 2(a) it can be seen that P>10 for all measurements in which DLM2 was used as the test object. From Figure 2(b) it can be seen that P<3 for all except one of the test measurements made with no hydrogen-rich object present. The operational criteria for practical operation of HYDAD-D are therefore specified as follows:

(a) P>10 indicates that a hydrogen-rich object (possibly a landmine) is present ("red" region in Figure 2);

(b) P<3 indicates that no landmine is present ("green" region); and

(c) P in the range 3-10 ("yellow" region) indicates an uncertain result.

In case (c) the recommended procedure would be to continue measurements in order to determine whether better counting statistics moved the result into the green region, If not then it should be taken as a red result.

Other applications (non-demining)

For the detection of hydrogen-rich materials in any other forms or shapes, for example explosives or narcotics in baggage or in cargo containers.

Related publications

1. See the web page *www.phy.uct.ac.za/hydad*
2. F.D. Brooks, M. Drosg, A. Buffler, M.S. Allie (2004)
   Detection of anti-personnel landmines by neutron scattering and attenuation, Applied Radiation and Isotopes 61, (2004) 27-34.
3. F.D. Brooks, M. Drosg (2005)
   The HYDAD-D antipersonnel landmine detector, Applied Radiation and Isotopes 63 (2005) 565-574.

Technical specifications

Not yet available.

8.4 Neutron Backscattering Imaging Detector (DUNBID)

Project identification			
Project name	Delft University Neutron Backscattering Imaging Detector	**Technology type**	Nuclear (neutron backscattering)
Acronym	DUNBID	**Readiness level**	●●●●5●●●●
Participation level	International	**Development status**	Ongoing
Financed by	Delft University and IAEA TC project	**Company/institution**	Delft University of Technology, Atomic Energy Authority, Egypt, International Atomic Energy Agency (IAEA)
Budget	—		
Project type	Technology development, Technology demonstration		
Start date	—		
End date	—		

Project description

The Egyptian collaboration partner is supported by Delft University of Technology within an IAEA (International Atomic Energy Agency) project in constructing a device to search for landmines based on the neutron backscattering imaging technique. The detector will be mounted on a remotely controlled vehicle. The operational properties of the device will be established by performing tests in the Egyptian desert.

Detailed description

The **neutron backscattering** (NBS) demining technique takes advantage of the fact that landmines contain many more hydrogen atoms than the dry sand in which they may be buried. The hydrogen in the mine is present in the explosive chemicals and in the plastic casing. The soil is irradiated with fast neutrons to find a landmine. The neutrons lose energy by scattering in the soil and become thermal. A thermal neutron detector monitors the slowed neutrons coming back from the soil. Hydrogen is a very effective moderator, therefore the thermal neutron flux will show an increase above a mine.

According to the developer, an advantage of the NBS method is its high speed of operation. Mines may be found within a second when a strong neutron source is used. Mines with metal content as well as metal-free mines may be found. Additional advantages of NBS-based devices over metal detectors or ground penetrating radar devices are their insensitivities to rocks and stones, metal objects and underground holes such as burrows.

The main limitation of the NBS method lies in its sensitivity to soil moisture. The hydrogen content of a landmine is comparable to that of sand with 10 per cent moisture, resulting in a loss of contrast between the mine and its surroundings at these moisture levels. The NBS method can therefore be applied most advantageously in arid countries.

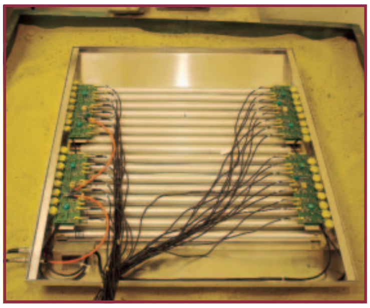


Figure 1. The DUNBID interior, showing the 16 proportional counter tubes and the four preamplifier boards.

The Delft University **Neutron Backscattering Imaging Detector (DUNBID)** consists of a two-dimensional position-sensitive slow neutron detector. An image is obtained of the neutron radiation which is scattered back from the soil and the mine. A concentration of hydrogen shows up as a "hot spot": a more or less circular area with a higher intensity than the surroundings. Such a hot spot is interpreted as a landmine. The advantage of using a two-dimensional image is that the sensitivity for mine detection is greatly enhanced in comparison to only monitoring the overall count rate.

The detector head consists of 16 ^{3}He proportional counter tubes, mounted side by side in a flat box of 80x70x7 cm. The sensitive area is 50x50cm^2 and counts are stored according to the measured position in a 16x16 array of pixels. This yields an image of the intensity of the backscattered neutrons with a pixel size of about 3x3cm^2. The preamplifiers for the tube signals are mounted inside the detector box and are connected with 3m cables to a PC used for data acquisition. The measurement is controlled from a laptop connected to the PC via a 30m Ethernet cable to maintain a safe distance from the neutron source.

The fast neutrons may be obtained from a radioactive neutron source or from a neutron generator. The application of a source with a strength of 10^7 n/s, which can still be handled without too many problems, will reduce the mine detection time to less than one second. Such short detection times allow for scanning speeds of a few kilometres per hour.

Test & evaluation

Figure 2. The DUNBID detector positioned on the sand during tests in Egypt. The position calculation electronics and the PC for data acquisition and measurement control are placed on the table.

The DUNBID detector was tested at the Nuclear Research Center about 30km north-east of Cairo, in open air, with the detector directly placed on the desert sand. A PuBe neutron source (200,000n/s) was used. Various types of real defuzed mines were buried at depths ranging from 5 to 20cm and images of the backscattered neutron radiation were measured. The presence of a mine and the determination of the position are currently done by visual inspection of images.

In the dry desert sand anti-tank mines were found at depths of 7cm (a dummy mine) and 15cm (type: M/71) while anti-personnel mines were found at 7cm depth (VS50) and 13cm (PMN). The maximum depth of detection will benefit from a more sophisticated data analysis method. A larger detector to capture the full mine response will also be of help. The minimum detection time for anti-personnel mines was about 5s, while anti-tank mines had minimum detection times slightly above 1s. With a suitable source scanning speeds of 1m/s should be possible.

A piece of wood (10x10x10cm) gave a clear mine-like response but a small iron cylinder (diameter 5cm, height 5cm) was not detected. No effect was noticed of bricks, pebbles and rocks in the sand, confirming that the NBS method is not sensitive to rocks or to iron in the soil. This makes it possible to distinguish between explosives and empty cartridge cases, which is an important advantage of the neutron backscattering technique over other techniques.

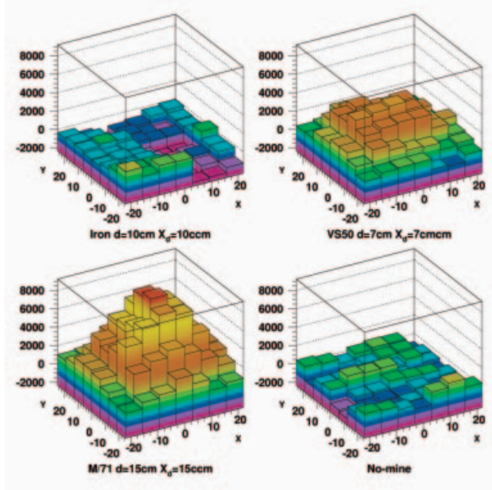


Figure 3. The four images show the pixel counts (number of neutrons per 60s) in the detector plane, corrected for background, of an iron cylinder, an anti-personnel mine (VS50) and an anti-tank mine (M/71). The last image, called no-mine, shows an example of the image noise caused mainly by soil inhomogeneities. The mines are clearly above the noise level.

Other applications (non-demining)

The NBS technique applied in the DUNBID system could possibly be used to detect explosives in other circumstances where the geometry is well defined and the materials involved are dry. The system has been demonstrated to be able to see explosives in or behind various kinds of walls in buildings.

Related publications

1. Bom V.R., C.W. van Eijk and M.A. Ali (2005)
"DUNBID, the Delft University Neutron Backscattering Imaging Detector", *Applied Radiation and Isotopes*, Vol. 63 November-December 2005, pp. 559-563. (8th International Conference on Applications of Nuclear Techniques, Crete, Greece, 12-18 September 2004.)

2. Bom V.R., C.W. van Eijk and M.A. Ali
Land mine detection with neutron back scattering imaging using a neutron generator, IEEE Transactions on Nuclear Science, accepted for publication.

3. Bom V.R., M.A. Ali, A.M. Osman, A.M. Abd El-Monem, W.A. Kansouh, R.M. Megahid and C.W. van Eijk
A feasibility test of land mine detection in a desert environment using neutron back scattering imaging, IEEE Transactions on Nuclear Science, accepted for publication.

4. Bom V.R. and C.W. van Eijk (2005)
Using the method of neutron backscattering imaging to detect hidden explosives, Conference CD N7-8, IEEE Nuclear Science Symposium, Puerto Rico, 2005, *www.rrr.tudelft.nl/~vb/IEEE-NSS-2005-HiddenExplosives.pdf.*

Technical specifications	*Delft University of Technology DUNBID*
1. Used detection technology:	Neutron backscattering imaging
2. Mobility:	Remote-controlled vehicle
3. Mine property the detector responds to:	Hydrogen content in explosives and plastic casing
4. Detectors/systems in use/tested to date:	One test system
5. Working length:	N/A
6. Search head:	
➢ size:	50x50 cm
➢ weight:	5kg
➢ shape:	flat box 70x80x7 cm
7. Weight, hand-held unit, carrying (operational detection set):	—
Total weight, vehicle-based unit:	10kg
8. Environmental limitations (temperature, humidity, shock/vibration, etc.):	Prototype system
9. Detection sensitivity:	
10. Claimed detection performance:	
➢ low-metal-content:	15cm depth[a)]
➢ anti-vehicle mines:	15cm depth
➢ UXO:	Not tested
11. Measuring time per position (dwell time):	AT: > 1 s, AP: > 5 s.
Optimal sweep speed:	< 1m/s
12. Output indicator:	Visual image inspection
13. Soil limitations and soil compensation capability:	Soil moisture must be low (< 5% weight)
14. Other limitations:	—
15. Power consumption:	—
16. Power supply/source:	Battery
17. Projected price:	Non commercial; 50.000 Euro
18. Active/Passive:	Active
19. Transmitter characteristics:	Neutron interrogation
20. Receiver characteristics:	—
21. Safety issues:	Radiation hazard due to neutron source, shielding necessary
22. Other sensor specifications:	2D position sensitive

a) Applies also to non-metallic mines.

8.5 Nanosecond Neutron Analysis System (SENNA)

Project identification			
Project name	Portable device for detection of explosives and other hazardous substances, based on nanosecond neutron analysis	**Project type**	Technology development, Technology demonstration, System/Subsystem Development
Acronym	SENNA	**Start date**	2003
Participation level	International	**End date**	2005
Financed by	US Civilian Research & Development Foundation (CDRF), Virginia; The Foundation for Assistance to Small Innovative Enterprises (FASIE), Moscow, APSTEC Ltd., St. Petersburg	**Technology type**	Nanosecond neutron analysis
		Readiness level	5
		Development status	Completed
Budget	US$400,000	**Company/institution**	Applied Physics Laboratory, V.G. Khlopin Radium Institute, St. Petersburg; APSTEC Ltd., N.L. Dukhov All-Russian Research Institute of Automatics (VNIIA)

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 (i.e. 10x) 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 built-in position-sensitive detector of alpha particles that accompany neutron emission in the D+T reaction.[18]

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 generated in the (n,n′γ) reactions of primary, fast 14MeV neutrons with the material of the inspected object are detected within a very

18. Each neutron is created simultaneously together with an alpha particle, which moves in a direction opposite to that of the neutron (the two are emitted "back-to-back"). These neutrons are therefore indirectly labelled ("tagged"). By detecting the accompanying alpha particle in time and space, one knows exactly when the neutron was created and in which direction it left the generator, moving towards the target; this is not possible with an ordinary neutron generator.

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 14MeV and velocity of about 5cm/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 (i.e. 100x) compared to traditional "neutron-in, gamma-out" methods.

Detailed description

The device, based on nanosecond neutron analysis and the associated particle technique, provides 3D "imaging" of the elemental composition of the inspected volume. 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. 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. Two BGO-based detectors 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.

All components will be combined in a single unit. The prototype is shown in Figure 1 below.

Figure 1. The SENNA portable device for detection of concealed explosives, here inspecting a suitcase.

Test & evaluation

Laboratory tests completed, field tests started.

Other applications (non-demining)

Stationary installations for the inspection of sea containers and other cargo. Anti-terrorism.

Related publications

1. Evsenin A.V., A.V. Kuznetsov, O.I. Osetrov, D.N. Vakhtin (2003)
   Detection of Hidden Explosives by Nanosecond Neutron Analysis Technique, H. Schubert, A. Kuznetsov (Eds.), Proceedings 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.
2. Kuznetsov A.V., V.P. Averianov, A.V. Evsenin, I.Yu. Gorshkov, O.I. Ossetrov and D.N Vakhtin (2003)
   "Portable Multi-Sensor for Detection and Identification of Explosive Substances, EUDEM2-SCOT 2003", in H. Sahli, A.M. Bottoms, J. Cornelis (Eds.), *International Conference on Requirements and Technologies for the Detection, Removal and Neutralization of Landmines and UXO,* Volume II, pp. 625-633, Vrije Universiteit Brussel, Brussels, September 2003, *www.eudem.info.*

Technical specifications	*Applied Physics Laboratory Nanosecond Neutron Analysis*
1. Used detection technology:	Neutron in, gamma out
2. Mobility:	Man portable
3. Mine property the detector responds to:	C/N/O ratios
4. Detectors/systems in use/tested to date:	SENNA prototype
5. Working length:	—
6. Search head:	
➢ size:	90x50x30cm. (TBD)
➢ weight:	25kg
➢ shape:	Suitcase
7. Weight, hand-held unit, carrying (operational detection set):	—
Total weight, vehicle-based unit:	25kg
8. Environmental limitations (temperature, humidity, shock/vibration, etc.):	—
9. Detection sensitivity:	100g of explosives
10. Claimed detection performance:	—
➢ low-metal-content mines:	—
➢ anti-vehicle mines:	—
➢ UXO:	—
11. Measuring time per position (dwell time):	60-120 seconds (60sec)
Optimal sweep speed:	—
12. Output indicator:	Colour image, landmine weight estimate
13. Soil limitations and soil compensation capability:	—
14. Other limitations:	—
15. Power consumption:	<100W (According to user requirements).
16. Power supply/source:	—
17. Projected price:	US$300,000 (commercial version)
18. Active/Passive:	Active
19. Transmitter characteristics:	Max 5×10^7 (10^8) 14 MeV neutrons per second into 4π[a)]
20. Receiver characteristics:	Secondary characteristic gamma rays detector: two scintillation detectors based on BGO[b)] crystal (dimensions: Ø6.1x 6.1cm^3) (One or several BGO- or NaI-based detectors).
21. Safety issues:	Operational safety distance: 7m (According to user requirements). Safe when switched off.
22. Other sensor specifications:	Vacuum tube lifetime: >10,000 measurement cycles (>30,000). Spatial resolution: 10cm in plane, 10-15cm in depth (Better than 10x10x10cm^3).

a) The neutrons are basically generated isotropically (uniformly in all directions).
b) Bismuth Germanate.

Remarks

Main figures are for the prototype: figures in square brackets are target production specifications.
Simultaneously inspected area: 30 x 30 x 30 cm^3 (TBD).
Radio control: Bluetooth (distances up to 200m).
In the production version the electronics will be combined with the search head.

8.6 Neutron Moderation Imaging

Project identification

Project name	Neutron Moderation Imaging
Acronym	—
Participation level	National
Financed by	DRDC Suffield, Canadian Center for Mine Action Technologies
Budget	~CAD150,000 per year
Project type	Basic technology research, Research to prove feasibility, Technology development

Start date	1999
End date	Ongoing
Technology type	Neutron imaging
Readiness level	●●③④○○○○○
Development status	Ongoing
Company/institution	DRDC Suffield, Bubble Technology Industries

Project description

Since 1994, Defence R&D Canada (DRDC) Suffield has undertaken research in support of the Canadian Forces and humanitarian demining to investigate nuclear methods of confirming the presence of bulk explosives in landmines or improvised explosive devices (IEDs). One branch of the work looks at larger systems, such as thermal neutron analysis and fast neutron analysis, whose physics mandate that they be stationary or vehicle-borne but which yield characteristic radiation that is specific to explosives. The other branch, which includes development of neutron and X-ray imagers, is aimed at nuclear technologies that could be amenable to hand-held use.

Detailed description

Neutron moderation landmine detection involves irradiating the ground with fast neutrons and subsequently detecting the thermalized neutrons which return. This technique has been studied since the 1950s, but only using non-imaging detectors. According to the developers, without imaging, natural variations in moisture content, surface irregularities and variations in sensor height produce sufficient false alarms to render the method impractical in all but the driest conditions.

The detector/source assembly is a 50cm x 50cm light-tight housing containing a planar neutron scintillation imager and a coplanar neutron source. More specifically, it consists of a neutron-sensitive scintillation screen sandwiched between a crossed grid of position-sensing, wavelength shifting fibres and a uniform sheet Cf-252 isotopic neutron source. (The present version uses a weak point Cf source to prove the concept. The sheet source has yet to be built.) The imager is coupled via a fibre optics bundle to a photomultiplier and processing electronics situated in a box attached to the top of the detector/source assembly. Neutron event positions are decoded by the crossed array of fibres and electronic circuitry. Instrument mass is roughly 13kg and power consumption is about 10W, supplied by batteries.

In addition to the detection unit there is a remote analysis unit (computer) connected by a wireless or hardwired serial link. This separation of function is intended to minimise radiation exposure to the operator from the weak neutron source resident in the detection unit.

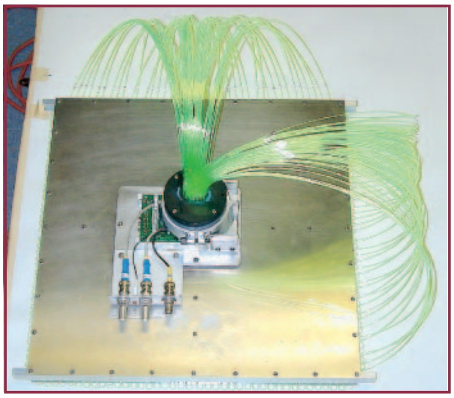


Figure 1. The top of the neutron moderation imager detection unit, removed from its light-tight shield. The ends of the fibres are seen exiting the detector plane and entering the multi-dynode photomultiplier tube which is used to decode neutron position.

Test & evaluation

Laboratory trials in a sand box have been combined with simulations to test expected performance. An example of the image of an anti-personnel surrogate mine is shown in Figure 2. For example, in sand with 0 per cent and 3 per cent water, a PMA2 may be readily detected at all depths up to at least 10cm. In sand with 10 per cent water, the signal is weak but measurable at 10cm. Detection times for flush-buried mines are less than 1s, making slow scanning a possibility for very shallow mines. For depths of 5 and 10cm, detection times are between 1 and 60s and hence the detector is more suitable as a confirmation detector.

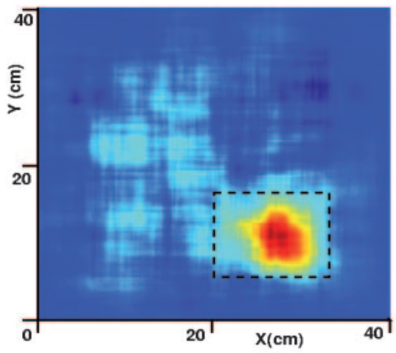


Figure 2. A neutron albedo[19] signal image of a block of wax, similar in size to a small to medium anti-personnel mine, obtained by the neutron moderation imager. The rough size and position of the block is indicated by the dotted rectangle. Background has been subtracted and spatial filtering has been done.

19. The *albedo* usually measures the optical reflectivity of a surface or body.

Related publications

1. McFee J.E., H.R. Andrews, E.T.H. Clifford, A.A. Faust, H. Ing and T. Cousins (2003)
   "Preliminary results from a prototype neutron moderation imager", *Proceedings of SPIE Conference on Penetrating Radiation Systems and Applications V*, Vol. 5199, San Diego, US, 3-8 August.
2. McFee J.E., H.R. Andrews, E.T.H. Clifford, A.A. Faust, H. Ing, T. Cousins and D.Haslip (2003)
   The feasibility of neutron moderation imaging for land mine detection, Subsurface Sensing Technologies and Applications 4(3), July, pp. 209-240.
3. McFee J.E., H.R. Andrews, H. Ing, T. Cousins, A. Faust and D. Haslip (2002)
   "A neutron albedo imager for land mine detection", *Proceedings of SPIE Conference on Detection and Remediation Technologies for Mines and Mine-like Targets VII*, Vol. 4742, Orlando, US, 1-5 April.

Technical specifications

Not yet available.

8.7 Other Bulk Detection Systems: XMIS (X-ray Mine Imaging System)

Project identification

Project name	Mobile Lateral Migration Radiography Mine Detection System	**Start date**	July 1998
		End date	December 2001
Acronym	XMIS (X-ray Imaging System)	**Technology type**	X-ray backscatter
		Readiness level	●●●●●⑥●●●
Participation level	National (US)	**Development status**	Stand-by
Financed by	US Army	**Company/institution**	University of Florida
Budget	US$450,000		
Project type	Technology development, Technology demonstration, System development (and demonstration in an operational environment)		

Project description

Lateral migration radiography (LMR), a new form of Compton Backscatter[20] X-ray Imaging (CBI), was applied to the detection and identification of buried landmines. A mobile LMR landmine detection system was developed and field tested. Weight for this initial system was about 175kg; weight for a prototype should be about 80kg. X-ray generator power level was 750 watts. The imaging capabilities of LMR make it well suited for use as a landmine detection confirmation sensor and for humanitarian applications it could also serve as a primary sensor.

An objective of this programme was to develop an LMR system concept and preliminary design which could yield a compact, field-deployable unit. This LMR system design includes an X-ray generator with articulating collimator, three X-ray detector panels, a computer with a data acquisition board and display, digital control electric motors to provide articulation and positioning, and an electric power generator, all mounted on a suitable vehicle platform. The resulting system has been named the **X-ray Mine Imaging System (XMIS)**. XMIS was employed on the vehicular test lanes at Fort A.P. Hill, Virginia, in October 2001. High quality images were obtained for a variety of buried landmines.

Unlike conventional CBI techniques which utilise only single-scatter photons, LMR uses both multiple- and single-scattered photons. LMR requires two types of properly

20. Compton scattering is the process by which photons (light particles, X-rays in this case) are deflected (scattered) when interacting with electrons in a material, a process which can be repeated if the photon has sufficient energy. Some of the photons do return in the direction they came from, and these are the ones detected here.

configured detectors: uncollimated detectors image primarily single-scatter photons while collimated detectors image predominately multiple-scatter photons. The uncollimated detector image contains primarily surface or near-surface features and can be used for removal of surface clutter. The collimated detector images also contain sub-surface features. Buried objects in the front collimated detector appear shifted to the rear while buried objects in the rear collimated detector appear shifted forward. The amount of shift can be correlated to the depth-of-burial (DOB). These image sets make LMR useful for imaging and identifying objects to depths of several X-ray photon mean free paths (~10cm) even in the presence of surface clutter.

Detailed description

For XMIS, the forced-air-cooled version of the LORAD LPX-160 constant potential X-ray generator provided an excellent source from the standpoint of performance, size and weight. The LPX-160 is a rugged, commercial X-ray tube designed for field inspections of pipe welds. The LPX-160 has a maximum X-ray spectrum energy of 160 kVp[21] and a maximum power level of 800W. The optimum X-ray source energy for the detection of mines with backscattered X-rays is in the range of 120 kVp to 160 kVp. Good imaging quality requires about two million source X-rays per pixel and this translates into an electric energy requirement of one joule per pixel. A pixel size of 15mm x 15mm provides good resolution for both anti-tank and anti-personnel mines.

A significant accomplishment in this research effort was the development of an X-ray source collimator design that uses a continuously rotating cylinder to synthesise a moving aperture from side-to-side with negligible retrace time. Coupled with the X-ray generator forward motion, this provides a raster scan of the ground. This collimator design is a key element in reducing the required X-ray head movement and in obtaining a simple, compact LMR detector system.

Careful detector design and deployment are critical for proper functioning of the LMR mine detection system. High performance organic scintillator block detectors are used for both the collimated and uncollimated detectors in the XMIS. The uncollimated detectors were 140cm long, 5cm wide and 2.5cm thick. The collimated detectors were 140cm long, 20cm wide and 2.5cm thick. The detector collimators were made from 1.5mm lead sheets. Photomultiplier/amplifier/bias-voltage-supply assemblies provided signal amplification and serve as the output device for each of the three plastic scintillator detectors. The photomultiplier tubes attach to the ends of the detectors.

Test & evaluation

Each scan generates an image set that includes an image from each of the three detectors. The final image is a cross correlation between the front and back collimated detector images following surface clutter removal by use of the uncollimated detector data. The detector images are acquired real time. For this initial system, the time required to perform a high resolution scan of a 0.5m x 0.5m area was 60s. The current capability (see *Other applications* below) is to perform a high resolution scan of a 1m x 1m area in 60s.

The LMR imaging capabilities make this system well-suited for a mine detection confirmation sensor. To this end, about 30 locations were selected on one of the test lanes at Fort A.P Hill where ground penetrating radar methods consistently yielded

21. Peak voltage (1kV = 1000 volts).

false alarms. These sites were imaged with the XMIS. In only two cases did the image set indicate a possible mine. For the other 28 locations, the XMIS images indicated only soil inhomogeneities.

An image of an anti-personnel mine representative of those acquired with XMIS on two of the test lanes at Ft. A.P. Hill is in Figure 1. The much larger anti-tank mines are easier to detect and their images are of similar quality. When viewing the image, the colour scheme designation for regions of highest signal intensity to regions of lowest signal intensity is white, red, yellow, green, light blue, dark blue and purple. Figure 1 shows an XMIS image of a TS 50 AP mine with a depth-of-burial (DOB) of 5cm. Plastic mines give a signal with an increased intensity relative to the signal intensity of the surrounding gravel or soil while metal mines give a decreased signal intensity. The mine is located in the bottom right centre of the image. The high intensity signal in the centre of the mine is due to the presence of void or air in the fuze well region of the mine. This is a distinguishing characteristic of LMR images of mines. The low intensity (blue) region in the top right centre of the image is a rock and is clearly distinguishable from the mine due to the lack of a central, bright zone. Total time required for the scan and image acquisition of this 0.5m x 0.5m area was 60s. Figure 2 shows a close-up of the XMIS detectors and the location on the test lane where the Figure 1 image was acquired.

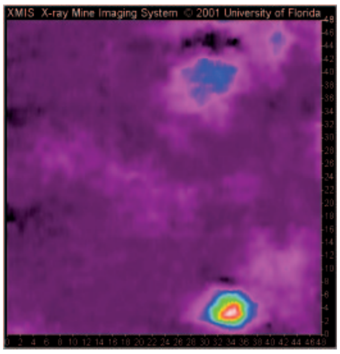


Figure 1. XMIS image of TS 50 anti-personnel mine with 5cm DOB (depth-of-burial) acquired on the Fort A.P. Hill test lane.

Figure 2. Close-up of XMIS detectors and location on test lane where the 5cm DOB TS 50 AP mine was located.

