4. Other Ground Penetrating Radar Systems

4.1 Portable Humanitarian Mine Detector (PHMD)

Project identification			
Project name	Portable Humanitarian Mine Detector	**End date**	31 October 2002
Acronym	PHMD	**Technology type**	Ground penetrating radar, metal detector, capacitance sensor
Participation level	European	**Readiness level**	●●●●●⑥●●● (6)
Financed by	UK Treasury Capital Modernisation Fund	**Development status**	Completed
Budget	£3,000,000	**Company/institution**	QinetiQ Ltd, Meodat GmbH, Guartel Technologies Ltd., Sensatech Research Ltd
Project type	Technology development, Technology demonstration, System/Subsystem Development		
Start date	1 July 2000		

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).

Figure 2. Bosnian deminer assessing space model.

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.

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
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.

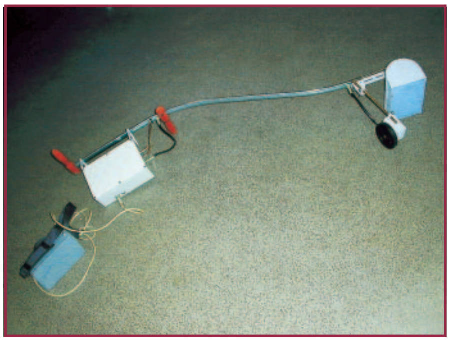

Figure 1. Hand-held prototype GPR.

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).