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.

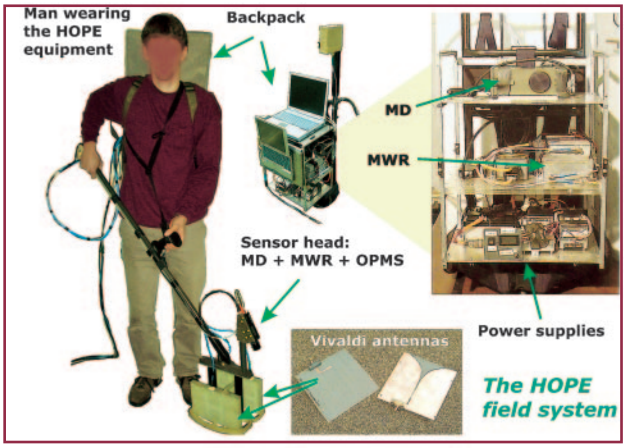

Figure 1. Essential elements of the HOPE multi-sensor system as it is to be operated in the field. Shown is the experimental equipment for the microwave radiometer (MWR), metal detector (MD) and optical position monitoring system (OPMS) demonstrator.

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.

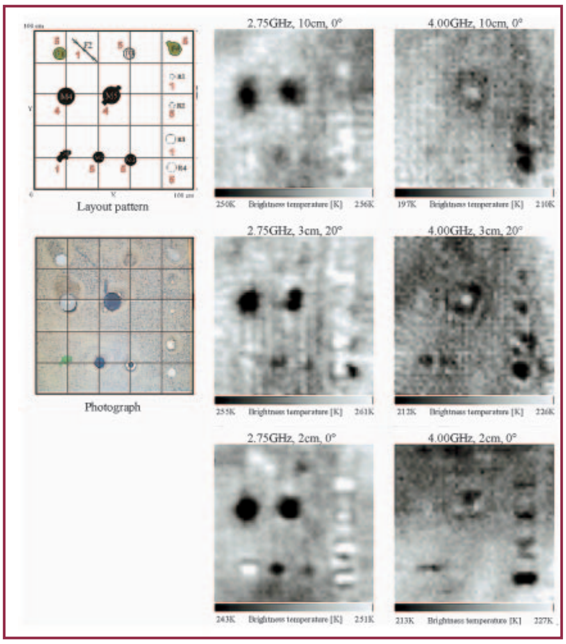

Figure 2. Photograph, layout pattern, and brightness temperature images of the measurement of scene S1 (laboratory experiments). Results for two centre frequencies, two tilt angles and various ground distances of the antenna are shown.

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).