Other applications (non-demining)

Radiography by selective detection (RSD) is a new type of X-ray Compton Backscatter Imaging where different components of the X-ray backscatter field are preferentially selected to enhance the contrast and detection of specific features. LMR is a variant of RSD. The landmine results demonstrated the ability of this technique to detect voids and air spaces. As a result, RSD was applied to the detection of sub-surface features including: cracks, voids, delaminations and corrosion. A wide variety of materials have been imaged including: aluminium, plastics, honeycomb structures, laminates, steel, reinforced carbon-carbon composites, concrete and titanium. About two years ago, the University of Florida constructed six specially-designed RSD scanner systems for Lockheed Martin Space Systems Co. and NASA. These systems went through operational test and evaluation and reliability trials and are now being used to detect defects in the spray-on foam insulation used on the external fuel tank of the space shuttle. Figure 3 shows one of the RSD scanners built for Lockheed. *This RSD*

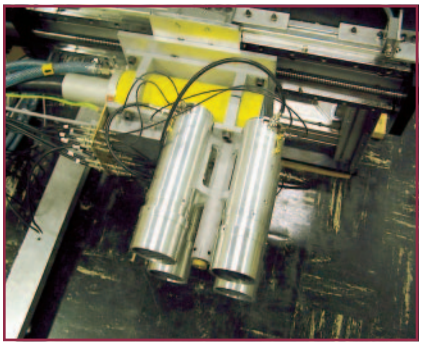


Figure 3. The RSD scanner system built for Lockheed Martin Space Systems Co.

system development has led to significant improvements in detectors, data acquisition and system control and in system integration. An LMR mine detection system using these advances would be less than half the weight, four times faster and obtain even higher quality images than was achieved with the preliminary system used in the field tests at Fort A.P. Hill in October 2001.

Related publications

1. Shedlock D., E. Dugan, A. Jacobs, and B. Addicott (2005)
   "Optimization of a RSD X-Ray Backscatter System for Detecting Defects in the Thermal Foam Insulation for the Space Shuttle", *Proceedings of SPIE 50th Annual Meeting, Symposium on Optical Science and Technology, Penetrating Radiation Systems and Applications VII*, August 2005, San Diego, US.
2. Dugan E., A. Jacobs, D. Shedlock and D. Ekdahl (2004)
   "Detection of Defects in Foam Thermal Insulation Using Lateral Migration Backscatter X-ray Radiography", *Proceedings of SPIE 49th Annual Meeting, Symposium on Optical Science and Technology, Penetrating Radiation Systems and Applications VI*, Vol. 5541, pp. 47-57, August 2004, Denver, US.
3. Dugan E., A. Jacobs, Z. Su, L. Houssay, and D. Ekdahl (2003)
   "Detection of Land Mines Using Lateral Migration X-ray Radiography", *Proceedings of SPIE 48th Annual Meeting, Symposium on Optical Science and Technology, Penetrating Radiation Systems and Applications V*, Vol. 5199, pp. 1-11, 3-8 August, 2003, San Diego, US.
4. Dugan E., A. Jacobs, Z. Su, L. Houssay, and D. Ekdahl (2003)
   "Status of the XMIS Backscatter Radiography Land Mine Detection System", *SPIE Proceedings on Detection and Remediation Technologies for Mines and Minelike Targets VIII*, Vol. 5089, pp. 34-44, April 2003, Orlando, US.
5. Jacobs A., E. Dugan, S. Brygoo, D. Ekdahl, L. Houssay and Z. Su (2002)
   "Lateral Migration Radiography: A New X-Ray Backscatter Imaging Technique", *Proceedings of SPIE 47th Annual Meeting, Symposium On Optical Science and Technology, Penetrating Radiation Systems and Applications IV*, Vol. 4786, pp. 1-16, July 2002, Seattle, US.
6. Su. Z., A. Jacobs, E. Dugan, J. Howley, and J. Jacobs (2000)
   "Lateral Migration Radiography Application to Land Mine Detection, Confirmation and Classification", *Optical Engineering*, Vol. 39, No.9, September 2000, pp 2472-2479.

Technical specifications	*XMIS (X-ray Mine Imaging System)*
1. Used detection technology:	Backscattered X-rays
2. Mobility:	Vehicle mounted
3. Mine property the detector responds to:	Differences in electron density (i.e., differences in mass density + atomic number)
4. Detectors/systems in use/tested to date:	One mobile XMIS LMR preliminary design land mine detection system field tested at Fort A.P. Hill, Virginia
5. Working length:	Not applicable
6. Search head:	Lorad X-ray generator
➢ size:	18cm diameter x 77.5cm length
➢ weight:	15kg
➢ shape:	cylinder
7. Weight, hand-held unit, carrying (operational detection set):	—
Total weight, vehicle-based unit:	~80kg
8. Environmental limitations:	Limited by mobility/performance of vehicle on which mounted plus ability to penetrate high iron or high water content soil as indicated below. System can be made rugged, should not be impacted by humidity and should operate well over temperature range from 32 to 100°F.
9. Detection sensitivity:	PD: >95% for AP mines down to 5cm depth of burial. PFA: <5%.
10. Claimed detection performance:	
➢ low-metal-content mines:	Very good, especially for AP mines
➢ anti-vehicle mines:	Good
➢ UXO:	Unknown; never tested on UXOs
11. Measuring time per position (dwell time):	1 minute for high resolution image of 1m x 1m area
Optimal sweep speed:	—
12. Output indicator:	Real time high resolution images in greyscale or color
13. Soil limitations and soil compensation capability:	Imaging depth capability degrades rapidly in very high iron or high water content soil; unaffected by surface clutter and easily compensates for soil slopes.
14. Other limitations:	Imaging depth limited to about 10cm
15. Power consumption:	500W to 1kW
16. Power supply/source:	Gasoline electric generator
17. Projected price:	US$50,000 to US$75,000 (US$25,000 to US$50,000 for the X-ray generator)
18. Active/Passive:	Active
19. Transmitter characteristics:	X-ray generator maximum energy of 160kV
20. Receiver characteristics:	Scintillator detectors
21. Safety issues:	Very fine X-ray beam means that X-ray field is essentially background except directly under the beam.
22. Other sensor specifications:	Working size: 1.4m x 1.4m x 1m for initial test system. Sweep speed: 1m x 10m sweep in 10 minutes.

8.8 Coded Aperture X-ray Backscatter Imaging

Project identification

Project name	Coded Aperture X-ray Backscatter Imaging
Acronym	—
Participation level	International
Financed by	Defence R&D Canada Suffield, Canadian Center for Mine Action Technology
Budget	~CAD100,000 per year
Project type	Basic technology research, Research to prove feasibility, Technology development

Start date	2001
End date	Ongoing
Technology type	X-ray backscatter
Readiness level	●●❸❹○○○○○○
Development status	Ongoing
Company/institution	DRDC Suffield, University of California, San Diego

Project description

Since 1994, DRDC Suffield has undertaken research, in support of the Canadian Forces and humanitarian demining, to investigate nuclear methods of confirming the presence of bulk explosives in landmines or improvised explosive devices (IEDs). One principle area of investigation includes development of neutron and X-ray imagers aimed at nuclear technologies that could be amenable to person-portable use.

Detailed description

Nuclear imaging has long been one of the few techniques available to help in the identification of potentially dangerous objects in a non-intrusive manner. Typical nuclear imaging systems are transmission-based; that is, they require that the source and detector components be placed on opposite sides of the object under interrogation. This necessarily limits the number of scenarios in which the technique is applicable — buried landmine detection being a prime example. DRDC Suffield is investigating an approach, known as **coded aperture imaging**, where dual-energy X-ray sources and position-sensitive X-ray detectors can be located on the same side of the object under interrogation.

Based on the UCSD-designed HEXIS detector, the X-ray detection element consists of a 64mm x 64mm position-sensitive CZT[22] plane, with a crossed strip electrode pattern providing 0.5 x 0.5mm^2 pixels, all held in silicon rubber gaskets for shock and thermal mounting. The signal channels are then read out and digitised by dedicated ASICs.[23]

22. Cadmium zinc telluride (CZT) is a semiconductor used, among others, in radiation detectors.
23. Application-specific integrated circuit: an integrated circuit customised for a particular use, rather than a general-purpose one.

The detector plane and readout electronics are packaged into a single module with dimensions of only 7 x 7 x 10 cm^3, weighing 0.5kg, and presently uses about 4W. The detection module is then mounted into a shielding head which limits the field of view of the detector to the area of interest, and shields the detector plane from environmental background fields. Additionally, within the head are mounted the coded aperture mask and X-ray sources. A host computer is used to download the digitized event stream and apply the coded aperture imaging algorithms to produce the final backscatter image.

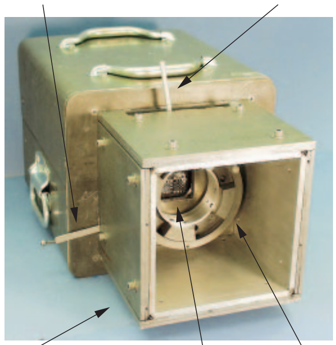


Figure 1. Front view of the experimental coded aperture imager designed for proof-of-principle experiments, showing the principal features of the design: coded mask, mask rotation and source selection.

Test & evaluation

Proof-of-principle trials have taken place in a laboratory sand box environment. The test system was shown to be capable of resolving both the shape and separation of multiple distributed objects using backscatter and fluorescent radiation, of observing energy-dependent variations in a target's backscattered flux, and being able to resolve shapes of objects buried in dense media. An example of the image of an AP surrogate mine is shown in Figure 3. Detection times for a mine buried to 1cm are in excess of 1 hour, but the developers hope that the larger data collection area of the full-scale prototype, optimised detector head geometry, and improved data analysis algorithms will improve this considerably. This system is therefore believed to have potential as confirmation detector suitable for shallowly buried (1-3cm) mines, but not a scanning sensor. Analysis of the proof-of-principle experiments will continue, with the goal being to develop improved algorithms to allow for faster image acquisition, greater spatial resolution and the ability to reconstruct a target's distance from the detector. Additionally, the potential to exploit the dual-energy approach to identify target composition will be investigated. A full-scale prototype is currently being constructed to further explore the capabilities of a portable coded aperture backscatter imaging system.

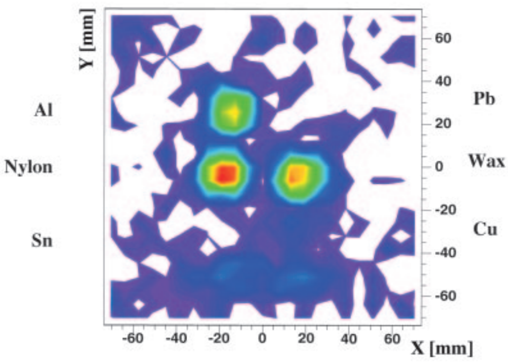


Figure 2. ^{241}Americium[24]-generated backscatter image of the multiple low-Z[25] targets placed within an obscuring aluminium can (imaging in air).

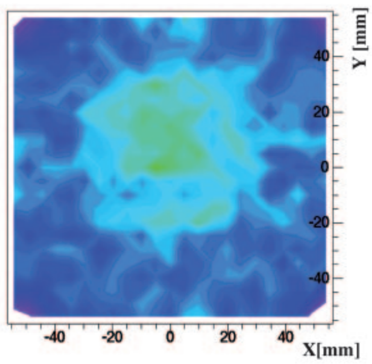


Figure 3. ^{241}Americium-generated backscatter image of a shallow buried PMA-2 (AP mine) simulant using sources (imaging of a more realistic scenario).

24. Radioactive source.

25. Z is an element's atomic number, and is equal to the number of protons in the nucleus of an atom of that element, and therefore to the number of electrons in the atom's shell (for a neutral atom); it is one of the main factors determining an element's position in the periodic table of

Related publications

1. Faust A.A., R.E. Rothschild, P. LeBlanc and J.E. McFee (2005)
   Development of a Coded Aperture X-ray Backscatter Imager for Explosive Device Detection, IEEE Transactions on Nuclear Science. Accepted for publication 16 June 2005.
2. Faust A.A., R.E. Rothschild and W.M. Heindl (2003)
   "Development of a Coded Aperture Backscatter Imager using the UC San Diego HEXIS Detector", *SPIE Conference on Detection and Remediation Technologies for Mines and Minelike Targets VIII*, April 2003, Orlando, US, Vol. 5089, pp. 95-106.
3. Faust A.A. (2002)
   "Detection of Explosive Devices using X-ray Backscatter Radiation", *SPIE Conference on Penetrating Radiation Systems and Applications V*, July 2002, Orlando, US, Vol. 4786, pp. 17-28.

Technical specifications

Not yet available.

elements. Low-Z materials, which include explosives, are more efficient at scattering X-rays than high-Z ones (e.g. most metals), and therefore are more contrasted — they stand out clearly — in an X-ray backscatter image.

9. Acoustic/ Seismic Systems

9.1 Sensing principle

Operating principle

Seismo-acoustic methods are intended for detection of mines by vibrating them with acoustic or seismic waves that are generated and received by non-contact (acoustic) and contact (seismic) transducers respectively. These detection methods are based on the mechanical properties (specifically, the compliance[26]) that can differentiate the acoustic response of mines from other (usually non-compliant) objects buried in the ground (false targets), such as rocks, tree roots, metallic clutter, bricks, etc. The technique depends on the fact that a mine is a man-made «container» in contact with the soil in which it is buried, not on the material from which the mine is fabricated (metal, plastic, wood, etc.).

The container is an acoustically compliant article whose compliance is notably different from that of the surrounding soil (high vibration contrast). Dynamic interaction of the compliant container and the soil on top of it leads to specific linear and nonlinear effects used for mine detection and discrimination. The mass of the soil on top of a compliant container creates a classical mass-spring system with a well-defined resonance response. The mine's "vibration signatures" have been measured in numerous laboratory and field tests, which proved that the resonance and nonlinear responses of a mine/soil system can be used for the detection and discrimination of buried mines. Thus, the fact that the mine is buried is turned into a detection advantage.

The diagram [5] on the following page illustrates the techniques already used in seismo-acoustic landmine detection systems.

On the transmitter side, the vibration of a buried mine can be induced using:

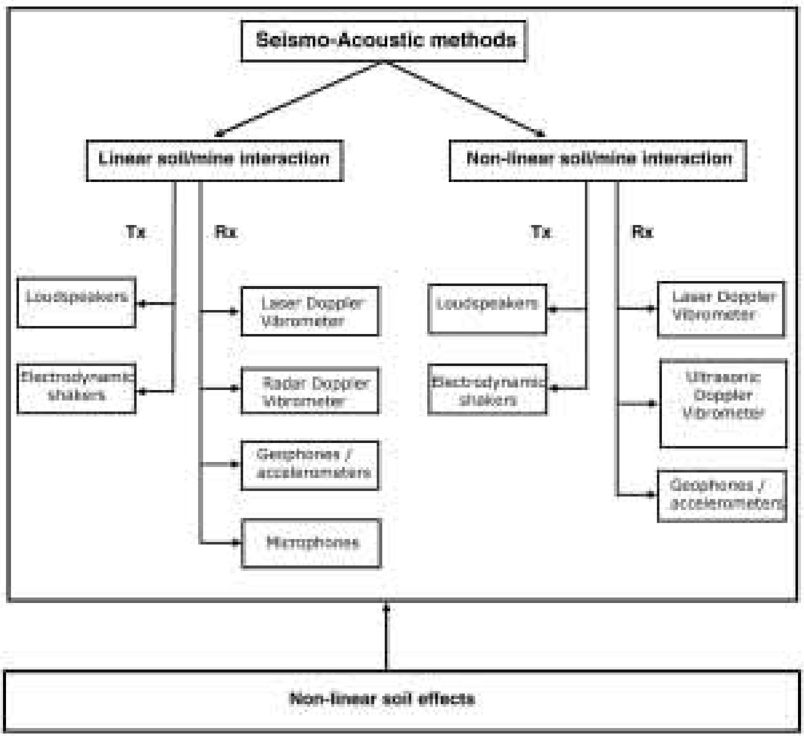
- Acoustic energy emitted by a powerful loudspeaker (airborne acoustic source), a large fraction of which is reflected off the ground surface. Only a small fraction penetrates into the soil in the form of seismic bulk waves that propagate through the soil and insonify a buried mine, causing a tiny (typically less than 1μm) but detectable vibration at the ground surface.
- Ground-coupled sources (e.g. shakers), placed at a safe distance from the danger area, directly generating seismic surface waves (Rayleigh waves).

26. In mechanical science, the compliance measures the deflection of an elastic body by an applied force.

On the receiver side, one can employ:

- Remote sensors (vibrometers) to detect the induced vibrations at the ground surface. Typical devices are laser Doppler vibrometers (LDV), but radar and ultrasonic systems have also been tested.
- Professional audio microphones to record the sound pressure of the acoustic field reflected off the ground from a vibrating buried object.
- Ground coupled sensors such as (low cost) geophones (velocity sensors) and accelerometers.

The typical frequency range where the resonance of a mine can be detected is (60-1000) Hz, corresponding to the lower part of the audible spectrum.



Application type

Close-in detection: hand-held (accelerometers, geophones, microphones), vehicle-based (e.g. vibrometers).

Strengths

- Remote sensing: system could be used outside of the mined area.
- Potentially low false alarm rate.
- Can complement existing sensors (as they are not at all based on electromagnetic properties).

Limitations

- The technology is most sensitive to dynamically compliant mines, which means that non-metallic mines are easier to detect than metallic ones or UXO.
- The use of LDVs seems to prevent operations in moderate to heavy vegetation.

- The principal factor limiting current performance is the limitation of existing sensing technology.
- Focused mainly on detection of anti-tank mines.

Potential for humanitarian demining

- Mine detection and discrimination in one single sensor.
- Likely to be employed for confirmation purposes (scanning applications might be feasible in countermine scenarios, e.g. by employing multiple beam LDV).
- Safe deployment of a low-cost, simple acousto-seismic coupling confirmation sensor using a single geophone with minimal electronics might still be a useful technology.

Estimated technology readiness

Low-Medium.

Related publications

1. MacDonald J., J.R. Lockwood, J. McFee, T. Altshuler, T. Broach, L. Carin, C. Rappaport, W.R. Scott, R. Weaver (2003)
   Alternatives for Landmine Detection, RAND Science and Technology Policy Institute, Report MR-1608, ISBN: 0-8330-3301-8.
2. Korman M.S., J.M. Sabatier (2002)
   Nonlinear acoustic Techniques for land mine detection, 5th International Symposium on Technology and the Mine Problem (MINWARA), Naval Postgraduate School, pp. 315-321, Monterey, US, 22-25 April 2002, *www.demine.org/SCOT/Papers/Sabatier.pdf*
3. Martin J.S., G.D. Larson, W.R. Scott Jr., C.T. Schroeder (2001)
   Use of elastic waves for the detection of buried land mines, White paper, *www.ee.duke.edu/~lcarin/DeminingMURI/IGARSS_2001.pdf*
4. Donskoy D.M. (1998)
   Non-linear seismo-acoustic technique for landmine detection and discrimination, Second International Conference on Detection of Abandoned Land Mines, IEE Conference Publication No. 458, pp. 244-248, Edinburgh, UK, October.
5. Bellan F., A. Bulletti, L. Capineri, C. Bruschini (2004)
   (Non-Linear) Acoustic Landmine Detection Study, EUDEM2 Technology Survey, November, *www.eudem.info*

9.2 Multi-Beam Laser Doppler Vibrometer (MB-LDV)

Project identification

Project name	Acoustic Technology for Landmine Detection	**Start date**	2000
Acronym	—	**End date**	Ongoing
Participation level	National	**Technology type**	Acoustic/seismic
Financed by	US Army Night Vision and Electronic Sensors Directorate, US Office of Naval Research, US Army Research Office	**Readiness level**	6 (of 9)
Budget	N/A	**Development status**	Ongoing
Project type	Technology development, Technology demonstration	**Company/institution**	University of Mississippi, National Center for Physical Acoustics

Project description

This is an applied research project to advance and characterise the performance of a landmine detection technology based on acoustic-to-seismic coupling or direct seismic energy to excite resonances in the buried mine. This causes regions of increased vibration over the mine which can be detected using Doppler vibrometers. Field tests, including blind tests, have been conducted using a variety of excitation devices and signals and vibrometer configurations.

Detailed description

Acoustic landmine detection using a **multi-beam laser Doppler vibrometer** (MB-LDV) as a vibration sensor has demonstrated promising results in laboratory and field experiments. The technique uses airborne sound or mechanical shakers to excite vibration in the ground and a scanning laser Doppler vibrometer (LDV) is then used to measure the ground vibration at multiple points. The presence of a buried landmine can be detected by studying the spatial distribution of the ground velocity spectra. A critical issue in landmine detection is operational speed. Use of a multi-beam LDV developed by MetroLaser, Inc., significantly reduces the time of the measurements. This vibrometer illuminates the ground with a linear array of 16 beams, and simultaneously measures the ground velocity at all 16 points. The 16 beams are spread uniformly across a 1-metre line, and the velocity sensitivity of each beam is approximately 1 micrometre/second. The vibrometer can work in a continuously scanning mode when all 16 beams move by using a rotating mirror in the transverse direction across the interrogated area. A two-dimensional velocity map of the ground over 1 square metre can be obtained in a time less then 20 seconds.

In order to produce a velocity image, the time domain data for each beam is divided into time segments, typically of length from 0.1s to 1s. Over each time segment, the velocity vs. time is Fourier analysed to generate the velocity vs. frequency data over each time segment. When the velocity spectra over each time segment and each beam has been computed, a velocity image over the entire scanned area can be generated at any selected frequency band. Each time segment in the continuous scanning method is an average over a finite length.

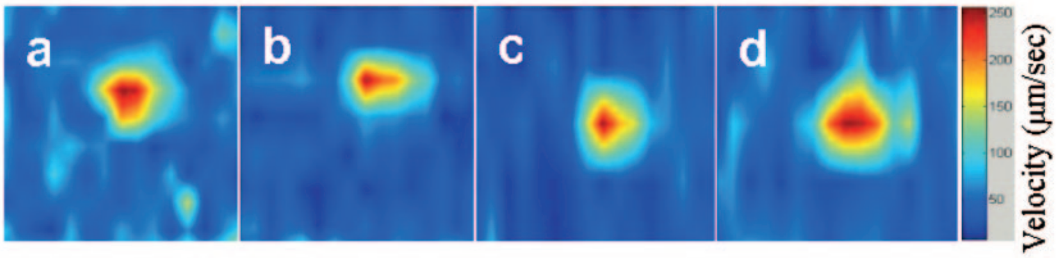


Figure 1. Images from the MB-LDV of a plastic anti-tank mine VS2.2 buried 15cm deep at different scanning speeds: a) 10cm/second; b) 20cm/second; c) 50cm/second; d) 100cm/second.

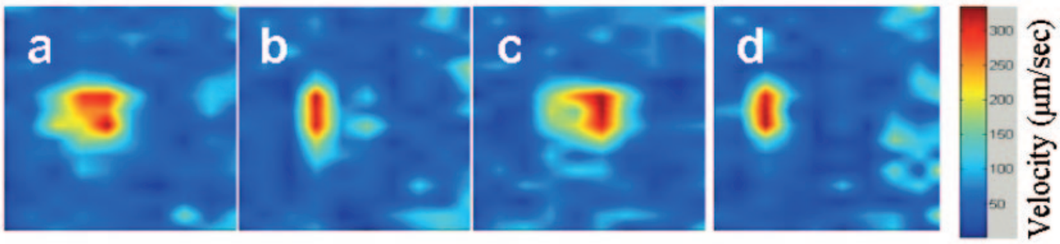


Figure 2. Images of a metal anti-tank mine M15 buried 15cm deep at different scanning speeds: a) 10cm/second; b) 20cm/second; c) 33cm/second; d) 50cm/second.

Test & evaluation

The acoustic technique has been successfully applied to outdoor detection of anti-tank mines found in surrogate US Army mine lanes. In a blind test for detection of anti-tank mines in which the testers did not know the location of mines or even whether mines were present, the technique achieved a 95 per cent probability of detection and 0.03/m^2 false alarm rate.

Related publications

1. Aranchuk V., J.M. Sabatier, A.K. Lal, C.F. Hess, R.D. Burgett and M. O'Neill (2005)
"Multi-beam laser Doppler vibrometry for acoustic landmine detection using airborne and mechanically-coupled vibration", *Proceedings of SPIE Conference on Detection and Remediation Technologies for Mines and Mine-like Targets X*, Vol. 5794, pp. 624-631, Orlando, US, 2005.

2. Xiang N., J.M. Sabatier and M. Bradley (2004)
"Field study using co-located landmine detection systems between laser Doppler vibrometer-based A/S coupling and GPSAR techniques", *Proceedings of SPIE Conference on Detection and Remediation Technologies for Mines and Mine-like Targets IX*, Vol. 5415, pp.1194-1200, Orlando, US, 12-16 April 2004.

3. Xiang N. and J. M. Sabatier (2003)
"An experimental study on anti-personnel landmine detection using acoustic-to-seismic coupling ", *Journal of the Acoustical Society of America*, 113, 2003, pp. 1333-1341.

4. Sabatier J.M. and N. Xiang (2001)
"An investigation of acoustic-to-seismic coupling to detect buried antitank landmines", *IEEE Transactions on Geoscience and Remote Sensing*, 39 (6), 2001, pp.1146-1154.

5. Gilbert K.E., J.M. Sabatier (2000)
Method for detecting buried objects by measuring seismic vibrations induced by acoustical coupling with a remote source of sound, US Patent No. 6081481, 27 June 2000.

Technical Specifications	*University of Mississippi MB-LDV*
1. Used detection technology:	Acoustic/seismic
2. Mobility:	Vehicle-based
3. Mine property the detector responds to:	Mechanical resonance
4. Detectors/systems in use/tested to date:	The technology has been tested using several different hardware configurations in outdoor simulated mine lanes.
5. Working length:	Not applicable
6. Search head:	
➢ size:	—
➢ weight:	—
➢ shape:	—
7. Weight, hand-held unit, carrying (operational detection set):	—
Total weight, vehicle-based unit:	—
8. Environmental limitations (temperature, humidity, shock/vibration, etc.):	None known
9. Detection sensitivity:	1 micrometre/second
10. Claimed detection performance:	
➢ low-metal-content mines:	PD: 95%, FAR: 0.03/m^2 for anti-tank mines
➢ anti-vehicle mines:	PD: 95%, FAR: 0.03/m^2
➢ UXO:	
11. Measuring time per position (dwell time):	—
Optimal sweep speed:	20 s/m^2
12. Output indicator:	Image of the mine location
13. Soil limitations and soil compensation capability:	None known
14. Other limitations:	—
15. Power consumption:	—
16. Power supply/source:	—
17. Projected price:	—
18. Active/Passive:	Active
19. Transmitter characteristics:	—
20. Receiver characteristics:	—
21. Safety issues:	None
22. Other sensor specifications:	—

Remarks

The University of Mississippi has conducted applied research for the acoustic technology for landmine detection. Functional prototype apparatuses have been used for this research. No engineering efforts have yet been made to optimize the size, weight and power consumption of the system.

9.3 Scanning Laser Doppler Vibrometer (SLDV)

Project identification

Project name	Scanning Laser Doppler Vibrometer	**End date**	November 2004
Acronym	SLDV	**Technology type**	Acousto/seismic (optical detection, laser vibrometry)
Participation level	National, Germany	**Readiness level**	6 (of 9)
Financed by	German Federal Office of Defence Technology and Procurement	**Development status**	Stand-by
Budget	N/A	**Company/institution**	Kayser-Threde GmbH (sensor), FGAN-FOM (data analysis)
Project type	Technology demonstration		
Start date	September 2000		

Figure 1.The SLDV Model III during field test.

Project description

The **Scanning Laser Doppler Vibrometer (SLDV)** is an acousto-optical sensor which analyses soil surface vibrations induced by its internal acoustic transmitter and which are modified/modulated by buried objects. 2D surface scans through its optical receiver and detailed frequency analysis allow discrimination between natural or harmless objects and potentially threatening devices. Its main advantage is the fact that this sensor is absolutely independent of any metal content in mines and will not be confused by ambient metal fragments. Furthermore it is not dependent on the soil's dielectric or magnetic properties.

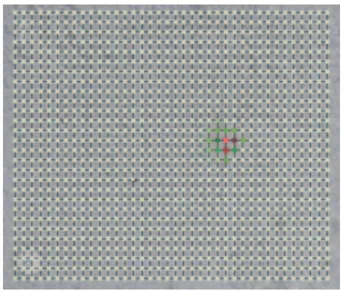


Figure 2. Two-dimensional distribution of measurement points on the soil surface (sample with a detected PMN surrogate).

Detailed description

The sensor's powerful sound transducer emits a strong acoustic field towards the soil surface. Part of this acoustic energy enters the soil and propagates as Biot Type II waves. If these waves hit buried objects, such as mines, a fraction of the acoustic energy is redirected towards the soil surface, inducing tiny surface vibrations. These vibrations are picked up by the laser beam of the SLDV optical receiver, which is focused at the soil surface and which is scanning the soil surface itself in a 2D pattern of discrete measurement points over an area of about 1m^2 (Figure 2). During data taking, each of the measurement points is illuminated by the laser until a predefined signal quality value has been reached. Subsequent amplification, filtering and spectral analysis of these vibrations finally creates a "vibration image" of the soil surface above the buried object. Data are displayed in real-time as colour coded images. Examples are shown in Figures 3 to 6.

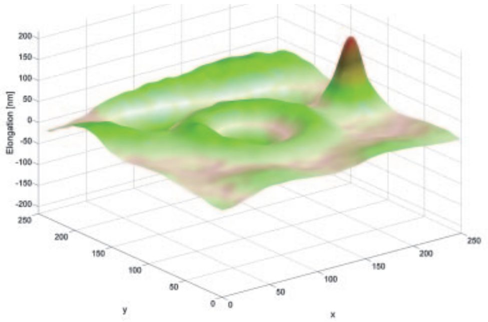


Figure 3. Amplitude of soil vibrations caused by clutter object besides buried land mine (surrogate) at 220 Hz. Courtesy of FGAN-FOM, Ettlingen.

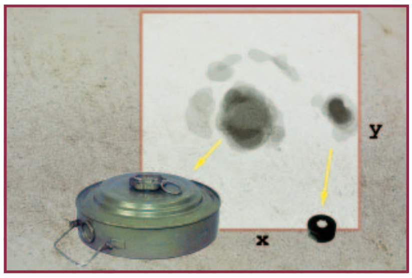
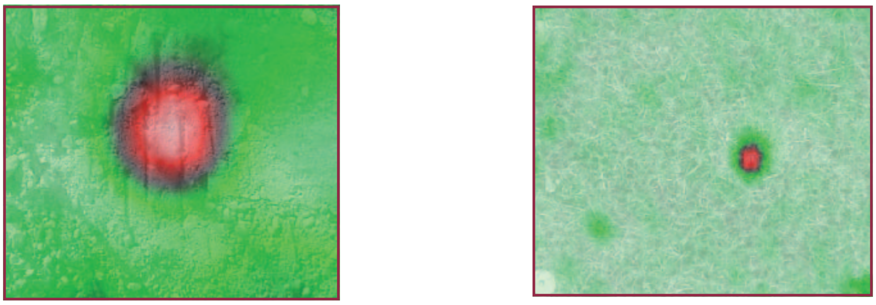


Figure 4. Combined 2D data (image) for different minelike objects. Courtesy of FGAN-FOM, Ettlingen.



Figures 5 and 6. Colour-coded images of soil surface vibrations of buried mine surrogates – the PT-Mi-Ba III 12cm under gravel (left) and the PMN 3cm under grass (right). Both samples have transparent images of the soil surfaces included for reference. Areas of enhanced vibration levels are shown in red, whereas ambient soil condition (no vibration) is shown in green.

Since the composition of the recorded acoustic spectrum is directly determined by the object's size and internal structure, it is possible to discriminate mine-like targets from harmless clutter objects, such as stones, wood, cans, etc. Figure 7 demonstrates the difference between the acoustic spectrum above a mine (PMN surrogate) and a measurement point only 5cm from this object.

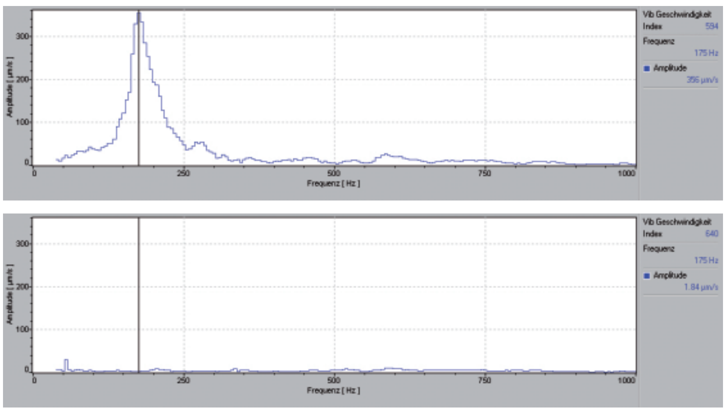


Figure 7. The acoustic spectra from above (upper image) and (lower image) from 5cm away from the same PMN surrogate.

The system is currently operating at a speed of a few minutes per square metre. According to the manufacturer, modifying the scanning strategies and improving the signal analysis algorithms should be able to increase this performance significantly.

Test & evaluation

SLDV has been operated under realistic outdoor conditions at a number of test sites, including the Joint Research Centre in Ispra (Italy) and the Netherlands Organisation for Applied Scientific Research. Public data, including a description of the Joint Research Centre test facility, is available at *http://demining.jrc.it/msms/*.

Other applications (non-demining)

SLDV can also be applied, for example, in archaeology to locate buried fragile objects which are difficult to detect by means of GPR due to unfavourable soil conditions.

Related publications

1. Klein V., M. Hebel, M. Resch (2005)
   "SLDV III: the next generation of acousto-optical landmine detection", *Proceedings of SPIE Conference on Detection and Remediation Technologies for Mines and Mine-like Targets X*, Vol. 5794, pp. 694–705, Orlando, US, 2005.
2. Hebel M., K.-H. Bers, V. Klein (2004)
   "Model-based mine verification with scanning laser Doppler vibrometry data", *Proceedings of SPIE Conference on Detection and Remediation Technologies for Mines and Mine-like Targets IX*, Vol. 5415, pp. 80-90, Orlando, US, 12-16 April 2004.
3. Klein V., P. Lutzmann, T. Mechnig (2002)
   "(Spectral) Pattern Recognition as a Versatile Tool Towards Automatic Land Mine Detection – A New European Approach", Pan-American/Iberian Meeting on Acoustics, Cancun, 4 December 2002. *The Journal of the Acoustical Society of America*, Vol. 112, Issue 5, November 2002, pp. 2325-2326.

Technical specifications	***Scanning Laser Doppler Vibrometer***
1. Used detection technology:	Laser vibrometry
2. Mobility:	Vehicle mounted
3. Mine property the detector responds to:	Reflection / modulation of acoustic energy
4. Detectors/systems in use/tested to date:	1
5. Working length:	Not applicable
6. Search head:	
➢ size:	90cm x 60cm x 80cm
➢ weight:	80kg
➢ shape:	Compact, modular
7. Weight, hand-held unit, carrying (operational detection set):	—
Total weight, vehicle-based unit:	80kg
8. Environmental limitations (temperature, humidity, shock/vibration, etc.):	Normal vehicle vibrations and mechanical load due to truck driving across uneven terrain are OK.
9. Detection sensitivity:	AT down to 30cm below surface
10. Claimed detection performance:	
➢ low-metal-content mines:	—
➢ anti-vehicle mines:	—
➢ UXO:	—
11. Measuring time per position (dwell time):	0.5 s
Optimal sweep speed:	User selectable
12. Output indicator:	Real-time 2D colour coded image
13. Soil limitations and soil compensation capability:	Extremely high water content
14. Other limitations:	—
15. Power consumption:	900W
16. Power supply/source:	24 through 30V DC or 110 / 230V AC
17. Projected price:	—
18. Active/Passive:	Active
19. Transmitter characteristics:	Sound
20. Receiver characteristics:	Laser (Helium-Neon, 633 nm wavelength)
21. Safety issues:	No hazards
22. Other sensor specifications:	—

Remarks

The sensor does not depend on any metal content in mines and will not be confused by ambient metal fragments. Furthermore, the SLDV is not dependent on the soil's dielectric or magnetic properties.

9.4 Seismic Landmine Detection System

Project identification

Project name	Detection of buried landmines using audio frequency seismic surface waves	**Start date**	April 1997
Acronym	—	**End date**	May 2006
Participation level	National, US	**Technology type**	Seismic/acoustic
Financed by	Various agencies, US Department of Defense	**Readiness level**	●●●●⑤●●●●
Budget	US$300,000 (FY 2005)	**Development status**	Ongoing
Project type	Basic technology research, Research to prove feasibility, Technology development, Technology demonstration, System/Subsystem development	**Company/institution**	Georgia Institute of Technology

Project description

The concept being studied is based on the direct excitation of seismic surface waves (Rayleigh waves) with a remote ground-coupled source. These waves propagate across an area of interest and the resulting surface normal displacement[27] is measured locally using an array of non-intrusive sensors.[28] The Rayleigh wave is particularly well suited to this application because it decays exponentially into the medium and therefore interrogates only the near surface soil where landmines are buried. The system images landmines by exploiting spatial and temporal characteristics of their interactions with the incident wave field. These include a backscattered surface wave and persistent local motion due to the excitation of mechanical resonances of the mine. The system concept has been demonstrated using detailed three-dimensional numerical models, laboratory scale experiments and experiments at several field sites. Figure 1 shows the arrangement of the system.

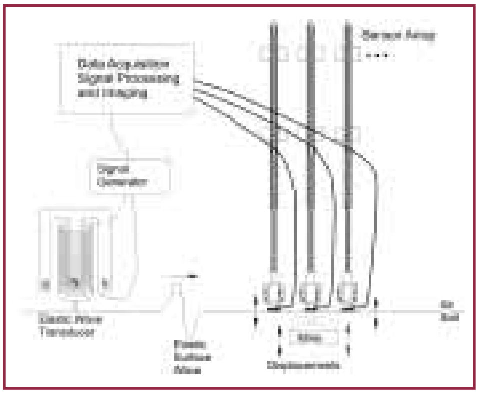


Figure 1. Configuration of seismic landmine detection system

Several different types of seismic sources and non-intrusive sensors have been tested and proven effective for imaging inert landmines and landmine simulants in the context of this

27. Displacement perpendicular to the surface.
28. Sensors do not alter the motion of the soil.

system. The sensors that have been investigated include an 8GHz radar-based vibrometer, a 50kHz ultrasonic vibrometer, a ground-coupled accelerometer and a near-ground microphone.[29] All of these have been demonstrated in a laboratory setting but only the radar-based vibrometer and accelerometer designs have been proven in field tests. Seismic sources have included electrodynamic shakers, loudspeakers and electrical arc sources. The vast majority of work to date has been with sources directly coupled to the ground so as to preferentially excite Rayleigh waves. Successful detections have been achieved for a variety of anti-personnel and anti-tank landmines. Figure 2 shows an image of a TS-50 anti-personnel mine that was formed from data collected in the laboratory experimental model.

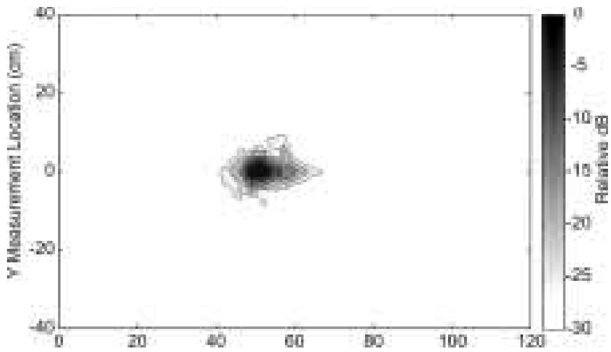


Figure 2. Image of a TS-50 AP mine buried 1.3 cm deep in a laboratory experiment.

Detailed description

The system is currently configured with commercial off-the-shelf (COTS) signal-conditioning hardware. Imaging algorithms are implemented on a desktop PC. Packing and power consumption have not been considered for a field-operable system beyond the specific requirements of the sensor arrays, all of which have been custom fabricated. During field trials, a 3kW portable generator easily powered the measurement system, computers, climate control and several ancillary devices. The sensor array has been supported from and relocated using a COTS three-axis positioning system in both the laboratory and field experiments. Figure 3 shows a two-element array of radar-based sensors on this system during a field experiment.

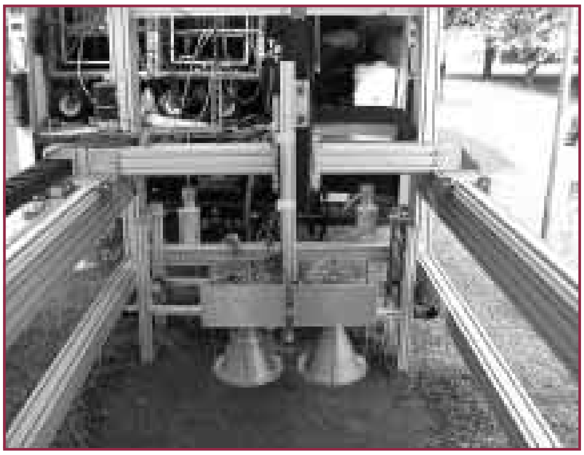


Figure 3. Seismic landmine detection system with radar-based sensors during a field experiment.

Test & evaluation

System development began in 1997. The system concept was tested using linear elastic finite-difference time domain numerical models for both the soil and the landmine

29. The accelerometers and microphones potentially represent quite low cost items.

structure. These models have evolved throughout the project and have shown good agreement with experimental data and analytical models. Experimental testing began in a small laboratory model filled with damp compacted sand, which has been found to be a good soil surrogate. A larger laboratory model filled with 50 tons of damp compacted sand has been used since 2000. This model is shown in Figure 4.

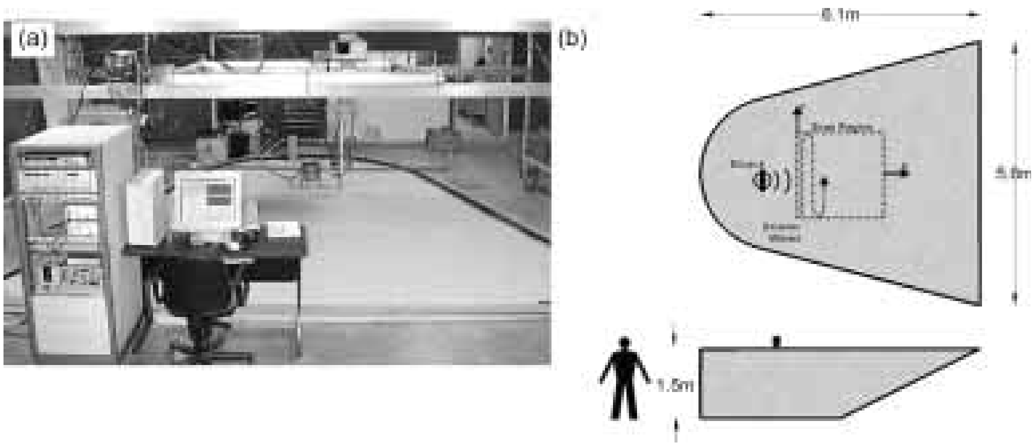


Figure 4. Laboratory experimental model (a) photograph and (b) scaled drawing.

Field-testing began in 2001. Since then the system has been tested at three different sites with disparate soil conditions in Georgia and at two US Government field test sites outside the state.

Other applications (non-demining)

An alternative configuration of the system has been explored in which bulk waves, rather than Rayleigh waves, are used. In this configuration the system is suitable for the detection of more deeply buried targets such as UXO and buried structures.

Related publications

1. Scott W.R, G.D. Larson and J.S. Martin (2006)
   "Seismic Landmine Detection", Chapter 11 in *I.D. Mines*, C. Baum (Ed.), Taylor & Francis, publication expected in 2006.
2. Martin J.S., G.D. Larson and W.R. Scott Jr. (2005)
   "Surface-Contacting Vibrometers for Seismic Landmine Detection", *Proceedings of SPIE Conference on Detection and Remediation Technologies for Mines and Mine-like Targets X*, Vol. 5794, pp. 590-600, Orlando, US, 2005.
3. Scott W.R.,Jr., J.S. Martin and G.D. Larson (2001)
   "Experimental Model for a Seismic Landmine Detection System", *IEEE Transactions on Geoscience and Remote Sensing*, Vol. 39, June 2001, pp. 1155-1164.

Technical specifications	*Seismic Landmine Detection System*
1. Used detection technology:	Seismic/acoustic
2. Mobility:	Not completely addressed at this stage. Probably vehicle mounted with a forward speed of progression <10mph.
3. Mine property the detector responds to:	Mechanical mismatch to the surrounding soil. Primarily pressure-trigger compliance.[a]
4. Detectors/systems in use/tested to date:	The technology has been tested using several different hardware configurations indoors, and in outdoor simulated mine lanes.
5. Working length:	Not applicable
6. Search head:	This depends on the number of sensors in the array.
➢ size:	Not available, >2cm^2 in plane, >10cm vertical
➢ weight:	Not available, > 8oz.
➢ shape:	Not available, depends on sensor technology
7. Weight, hand-held unit, carrying (operational detection set):	—
Total weight, vehicle-based unit:	Not available, Packaging has only been addressed with respect to individual sensors.
8. Environmental limitations (temperature, humidity, shock/vibration, etc.):	Not available at this stage.
9. Detection sensitivity:	Varies with mine properties and burial depth. Contrast up to 30 dB has been demonstrated with TS-50 AP mines and VS-1.6 AT mines.
10. Claimed detection performance:	
➢ low-metal-content mines:	Varies, metal is not relevant to the detection physics.
➢ anti-vehicle mines:	Varies, mine size is only relevant relative to burial depth and spectral content of the interrogation signal. Neither large mines nor small mines are specifically problematic otherwise.
➢ UXO:	Unknown
11. Measuring time per position (dwell time):	~100 ms per measurement depending on the source strength, reverberation, and ambient noise level.
Optimal sweep speed:	There is no optimal speed. Slower movement improves SNR.
12. Output indicator:	2D image of scanned region.
13. Soil limitations and soil compensation capability:	Ground cohesion – Extremely loose dry soil or water-saturated soil may pose problems: soil must be sufficiently cohesive to support audio frequency surface waves with measurable amplitudes (>>1nm peak). Horizontal gradients or downwardly refracting vertical gradients may also pose problems. Compensation is not necessary.
14. Other limitations:	—
15. Power consumption:	TBD[b], currently the seismic source consumes ~ 100 W during a 25% duty cycle, which is the primary power draw for the system.
16. Power supply/source:	TBD, currently the system is running on 110VAC 60 Hz wall current (Standard US) supplied by a 3 KW portable generator.
17. Projected price:	TBD, This depends on the extent of the sensing array. Individual array elements are projected at <US$50 for the least expensive type studied (accelerometers).
18. Active/Passive:	Active

19. Transmitter characteristics:	Varies, most of the work to date has involved COTS electrodynamic shakers with 20 to 100 lb force limits operating well below their drive limits.
20. Receiver characteristics:	Varies, the least expensive sensor is based on a COTS accelerometer that lightly contacts the ground. Most of the work to date has been performed with a non-contact sensor that illuminates the ground with an 8-GHz radar signal. Other sensors include 50 kHz ultrasonic vibrometers and microphones.
21. Safety issues:	None.
22. Other sensor specifications:	—

a) In mechanical science, the compliance measures the deflection of an elastic body by an applied force.
b) To be determined.

Remarks

The concept has been studied in many different configurations, some of which are better suited to specific demining scenarios and logistical constraints than others. All of these configurations are based on the same physical principles and differ primarily in the nature of the sensor and the extent of the sensor array.

Target standoff distances have been less than 1m for all of the sensor technologies that have been tested to date. Standoff distances must be of less than 10m for the excitation signal to be effective.

10. Vehicle-based Multi-Sensor Systems

10.1 Improved Landmine Detection System (ILDS)

Project identification

Project name	Improved Landmine Detection Project	**Start date**	1994
Acronym	ILDP	**End date**	1997 (prototype) 2002 (production version)
Participation level	National, Canada	**Technology type**	Multi-sensor vehicle-mounted landmine detector with data fusion and confirmation sensor
Financed by	Defence R&D Canada, Canadian Department of National Defence	**Readiness level**	●●●●●●●●9
Budget	CAD6 million (prototype) + CAD24 million (production versions)	**Development status**	Completed (ongoing R&D on mid-life upgrades)
Project type	All steps from Basic technology research to System test and in-field operations	**Company/institution**	Defence R&D Canada (production units built under license by General Dynamics Canada)

Project description

The D6300 **Improved Landmine Detection Project** was started in 1994 to design and build an advanced development prototype of a tele-operated, vehicle-mounted, multi-sensor mine detector for low metal content and non-metallic mines to meet the Canadian requirements for peacekeeping on roads and tracks. The approach taken was to employ multiple detectors based on technologies which had limited success for the high intensity conflict problem or in a single sensor role, chiefly because of high false alarm rates. The output of these detectors would then be combined using data fusion to reduce individual detector false alarm rates and provide redundancy. A tele-operated platform was chosen to improve safety to the operators and the platform was custom-designed to have a low signature, in particular ground pressure, with respect to anti-tank mine fuzes to increase system survivability. Defence R&D Canada (DRDC) conceived and designed the prototype system and carried out the integration of the components. The prototype was completed in October 1997 and a US patent was granted in 2000. The initial concept included a protection vehicle which would lead the detection vehicle and clear anti-personnel mines and magnetically fuzed anti-tank mines, but a prototype of that vehicle was not built during this phase of the project. (The protection vehicle was actually built during the production project, see below.)

The Canadian Forces initiated a follow-on project, L2684, and a contract was awarded in 1998 to General Dynamics Canada (GDC) to design and build four systems for field deployment. The systems were based on the prototype concept and the DRDC-owned intellectual property from the prototype was licensed to GDC. Four production units were delivered to the Canadian Forces in 2002. ILDS was deployed in Afghanistan in 2003, making the system the first militarily fielded, tele-operated, multi-sensor vehicle-mounted mine detector and the first with a fielded confirmation sensor.

Detailed description

The ILDS is intended to meet Canadian military requirements for mine clearance in rear area combat situations and peacekeeping on roads and tracks. The system consists of two tele-operated vehicles, plus a command vehicle. The protection vehicle leads the way, clearing anti-personnel mines and magnetic and tilt-rod-fuzed anti-tank mines. It consists of an armoured personnel carrier equipped with a forward-looking infra-red imager, a finger plow or roller and a magnetic signature duplicator. The detection vehicle, intended for low-metal content and non-metallic anti-tank mines, follows. It consists of a purpose-built vehicle carrying forward-looking infrared and visible imagers, a 3m-wide, down-looking sensitive electromagnetic induction detector and a 3m-wide down-looking ground-probing radar, which all scan the ground in front of the vehicle. Scanning sensor information is combined using a suite of navigation sensors and custom-designed navigation, co-registration, spatial correspondence and data fusion algorithms. Suspicious targets are then confirmed by a thermal neutron activation detector.

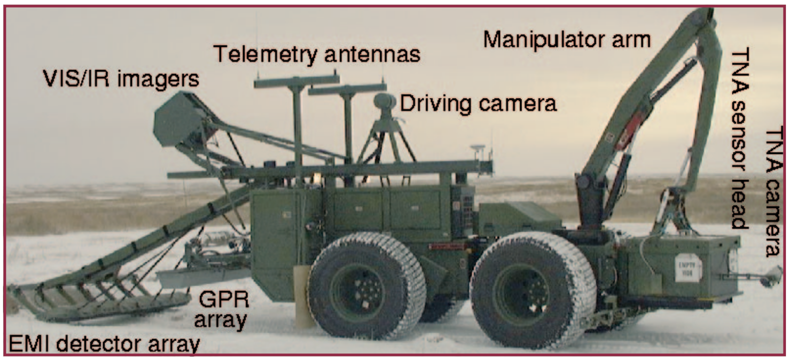


Figure 1. The ILDS remote detection vehicle (RDV). The command vehicle for the RDV and PV is not shown.

Figure 2. The ILDS protection vehicle (PV), which precedes the RDV and removes anti-personnel mines and some types of anti-tank mines such as magnetic influence and tilt-rod activated mines prior to the RDV searching for the remaining anti-tank mines.

Test & evaluation

Testing and evaluation of individual sensors has been ongoing since 1994. Results of individual scanning sensor experiments and of the thermal neutron analysis (TNA) sensor have been reported in a number of publications, such as the SPIE conference proceedings. Development and testing of the data fusion methodology started in 1996, initially using a non-tele-operated surrogate vehicle instrumented in a similar fashion to the ILDS.

The first full system trial of the prototype was conducted in November 1997. The aim of the trial was to provide a fairly realistic but tough detection scenario approximating operational conditions. Mines were buried at DRDC Suffield in a well-compacted dirt road approximately 5km long. During 32 hours of actual operation over 11 days, 78.5km of road were covered, at an average speed of 2.45km/h. In total, 759 mines were traversed, of which 67.2 per cent were low metal content and 32.8 per cent were metallic. One hundred mine targets were used, consisting of four different kinds of low-metal anti-tank mines, three kinds of metal anti-tank mines and two kinds of low-metal anti-personnel mines. Mines were unfuzed but an amount of metal equivalent to that in the fuze was placed in the fuze wells of the low-metal mines. Mines were buried using tactical methods between 3.8cm and 17.8cm depth (top of mine to ground surface), with an average depth of 10.2cm. Mine positions were ground truthed at burial to an accuracy of 2cm. The scored trials were "blind". Night and day operations were conducted and both temperate and cold weather conditions were encountered. The system functioned well under most of the conditions, although flat diurnal temperature profiles, fog and ground frost led to sub-optimal infra-red performance for some periods during the trial. A few experienced operators were used together with a large number of neophyte operators. Finally, the TNA confirmatory detector was not employed for these trials since the automatic trailer control was not yet implemented. Early studies revealed an improvement in performance due to inexperienced detector operators gaining experience and suggested that the minimum operator training time needed was about one week. For the second half of the trials (when operator inexperience was no longer a factor) and using an optimum halo distance of 60cm, the mean estimated probabilities of detection (PD) and false alarm rate (FAR) were: 85 per cent and 0.2/m of forward travel for all anti-tank mines; 100 per cent and 0.22/m for metal anti-tank mines and 78 and 0.22/m for low-metal anti-tank mines. A small quantity of low-metal anti-personnel mines was used in the trial. Performance against them was poor, partly because ILDS was intended only for anti-tank mines, and partly because the ground truth was not good enough to accurately localise the small anti-personnel mines for reliable scoring.

In 1998, a team of DRDC and GDC personnel operated the prototype ILDS in the US Government GSTAMIDS Advanced Technology Demonstrator trials. The trials evaluated five vehicle-mounted mine detection systems, four of them American, for on and off road detection of anti-tank landmines. Trials were conducted at the Aberdeen Test Center, Aberdeen, Maryland, in June, and at the Energetic Materials Research and Testing Center, Socorro, New Mexico, in July. The test set up and procedures were established independent of the participants. All scored tests were blind and scoring was independently conducted. The trials are discussed in detail in a 200-page report by the Institute for Defense Analysis (1998).

More than 4,000m^2 of road and off-road lanes contained 167 mines at Aberdeen and more than 3,200m^2 contained 146 mines or mine surrogates at Socorro. Mixtures of non-metallic surrogate, low-metal and metallic anti-tank mines, buried from 0 to 10cm depth, were used at both locations. Mines were unfuzed, but an equivalent amount of metal to that in the fuze was added to the vacant fuze well. Conditions at ATC were hot and damp, occasionally raining, with temperatures most days in excess of 30°C. Conditions at Socorro were extremely hot and dry. Ambient temperatures exceeded 40°C and occasionally reached 45°C while temperatures on the surface of the ILDS prototype occasionally reached 50°C. Although some intermittent sensor failures occurred due to the heat, all tests were completed on schedule.

Positional resolution for fuzed detections was roughly the same for different sites and for on and off road. It was approximately 12cm. Although a halo radius of 1m (from the edge of the mine) was used in the tests to determine a detection, given the above positional resolution, a halo radius as low as 25cm would have caused very little degradation of performance.

The ILDS prototype placed first or second out of the five competitors on every test, although there were no huge differences between the competitors. PD was generally in the low 90 per cent range, with FAR of roughly 15 mines per 100 metres. It should be noted that the TNA was used only sporadically in the scored runs and was not relied on for final decisions. This was done for two reasons. First, about one third of the mines contained no explosives and hence could not be confirmed by the TNA. However, it was not known in advance which ones had no explosives. Second, there were tight time constraints imposed on completing a lane once it was started. These constraints were designed by the trial organisers for systems which had no confirmation sensors and thus precluded using TNA to confirm every fuzed detection from the scanning sensors.

Limited in-house and independent performance evaluations have been done with the prototype TNA operated separately from the other ILDS detectors. Most tests took place in extreme conditions. Probability of detection, probability of false alarm and count time can always be traded off for a given explosive mass, depth and horizontal offset. In the independent experiments at Socorro and Aberdeen in 1998 against various anti-tank mines at operational depths, using a two-minute count time, PD was between 95 and 100 per cent for a PFA of 32-35 per cent and was 79 per cent for a PFA of 0 per cent. It must be recognised that, at the time of those tests, the prototype TNA still had significant problems with temperature stability and background correction.

Since then, substantial improvements in the TNA system have been made in developing the production version. Detailed results will be published in the near future. As an example of present performance, the time to detect various anti-tank mines with a 93 per cent confidence at depths of 10cm or less ranges from 1 to 29s. It is thus expected that the TNA should be able to achieve in practice a PD of at least 95 per cent with a PFA of less than 10 per cent, for counting times less than one minute, when interrogating anti-tank mines at depths of 15cm or less. The overall system PD would thus be slightly reduced (~5 per cent), while the false alarm rate would be reduced by more than a factor of ten. This puts the false alarm rate at an operationally practical level.

Related publications

1. McFee J.E., K.L. Russell, R.H. Chesney, A.A. Faust and Y. Das (2006)
"The Canadian Forces ILDS - A militarily fielded, multi-sensor, vehicle-mounted, tele-operated landmine detection system", *Proceedings, SPIE Conference on Detection and Remediation Technologies for Mines and Mine-like Targets XI*, Orlando, US, 17-21 April 2006, to be published.

.2. Faust A.A., R.H. Chesney, Y. Das, J.E. McFee and K.L. Russell (2005)
"Canadian tele-operated landmine detection systems Part I: The improved landmine detection project", *International Journal of Systems Science,* 36(9), July 2005, pp. 511-528.

Technical specifications:

- Prototype: see referenced publications.
- Production version: contact GDC (General Dynamics Canada, *www.gdcanada.com*).

10.2 Kawasaki MINEDOG

Project identification			
Project name	Humanitarian Demining Project of Kawasaki	**Start date**	April 2002
Acronym	MINEDOG	**End date**	March 2007
Participation level	National, Japan	**Technology type**	Ground penetrating radar
Financed by	—	**Readiness level**	●●●●●⑥●●●
Budget	About US$700,000	**Development status**	Ongoing (commercial development)
Project type	Technology demonstration, System/Subsystem development	**Company/institution**	Kawasaki Heavy Industries Ltd.

Project description

Kawasaki Heavy Industries, Ltd. has developed the BULLDOG System, a humanitarian demining system that features, according to the manufacturer, excellent safety and working efficiency. The system consists of the **MINEDOG** and MINEBULL vehicles. The MINEDOG is a mine detection vehicle equipped with various mine detection sensors and cameras, whereas the MINEBULL is an anti-personnel mine clearance vehicle equipped with a digging drum to excavate and detonate anti-personnel mines, as well as with a device to collect iron fragments within the dug soil. Each vehicle should be operated by means of a remote-control device. The MINEBULL can however also be operated by an operator on board.

Demonstration tests of the BULLDOG System using various simulated mines and non-activated actual mines were conducted in Afghanistan at the UN's Central Demolition Site (CDS) near Kabul, as well as (MINEBULL only) at the actual mine belt of Kabul International Airport (KIA) from June 2004 to February 2005. Concerning the CDS tests, the MINEDOG could detect 100 per cent of the real mines with a very low false alarm rate, and the MINEBULL could remove the simulated anti-personnel mines with a high clearance rate while collecting iron fragments with a very high collection rate. Concerning the real clearance test at the KIA, MINEBULL could destroy 32 anti-personnel mines in a one-time trial within a 50m by 2m mine belt, which was confirmed by post-inspection to represent a perfect mine clearance operation (100 per cent mine clearance). These tests included the performance demonstration of the remote-control system and the blast-proof structures. Remote-control operation of each vehicle could be easily performed at a safe distance of 500m to 900m, and easy operability was proven. The blast-proof structure of the MINEBULL was confirmed using explosives (PE3-A) of various weights ranging from 0.1kg to 8kg.

The developer reports that all test results were excellent. In addition, during the test period, the opinions and requests for improvement of devices and operational procedure were gathered from test staffs of the local NGO and UNMACA (United Nations Mine Action Centre for Afghanistan) and were taken into account as soon as possible for an improvement of the BULLDOG system. Improved MINEDOG and MINEBULL vehicles are being newly produced as from April 2005 and it is planned to introduce them into Afghanistan in 2006.

The following section deals only with the MINEDOG vehicle.

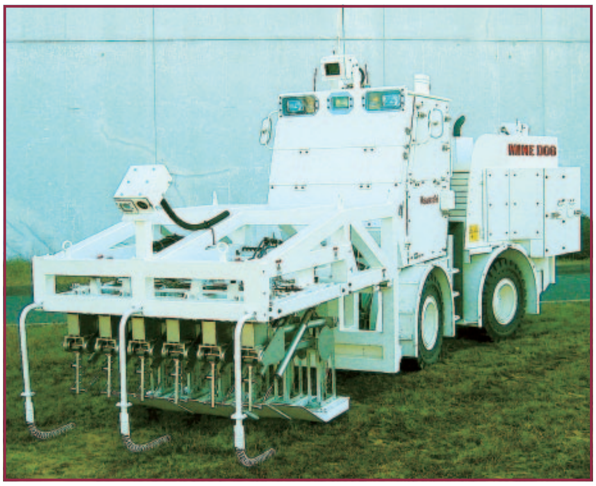


Figure 1. The Kawasaki MINEDOG vehicle.

Detailed description

MINEDOG is exclusively dedicated to the detection of buried landmines and unexploded ordnance (UXO). It is also able to provide an image of the scenery in front of itself to the remote control operator, who can identify potential obstacles on the surface, e.g. scattered mines and UXO, from the image or video as well as from a «caution frame» displayed on the remote control screen.

MINEDOG is a four-wheel vehicle and can move at up to 20km/h but in detection mode it operates at 0.5 to 2km/h according to soil conditions.

In a minefield, MINEDOG should only be remote controlled from a distant and safe position. It has a blast and bullet-proof structure to endure continuous anti-personnel mine explosions under its wheels and can continue detection until it automatically stops immediately after having detected an anti-tank mine or UXO. During detection, six mine detectors installed on sleds softly touch the ground, thanks to sensor stabilisers, as the vehicle goes forward. Even if a sled touches any surface mine, it does not cause detonation due to the very low impulse pressure. When the sensors detect landmines or UXO, MINEDOG marks the detected position precisely with red ink. If the detected object is an anti-tank mine or large UXO, it automatically stops after marking a long red line.

Test & evaluation

As a result of the tests in Afghanistan, the following features were able to be confirmed according to the manufacturer.

Safety: The system could be operated from a safe distance of 500m.

Performance: High detectability with a low false alarm on a flat area at the CDS:

a) For anti-tank mines buried 30cm deep at a test area contaminated with metal fragments, 100 per cent detection and 0.0 pieces/m^2 was recorded.

b) For anti-personnel mines buried 15-30cm deep at a test area contaminated with metal fragments, 100 per cent detection and 0.2 pieces/m^2 was recorded.

Operability: Easy remote control operation from out of sight.

Related publications

1. Jane's Defence Weekly
   Mine-clearing system tested successfully in Afghanistan (2005), 7 September 2005.
2. Sumi I. (2005)
   V & V test of BULLDOG System in Afghanistan, IARP International Workshop on Robotics and Mechanical Assistance in Humanitarian Deming (HUDEM2005), Tokyo, Japan, 21-23 June 2005. (Proceedings available from *www.itep.ws*).
3. Final Report (Summary) for Humanitarian Mine Clearance Equipment in Afghanistan, Japan International Cooperation System, 31 March 2005, *www.mineaction.org/doc.asp?d=452*

Technical specifications	*Kawasaki Heavy Industries, Ltd. MINEDOG*
1. Used detection technology:	GPR
2. Mobility:	Vehicle-based
3. Mine property the detector responds to:	Difference of dielectric constant (ε) and/or conductivity (σ) between a mine and the soil.
4. Detectors/systems in use/tested to date:	2 systems (14 detectors)
5. Working length:	Not applicable
6. Search head:	Sled type (incl. Box-type head)
➢ size:	Sled: 70cm(L) x 25cm(W) x 20cm(H)/1 channel, Head: 40cm(L) x 25cm(W) x 6cm(H). Overall detection width: 1.5m (6 channels).
➢ weight:	4kg/1 channel
➢ shape:	Sled-shape
7. Weight, hand-held unit, carrying (operational detection set):	—
Total weight, vehicle-based unit:	8.5 tons
8. Environmental limitations (temperature, humidity, shock/vibration, etc.):	-20°C to +60°C, Humidity: less than 100% (rain proof), Shock/Vibration: Equivalent to construction machinery.
9. Detection sensitivity:	—
10. Claimed detection performance:	
➢ low-metal-content mines:	PD: 100%, with low FAR against AP-mines buried at 30cm or less, and AT-mines buried at 50cm or less under good conditions.
➢ anti-vehicle mines:	Same as above.
➢ UXO:	Same as AT-mines.
11. Measuring time per position (dwell time):	—
Optimal sweep speed:	Total target detection time: Min. 0.5sec - Max. 4s, depends on mine depth and size, and vehicle speed.[a)]
12. Output indicator:	Target symbol on the remote control display.
13. Soil limitations and soil compensation capability:	Relatively flat ground with allowable swell of +20cm for every 1m progress, and allowable depression of -20cm for every 1m progress. Low PD with high FAR on ground containing mineralised (magnetic) stones. High PD with low PFA on ordinary ground contaminated with metal fragments. Before starting detection operation, the system should be calibrated on the site ground condition.
14. Other limitations:	Should not be used on a slippery ground because vehicle slipping causes missed targets and higher false alarm rate.
15. Power consumption:	—
16. Power supply/source:	Vehicle generator.
17. Projected price:	US$700,000
18. Active/Passive:	Active
19. Transmitter characteristics:	Mono-pulse radar
20. Receiver characteristics:	—
21. Safety issues:	None (and remote controlled vehicle).
22. Other sensor specifications:	Visible and ultra-violet cameras are installed to detect scattered mines or UXO.

a) The mine detection requires the acquisition of an object shape from many radar echoes, and therefore the GPR sensor has to run over the object. After having detected a mine, the position of the mine is immediately determined from the sensor position when the sensor moved past the centre of the mine's shape. The total target detection time is therefore a minimum of 0.5s where an anti-personnel mine (small mine) is buried flush and the vehicle speed (detection speed) is 2km/h, and maximum of 4s where an anti-tank mine is buried 50cm deep with a vehicle speed of 0.5km/h.

Remarks
Mobility: max. 2km/h (in detection operation by remote control); max. 20km/h (in transportation by riding in the vehicle).

10.3 LAMDAR-III (Mine Hunter Vehicle Sensor 2)

Project identification

Project name	GPR Pulse Radar
Acronym	LAMDAR-III
Participation level	National, Japan
Financed by	Japan Science and Technology Agency
Budget	N/A
Project type	Technology development, System/subsystem development
Start date	September 2002
End date	March 2006

Technology type	Metal detector, Ground penetrating radar
Readiness level	●●●●●⑥○○○
Development status	Ongoing
Company/institution	Tau Giken Co., Ltd., University of Electro-Communication

Project description

The developer describes the **LAMDAR–III** as being a highly sensitive ground penetrating radar (GPR). This GPR consists of five transmitting and six receiving spiral antennae in an array, with the electronic circuits designed to work for the detection of different targets such as landmines, metal fragments, UXO, rocks, etc. The radar transmits a very short pulse signal of approximately 150ps. The reflection of this pulse signal from the soil and from the various targets inside the soil is used to determine their position underground. The acquired data is processed using SAR (synthetic aperture) algorithms[30] to generate a 3-D image, and the target can be identified visually. The GPR dimension is 75 x 30 x 40cm with a weight of about 27kg. The system can be used in a high-speed scanning configuration with high-resolution signal analysis.

Detailed description

GPR has been demonstrated to be a very successful sensing device for various kinds of investigations and detection of buried targets such as pipes (water, gas, electricity), cables, archaeological objects, voids, etc. The developer notes that when using impulse GPR it is required to reduce the pulse width to increase resolution, and to increase the transmitting power in order to enhance the return signal (whose level is normally very weak). Increasing the resolution is a challenging issue in GPR; it is, however, greatly desired for the clear imaging of very closely buried targets.

30. SAR algorithms refer to the computations, carried out after data has been acquired with a moving platform, to enhance and "sharpen" the resulting raw radar image as if it had been acquired with a larger and more focused antenna.

Figure 1: LAMDAR-III mounted on the front of the Mine Hunter Vehicle.

In each scan of the LAMDAR–III system, each transmitting antenna sends a pulse signal and the corresponding two receiving antennae receive the reflected pulse signal one at a time (by means of a delay generator). The signal is then sampled and used for target detection. The analysis of this sampled data is done using synthetic aperture radar algorithms.

The LAMDAR-III GPR has been mounted in the front part of the MHV (Mine Hunter Vehicle), as shown in Figure 1, which performs the scanning mechanically and keeps the sensor near the ground surface. The GPR is able to scan two rows at once, covering about a $1m^2$ area of the ground. The acquired data is first stored in a PC and then analysed using the previously mentioned SAR algorithm (see also Figure 2).

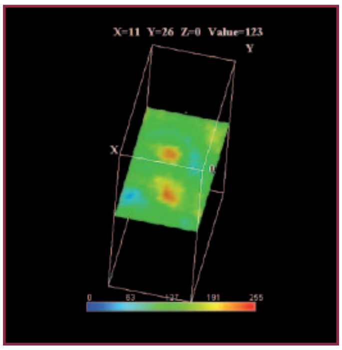


Figure 2. A 3-D view of two landmines at a depth of 5cm.

According to the manufacturer, the advantages of the system, enabled by the use of the array antenna, include high speed scanning and much better visual target identification. The analysis software can be manipulated at the user's convenience to take into account factors such as weather, soil content or noise reduction, allowing clear image-based identification of the various targets encountered. Research is still ongoing to get the best and clearest identification of various targets and also to modify the radar hardware in order to identify targets buried deeper than 20cm.

Test & evaluation

Several tests have been conducted at indoor and outdoor test sites in Japan. The manufacturer reports that analysis of the acquired data allowed a successful detection of the different types of buried anti-personnel landmines. Outdoor test and evaluation is ongoing (first quarter 2006) at the Croatian test site of Benkovac.

Related publications

1. Ishikawa J., M. Kiyota, K. Furuta (2005)
"Evaluation of Test Results of GPR-based Anti-personnel Landmine Detection Systems Mounted on Robotic Vehicles", *Proceedings of the IARP International Workshop on Robotics and Mechanical Assistance in Humanitarian Demining (HUDEM2005), 21-23 June 2005, Tokyo, Japan.*

2. Ishikawa J., M. Kiyota, K. Furuta (2005)
"Experimental design for test and evaluation of anti-personnel landmine detection based on vehicle-mounted GPR systems", *Proceedings of SPIE Conference on Detection and Remediation Technologies for Mines and Mine-like Targets X*, Vol. 5794, pp. 929-940, Orlando, US, 2005.

Technical specifications	*Tau Giken Co. Ltd./ University of Electro-Communication LAMDAR-III*
1. Used detection technology:	Impulse GPR array with SAR imaging algorithms, and metal detector
2. Mobility:	Vehicle-based
3. Mine property the detector responds to:	Dielectric characteristics (see *GPR Operating Principles*) and metal content.
4. Detectors/systems in use/tested to date:	One unit
5. Working length:	—
6. Search head:	
➢ size:	75 x 30 x 40cm
➢ weight:	27kg
➢ shape:	Rectangular box
7. Weight, hand-held unit, carrying (operational detection set):	—
Total weight, vehicle-based unit:	—
8. Environmental limitations (temperature, humidity, shock/vibration, etc.):	—
9. Detection sensitivity:	~20cm depth from the surface level
10. Claimed detection performance:	
➢ low-metal-content mines:	20cm depth
➢ anti-vehicle mines:	N/A
➢ UXO:	N/A
11. Measuring time per position (dwell time):	4min/m^2
Optimal sweep speed:	—
12. Output indicator:	3D visual display. Signal waveform display.
13. Soil limitations and soil compensation capability:	—
14. Other limitations:	—
15. Power consumption:	4W for GPR
16. Power supply/source:	12V DC
17. Projected price:	—
18. Active/Passive:	Active
19. Transmitter characteristics:	Baseband pulse (time period 150 ps)
20. Receiver characteristics:	Triggered by delay generator
21. Safety issues:	—
22. Other sensor specifications:	—

Remarks

Specifications of Mine Hunter Vehicle, the mine detecting robot on which the sensor is mounted, are as follows:

- Size: L × W × H: 2,450mm × 1,554mm × 1,490mm.
- Weight: 1500kg.
- Drive: Hydrostatic transmission driven by a diesel engine.
- The robot features a sensor arm and a manipulator.
  - The sensor arm detects mines by using the GPR. It is a horizontal multi-axis articulated SCARA-type arm.
  - The manipulator has a high-pressure air blower and a gripper. It is a vertical multi-articulated arm with 6 degrees of freedom.

10.4 Light Ordnance Detection by Tele-operated Unmanned System (LOTUS)

Project identification			
Project name	Light Ordnance Detection by Tele-operated Unmanned System	**Technology type**	Ground penetrating radar, infra-red and metal detector
Acronym	LOTUS	**Readiness level**	6
Participation level	European	**Development status**	Completed
Financed by	Co-financed by EC ESPRIT FP IV	**Company/institution**	PipeHawk plc, DEMIRA e.V., Institut Dr. Foerster, Netherlands Organization for Applied Scientific Research
Budget	N/A		
Project type	Technology demonstration		
Start date	1 February 1999		
End date	31 January 2002		

Project description

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

Detailed description[31]

The project consortium reports that the sensors used — ground penetrating radar, infra-red and metal detector — are multi-spectral and multi-dimensional. These sensors have been studied in the previous European GEODE R&D project and 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 successfully tested in the Bosnian Mine Detection trial in Vidovice in August 2002. The MINEREC GPR array was used with a metal detector array from Foerster GmbH, and an infra-red camera from the Netherlands Organisation for Applied Scientific Research- Physics and Elelectronics Laboratory (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 of the Bosnian trial was, according to the consortium, to

31. R.J. Chignell, *LOTUS – A Major Technology Milestone for Demining*, pp. 5-6.

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 in Figures 1 and 2. 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 immediately in front of the vehicle. Each of the sensors has its own computer to process its 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.

Figure 1. Rear view of the LOTUS trial vehicle.

Figure 2. Side view of the LOTUS trial vehicle.

PipeHawk plc reports that the success of the Bosnian trial in 2002 has enabled it to carry out a thorough review of the GPR-centred detection technology, the operational requirements for effective mine and UXO detection and the system issues. From this review 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 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 safe 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 seeking funding to build prototype operational vehicles.

Test & evaluation

Demonstration trials were carried out in Bosnia in 2001 and the following was reported[32] 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

32. R.J. Chignell, *op.cit.*, pp. 7-9, *www.eudem.info.*

of sensors post-fusion was analysed 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. Detection of the smallest mine at the deepest depth required the most sensitive settings for the sensors and potentially 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 on 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 on this one sensor, fusion only reduced the false alarm rate by around 5 per cent.

With small low-metal targets— laid close to the maximum detection depth of the metal detector in the higher numbered Bosnian test lanes — the fusion output from the sensor suite produced a false alarm rate of between 17 per cent and 25 per cent 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 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 per cent 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 1 per square metre identified by the LOTUS system's investigation as the entry point for a vehicle-based detection product into use. Ongoing development would progressively improve this figure.

The infra-red camera was limited by external noise and clutter. 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, 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 ongoing 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 off-the-shelf 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.

Related publications

1. Schavemaker J., E. den Breejen and R. Chignell (2003)
   "LOTUS Field Demonstration in Bosnia of an Integrated Multi-Sensor, Mine Detection System for Humanitarian Demining", in H. Sahli, A.M. Bottoms, J. Cornelis (Eds.), *EUDEM2-SCOT 2003, International Conference on Requirements and Technologies for the Detection, Removal and Neutralization of Landmines and UXO*; Volume II, pp. 613-617, Vrije Universiteit Brussel, Brussels, September 2003, *www.eudem.info*
2. Chignell R.J. (2003)
   LOTUS – A Major Technology Milestone for Demining, www.eudem.info

Technical Specifications	*LOTUS GPR[a)]*
1. Used detection technology:	GPR array, pulsed
2. Mobility:	Vehicle-based
3. Mine property the detector responds to:	Dielectric characteristics (see *GPR Operating Principles*).
4. Detectors/systems in use/tested to date:	Prototype
5. Working length:	Not applicable
6. Search head:	
➢ size:	Array width: x axis: 0.75m (Options of 2m, 3m & 4m), y axis: 4mm (>6m), height: cameras specify highest mounting point required, ~2m.
➢ weight:	—
➢ shape:	—
7. Weight, hand-held unit, carrying (operational detection set):	—
Total weight, vehicle-based unit:	—
8. Environmental limitations (temperature, humidity, shock/vibration, etc.):	Laboratory prototypes (Close to a full military specification).
9. Detection sensitivity:	—
10. Claimed detection performance:	
➢ low-metal-content mines:	Max depth range: 12cm (20cm). PD: All mines detected in trial, but limited statistics. PFA: see Test & evaluation (Compatible with the requirements of productive vehicle-based operation).
➢ anti-vehicle mines:	Max depth range: 30cm (30cm, plastic). PD: All mines detected in trial, but limited statistics. PFA: see Test & evaluation (Compatible with the requirements of productive vehicle-based operation).
➢ UXO:	(Metal max. depth range: 1m.)
11. Measuring time per position (dwell time):	—
Optimal sweep speed:	1.8km/h (planned to rise to 3km/h, through 8km/h to 20km/h).
12. Output indicator:	—
13. Soil limitations and soil compensation capability:	—
14. Other limitations:	—
15. Power consumption:	—
16. Power supply/source:	Vehicle powered
17. Projected price:	—
18. Active/Passive:	Active
19. Transmitter characteristics:	Transmitted power: ~44dBm peak.
20. Receiver characteristics:	Bandwidth: 300MHz to 3GHz with some roll off at high frequency (200MHz to 3.3GHz with no roll off).
21. Safety issues:	None
22. Other sensor specifications:	Resolution: Measurement spacing: 50mm cross track, 25mm along track (15mm square). Primary detection algorithm: various. Feature extraction: to be developed.

a) Main figures are for the prototype: figures in square brackets are target production specifications.

10.5 SAR GPR (Mine Hunter Vehicle Sensor 1)

Project identification

Project name	SAR-GPR	**Start date**	September 2002
Acronym	—	**End date**	March 2006
Participation level	National, Japan	**Technology type**	Metal detector, ground penetrating radar
Financed by	Japan Science and Technology Agency	**Readiness level**	●●●●●⑥●●●
Budget	N/A	**Development status**	Ongoing
Project type	System/subsystem development	**Company/institution**	Tohoku University

Project description


Figure 1. SAR-GPR mounted on MHV.

SAR-GPR is a sensor system composed of a ground penetrating radar (GPR) and a metal detector for landmine detection. The GPR employs an array antenna for advanced signal processing to achieve better subsurface imaging. This system, combined with synthetic aperture radar (SAR) algorithms[33], can suppress clutter and can image buried objects in strongly inhomogeneous material. SAR-GPR is a stepped frequency radar system, whose radio frequency component is a newly developed compact vector network analyser.[34] The size of the system is 30cm x 30cm x 30cm, composed of six Vivaldi antennae and three vector network analysers. The weight of the system is about 20kg, and it can be mounted on a robotic arm on a small unmanned vehicle such as the Mine Hunter Vehicle.

Detailed description

Dual sensor is a common new approach for landmine detection. SAR-GPR also employs the combination of metal detector and GPR. However, imaging by GPR is very difficult

33. SAR algorithms refer to the computations, carried out after data has been acquired with a moving platform, to enhance and "sharpen" the resulting raw radar image as if it had been acquired with a larger and more focused antenna.
34. A measurement instrument used in electrical engineering to acquire data at high frequencies and over a wide frequency range.

in strongly inhomogeneous material due to strong clutter. The developers propose therefore to use a synthetic aperture radar approach to solve this problem, and have developed SAR-GPR equipment to be mounted on a robot arm.

SAR-GPR antennae scan mechanically near the ground surface to acquire the radar data. In fact, an array antenna composed of six elements is employed, in order to suppress the ground clutter.[35] The data is then processed for subsurface imaging.

In order to achieve the optimum SAR-GPR performance, the developer believes that: (i) an adaptive selection of the operating frequencies is quite important, and that (ii) an antenna mismatch[36] causes serious problems in GPR. Most conventional GPR systems employ impulse radar, because it is compact and data acquisition is fast. However, according to the developer, most impulse radar systems have disadvantages such as signal instability, especially time drift and jitter, strong impedance mismatch to a coaxial cable, which causes serious ringing, and fixed operating frequency range. An alternative is represented by the use of systems such as vector network analysers, a synchronised transmitter-receiver measurement equipment composed of a synthesiser and a coherent receiver. These enable quite flexible selection of operation frequencies and stable data acquisition. The developer has therefore chosen to equip the SAR-GPR with three sets of vector network analysers operating in the 100MHz-4GHz frequency range. The optimal operational range can actually be selected as a function of the soil conditions.

Test and evaluation

The developer reports that, thanks to the very strong signal processing with rich datasets acquired by an array antenna, the SAR-GPR image can reduce the effect of clutter drastically. Figure 2 shows an example of the raw data acquired by SAR-GPR and the 3-D image after signal processing by the SAR-GPR algorithm.

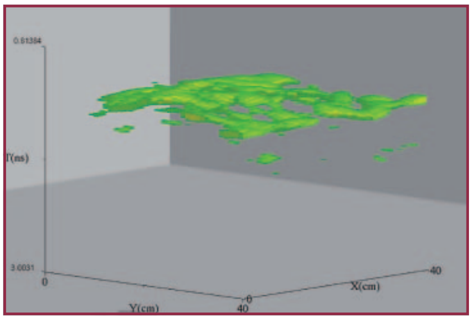


Figure 2a. Common offset raw GPR profile.

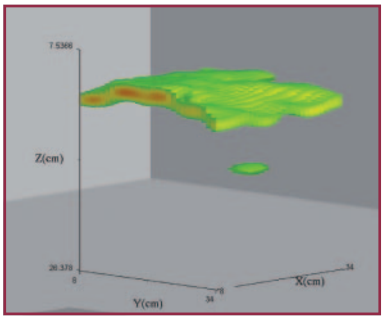


Figure 2b. Processed GPR profile after CMP stacking and migration (a buried landmine is visible as an isolated object, situated below the strong reflection due to the ground surface).

35. Technically, a Common Midpoint (CMP) technique is adopted to gather data sets acquired at one position by the array antennae.
36. This refers to suboptimal coupling of the GPR antenna to the ground, resulting in an increase of the radar energy which is reflected back at the air-ground interface, rather than penetrating the ground to then reach the target.

Figure 3 shows an example of horizontal slices of GPR images acquired at a Japanese test lane, representing the ground at three consecutive depths, as if one were looking from above.

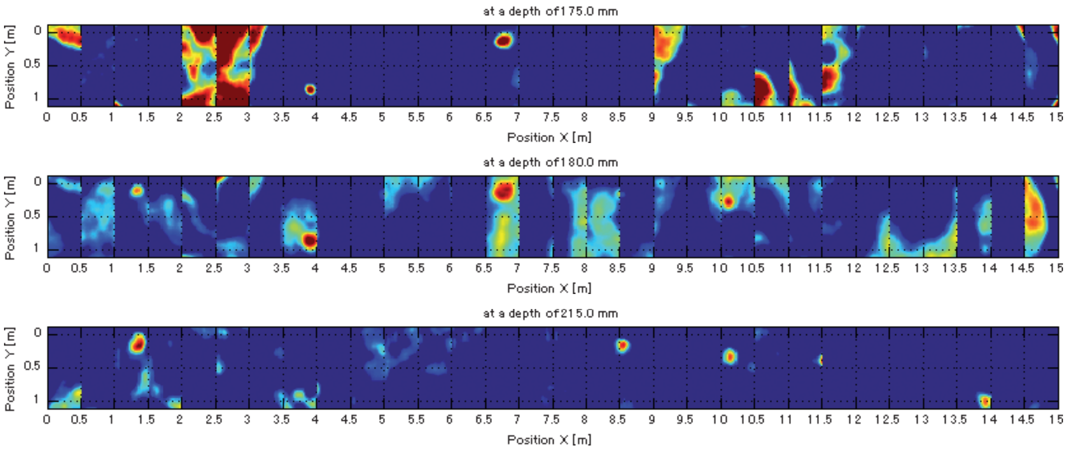


Figure 3. Horizontal slices of GPR image by SAR-GPR.

Related publications

1. Ishikawa J., M. Kiyota, K. Furuta (2005)
   "Evaluation of Test Results of GPR-based Anti-personnel Landmine Detection Systems Mounted on Robotic Vehicles", *Proceedings of the IARP International Workshop on Robotics and Mechanical Assistance in Humanitarian Demining (HUDEM2005)*, 21-23 June, 2005, Tokyo, Japan.

2. Ishikawa J., M. Kiyota, K. Furuta (2005)
   "Experimental design for test and evaluation of anti-personnel landmine detection based on vehicle-mounted GPR systems", *Proceedings of SPIE Conference on Detection and Remediation Technologies for Mines and Mine-like Targets X*, Vol. 5794, Orlando, US, 2005, pp. 929-940.

3. Sato M., X. Feng, T. Kobayashi, Z.-S. Zhou, T. G. Savelyev, J. Fujiwara (2005)
   "Development of an array-antenna GPR system (SAR-GPR)", *Proceedings of SPIE Conference on Detection and Remediation Technologies for Mines and Mine-like Targets X*, Vol. 5794, Orlando, US, 2005, pp. 480-487.

4. Feng X., Z. Zhou, T. Kobayashi, T. Savelyev, J. Fujiwara and M. Sato (2005)
   "Estimation of ground surface topography and velocity models by SAR-GPR and its application to landmine detection", *Proceedings of SPIE Conference on Detection and Remediation Technologies for Mines and Mine-like Targets X*, Vol. 5794, Orlando, US, 2005, pp. 514-521.

5. Sato M., Y. Hamada, X. Feng, F. Kong, Z. Zeng, G. Fang (2004)
   "GPR using an array antenna for landmine detection", *Near Surface Geophysics*, 2, 2004, pp. 3-9,.

6. Feng X. and M. Sato (2004)
   "Pre-stack migration applied to GPR for landmine detection", *Inverse Problems*, 20, 2004, pp1-17.

7. JST (Japan Science and Technology Agency) Humanitarian Demining Website: *www.jst.go.jp/kisoken/jirai/EN/index-e.html.*

Technical specifications	*Tohoku University GPR-SAR*
1. Used detection technology:	GPR array with SAR imaging algorithms, and metal detector
2. Mobility:	Vehicle-based
3. Mine property the detector responds to:	Dielectric characteristics (see *GPR Operating Principles*) and metal content.
4. Detectors/systems in use/tested to date:	One unit
5. Working length:	Not applicable
6. Search head:	
➢ size:	30cmx30cmx30cm
➢ weight:	17kg
➢ shape:	Rectangular box including antenna and radar in one unit.
7. Weight, hand-held unit, carrying (operational detection set):	—
Total weight, vehicle-based unit:	17kg (sensor unit) +30kg (controller)
8. Environmental limitations (temperature, humidity, shock/vibration, etc.):	—
9. Detection sensitivity:	—
10. Claimed detection performance:	
➢ low-metal-content mines:	20cm depth
➢ anti-vehicle mines:	Not applicable
➢ UXO:	Not applicable
11. Measuring time per position (dwell time):	6 min/m^2
Optimal sweep speed:	—
12. Output indicator:	PC display. GPR: 3D slices, MD: 2D image.
13. Soil limitations and soil compensation capability:	—
14. Other limitations:	—
15. Power consumption:	—
16. Power supply/source:	100/200V AC
17. Projected price:	—
18. Active/Passive:	Active
19. Transmitter characteristics:	100MHz-4GHz Stepped Frequency
20. Receiver characteristics:	Synchronized to Transmitter
21. Safety issues:	None
22. Other sensor specifications:	—

Remarks

Specifications of the Mine Hunter Vehicle, the mine detecting robot on which the sensor is mounted, are as follows:

- Size: L × W × H: 2450mm × 1554mm × 1490mm.
- Weight: 1500kg.
- Drive: Hydrostatic transmission driven by a diesel engine.
- The robot features a sensor arm and a manipulator.
    - The sensor arm detects mines by using the GPR. It is a horizontal multi-axis articulated SCARA-type arm.
    - The manipulator has a high-pressure air blower and a gripper. It is a vertical multi-articulated arm with 6 degrees of freedom.

10.6 Test and Demonstration of Multi-sensor Landmine Detection Techniques (DEMAND)

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	€3,700,000
Project type	Technology development, Technology demonstration, System/subsystem development
Start date	1 February 2001

End date	29 February 2004
Technology type	GPR, metal detector, trace explosive detection
Readiness level	●●●●●6●●●
Development status	Completed
Company/institution	Technische Universität Ilmenau, Ingenieria de Sistemas y Software, Meodat GmbH, Schiebel Elektronische Geräte GmbH, Ingegneria dei Sistemi SpA, Biosensor Applications Sweden AB, Swedish Rescue Services Agency

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 South-East Europe.

Detailed description

Within the DEMAND project a new ultra wideband (UWB) ground penetrating radar (GPR) employing M-sequences, a stacked metal detector array (Schiebel 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.

Figure 1

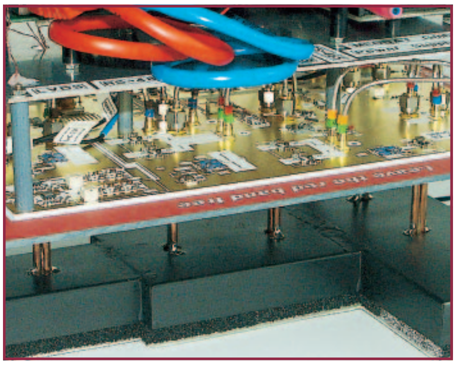


Figure 2

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 (see *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 *GICHD Metal Detectors and PPE Catalogue 2005*. Details on the biosensor system are provided in Section 6.3. The ground penetrating radar is based on radar electronics using the M-sequence technique developed by Meodat 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 pictures below provide an impression of one UWB module and a complete array.

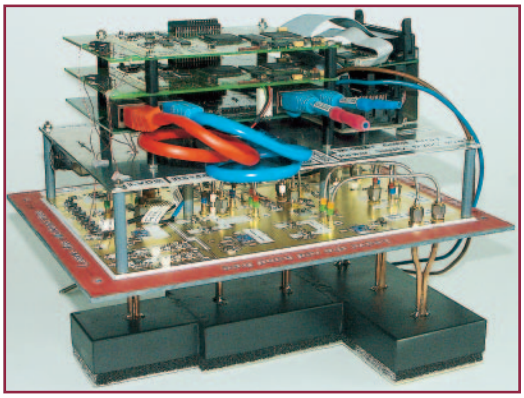


Figure 3

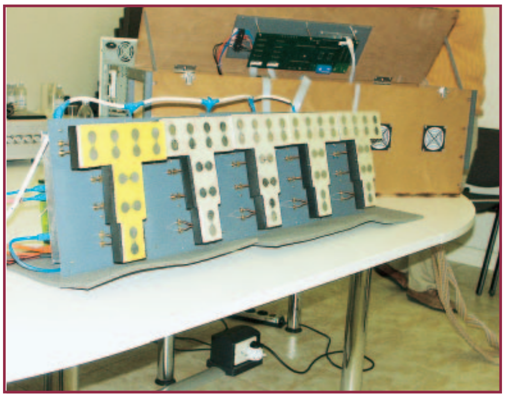


Figure 4

The project's partners believe that 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.

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 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 commercial off-the-shelf geographical information 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 as well as the explanation facilities of the expert system.

Test & evaluation

Laboratory and field tests were carried out with the prototype; the corresponding results are published in full in the *DEMAND 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 metre by using the GPR, while maintaining a detection probability of 94 per cent. This corresponds to a reduction in false alarms of 57 per cent.

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. DEMAND consortium (2004)
   DEMAND Final Report, 2004 www.eudem.info
   Extracted from the *Abstract*: "*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.*"
2. Crabbe S., J. Sachs, G. Alli, P. Peyerl, L. Eng, M. Khalili, J. Busto and A. Berg (2004)
   "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", *Proceedings of SPIE Conference on Detection and Remediation Technologies for Mines and Mine-like Targets IX*, Vol. 5415, Orlando, US, 12-16 April 2004.
3. Crabbe S., J. Sachs, G. Alli, P. Peyerl, L. Eng, R. Medek, J. Busto and A. Berg (2003)
   "Recent Results achieved in the 5th FP DEMAND Project", in H. Sahli, A.M. Bottoms, J. Cornelis (Eds.), *EUDEM2-SCOT 2003, International Conference on Requirements and Technologies for the Detection, Removal and Neutralization of Landmines and UXO*; Volume II, pp. 617-625, Vrije Universiteit Brussel, Brussels, September 2003, *www.eudem.info.*

Technical specifications	*DEMAND GPR*[a)]
1. Used detection technology:	Polarimetric GPR array
2. Mobility:	Vehicle-based
3. Mine property the detector responds to:	Dielectric characteristics (see *GPR Operating Principles*), plus linearity/compactness or symmetry of the case.
4. Detectors/systems in use/tested to date:	Prototype
5. Working length:	Not applicable
6. Search head:	
➢ size:	Array width: x axis: 1,000mm (arbitrary), y axis: 300mm, height: 400mm.
➢ weight:	40kg (<40kg)
➢ shape:	—
7. Weight, hand-held unit, carrying (operational detection set):	—
Total weight, vehicle-based unit:	—
8. Environmental limitations (temperature, humidity, shock/vibration, etc.):	Temperature: 0°C to +35°C (-20°C to +40°C).
9. Detection sensitivity:	
10. Claimed detection performance:	
➢ low-metal-content mines:	PD: 0.94[b)] (>0.98), PFA: 0.35[b)] (<0.25).
➢ anti-vehicle mines:	—
➢ UXO:	—
11. Measuring time per position (dwell time):	—
Optimal sweep speed:	(30cm/s)
12. Output indicator:	—
13. Soil limitations and soil compensation capability:	Soil: grassy, stony (All world).
14. Other limitations:	—
15. Power consumption:	250W (TBD)
16. Power supply/source:	—
17. Projected price:	—
18. Active/Passive:	Active
19. Transmitter characteristics:	Transmitted power: 1mW
20. Receiver characteristics:	Bandwidth: 4GHz (5GHz)
21. Safety issues:	—
22. Other sensor specifications:	Resolution: 5cm cross-range, 4cm range (3cm). Primary detection algorithm: full 3D Kirchhoff migration (TBD). Feature extraction: geometrical target features, polarimetric (e.g. orientation, elongation factor).

a) Main figures are for the prototype: figures in square brackets are target production specifications.
b) Best results obtained during field tests in calibration area.

Remark
Target depth range: 20cm.

11. Remote Sensing Systems

11.1 Sensing principle

Operating principle

The principles of information theory provide that information is potentially available at altitude from the energy field arising from the Earth's surface, and in particular from its spectral, spatial and temporal variations.[37] Both the electromagnetic and the gravitational fields are of interest. To capture the information one must measure the variations of these fields and relate them to the information desired. Here we restrict our consideration to the electromagnetic field. The following figure shows the layout and principal nomenclature for the entire electromagnetic spectrum. Electromagnetic waves are split into different categories based on their frequency (or, equivalently, on their wavelength). Visible light, for example, ranges from violet to red. Violet light has a wavelength of 400nm, and a frequency of 7.5×10^{14} Hz. Red light has a wavelength of 700nm and a frequency of 4.3×10^{14} Hz. Any electromagnetic wave with a frequency (or wavelength) between those extremes can be seen by humans (visible spectrum).

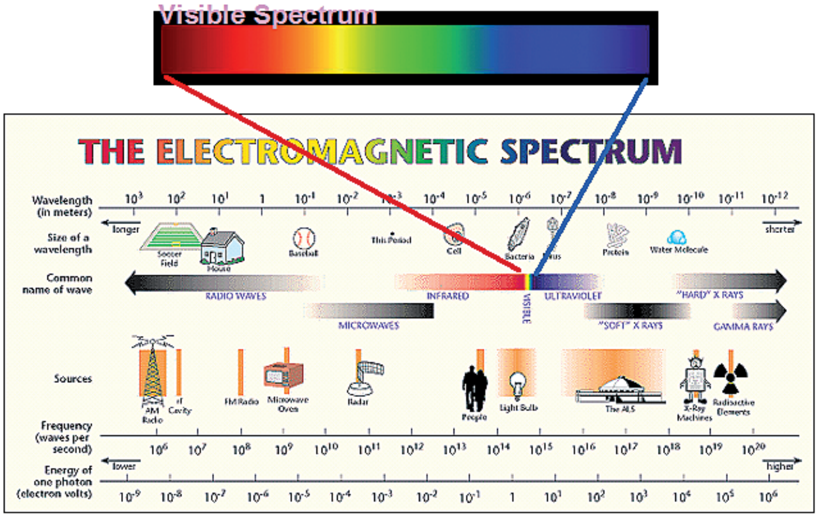


Figure 1. Electromagnetic sprectrum overview, part I © Advanced Light Source, Lawrence Berkeley National Laboratory www.lightsources.org/cms/?pid=1000166.

Of particular interest in Earth-surface remote sensing are the optical (visible-red, green, blue), infrared and microwave wavelengths.

37. That is, its changes as a function of frequency, in space and in time.

The energy field arising from the Earth is, or course, finite in magnitude. The data collection process must divide this finite quantity spatially into pixels. The power level in each pixel can further be divided into a number of spectral bands. Combining the resulting spatial and spectral information leads to the possibility of labelling (i.e. identifying the contents of) individual pixels, or groups of pixels, in a scene, thereby detecting characteristic image features.

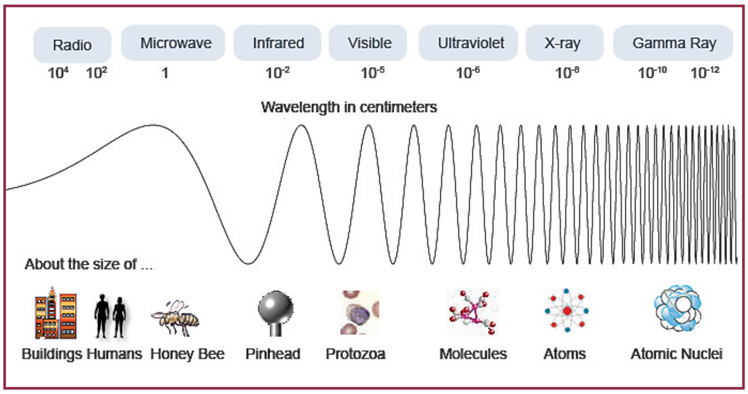


Figure 2. Electromagnetic sprectrum overview, part II.

Performances can be increased by using multi- or hyper-spectral sensors, which operate over several wavelength bands and provide more information than "images" from common broadband sensors.

Application type

Remote detection: airborne, vehicle.

Strengths

- The original motivation for using remote sensing (airborne and spaceborne) systems had to do with the synoptic view from an altitude. If one goes higher, one can see more, covering a wider area. This would presumably lead to a more economical way of gathering data (reduced scan time).
- Multispectral imaging has the advantage of measuring different physical parameters simultaneously, and without major spatial co-registration problems.
- Temporal infrared (heat) sensing can detect the thermal contrast between a mine and the surrounding soil (due to differences in thermal conductivity).
- Polarisation techniques allow discrimination between man-made and natural objects.
- In some circumstances it is also possible to detect anomalies in the light emitted or reflected by the soil and vegetation patches above buried mines (soil disturbances and vegetation stress).
- A number of techniques, such as change detection, multi-temporal analysis and image fusion, can be used to extract features from the recorded (high-resolution) images, including space-borne imagery.

Limitations

- Image processing capabilities can be crucial; large amounts of data.
- It can be very difficult to differentiate a mine from the background (in particular anti-personnel mines) due to low contrast and the presence of highly textured backgrounds. (But this does not necessarily represent an insurmountable obstacle to the detection of minefields as a whole.)
- Some imaging results can depend quite heavily on environmental conditions.
- Cameras and data acquisition system are very expensive.

Potential for humanitarian demining

The focus of remote sensing for humanitarian demining applications has moved over the years from the detection of individual mines to mapping/identification of suspect areas for area reduction and clearance planning, via the detection of direct and indirect "minefield indicators" (e.g. changes in infrastructure and agricultural land use, minefield fencing, trenches, paths, detours, etc.), combined with collected ancillary information and prior knowledge/intelligence. These applications have a very high potential for humanitarian demining.

Estimated technology readiness

Technology: High. Data processing: Medium.

Related publications

1. Chang C.I. (2003)
   Hyperspectral imaging: techniques for spectral detection and classification, Kluwer Academic, New York, US.
2. MacDonald J., J.R. Lockwood, J. McFee, T. Altshuler, T. Broach, L. Carin, C. Rappaport, W.R. Scott, R. Weaver (2003)
   Alternatives for Landmine Detection, RAND Science and Technology Policy Institute, Report MR-1608, ISBN: 0-8330-3301-8.
3. Carruthers A., J. McFee, D. Bergeron, Y. Das, R. Chesney, K. Russell (1999)
   Scoping Study For Humanitarian Demining Technology, Technical Report, DRES TR 1999-121, CCMAT.
4. Maathuis B. (2001)
   Remote sensing based detection of landmine suspect areas and minefields, PhD thesis, Hamburg University, Department of Geosciences, Germany, 19 December, pp 228. *www.sub.uni-hamburg.de/opus/*
5. Cremer F. (2003)
   Polarimetric infrared and sensor fusion for the detection of landmines, PhD thesis, Delft University of Technology, The Netherlands, ISBN 9-0598-6032-2.

11.2 ARC (Airborne Minefield Area Reduction)

Project identification

Project name	Airborne Minefield Area Reduction
Acronym	ARC
Participation level	Supranational (European)
Financed by	Co-financed by EC-IST
Budget	€ 3,500,000
Project type	Technology development, Technology demonstration, System/subsystem development, System test & in-field operations
Start date	January 2001
End date	October 2004
Technology type	Airborne multisensor survey
Readiness level	8
Development status	Completed
Company/institution	GEOSPACE, Schiebel, FOI, GTD, IMEC, TNO Defence and Security, CROMAC

Project description

The major objectives of the **ARC** project have been the development of an information system, including an advanced geographical information system (GIS), allowing the fusion of (a) measured image data, (b) mine action information system (MAIS) data and (c) geographical information, to be used for general mine action assessment and in particular area reduction.

According to the developers, the validation in controlled environments and real minefields allowed the ARC project to achieve effective results for general mine action assessment in a way which is acceptable for mine action centres and demining organisations. ARC contributed to improved efficiency of the survey by: (i) increasing the scanning speed of the suspected area (compared to manual-, dog- or mechanically-based operations), (ii) reducing costs of surveys and (iii) providing accurate and reliable survey data.

During the project a remote sensing platform and an interpretation system for minefield survey have been developed by using: (i) a low-cost, low-maintenance but easy-to-control and autonomous operating unmanned aerial vehicle (UAV) and (ii) recent developments in high spectral and spatial resolution imaging sensors, image processing and image interpretation. Moreover the ARC project financed and technologically supported the Croatian Mine Action Centre (CROMAC) in developing a helicopter-based aerial survey system.

Results

1. The results of the ARC system can be presented graphically to end-users to provide a measure of quantifiable success. Detailed large-scale digital geo-coded colour image

maps (1:2,000 to 1:5,000) of each surveyed area can be produced, on which the location of the suspected mined area found by the ARC system has been indicated — in digital form for entry into the ARC GIS. These maps can be used for: planning demining activities, land use planning and Infrastructure rehabilitation planning (roads, bridges, schools, etc.). The digital maps contain:

- The original suspect minefield area boundary;
- The delineated contour produced by the ARC system; and
- The contour produced by CROMAC after technical survey and clearance using current practices.

2. The ARC-GIS contains all the collected data: maps, satellite images, optronic sensors images, results of the image analysis and data fusion, and contextual data including MAIS data.

3. The area reduction results have been analysed carefully. The uncertainty of the system has been analysed by comparing the CROMAC technical survey and clearance results and the ARC area reduction results, which have been classified into three categories: *Definitely a minefield*, *Probable minefields* and *Possible minefields.*

4. Detection and identification of signatures (spectral, thermal and spatial – shape) are associated to different objects (mine field indicators, man-made objects, background).

Detailed description

Figure 1 shows the equipment to be deployed when building the ARC System, which has three main components (or segments):

- ARC Airborne Platform (see Figure 2):
  - CI-1.1: UAV (includes: GPS/INS positioning sensor);
  - CI-1.2: Payload Mounting;
  - CI-1.3: Optronic Sensor Set Payload;
    - CI-1.3.1: Thermal IR Camera (ThermaCam),
    - CI-1.3.2: Multispectral Camera (Duncantech);
  - CI-1.4: Data Acquisition Unit Onboard;
- ARC Control Station (on-site):
  - CI-2.1: UAV Control Station — UAV navigation, and flight mission data loading;
  - CI-2.2: Payload Control Station — flight mission data loading, storage, and pre-processing;
- ARC Ground Station (Headquarter):
  - CI-3.1: GIS System (See Figure 3);
    - CI-3.1.1: GIS Server Station;
    - CI-3.1.2: GIS Client Workstation, which deploys the software for the functionalities of Mission Planning, Data Interpretation, Visual Interpretation (Human Reasoning), and Product Exploitation;
  - CI-3.2: Automated Georeferencing Module (AGM);
  - CI-3.3: Image Processing Workstations;
  - CI-3.4: Image Interpretation Workstation (Data Fusion).

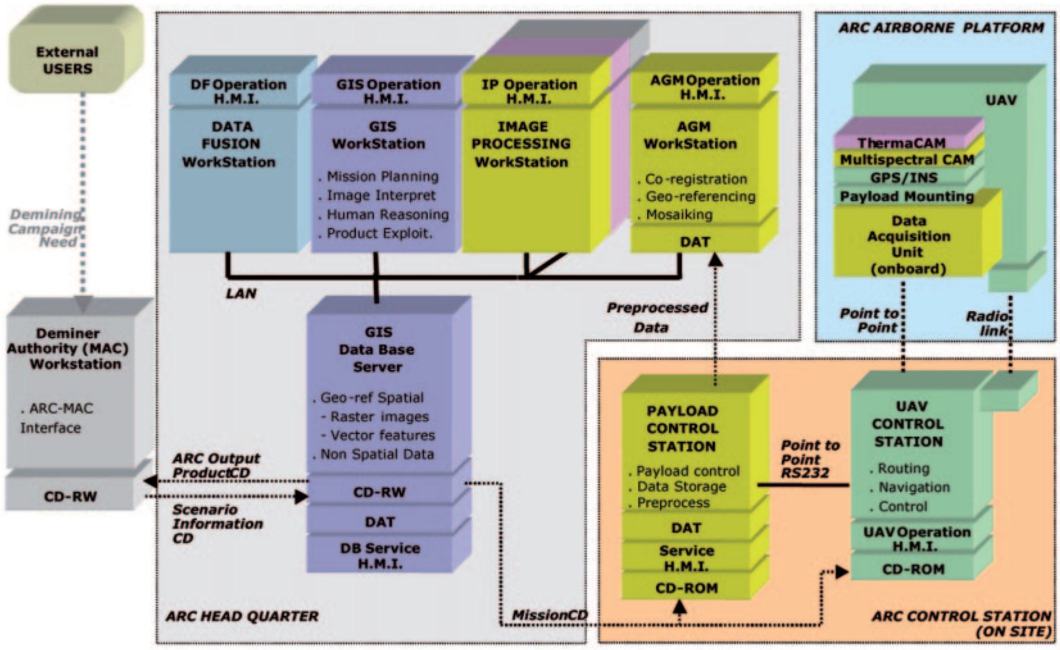


Figure 1. ARC system architecture.

Figure 2. ARC data acquisition system.

Test & evaluation

The ARC system (*www.arc.vub.ac.be*) has been extensively tested during five trials in three suspected minefields in Croatia: a fertile valley surrounded by hills (Glinska Poljana), a very flat agricultural area (Milekovi) and a rocky site near the coast (Pristeg). In each test site limited technical survey and full mine clearance have been performed after the flight campaigns. For each of the sites, GIS scenario information, automatic geo-referencing, image interpretation, image analysis, knowledge formulation and finally data fusion have been carried out. The system demonstrated:

1) The use of the ARC products (GIS database and reports) for enhancing the general mine action assessment process, and as inputs for the planning/preparation of technical survey and clearance phases; and
2) The use of the ARC area reduction results as inputs for planning/preparation of technical survey and clearance phases.

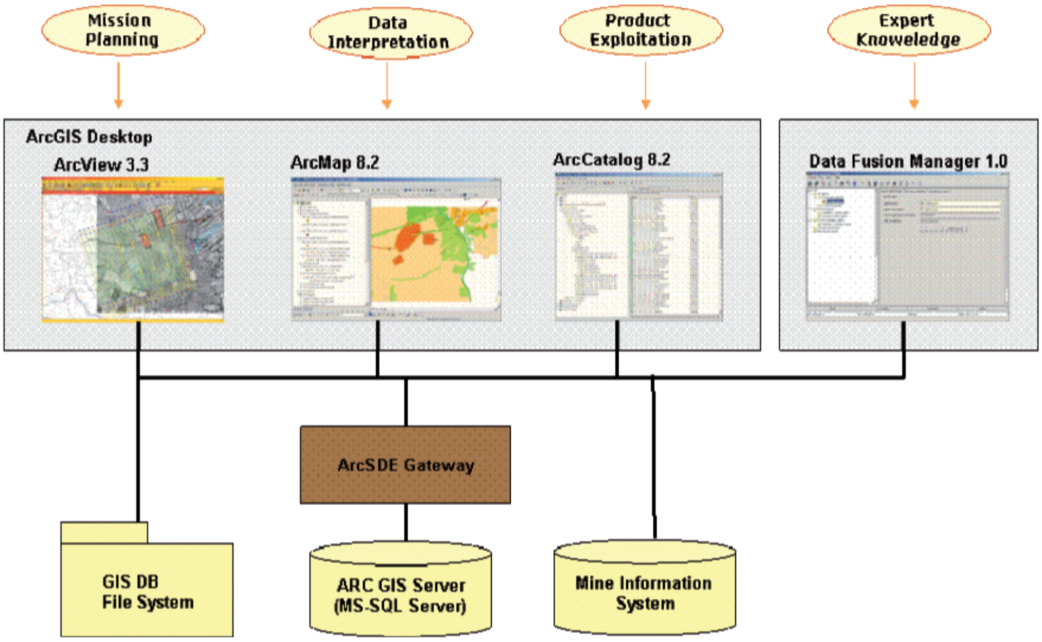
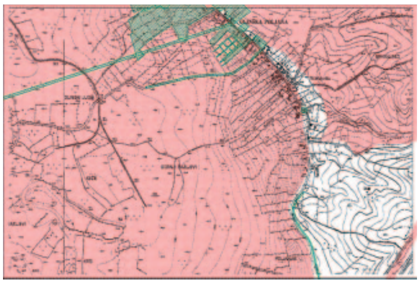
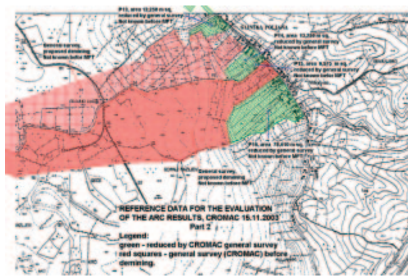


Figure 3. ARC software components and interaction.

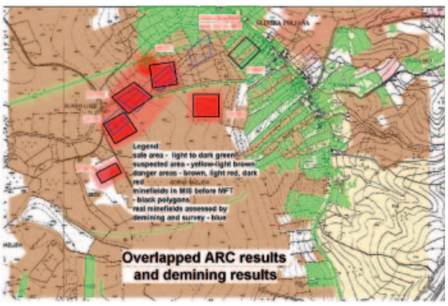
Results from the Milekovi tests are illustrated in Figure 4, with the reduction of the suspected area and the determination of the safe area being the best results shown in the analysed data. Part of the declared safe areas coincides with the results of the survey made by CROMAC. In terms of costs, a rough estimation has been made by considering only area reduction and the extreme case where the data acquired during a day needs five days for analysis. Total costs amounted to €39,970. Preliminary estimation of the manpower and costs by CROMAC (50 per cent European Community co-financed, 50 per cent CROMAC) is 14 personnel months and €72,270.



Original suspected area provided by CROMAC



Technical survey & clearance by CROMAC



Compared ARC v.s. CROMAC results

Figure 4. Milikovici area reduction results.

The following table summarises the capabilities of the system to detect minefield indicators.

Table 7. Summary of ARC system capabilities to identify minefield indicators

Type of indicators	VNIR		TIR		Satellite	
	Visual	Automatic	Visual	Automatic	Visual	Automatic
Trenches	Y	Y	Y	N		Y
Protection walls (dry walls)	Y	Y	Y	N		N
Foxholes	N	N	NA	N		NA
Embankment	Y	N	Y	N		N
Leftover military equipment	Y	N	Y	N		NA
Poles, laying and standing	Y	Y	Y	N		NA
Foundation of base camps	N	N	N	N		N
Watchtower	Y	N	Y	N		NA
Minefield markings						
•Poles	Y	Y	Y	N		NA
•Markers	N	N	N	N		NA
Roads and footpaths/ tracks						
•Roads out of use	Y	Y	Y	N		Y
•New access and services paths	Y	Y	N	N		N
•Restricted access	N	N	N	N		NA
Vegetation changes						
•Regeneration of natural vegetation on arable land	Y	Y	N	N		Y
• Changes in wild vegetation	Y	Y	N	N		Y
Destruction of houses/ building	Y	Y	Y	N		NA
Scattered man made object	Y	Y	Y	Y		NA
Circular man made object	Y	Y	Y	Y		NA
Circular soil disturbance	N	N	Y	Y		NA
Circular vegetation disturbance	N	N	Y	Y		NA
Alignment of disturbances	N	N	N	N		NA
Direct identification of AT mine	Y	N	N	N		NA
Direct identification of AP mine	N	N	N	N		NA

Y: yes, N: no, NA: not applicable.

Other applications (non-demining)

The system could be used for any airborne survey application.

Related publications

1. Chan J.C., H. Sahli, Y. Wang (2005)
   "Semantic risk estimation of suspected minefields based on spatial relationships analysis of minefield indicators from multilevel remote sensing imagery", *Proceedings of SPIE Conference on Detection and Remediation Technologies for Mines and Mine-like Targets X*, Vol. 5794, pp. 1071-1079, Orlando, US.
2. Sjökvist S., et al. (2003)
   "Minefield Temporal Feature Extraction Supported by Heat Transfer Modelling", in *EUDEM2-SCOT, International Conference on Requirements and Technologies for the Detection, Removal and Neutralization of Landmines and UXO*, Vrije Universiteit Brussel, Brussels, Belgium, September.
3. Eisl M.M, M. Khalili (2003)
   "ARC - Airborne Minefield Area Reduction ", in *EUDEM2-SCOT, International Conference on Requirements and Technologies for the Detection, Removal and Neutralization of Landmines and UXO*, Vrije Universiteit Brussel, Brussels, Belgium, September.
4. Eisl M. (2003)
   Integriertes Luftgestütztes Datenerfassungs- und Analysesystem (in German), AGIT (Applied Geographic Information Technologies), Salzburg, Austria, 3 July.
5. Shutte K., et al. (2001)
   ARC: A Camcopter based mine field detection system, Fifth International Airborne Remote Sensing Conference, San Francisco, US, 17-20 September 2001.
6. Sjökvist S. (2001)
   Optical Detection of Land Mines, Nordic Demining Research Forum (NDRF) Conference, August 2001.

Technical specifications	*ARC (Airborne Minefield Area Reduction) System*
1. Used detection technology:	Remote sensing; UAV-based system & Satellite
2. Mobility:	UAV
3. Mine property the detector responds to:	None
4. Detectors/systems in use/tested to date:	Visible & near Infrared, Thermal Infrared
5. Working length:	Not applicable
6. Search head:	Payload
➢ size:	40x40cm
➢ weight:	13.5 Kg
➢ shape:	Rectangular
7. Weight, hand-held unit, carrying (operational detection set):	—
Total weight, vehicle-based unit:	UAV weight 43kg/Payload 25kg
8. Environmental limitations (temperature, humidity, shock/vibration, etc.):	–2 to +38 °C; wind speed +/- 23 kn.
9. Detection sensitivity:	No mine detection
10. Claimed detection performance:	
➢ low-metal-content mines:	—
➢ anti-vehicle mines:	—
➢ UXO:	—
11. Measuring time per position (dwell time):	Real time
Optimal sweep speed:	—
12. Output indicator:	Set of thematic maps
13. Soil limitations and soil compensation capability:	Dense vegetation, water
14. Other limitations:	—
15. Power consumption:	—
16. Power supply/source:	Internal supply
17. Projected price:	Not estimated
18. Active/Passive:	Passive
19. Transmitter characteristics:	Not applicable
20. Receiver characteristics:	See remarks
21. Safety issues:	Operated from safe area
22. Other sensor specifications:	—

Remarks

Duncantec VNIR multispectral camera and ThermaCAM SC3000 thermal infra-red camera: see the manufacturers' websites for detailed information on sensor specifications.

11.3 General Aerial Survey

Project identification			
Project name	General Aerial Survey	**Technology type**	Airborne multisensor survey
Acronym	OZI	**Readiness level**	●●●●●●●⑧●[38]
Participation level	International, National	**Development status**	Stand-by in 2004 and 2005, upgrading and continuing of the application expected in 2006 with support from the Croatian Ministry of Science
Financed by	EC (ARC), IFT (ARC), CROMAC (HEP), HTF Croatia without Mines (Velebit)	**Company/institution**	CROMAC - Centre for Testing, Development, Training
Budget	n/a		
Project type	Technology demonstration, System test & in-field operations		
Start date	September 2001		
End date	October 2003		

Project description

The **General Aerial Survey** system is a spin-off of the European ARC project and has been developed by the Croatian Mine Action Centre (CROMAC) ARC team (see section 11.2). It was developed as a part of the overall project but was recognised as a means of providing sustainable general aerial survey of minefields and suspected areas, affordable within a short time (1.5 to 2 years). According to the developer, this solution is feasible in many countries contaminated by landmines and UXO, at an affordable cost. The basic features of the successful development and deployment of the aerial general survey included the following:

- Use of small manned helicopters (for example, Bell-206), which are available in every country contaminated by landmines and UXO and avoid the expensive development of a platform.
- Use of experienced domestic pilots who will be trained for aerial survey of minefields and risk-suspected areas.
- Use of commercial off-the-shelf sensors, computers and global positioning system (GPS) receivers.
- Use of fully digital electro-optical cameras ranging from thermal infrared, to near-infrared and visible wavelengths, and enable full interoperability with geographic information systems (GIS) and mine action information systems (MAIS) employed by local mine action centres (MACs).

38. Technology has been proven to work in its final form and under expected conditions: i) in 2002: general survey of the electricity high voltage networks; ii) in 2003: mine suspected area in a mountainous region (Tulove Grede) and, within the frame of the European ARC project, in continuous data acquisition mode.

- Use of simple and cheap unstabilised gimbals that enable manual presetting of imaging angles. Provide passive dumping of sensor vibrations.
- Integration of all sensors, their frame grabbers, personal computers and GPS receivers into the acquisition system.
- Provision for simple installation of the system on the helicopter (in our example, the time needed for installation was less than two hours).
- For navigation, GPS data and a moving digital map is used — while GPS time is used for synchronisation of imagery and route data.
- Provision of full compatibility and interoperability with GIS and MAIS of mine action centres (in MapInfo format).
- Maps, orthophoto maps and geocoded images provided by MACs are used as the basis for navigation.
- Use of commercial off-the-shelf remote-sensing software for interpretation of images and data (TNTmips, ErMapper, Image Analyst).
- The system provided efficient communication to MACs and gather critical feedback from MACs (statement of need, specific task for the surveyed area, evaluation of results).

A team for aerial survey of minefields and risk-suspected areas was established — and trained for each survey mission.

Detailed description

The General Aerial Survey system uses digital, electro-optical sensors with computer-controlled acquisition and GPS-based navigation. The sensors are (see Figure 1):

- Four-channels digital camera (MS-3100); 1392x1039 pixels, eight bits, for three visible and one near infrared channel (very near infrared — VNIR), with wavelength ranging from 400nm to 900nm, and with optical objectives having focal lengths of 17, 24 and 28mm.
- Thermal infra-red (TIR) camera (modified THV-1000); 600x390 pixels, eight bits, wavelengths 8–14 µm with two fields of view.
- Hyper-spectral line scanner (HSLS); 1170 pixels, 8 bits and 45 channels for wavelengths 430–900 nm.

After acquisition, images and data are exported to the interpretation computers. The flight route, data and the logs of images are synchronised by the GPS time. This enables geo-referencing of the images.

The next step in processing is the derivation of the flight routes and of mosaics of images. Mosaics are used for the assessment of the completeness of spatial coverage — registering image to image can produce them or, if needed, geocoding can follow this process. The interpretation is performed on the original images if spectral information is more important than spatial information; in the opposite case, the interpretation is performed on the mosaics.

Basic kinds of output of the survey are: raw images, vectors of detected objects, non-geocoded mosaics, geocoded mosaics, list of detected minefield indicators, description, attributes and coordinates, classification map and many other maps (depending on the precise purpose and aim of the aerial survey).

The general aerial survey of minefields and suspected areas is an intelligence-gathering, processing and dissemination process — not a cartographic process. The typical tasks of an aerial survey are to detect/identify and determine coordinates or delineate, in minefield or suspected areas:

- trenches, man-made embankments, bunkers;
- agricultural areas in use;
- access roads and paths, including to rivers, brooks, channels;
- rivers, brooks and channels;
- protection embankments;
- other minefield indicators;
- reference points of the minefield records from the MAC's MAIS; and
- the state of objects (e.g. if a house is intact or damaged).

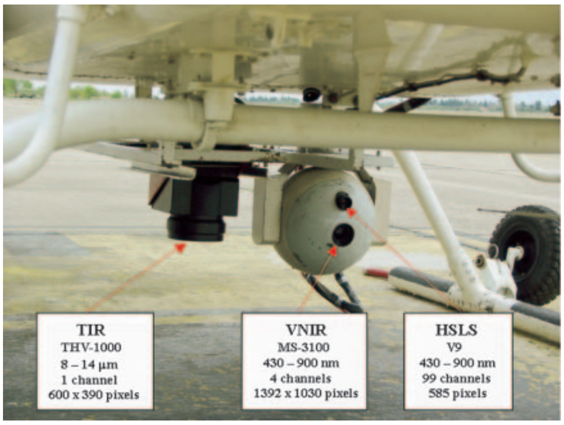


Figure 1. Three digital sensors, installed on board the Bell-206 helicopter, were used for vertical and oblique imaging. VNIR and TIR sensors were used in imaging mode, whereas HSLS was used only in spatial sampling mode.

Figure 2. The pilot and co-pilot see the real time position of the helicopter on the large screen, while the background can be a map, ortho photomap or geocoded satellite image. On the map an area of interest is displayed, together with the planned and realised flight routes.

Figure 3. A view of the flight route on the topographic map at the scale 1:25,000. This serves as an example of the aerial survey of the electricity high voltage network (state of the towers, vegetation) and access field roads from the asphalt road on the left side of the network corridor.

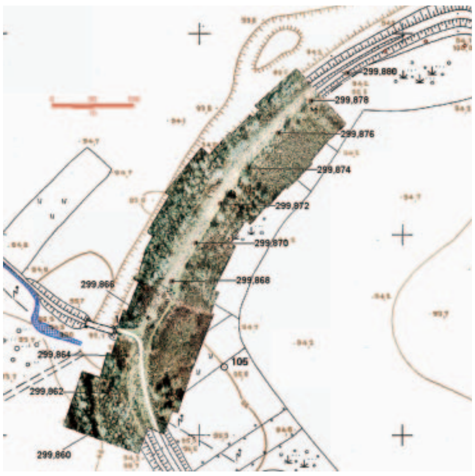


Figure 4. Output of the survey: geocoded mosaic, overlaid over the map at the scale 1:5,000. The aim of the aerial survey was to provide information about the status of the access road that was out of use for more than ten years.

Test & evaluation

The general aerial survey of minefields and risk-suspected areas was operationally validated in several missions over flat terrain in 2002 (electricity high voltage networks, Drenov bok, Dubica, 14km; set of networks near Ernestinovo, 167km) and in difficult mountainous terrain in 2003 (Tulove grede, Velebit).[38] A cost-benefit analysis shows that the aerial survey is efficient for cases of corridor-like objects and for wide suspected areas and minefields that have limited access. It can provide missing information or increase completeness, accuracy and reliability of information on minefield indicators and reference points of mine records over large areas in a short time. Within the frame of the European ARC project, a system was used for the continuous data acquisition of minefields and mine suspected areas in 2003 in the regions of Milekovići and Pristeg. Imagery, calibrating markers coordinates and ground truth data are available at the CROMAC Testing, Development and Training (TDT) Centre. Repairs, upgrading and continuing of the application is expected in 2006 with support of the Croatian Ministry of Science for the aerial general survey of mine suspected areas. Imagery and data will be processed and interpreted with the application of the generic SMART methodology, under the auspices of the International Test and Evaluation Programme (ITEP), in cooperation with the Royal Military Academy (RMA) and the CROMAC TDT Centre. Fixed-wing aircraft will also be used.

Related publications

1. Bajić M., H. Gold, Z. Pračić, D. Vuletić (2004)
   Airborne sampling of the reflectivity by the hyper spectral line scanner in a visible and near infrared bands, Proceedings of the 24th EARSeL Symposium, New Strategies for European Remote Sensing, Dubrovnik, Croatia, 25-27 May 2004, Millpress, Rotterdam, pp. 703-710.
2. Bajić M., (2003)
   "Survey of suspected mined areas from a helicopter", *Journal of Mine Action*, James Madison University, Issue 7.3, pp. 54-58.
3. Gold H., M. Bajić, (2002)
   Contribution of the airborne remote sensing to demining of the mountains, case study Tulove Grede Velebit, GIS ODYSSEY 2002 International Conference, Split, Croatia, 2-6 September 2002, Proceedings.
4. Tadić T., M. Bajić, (2002)
   Airborne remote sensing for the general survey of damaged and mined high voltage network, GIS ODYSSEY 2002 International Conference, Split, Croatia, 2-6 September 2002, Proceedings.
5. Kalajžić M., (2005)
   Methods for assessment of the operating possibilities of airborne reconnaissance by electro-optical sensors, MSc thesis (in Croatian), Faculty of Traffic Engineering, University of Zagreb, Croatia, Zagreb, 19 December.

38. (1) M. Bajić, Z. Pračić, D. Vuletic, A. Krtalic, H. Gold, R. Pernar, R. Sapina, *Continuous Data Acquisition*, *Internal Technical Report*, *Part I*, Version: 2.0.0, 21.11.2003, Restricted to ARC Consortium; *Part II Appendices,* Version 0.0.1, 21.11.2003, Restricted to Consortium; *Part III CDA Data documentation*, Version 0.0.1, 24.11.2003, Restricted to Consortium. (2) CROMAC ARC Team, *Trial II Evaluation Report*, D15, Version 2.0.0, 8.05.2001, Restricted to ARC Consortium.

11.4 Space and Airborne Mined Area Reduction Tools (SMART)

Project identification			
Project name	Space and Airborne Mined Area Reduction Tools	**Start date**	May 2001
Acronym	SMART	**End date**	*Phase I:* October 2004 *Phase II*: December 2007
Participation level	*Phase I*: European, *Phase II:* International	**Technology type**	Software tools to help area reduction by remote sensing
Financed by	*Phase I:* Co-funded by the European Commission	**Readiness level**	7
Budget	*Phase I:* € 4,590,000	**Development status**	*Phase I:* completed *Phase II:* planned
Project type	Technology development, Technology demonstration, System/subsystem development, System test & in-field operations	**Company/institution**	*Phase I:* TRASYS, Renaissance/RMA, ULB, DLR, ENST, Zeppelin, CROMAC, RST, IXL *Phase II:* CROMAC, Renaissance/RMA

Project description

Area reduction has been recognised as a mine action activity where reduction in time and resources could help greatly. Long-term empirical data from the Croatian Mine Action Centre (CROMAC) allows estimates that only around 10 per cent to 15 per cent of the suspected area in Croatia is actually mined. Minefield records alone do not provide enough information for the proper allocation of limited demining resources to really mined areas. Their completeness and reliability are not high enough. Decision makers need additional information. It is also estimated that 90 per cent of the suspected areas in Croatia cannot be reached from the ground.

SMART is intended to provide some of this additional information, which would help in two ways: it can reinforce the suspicion of some places and reduce the suspected area in others. The goal of the SMART project is to provide a geographical information system (GIS)-based system — the SMART system — augmented with dedicated tools and methods designed to use multi-spectral and radar data to assist the human analyst in the interpretation of the mined scene. The use of SMART includes a short field survey to collect knowledge about the site, a flight campaign to record the data, and the use of the SMART system by operators to detect indicators of presence or absence of minefields. The operators prepare thematic maps that synthesise all the knowledge gathered with these indicators. These maps of indicators can be transformed into "danger maps" showing how dangerous an area may be, based on the location of known indicators.

This method has the following characteristics:

- The priority is more to help find areas that are not mined than areas that are mined.
- There is no detection of individual mines, but detection of clues to the presence or absence of mines or minefields.
- Confidence maps are provided in order to improve the interpretation of the danger maps.
- Results have been evaluated by blind tests.

Detailed description

The SMART system is a set of software tools that can be used through a GIS such as ArcMap or ArcCatalog. At the end of Phase I, most of the tools have been integrated into the GIS.

The tools include:

- Classifiers (to detect lands that have been abandoned or are still used);
- Detectors of indicators of presence or absence of minefields (at roads, rivers, power lines, hilltops, etc.);
- A data fusion module to combine outputs of several classifiers; and
- Tools to produce danger maps (maps of locations of indicators and confidence maps).

The system generates danger maps (location maps and confidence maps, see Figure 1) which provide a synthesis of what has been detected using the remote sensing data and knowledge from experts (mining methods, historical background, etc.). Continuous location maps provide a continuous value of "danger" based on the information gathered through the SMART process. Confidence maps help operators in the use of the location maps during their area reduction work.

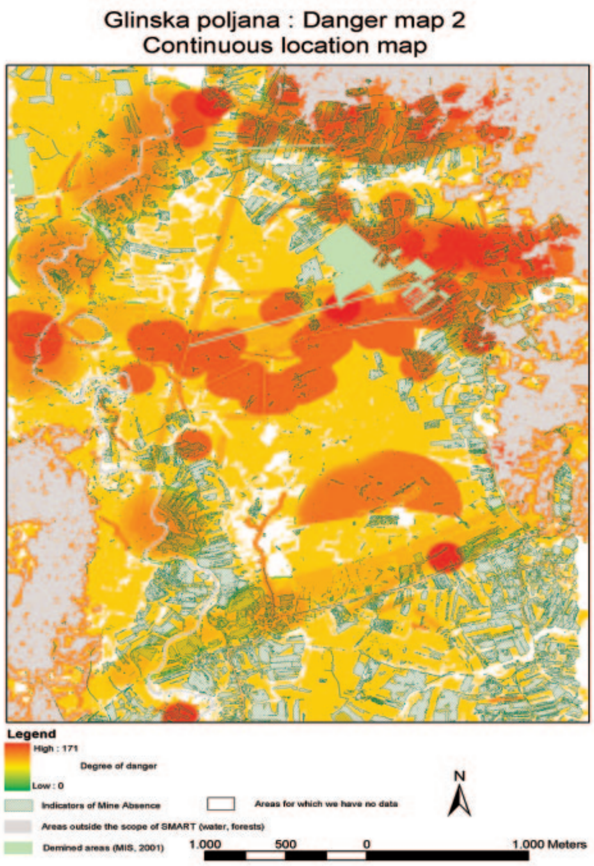


Figure 1. A continuous location map from SMART (covering an area of 3.6km by 4.8km).

Figure 2 shows mine absence indicators (light green) identified by SMART inside an area that was actually mined (red) in the region of Glinska Poljana, Croatia; the whole picture covers an area of 1,300m x 850m; the error covers 26m^2. Only 0.1 per cent of what was proposed for reduction during the SMART validation was actually mined. These errors were located at the borders of the areas.

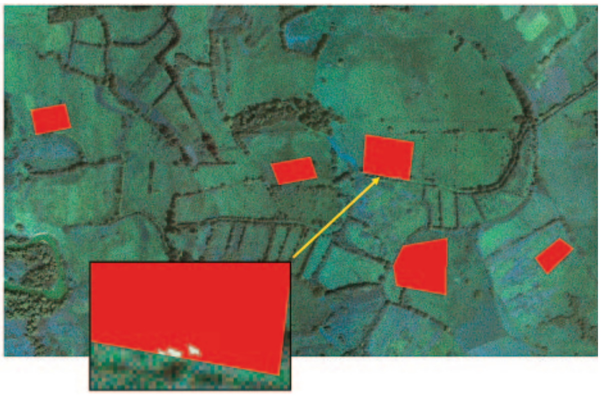


Figure 2. SMART's mine absence indicators (green) in a mined area (red) of Glinska Poljana.

Test & evaluation

Validation for Phase I was done by blind tests in three test sites in Croatia: a fertile valley surrounded by hills (Glinska Poljana), a very flat agricultural area (Ceretinci) and a site near the coast (Pristeg). In each test site mine clearance was performed after the flight campaign to have the true status of the mine presence. This information was, of course, not made available before the production of the danger maps.

From the danger maps, a first selection of areas to be proposed for area reduction was carried out; areas considered as suspect were also selected. For some areas the information available was not sufficient to make a determination, due to the presence of water, forests, etc.

The three test sites cover an area of 33km². A section was used for training. The validation area covered more than 11km², and was composed of the following categories:

1. Areas that clearance showed to have been mined;
2. Areas that clearance showed not to have been mined;
3. Areas proposed for clearance after general or technical surveys; these areas are considered as suspect with the highest degree of danger;
4. Areas proposed for technical surveys after general surveys; these areas are considered as suspect with a high degree of danger;
5. Areas that general surveys showed to be safe;
6. Areas that are used by their owners although still listed as suspect; these areas are considered safe.

If we consider only the part of the validation where we know the ground truth (categories 1, 2, 5 and 6 above), and not where there is even a slight doubt (categories 3 and 4 above), then the area is 3.9km² (Glinska Poljana: 0.63km², Ceretinci: 1.7km², Pristeg: 1.5km²). On average 26 per cent of the mine-free area has been proposed for reduction after the use of SMART:[39] Glinska Poljana — 7.7 per cent, Ceretinci — 47 per cent, Pristeg - 9.0 per cent. On the other hand 0.10 per cent (976m²) of what was proposed for reduction turned out to be actually mined[40]: Glinska Poljana — 0.058 per cent (26m²), Ceretinci - 0.12 per cent (924m²), Pristeg — 0.020 per cent (26 m²). These errors are located at the borders of the areas proposed for reduction, and it should be easy to eliminate them by being more conservative on the limits of these areas.

39. Computed by the producer's accuracy (also known as reference accuracy, sensitivity or recall, linked to the omission error).
40. Computed by the commission error (linked to user's accuracy, also known as precision or predictive value).

In addition to this technical evaluation, a panel of independent mine action experts working in Croatia has evaluated the method and danger maps, and recognised their contribution for an early stage of area reduction. It has been found that they might be even more suited for risk assessment. In order to reduce an area one must be very confident that the area is risk-free. With few indicators of mine absence it may be difficult to reach a satisfying level of confidence. In this approach, however, the production of danger maps is useful in the first stages of area reduction. Later surveys will not have to spend time in spots where danger maps indicate that there are a lot of indicators of mine presence. But by focusing on areas where indicators of mine absence have been detected they can help reinforce the confidence that these areas should indeed be reduced.

Two points have not been completely covered by the validation of Phase I and may be addressed, together with the deployment of the system, or part of it, in Croatia during Phase II:

1. The cost-effectiveness analysis was performed but only partially, and more could be done to better assess the economic relevance of an airborne approach to area reduction.
2. No analysis has yet been done regarding how the input can influence the results, for instance which sensors provide the most useful information, which tools extract the most relevant information, etc.

Related publications

1. Yvinec Y. (2005)
   A validated method to help area reduction in mine action with remote sensing data, 4th International. Symposium on Image and Signal Processing and Analysis (ISPA 2005), Zagreb, Croatia, September.
2. Acheroy M. (2005)
   Image and signal processing for spaceborne and airborne reduction of mined areas, Proceedings of the 4th International Symposium on Image and Signal Processing and Analysis (ISPA 2005), Zagreb, Croatia, September.
3. Yvinec Y. (2004)
   European project of Remote Detection: SMART in a nutshell, Proceedings of Robotics and Mechanical Assistance in Humanitarian Demining and Similar Risky Interventions, Brussels-Leuven, Belgium, June.
4. Yvinec Y., D. Borghys, M. Acheroy, H. Süß, M. Keller, M. Bajic, E. Wolff, S. Vanhuysse, I. Bloch, Y. Yu and O. Damanet (2003)
   SMART: Space and Airborne Mined Area Reduction Tools – Presentation, EUDEM2-SCOT-2003 International Conference on Requirements and Technologies for the Detection, Removal and Neutralization of Landmines and UXO, Vrije Universiteit Brussel, Brussels, Belgium, pp. 595-602.

Papers on SMART can be found at *www.smart.rma.ac.be/*

Technical specifications	Renaissance/RMA SMART
1. Used detection technology:	Remote sensing (airborne and spaceborne)
2. Mobility:	Airborne
3. Mine property the detector responds to:	None
4. Detectors/systems in use/tested to date:	Detectors: multi-spectral, radar, panchromatic satellite data and high-resolution films.
5. Working length:	Not applicable
6. Search head:	
➢ size:	Related to the sensors used
➢ weight:	Related to the sensors used
➢ shape:	Related to the sensors used
7. Weight, hand-held unit, carrying (operational detection set):	—
Total weight, vehicle-based unit:	Related to the sensors and platform used
8. Environmental limitations (temperature, humidity, shock/vibration, etc.):	Temperature and humidity: limitations unknown, shock/vibration: Related to the sensors and platform used, and to the data acquisition conditions.
9. Detection sensitivity:	Related to the sensors used
10. Claimed detection performance:	
➢ low-metal-content mines:	NO CLAIM (the system does not detect individual mines)
➢ anti-vehicle mines:	NO CLAIM (the system does not detect individual mines)
➢ UXO:	NO CLAIM (the system does not detect UXO)
11. Measuring time per position (dwell time):	—
Optimal sweep speed:	Related to the sensors and the platform used
12. Output indicator:	Output is a set of thematic maps
13. Soil limitations and soil compensation capability:	Sensors provide no useful information on water or forests.
14. Other limitations:	Cloudy weather
15. Power consumption:	Related to the sensors and the platform used
16. Power supply/source:	Related to the sensors and the platform used
17. Projected price:	Unknown (until Phase II is completed)
18. Active/Passive:	Both
19. Transmitter characteristics:	Related to the sensors used
20. Receiver characteristics:	Related to the sensors used
21. Safety issues:	None
22. Other sensor specifications:	—

Remarks

SMART is *not* a detector of mines. It is a set of software tools and methods to be used by experienced operators in order to help area reduction from remote sensing data and expert knowledge.

SMART uses the input it is given: airborne data, satellite data and expert knowledge (about the history of the conflict, the type of mine laying, the indicators of presence or absence of minefields, etc.).

During the validation in Croatia the imagery used came from the following sensors.

- Daedalus multispectral scanner; it provides 11 channels from 0.38 to 13µm with a resolution of 1m; the sensor weighs around 67kg and was installed in a Cessna Caravan.
- RMK high resolution camera; the spectral resolution ranges from 0.5 to 1.2µm (visible) and the spatial resolution from 3 to 5cm; the weight is around 108kg and the size around 50 x 50 x 50cm; it was installed in a Cessna Caravan.
- E-SAR: a synthetic aperture radar integrated into a Dornier aircraft with a ground segment; the bands used are P (resolution 4m, full polarimetric), L (resolution 2m, full polarimetric), C and X (both with resolution 1.5m, polarisation VV).
- KVR panchromatic images with a resolution of 2m, installed on the COSMOS satellites.

11.5 Polarised Camera System for Landmine Detection

Project identification

Project name	Development and construction of a camera system for landmine detection
Acronym	—
Participation level	National, Netherlands
Financed by	Dutch Ministry of Defence
Budget	Not available
Project type	Technology development, Technology demonstration, System/subsystem development

Start date	July 2002
End date	October 2005
Technology type	Polarisation camera
Readiness level	6
Development status	Demonstation system completed
Company/institution	TNO Defence, Security and Safety

Project description

The *Development and construction of a* ***camera system for land mine detection*** project aims to develop a camera system to aid in mechanical mine clearance and mined area reduction. As a possible end-user, the HALO Trust has been closely involved in the execution of the first two phases of the project.

The HALO Trust has developed an anti-tank mine roller system in order to demine an area faster. This roller system, which is mounted on a wheel loader, is used for area reduction. A detonation of an anti-tank mine will cause damage to the rollers. Repairing a damaged roller costs time and money. An automatic detection system on the wheel loader that provides the driver with an early warning can avoid detonations and gain time. Such an automatic detection system can be realised with a camera system that utilises the polarisation properties of light. The quality of the area reduction remains the same, even when the detection system misses a mine. In this case the roller will detonate the mine as it will do without the detection system.

Description of activities

The Defence, Security and Safety section of the Netherlands Organization for Applied Scientific Research (TNO) has developed a polarisation camera for the above purpose. The development process of this camera system was in three phases.

- Phase 1, the inventory phase, has resulted in a scenario description and a first set of requirements.
- In Phase 2, the feasibility phase, the feasibility of different concepts has been studied. The results of the first two phases are extensively reported in an interim report [2].

- In Phase 3 a demonstrator system has been built, based on the most promising concept of Phase 2. This demonstrator system consists of a polarisation camera that has been developed and constructed for this purpose. In addition to this camera, software has been developed for automatic detection of landmines and the visualisation of the results.

The results of this last phase are extensively reported in the final report [1].

Detailed description

The following project results have been accomplished:

1. A polarisation camera, without any moving parts, has been constructed. This camera is robust and can be mounted on a moving platform. According to the developer, the camera is a unique polarisation measurement system.

2. Detection software has been developed. With this software, landmines can be detected automatically in images that are recorded with the polarisation camera. The detection results can be visualised in the recorded images.

Figure 1. The polarisation camera.

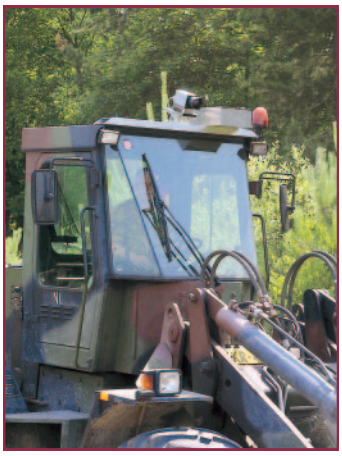


Figure 2. The polarisation camera mounted on the wheel loader. The metal box right of the camera contains the computer.

Test & evaluation[41]

To demonstrate the capabilities of the polarisation camera system it was mounted on a wheel loader of the Corps of Engineers. Two field demonstrations were given at the Engineer Training Centre. These demonstrations took place on a sand road partly covered with vegetation and on a grass road. During the demonstrations, recordings were made of surface-laid landmines. Enhanced polarisation contrast was shown in real time. The mines were detected automatically in off-line processing of these recordings. Detection results were visualised in the recorded images. The next step will be to test the system in a real operation.

41. *Note:* Tests with polarised cameras were also executed by FOI in Sweden (ITEP Project 2.5.2.1, www.itep.ws), which reports rather negative results. The test scenario is, however, not directly comparable, given that FOI has been looking at a variety of targets and in some quite tough surroundings (e.g. forest background), rather than the specific area reduction application envisaged here, with emphasis on surface-laid AT and larger AP mines on stony background or short grass. Also, TNO uses a visible light system without any moving parts, whereas FOI employs infra-red cameras equipped with rotating polarisers.

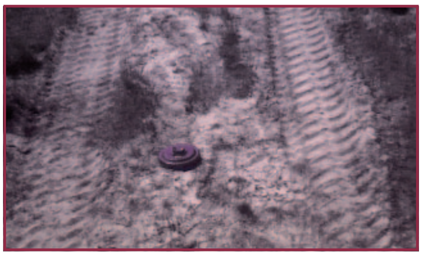


Figure 3. An example of raw data image.

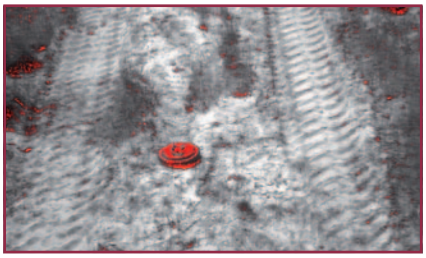


Figure 4. Polarisation enhancement of the raw image shown in Figure 3.

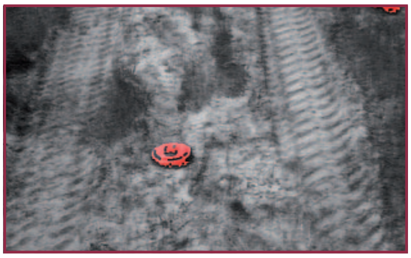


Figure 5. Example of detection result of the images shown in Figures 3 and 4.

Other applications (non-demining)

The constructed polarisation camera is applicable in landmine detection scenarios, but also in other detection scenarios. For example, road proving and roadside inspection/detection of improvised explosive devices can also benefit from the possibilities of a polarisation camera. At the moment roadside inspection is done with only binoculars. As a better alternative, one or more polarisation cameras can be placed on an armoured, manned or unmanned vehicle. Polarisation images can be used for automatic detection, but also as an image enhancement tool for the human observer. In future, this polarisation camera can be an important additional technique in the active search phase of the «Search» concept. Applications not related to landmine detection are the detection of camouflaged vehicles or the suppression of reflections from car windows in order to look inside cars.

Related publications

1. de Jong W., J.G.M. Schavemaker (2005)
   Development and construction of a camera system for landmine detection, Final Report; TNO Defence, Security and Safety; The Hague; TNO-DV1 2005 A147; November 2005. *www.itep.ws/pdf/TNO_DV1_2005_A147_ITEP.pdf*
2. Schavemaker J.G.M., W. de Jong, M.G.J. Breuers, J. Baan (2004)
   Development of Camera System for landmine detection, TNO Physics and Electronics Laboratory; The Hague; FEL-04-B152; July 2004. *www.itep.ws/pdf/FEL_report_04_B152_ITEP.pdf*
3. de Jong W., J.G.M. Schavemaker, M.G.J. Breuers, J. Baan and R. M. A. Schleijpen (2004)
   "Development and implementation of a camera system for faster area reduction", *Proceedings of SPIE Conference on Detection and Remediation Technologies for Mines and Mine-like Targets IX*, Vol. 5415, Orlando, US, 12-16 April 2004.
4. de Jong W., P. Straw, R. Schleijpen, J. Schavemaker and J. Baan (2004)
   Development and Implementation of a Camera System for Faster Area Reduction, in The UXO/Countermine Forum 2004, St. Louis, US, March.

Technical specifications — *TNO Polarisation Camera*

1. Used detection technology:	Advanced camera system that uses the polarisation properties of visible light
2. Mobility:	Vehicle-based
3. Mine property the detector responds to:	Relative flatness of mine surfaces when compared to a more rough natural background.
4. Detectors/systems in use/tested to date:	One demonstrator system
5. Working length:	Not applicable
6. Search head:	Camera including lens
➢ size:	24L x 10H x 9W cm
➢ weight:	2.3kg
➢ shape:	box
7. Total weight, vehicle-based unit:	Camera plus computer: 6kg
8. Environmental limitations (temperature, humidity, shock/vibration, etc.):	—
9. Detection sensitivity:	Part of the mine should be above the surface
10. Claimed detection performance:	
➢ low-metal-content mines:	Metal content is not an issue
➢ anti-vehicle mines:	>50% at a FAR < 0.01 m^{-2} (this number is an average for different mine types under different illumination conditions). Detection rate of TM62P > 99%.
➢ UXO:	Not tested
11. Measuring time per position (dwell time):	—
Optimal sweep speed:	Forward speed of vehicle is several m/s; at a sweep width of about 4m.
12. Output indicator:	Detection location indicated in output images.
13. Soil limitations and soil compensation capability:	Not relevant
14. Other limitations:	Will only operate under daylight conditions. Results can depend strongly on environmental conditions. Advanced image processing can partly neutralise this dependence.
15. Power consumption:	< 200 W
16. Power supply/source:	12V DC for camera and computer
17. Projected price:	—
18. Active/Passive:	Passive
19. Transmitter characteristics:	Not relevant
20. Receiver characteristics:	CCD elements sensitive to visible light
21. Safety issues:	None
22. Other sensor specifications:	Detection range: Up to 15 m in front of vehicle (depends on lens and camera orientation).

11.6 ClearFast

Project identification

Project name	Concept for Low-risk Efficient Area Reduction Based on the Fusion of Advanced Sensor Technologies	**Start date**	Phase 2: 1 February 2003
		End date	30 May 2005
		Technology type	Thermal infrared
		Readiness level	●●●●⑤●●●●
Acronym	ClearFast	**Development status**	Completed
Participation level	European	**Company/institution**	IMEC-ETRO (coordinator), Rheinmetall Landsysteme GmbH, TAMAM, BACTEC
Financed by	Co-financed by EC-IST		
Budget	€ 4.4 million		
Project type	Technology development, Technology demonstration		

Project description

The **ClearFast** concept's aims have been to develop a demonstrator system for *Stand-off Minefield Survey* for the purpose of *Technical Survey* — in particular area reduction by means of multispectral and thermal imaging and the related image analysis and interpretation.

The ClearFast objectives were:

1. The use of multispectral/thermal imaging modalities for a stand-off survey of hazardous areas, and possible identification of the boundaries of the hazard.
2. The use of multispectral/thermal imaging sensor under changing natural illumination, and subsequent image sequence analysis for the detection and location of abnormalities in the thermal behaviour of the ground.
3. The investigation of the possibilities of using Level-2A results for setting up an operational plan and taking decisions on how to approach the zone-of-fear to complete the technical survey by other means, i.e. manual teams, dogs or multi-sensor systems.

Dynamic thermal infrared (IR) techniques have been used since the 1980s for non-destructive evaluation and for geologic applications. The use of the thermal IR technique is based on the thermal radiation contrast of objects with respect to their background. All objects at temperatures greater than absolute zero emit electromagnatic radiation at all wavelengths, whereby the radiation corresponding to the wavelengths from 3 μm to 100 μm is referred to as *thermal IR radiation*. The magnitude of the spectral radiation of an object depends on its temperature. The difference of the thermal characteristics, i.e., the heat capacity, the thermal conductivity, and the thermal diffusivity, between buried objects and the background is the basis for using infrared techniques to detect landmines. Indeed, the presence of a buried object affects the heat conduction inside the soil during natural heating conditions. Consequently, the temperature of the soil surface above the buried object may be different from that of the surrounding area. This temperature contrast could be measured by an infrared imaging system.

The performance of the *Stand-off Minefield Survey* demonstrator has been tested in an operational setting. According to the developers, ClearFast proposes a novel concept for area reduction and the identification of safe routes to launch technical surveys. The major results of the project have been the explicit formulation of the capabilities and limitations analysed from different viewpoints, i.e. (a) physical — weather conditions, soil types, local resources, minefield ageing, etc.; (b) operational — scenario and logistics; and (c) economic — resource demands and intrinsic costs of the multi-temporal/multi-spectral infrared system.

Results from field tests have been analysed in order to indicate how the *Stand-off Minefield Survey* can support other systems, technically and operationally, i.e. dogs, manual, mechanical and, in particular, multi-sensor systems for the completion of the technical survey.

Detailed description

The system components (see Figure 1) are structured in the following sub-components:

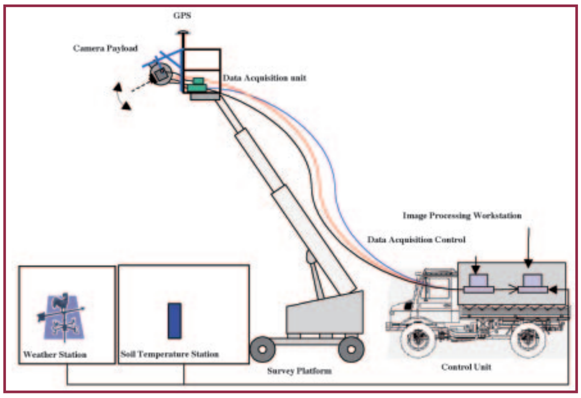


Figure 1. ClearFast deployment view.

- CI-1: ClearFast Survey Platform:
  - CI-1.1: Sky-lift (tower);
  - CI-1.2: Payload mounting;
  - CI-1.3: Stabilised payload & pan/tilt device (gimbal);
  - CI-1.4: Multispectral /thermal infrared (MSIR) camera & visible camera;
  - CI-1.5: Global positioning system (GPS);
  - CI-1.6: Data acquisition unit;
  - CI-1.7: Blackbodies and data logger.
- CI-2: ClearFast Auxiliary Data Station:
  - CI-2.1: Weather station, including solar/sky radiation;
  - CI-2.2: Soil temperature station;
  - CI-2.3: Auxiliary data control unit (monitoring of auxiliary data and blackbody).
- CI-3: ClearFast Control Station:
  - CI-3.1: Data acquisition control unit;
  - CI-3.2: Image processing workstation;
    - CI-3.2.1: Data archive module;
    - CI-3.2.2: Calibration and co-registration module;
    - CI-3.2.3: Mosaics and map production module;
    - CI-3.2.4: Multispectral/thermal image processing modules.

Test & evaluation

An overview of the detection performance and the test and evaluation conditions are shown in the table below. Several trials have been conducted during the project life time — in a dummy minefield in the Netherlands (referred to as TNO/FOI SandLane), in a dummy minefield in Germany (referred to as DataGathering SandLane, DataGathering Vegetation Lane, Extensive DataGathering), and on a live minefield in the United Nations Buffer Zone in Cyprus in the period of 15 to 30 November 2004. All details are available at the project website *www.clearfast.vub.ac.be.*

One of the main factors affecting performance is the soil diffusivity. During the DataGathering trials, the soil diffusivity was very low compared to other trials (due to high temperature). Consequently the thermal contrast was low and this affected the detection performance.

Figure 2. Deployment in Cyprus – minefield test.

The DataGathering trials on the vegetation lane proved that, under condition of dense vegetation, it is impossible to reliably detect and classify any landmines. This is mainly due to the nadir[42] observation angle. This implies that the IR method should be used in low vegetation conditions.

During the Extensive DataGathering trials very bad weather conditions were experienced (heavy rain); the anomaly detection performance was nevertheless reasonable. The results in the Extensive DataGathering also showed that mild ground cover, such as low grass or moss, still allows detection under the nadir observation angle.

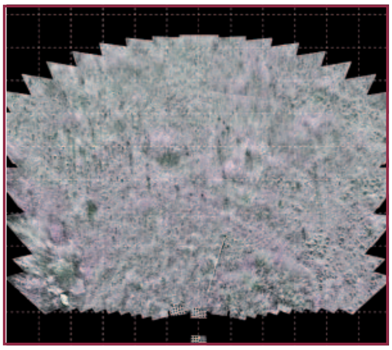


Figure 3. Mosaic of the minefield test.

The detection and subsequent classification seem to be limited by the depth of burial. The limiting burial depths, as confirmed in the Extensive DataGathering, are of 6cm for anti-tank mines and 3-5cm for anti-personnel landmines.

The performance envelope of the system is summarised in the table on the following page.

42. Downward facing.

Table 8. Performance envelope of ClearFast system

Area	TNO/FOI SandLane	DataGathering SandLane	DataGathering Vegetation Lane	Extensive DataGathering	Cyprus accreditation	Cyprus minefield 2230
Acquisition height	10 m	15 m	15 m	8 m	10 m	12 m
Ground resolution	1.5 cm	0.8 cm	0.8 cm	1.2 cm	0.5 – 0.75 cm	0.5 – 3.3 cm
Surveyed area	12 m^2	24 m^2	24 m^2	9 m^2	100 m^2	980 m^2
Soil diffusivity	6.4e-7	1.6e-7	1.3e-7	7.6e-7	4.7e-7	5.3e-7
Clutter	None	Low (rocks/ stones)	None (none visible)	Low (bottles, cans)	Low (rocks)	Medium (rocks)
Obscuring vegetation	None	Sparse	Dense	None (nadir orientation)	Low (shrubs)	Medium (bushes / shrubs)
Ground cover	None	None / grass	N/A	Grass / moss	None	None
Weather conditions	Sunny	Sunny & hot	Sunny & hot	Changing	Sunny	Sunny
Burial depth	0 – 6 cm	0 – 2 cm	0 cm	0 – 6 cm	10 – 15 cm	0 - ?? cm
Period	Jul 2001	Aug 2003	Aug 2003	June 2004	Nov 2004	Nov 2004
Anomaly detection & selection	Det. 12/35 FA 4	Det. 0/3 FA 25	Det. 0/4 FA 11	Det. 6/6 FA 19	Det. 0/3 FA 118	Det. 4/16 FA 525
Thermal parameter estimation	Good Class. 10/35 FA 0	Good Class. 0/3 FA 1	N/A	Good Class. 0/6 FA 2	Good Class. 0/3 FA 0	Good Class. 4/16 FA 25

Det: detection; FA: false alarms; Class: classification.

Related publications

1. Cremer F., T.T. Nguyen, L. Yang, and H. Sahli (2005)
"Stand-off thermal IR minefield survey: System concept and experimental results", *Proceedings of SPIE Conference on Detection and Remediation Technologies for Mines and Mine-like Targets X*, Vol. 5794, Orlando, US, 2005.

2. Nguyen T.T., D.N. Hao, P. Lopez, F. Cremer and H. Sahli (2005)
"Thermal infrared identification of buried landmines", *Proceedings of SPIE Conference on Detection and Remediation Technologies for Mines and Mine-like Targets X*, Vol. 5794, Orlando, US, 2005.

3. López P., H. Sahli and D. Cabello (2003)
"Detection and Classification of Landmines from Infrared Images", in *EUDEM2-SCOT, International Conference on Requirements and Technologies for the Detection, Removal and Neutralization of Landmines and UXO*, Vrije Universiteit Brussel, Brussels, Belgium, September 2003, pp. 385-392.

4. López P., H. Sahli, D. Vilarino, D. Cabello (2003)
Detection of perturbations in thermal IR signatures: an inverse problem for buried land mine detection, SPIE's Smart Structures/NDE Meeting, San Diego, California, US, March 2003, pp. 242-252.

5. López Martínez P. (2003)
Detection of Landmines from Measured Infrared Images using Thermal Modeling of the Soil, PhD thesis, University of Santiago de Compostela, Spain, ISBN 8468815861.

6. Cremer F. (2003)
Polarimetric infrared and sensor fusion for the detection of landmines, PhD thesis, Delft University of Technology, The Netherlands, ISBN 9059860322, 2003.

Technical specifications	*ClearFast*
1. Used detection technology:	Thermal Infrared
2. Mobility:	Shipped on one pallet
3. Mine property the detector responds to:	Temperature variation (e.g. due to solar heating).
4. Detectors/systems in use/tested to date:	One
5. Working length:	Not applicable
6. Search head:	
➢ size:	40x40cm
➢ weight:	10kg
➢ shape:	Circular
7. Weight, hand-held unit, carrying (operational detection set):	—
Total weight, vehicle-based unit:	+/- 500kg
8. Environmental limitations (temperature, humidity, shock/vibration, etc.):	Tested from below 0°C to +30°C. Needs a steady platform; is limited by wind.
9. Detection sensitivity:	Better than 0.1°C
10. Claimed detection performance:	
➢ low-metal-content mines:	10/35
➢ anti-vehicle mines:	4/16
➢ UXO:	Not available
11. Measuring time per position (dwell time):	At least 12 hours per position (20x30 m sweep size)
Optimal sweep speed:	—
12. Output indicator:	On screen
13. Soil limitations and soil compensation capability:	None
14. Other limitations:	Clutter and vegetation affects performance
15. Power consumption:	1-2 kW for prototype
16. Power supply/source:	Generator
17. Projected price:	170 kEuro (Thermal IR camera expensive)
18. Active/Passive:	Passive
19. Transmitter characteristics:	—
20. Receiver characteristics:	3-5 μm
21. Safety issues:	Needs safe location to place sky lift.
22. Other sensor specifications:	—

12. Concluding remarks

As mentioned in the *Introduction*, over the last 10 years considerable funding and effort has been invested worldwide in order to develop new technologies for humanitarian demining. A first analysis of the general disappointment that only few of these technologies have progressed quickly from research and development to field use points to: (i) the complexity of the problem, including environmental and operational aspects; (ii) the mismatch between research ideas and application requirements in the field, and (iii) the significant non-technological problems in funding the resources to turn prototypes into fully tested commercial products ready to use in the field.

This *Guidebook* is an attempt to present and summarise emerging sensing technologies and systems, not only for close-in landmine detection but also for area reduction, which could be applicable to humanitarian demining operations. Systems which seemed to be primarily targeted at defence applications have in general not been included. However, it is acknowledged that military detection requirements are moving to some extent towards those expected for humanitarian demining. It is therefore possible that such systems could find application, in a suitably modified form, in humanitarian demining scenarios, or at least in peace-keeping operations. This is particularly true for sensing platforms aimed at road clearance, where the R&D drive is mostly coming from the defence sector.

Profiting from the developments in the military sector is on the other hand less likely for technologies and systems where military and humanitarian requirements show less overlap. This could be the case for example for simple contact seismic/acoustic systems, which are probably less acceptable in military scenarios and therefore subject to relatively little funding.

Concerning the individual technologies and systems featured in this *Guidebook*, from the analysis of the technology readiness one can conclude the following:

➢ Electromagnetic-based systems

- ➢ Metal detectors are definitely better now than 10 years ago (higher sensitivity, improved ergonomic design, man-machine interface and soil signal rejection). Enhanced metal detectors (MDs), for example with discriminatory capabilities, show interesting potential but are still fielded only in small numbers, for example on vehicle-based systems for “wide area detection”.

- Ground penetrating radar (GPR) technology reached the stage of production and intensive testing, and some deployment in the field. These developments did definitely profit from the expertise gained from other applications of GPR (such as non-destructive testing and subsurface sensing), the well known basic theory and limitations, as well as the operational use. Most of the GPR systems being developed or used are combined with metal detectors and employed as confirmatory sensors. Combined MD and GPR systems are nowadays used as hand-held or vehicle-mounted systems. Most of the presented vehicle-based systems are in a stage of testing for applications such as road clearance, and moving from prototype to real production could take a few years for some systems (Japan, US).

Trace explosive detection

Great progress has been made in this domain, with several systems being tested and available as pre-production units. Rather than the pure performance of the sensors themselves, the main problem seems to lie with their use within an appropriate operational procedure, deciding whether to employ them either as area reduction sensors, or in selected scenarios for confirmation purposes, or still as training or benchmarking tools in combination with mine detection dogs, taking in due account the sampling issue and the influence of environmental parameters. Answers are likely to be forthcoming once there will be a clear commitment from donors and end-users for extensive testing. Much more R&D seems to be appropriate, given the potential impact of this type of systems, such as being able to declare an area free from explosives.

Bulk detection systems

The possibility of directly detecting a macroscopic amount of material, and possibly of classifying it as explosive, is *per se* quite appealing. In practice two routes have been taken, either by employing radiation capable of penetrating the soil (and the mine case), typically using neutrons and/or X- or gamma rays, or electromagnetic radiation capable of being highly compound specific (nuclear quadrupole resonance — NQR— systems, which present no radiation danger). A number of problems have been encountered, related for example to the one-sided sensor configuration, the reduced amount of explosives in small AP mines and/or the depth of AT mines, and the need for appropriate and often intense (neutron) sources and corresponding detectors to detect the weak and/or complex return signals.

- Concerning penetrating radiation systems, no breakthroughs seem to have occurred, although selected applications are possible, such as for the confirmation of AT mines on roads, or for the characterisation of the contents of unexploded ordnance. R&D investments seem to have been substantially reduced in this area. Time will tell if new versions of existing systems, e.g. neutron moderation, will find their way.
- NQR is still being pursued by a number of research groups, trying in particular to surmount the TNT detection problem for small buried anti-personnel mines, and to quantify exactly the minimum amount of detectable explosive. Significant R&D and test and evaluation seems to be still required to get to a fieldable system, which would however have the great advantage of really

being sensitive to a physical parameter characteristic of a mine, i.e. its explosive content (for non-metallic mines).

➢ Remote sensing

These systems are based on off-the-shelf opto-electronic technologies, ranging from visible to thermal infra-red and multispectral sensors. They have the characteristic that they could be mounted on vehicles, or on airborne platforms, and used for area reduction. Airborne survey in particular is shifting from experimental towards "production survey": a *coherent framework emerges* with opportunities for improvement, both on the sensor (e.g. polarised infrared cameras) and on the software side (e.g. integrated global information system environments, or image interpretation methods). It involves the total use and integration of all available information over an area — aerial and satellite multimodal data, ground surveys, interviews and local knowledge about land use — ranging from small-scale to large-scale, from the past to the present status. The means to obtain all this information are generally known, whereas the integration and structuring schemes are emerging and being validated, often in collaboration with national mine action centres.

➢ Other detection principles

The other detection principles illustrated in this *Guidebook*, in particular seismo-acoustic (which has seen a substantial increase in interest level during the past 10 years), have shown potentially interesting R&D results, which should be turned into test and evaluation criteria. A collaboration between developers and end users would allow to clarify the potential, the operational use as well as the developments to be undertaken.

Increased efforts are also being allocated to better understand the soil influence and environmental limitations, which do represent in many cases the limiting factor. These aspects were unfortunately somewhat neglected in the past.

From a general point of view we can summarise some of the most notable developments which have taken place in humanitarian demining sensing related R&D during the past 10 years with: (i) an increased understanding of the problem, (ii) a shift from a focus on the individual sensor as a solution towards the individual sensor as part of a set of tools, (iii) an increased emphasis on area reduction and the detection of minefield indicators rather than individual mines, (iv) an increased emphasis on trace explosive detection, (v) the gaining of importance of systematic test and evaluation (in particular via ITEP).

Finally, expanding on what was discussed at the beginning of this section we note that in a number of cases demining related developments have been terminated or at least put on hold.[42] This is usually due to a combination of factors such as: (i) insufficient funding or system performances, (ii) incorrect evaluation of the problem and/or excessive expectations on the system performance (due for example to lack of precise equipment specifications, lack of precise benchmarks and/or a baseline to which new technology has to be compared), (iii) focusing on the wrong target application, (iv) lack of communication between the concerned actors, or (v) a re-evaluation of the expected return on investment.

42. Applications in other domains, such as non-destructive testing, remote sensing or security, might however very well be pursued and in turn be profitable to humanitarian demining in the future.

With respect to the latter, without going into a detailed market analysis, it has become clear in the past years that the market for humanitarian demining sensing technologies and systems is nowhere as large as initially assumed. Other markets, such as security, are likely to draw the largest share of the sensing equipment developers' attention, together with military mine clearance, where investments are likely to continue to be relevant in the years to come.[43] The landmine problem is, however, far from solved and landmine detection and area reduction are still the most important elements in the humanitarian demining equation. Research and development of practical detection technologies and systems that are appropriate for humanitarian demining, duly taking into account the lessons learned and the developments outlined in this section, continues therefore to represent one of the most significant contributions to the solution of the landmine problem.

43. Similar arguments are likely to apply to UXO detection vs. the military requirements for range remediation.

Annex 1

Schematic overview of other systems and technologies

The following table presents a schematic, non-exhaustive overview of other landmine detection and area reduction sensing technologies and systems the editorial team was aware of. These do not appear in full in the main section of this Guidebook either because information was requested but not forthcoming in time or difficult to obtain, or the contacted organisation did not express its interest in having a full entry, or the system did not appear to be mature or representative enough for humanitarian demining applications. Apart from a couple of representative exceptions, systems which seemed to be primarily targeted at defence applications have not been included. In general the proportion of systems for which demining related developments have been terminated or at least put on hold is higher than for the entries in the main section, although applications in other domains, such as non-destructive testing or remote sensing, might again very well be pursued.

The information provided in the following table is meant to be sufficient for an overview and to provide the reader with basic information to start a more in-depth search. The entries are subdivided following the same categories employed in the main section (with the addition of a couple of entries representing enhanced metal detectors), however without any particular ranking inside each category. Where available related *references* (in a short form) and *websites* are reported as well. Bold characters are used to point to the system name, sensor type or contact person which appears to best characterise an entry.

Technology	System name & origin	Basic characteristics & references	Contact person	Additional information
1. Enhanced Metal Detectors	**Meandering Winding Magnetometer** (MWM) Jentek Sensors, Inc., US	Hand-held or vehicle-based. Metal detector relying on shaped magnetic field patterns, and featuring «imaging» capabilities. Quantitative estimates of size and depth for known object shapes are also potentially possible. *References*: N.J. Goldfine, et al., *Proceedings SPIE*, Vol. 5089 (2003), pp. 872-883; *Proceedings. SPIE*, Vol. 4038 (2000), pp. 56-65; *Proceedings SPIE*, Vol. 3710 (1999), pp. 89-100.	Neil Goldfine	Development likely ongoing for other applications (e.g. Non-Destructive Testing).
2. Enhanced Metal Detectors	**DIPS (Digital Induction Pulse Sensor)** EPPRA sas, France	Hand-held. Prototype developed and tested in Namibia/Angola with MgM, within the European MINESEYE project, 1999-2001 (see also www.mgm.org). *Website*: www.eppra.com	Carmen Dumitrescu, Peter Choi	Development possibly on hold for humanitarian demining.
3. Other Low-frequency Electro-magnetic	**Non-metallic Mine Detector (NMD 78, NMD 79)** -, South Africa	Vehicle-based. Currently 30 systems available, as well as technology transfer opportunities. *References*: UNMAS & GICHD, *Mine Action Technology Newsletter*, October 2005, Issue No. 3 (see www.gichd.ch); Peter Stiff, *Taming the Landmine*, Jan. 1986, Galago Publishing Company.	Martin Bird, Eugene Lombard, Boet Joubert	Used in the Rhodesia "bush war" (late 1970s) for the AT detection on roads ("anomaly detector"). Developments likely stopped since then.
4. Ground Penetrating Radar	**Sencion Alpha Pro 4** COS Co. Ltd, Japan	Hand-held. GPR combined with a metal detector. *References*: *Final Report (Summary) for Humanitarian Mine Clearance Equipment in Afghanistan*, Japan International Cooperation System, 31 March 2005, www.mineaction.org/doc.asp?d=452. *Website*: www.cos.co.jp/, www.jics.or.jp/jics_html-e/activities/grantaid/afg2003_01.html	-	Field tested in Afghanistan (2004-2005), and possibly earlier in Cambodia.
5. Ground Penetrating Radar	**Mine Eye** JAHDS and GeoSearch, Japan	Hand-held. Originally based on the LLNL MIR radar module. Developments ongoing since the mid-'90s. *Website*: www.jahds.org/, www.geosearch.co.jp/	Hiroshi Tomita	Likely to have been field tested in Cambodia and Thailand.

Technology	System name & origin	Basic characteristics & references	Contact person	Additional information
6. Ground Penetrating Radar	**HUMUS ATR** platform FOI, Sweden	Hand-held. GPR with classification capabilities. *References*: ITEP Project 2.2.2.5 (report pending). *Website*: www.swedec.mil.se/index.php?c=news&id=17971	Staffan Abrahamsson	Research on GPR at FOI has been ongoing for the past 10-15 years.
7. Ground Penetrating Radar	- **Tricon** Germany	Vehicle-based (**Pookie**). *References*: W. Lawrence, Pookie Rides Again, *MAIC Journal of Mine Action*, Issue 6.2, August 2002 (see maic.jmu.edu). *Website*: www.tricon-online.de	Stefan Schultheiss	Uses a COTS GPR array from Sensors and Software, and has been field tested in Africa.
8. Ground Penetrating Radar	**LANDMARC** LLNL (Lawrence Livermore National Laboratory), US	Hand-held. Based on the LLNL MIR (**Micropower Impulse Radar**). *References*: S. Azevedo, LANDMARC (land mine detection), *IEEE Potentials*, 17(4), Oct-Nov 1998, pp. 19-20. *Website:* www.llnl.gov/str/Azevedo.html	Stephen Azevedo	Looks like developments stopped around 1998.
9. Other Ground Penetrating Radar	**SRI Airborne GPR**, Forward looking GPR, and harmonic GPR, SRI International, US	Vehicle-based and airborne. For airborne system: mostly surface minefield detection. *Website:* www.sri.com/esd/ -> Penetrating Radar.	-	Unlikely to have been tested for humanitarian demining applications.
10. Other electromagnetic	**EDIT-3/RMPA** (Resonant Microstrip Patch Array) Stolar Research Corporation, US	Hand-held "simplified" GPR. *References*: Fully featured in the GICHD *Metal Detectors and PPE Catalogue 2005*; *NVESD EDIT Fact Sheet* (*www.humanitariandemining.org -> Detection -> Handheld Detectors*). *Website:* www.stolarhorizon.com/	Larry Stolarczyk (Stolar), Joseph Duncan (Stolar), Richard Walls (US Army NVESD)	Tested by US Army. Prototypes available for technical testing. Developments ongoing for other applications.
11. Trace explosive detection	**Portable field detector** FOI, Sweden	Hand-held (battery operated sampling unit) and vehicle based (gas chromatograph and thermoionic analysis unit). *References*: L. Sarholm, Presentation of Mine Clearance research project at FOI, NDRF Summer Conference 2002 (see www.ndrf.dk -> Past Events); A. Kjellström, *Chemical detection of explosives - Analysis of air and soil*, same conference.	Lena Sarholm, Ann Kjellström	Field tests were planned for 2003.

Technology	System name & origin	Basic characteristics & references	Contact person	Additional information
12. Bulk explosive detection: NQR	- King's College London, UK	Hand-held and/or vehicle-based. Noise excitation based device, featuring wide excitation bandwidths and low power consumption. Laboratory demonstrator available. *References*: J.A.S. Smith, et al., *Proceedings EUDEM2-SCOT International Conference*, 2003, pp. 715-721 (see www.eudem.info) *Website:* www.nqrconsultancy.co.uk/	**John Smith**	Research on NQR for the detection of explosives at KCL has been ongoing for the past 10-15 years, at least.
13. Bulk explosive detection: NQR	**NQDR (Nuclear Quadrupole Double Resonance)** J. Stefan Institute, Ljubljana, Slovenia	Possibly man-portable. Use of an external magnetic field to increase NQR resolution and sensitivity (in particular for the detection of TNT). *References*: T. Apih, et al., *Proceedings EUDEM2-SCOT International Conference*, 2003, pp. 722-727 (see www.eudem.info). *Website:* www.ijs.si/ijs/dept/f5-nmr/	Tomaz Apih, Robert Blinc	See also T. Apih, J.A.S. Smith, J. Seliger, NATO Science for Peace project 978007 "Minefield Detection", 2003-2006
14. Bulk explosive detection: NQR	- Kaliningrad State University, Russia	Hand-held and/or vehicle-based. Various systems and techniques developed over the years. *References*: see Websites below. *Website:* www.albertina.ru/, www.ksu.kern.ru/minedet/, http://www.ksu.kern.ru/grechishkin/ww8.htm	**Vadim Grechishkin**	Research on NQR for the detection of explosives at KSU has been ongoing for the past 10-15 years, at least.
15. Bulk explosive detection: NQR	- Darmstadt Technical University & Ruhr University Dortmund, Germany	Possibly man-portable. *References*: J. Altmann, et al., *Proceedings EUDEM2-SCOT International Conference*, 2003, pp. 722-727 (see www.eudem.info); M. Nolte, et al., Journal of Phys. D: Applied. Phys. 35 939-942, 2002.	Franz Fujara (Darmstadt), Jürgen Altmann (Dortmund)	Developments still somewhat far from practical field applications.
16. Bulk explosive detection: NQR (+GPR)	**Advanced Mine Detector (AMD)** GE Security and CyTerra Corporation, US	Hand-held. Combination of GPR, metal detector and NQR, for defence applications. *Website:* www.cyterra.com -> Countermine.	-	Ongoing developments, little public information available.

Technology	System name & origin	Basic characteristics & references	Contact person	Additional information
17. Bulk explosive detection: NQR	- Osaka University, Japan	TBD. *References*: M. Tachiki, et al., *Proceedings of HUDEM 2005 (Robotics and Mechanical Assistance in Humanitarian Demining)*, 2005, pp. 109-111 (see www.hudem2005.org and www.itep.ws). *Website:* www.jst.go.jp/kisoken/jirai/kadai/explosive-e.pdf	Hideo Itozaki	Project probably still in early phases.
18. Bulk detection systems: Neutron based, diverse methods	- Exdet Ltd., US/Russia	Hand-held. Dual portable system: neutron backscattering (hydrogen detection) to be followed by thermal neutron activation (nitrogen detection). *References*: G. Pekarsky, *Proceedings 2nd Intnl. Conf. on the Detection of Abandoned Land Mines*, 1998 (IEE Conf. Publ. No. 458), pp. 147-151; A. Toor, A.A. Marchetti, *Monte Carlo Simulations for Mine Detection*, LLNL Report UCRL-ID-138119, March 2000.	**Gregory Pekarsky**, Vitaly Bystritski	Detectors might have been used by Russian Army. Unclear if developments have been pursued since.
19. Bulk detection systems: TNA	- Kyoto University, Nagoya University, Japan	Likely to be vehicle-based. *References*: K. Yoshikawa, et al., *Proceedings of HUDEM 2005 (Robotics and Mechanical Assistance in Humanitarian Demining)*, 2005, pp. 116-119 (see *www.hudem2005.org* and *www.itep.ws*); T. Iguchi, et al., same *Proceedings*, pp. 112-115; Y. Takahashi, et al., same Proceedings, pp. 120-123. *Website:* www.jst.go.jp/kisoken/jirai/kadai/explosive-e.pdf	Kiyoshi Yoshikawa (Kyoto), Tetsuo Iguchi (Nagoya)	Several sub-projects, in particular on a discharge-type fusion neutron source and on gamma rays detectors, probably still in early phases.
20. Bulk detection systems: Neutron, fast	**PNCAS (Pulse Neutron Chemical Analysis Sensor)** EPPRA sas, France	Man portable or (more likely) vehicle-based. Relies on a very short pulse plasma neutron generator and a large area very fast gamma ray detector. Prototype developed and tested in Namibia/Angola with MgM, within the European MINESEYE project, 1999-2001 (see also *www.mgm.org*). *References*: C. Bruschini, *ExploStudy, Final Report*, p. 33, Feb. 2001 (see *www.eudem.info*). *Website:* www.eppra.com	Carmen Dumitrescu, Peter Choi	Development possibly on hold for humanitarian demining, ongoing in other domains (e.g. security).

Technology	System name & origin	Basic characteristics & references	Contact person	Additional information
21. Bulk detection systems: Neutron, fast	**SuperSenzor** HiEnergy Technologies, US	Man portable or vehicle-based. Relies on the associated particle technique and high resolution Germanium gamma rays detectors to yield a quantitative empirical determination of the Carbon, Nitrogen and Oxygen ratios, and the chemical formula, of the substance under analysis. *References*: B.C. Maglich, et al., *Proceedings EUDEM2-SCOT International Conference, 2003*, pp. 761-765 (see *www.eudem.info*); *Website:* www.hienergyinc.com/	Bogdan Maglich	Tested as a confirmation sensor for AT mines by NVESD in 2003. Related activities possibly ongoing.
22. Bulk detection systems: Neutron, fast	- **EADS SODERN**, France	Vehicle-based. Associated particle technique based system, mainly for defence applications and as a confirmation sensor for the time being (to be employed in the Franco-German MMSR-SYDERA «Vehicle-Mounted Close-in Mine Detection System» project). *Website:* www.sodern.fr/	Philippe Le Tourneur	Demonstrator successfully field tested in 2004. Developments are ongoing.
23. Bulk detection systems: neutron backscatter	**DIAMINE** INFN (Italian National Institute of Nuclear Physics) Padova, Italy	Hand-held. Integration of a metal detector with a neutron backscatter system, for the detection and imaging of landmines and aimed specifically at humanitarian demining (2000-2002). *References*: G. Nebbia, et al., *Detection of hidden explosive in different scenarios with the use of nuclear probes*, INPC 2004 (see *www.fy.chalmers.se/conferences/inpc2004/*); G. Viesti, et al., *Proceedings EUDEM2-SCOT International Conference, 2003*, pp. 737-742 (see www.eudem.info).	Giancarlo Viesti, Giuseppe Nebbia	Interesting concept and with attention to HD, did however not reach the full development stage. The project included an in-depth Soil Report by the Ruđer Boškovic Institute, Zagreb, Croatia.
24. Other bulk detection systems: X-ray backscatter	- **YXLON** GmbH, Germany	Vehicle-based. Detection has been apparently proven down to 20 cm depth. Prototype featured relatively long detection times. *References*: W. Niemann, et al., *Detection of buried landmines with X-ray backscatter technology*, Proceedings 8th ECNDT, Barcelona, June 2002. Available in Insight Vol 44 No 10, October 2002. *Website:* www.yxlon.com	-	Field tested by German MoD (1997-2000) as a direct imaging technique. Deemed possibly helpful as a confirmation sensor.

Technology	System name & origin	Basic characteristics & references	Contact person	Additional information
25. Acoustic/ seismic: **Impulse acoustics**	- Monash University, Australia	Hand-held. Simple non-contact method employing two stand-off acoustic microphones scanned over the target and used differentially, and an excitation loudspeaker. *References*: C. G. Don, A. J. Rogers, *Location of buried objects by an acoustic impulse technique*, Acoustic Australia, Vol. 22, No. 1, pp. 5-9, 1994; C.G. Don, A. J. Rogers, Journal Acoustic Society of America, 95, 2837-2838, 1994; US Patent No. 5,563,848, 08 October 1996.	Charles Don (retired)	Field testing unlikely to have been taken place. No recent developments known.
26. Acoustic/ seismic: **Non-linear acoustics**	- Stevens Institute of Technology, US	Vehicle based (hand-held variants might be possible). *References*: D. Donskoy, et al., Journal Acoustic Society of America, Vol. 111, No. 6, pp. 2705-2714, June 2002; several US patents. *Website:* www.soe.stevens-tech.edu/News/donskoy.html, www.stevens.edu/engineering/ceoe/People/donskoy.html	**Dimitri Donskoy**	Has pioneered non-linear acoustic landmine detection since the '90s. Systems extensively field tested with US Army.
27. Vehicle-Based Multi-Sensor Systems	**MMSR-SYDERA** Rheinmetall Landsysteme GmbH, Germany, Thales Airborne Systems and MBDA, France	Vehicle-based. Remote controlled mine detection and clearing system (metal detectors, GPR, multi-spectral opto-electronic and neutron based confirmation sensors), primarily for peace-keeping and defence applications. Five vehicles – decoy, detection, confirmation, command & control – to be combined according to the target scenarios. *References*: F. Le Gusquet, et al., Proceedings SPIE Vol. 5804 (2005), pp. 485-495. *Website*: http://www.rheinmetall-detec.de/index.php?lang=3&fid=950	Hermann Grosch, Axel Kaspari (Rheinmetall)	Franco-German collaborative project. Until 2007: development of prototypes.
28. Remote sensing systems	**Camcopter** using IR or GPR/SAR Schiebel Inc, US, Schiebel Technology, Elektronische Geräte GmbH, Austria	Airborne. Remotely controlled, fully autonomous aerial platform capable of mounting different sensors. *References*: T.R. Gendron, *Mechanically assisted Landmine Clearance and Detection*, MAIC Journal of Mine Action, Issue 3.2, Summer 1999 (see maic.jmu.edu); NVESD Camcopter & Landmine Survey and Detection System Fact Sheets (*www.humanitariandemining.org -> Detection -> Wide Area Detection/Area Reduction*). *Website:* www.schiebel.net	James Rolig (Schiebel Technology, Inc.), Charles Chicester and Karin Breiter (US Army NVESD)	Tested by US Army with Infrared and Synthetic Aperture Radar sensors. Developments might have been halted since these tests.

Technology	System name & origin	Basic characteristics & references	Contact person	Additional information
29. Remote sensing systems	**Mineseeker UWB** Mineseeker Foundation and QinetiQ, UK	Airborne. Airship mounting an Ultra Wideband Synthetic Aperture Radar (UWB SAR) by QinetiQ, in principle capable of high resolution, foliage penetration and buried target detection. Test reports (2000-2001) available from the Website. *Website:* www.mineseeker.com/		Developments might have been halted since the tests in Kosovo.
30. Remote sensing systems: Multi/ Hyperspectral	**CASI (Compact Airborne Spectrographic Imager)** CCMAT & Itres Research, Canada	Airborne or vehicle-based. Possible application to the detection of surface laid mines or of minefield indicators (rather than individual mines), or of mines on roads, in particular recently emplaced ones. Buried mine detection is possible under some circumstances. *References*: J. McFee, et al., Proceedings SPIE Vol. 5794 (2005), pp. 56-67; T. Ivanco, Proceedings SPIE Vol. 4394 (2001), pp. 365-378. *Website:* www.ccmat.gc.ca, www.itres.com	John McFee (CCMAT)	Ongoing developments. Research on multi/ hyperspectral imaging has been ongoing at CCMAT for the past 10-15 years, at least.
31. Remote sensing systems: **Infrared, Polarised**	- FOI, Sweden	TBD. Results seem rather negative («it is very difficult to distinguish man-made objects from the surrounding terrain and it is not possible to detect tripwires»). *References*: ITEP Project Nr. 2.5.2.1 (see www.itep.ws).	Goran Danielsson	See also footnote for the "Polarised camera system for landmine detection" entry (TNO, The Netherlands).
Older systems:				
32. Ground Penetrating Radar	**Zakros (or Zagros)** **CSIR**, South Africa	Vehicle-based GPR array. Developed early 1970s to early 1980s and extensively field tested.		
33. Bulk detection systems: **Neutron backscatter**	- **SAIC**, US	Hand-held neutron backscatter system, probably developed during the 1980s. *References*: G. M. Borgonovi, et al., *Landmines and Unexploded Ordnance Detection, in A Remotely Controlled Multi-Sensor Platform for Humanitarian Demining*, Report of the Advisory Group Meeting held 3-7 April 2000 at the IAEA Headquarters, Vienna, Austria, IAEA publication IAEA/PS/AG-1093.		

Annex 2

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This annex includes the contact details of the organisations appearing in this *Guidebook*. In the case of multi-partner projects, only the project leader is listed.

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Annex 3

Glossary of acronyms and abbreviations

2D	two dimensional
3D	three dimensional
Ab	antibody
AFPs	amplifying fluorescent polymers
Ag	antigen
AGM	automated georeferencing module
AIR	airborne
AM	amplitude modulation (AM broadcast radio)
AP	anti-personnel
APT	associated particle technique
AT	anti-tank
ATR	aided target recognition
BGO	Bismuth Germanate
CBI	Compton Backscatter X-ray Imaging
CDS	Central Demolition Site, Afghanistan
CMP	common midpoint
COTS	commercial off-the-shelf
CRDC	Defence R&D Canada
CROMAC	Croatian Mine Action Centre
CRREL	Cold Regions Research and Engineering Laboratory, US
CZT	cadmium zinc telluride
DARPA	Defense Advanced Research Projects Agency, US
DFID	Department for International Development, UK
DOB	depth of burial
DRDC	Defence R&D Canada
DRES	Defence Research Establishment Suffield
DSP	digital signal processor
EC	European Commission
EIT	electrical impedance tomography
ERC	explosive related compound
EUDEM	European Union in Humanitarian Demining project
FAR	false alarm rate
FMCW	Frequency Modulated Continuous Wave Radar
FNA	fast neutron analysis

FOI	Defence Research Agency, Sweden
FP	European Union's Framework Programme for Research and Technological Development
GDC	General Dynamics Canada
GICHD	Geneva International Centre for Humanitarian Demining
GIS	geographical information system
GPR	ground penetrating radar
GPS	global positioning system
HD	humanitarian demining
HMAU	Humanitarian Mine Action Unit
HSLS	hyper-spectral line scanner
IAEA	International Atomic Energy Agency
ICT	information and communication technologies
IED	improvised explosive device
INS	inertial navigation system
IR	infra-red
ITEP	International Test and Evaluation Programme for Humanitarian Demining
KIA	Kabul International Airport
LAN	local area network
LDV	laser Doppler vibrometer
LMR	lateral migration radiography
MAG	Mines Advisory Group
MAIS	mine action information system
MB-LDV	multi-beam laser Doppler vibrometer
MD	metal detector
MEDDS	Mechem Explosive and Drug Detection System
MgM	Menschen gegen Minen
MLBS	maximum length binary sequence
MSIR	multispectral /thermal infrared
MWR	microwave radiometer
NBS	neutron backscattering
NMR	nuclear magnetic resonance
NNA	nanosecond neutron analysis
NPA	Norwegian People's Aid
NQR	nuclear quadrupole resonance
NVESD	Night Vision and Electronic Sensors Directorate, US
OPMS	optical position monitoring system
PC	personal computer
PCA	principal component analysis
PD	probability of detection
PFA	probability of false alarm
PFNA	pulsed fast neutron analysis
PFTNA	pulsed fast-thermal neutron analysis

PRC	pseudo random code
QCM	quartz crystal microbalance
REM	remote detection system
REST	Remote Explosive Scent Tracing
RF	radio frequency
RFI	radio frequency interference
ROC	receiver operating curves
RSD	radiography by selective detection
RX	receiver
SAR	synthetic aperture radar
SNR	signal to noise ratio
SOPs	standing operating procedures
SPIE	The International Society for Optical Engineering
TBD	to be defined
TDT	Testing, Development and Training, CROMAC
TIR	thermal infra-red
TMAC	Thailand Mine Action Centre
TNA	thermal neutron analysis
TNO	Netherlands Organization for Applied Scientific Research
TNT	trinitrotoluene
TOF	time-of-flight
TRL	Technology Readiness Level
TX	transmitter
UAV	unmanned aerial vehicle
UNMACA	United Nations Mine Action Centre for Afghanistan
UWB	ultra wideband
UXO	unexploded ordnance

Units of measurements

cm	centimetre
dB	decibel
dBm	decibel (absolute power level, 0dBm=1mW)
eV	electron Volt
GHz	gigahertz
K	Kelvin
kg	kilogram
kHz	kilohertz
kVp	kiloVolt peak

lb	pound
m	metre
m^2	square metre
MeV	million electron Volt
MHz	megahertz
mm	millimetre
µs	microsecond
m/s	metre/second
ng	nanogram
nm	nanometre
n/s	neutrons per second
pg	picogram
ps	picosecond
s	second
V	Volt
W	Watt

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