# HOPE : – Raising the reliability of mine detection through an innovative a hand-held multi-sensor (MD, GPR, MWR) mine detector prototype with imaging capabilities

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**ABSTRACT**

***This paper deals with the HOPE project. HOPE is a European Esprit project that ran formally from January 1999 to January 2002. The goal was to develop a prototype of a hand-held system whose handling would be similar to a metal detector (MD) but where advanced processing and the use of additional complementary sensors would increase its discrimination capabilities. This would yield a significant decrease of the false-alarm rate which is typically quite high, e.g. 1000:1, for a MD due to the heavy metallic contamination of most minefields. The new system is also able to operate in conductive or magnetic soils which are difficult for a MD and it can detect pure plastic mines that may become a new threat in the future. The single sensors chosen are an enhanced MD, a ground penetrating radar (GPR) and a microwave radiometer (MWR). To allow imaging with all the sensors after a hand-operated and therefore irregular scanning of an area, an optical position monitoring system (OPMS) was added. For each sensor as well as for the OPMS, no off-the-shelf equipment could be used and specific hardware development was needed. The system was tested at the JRC test facility in Ispra, Italy, and in Sarajevo, Bosnia-Herzegovina, on an artificial minefield maintained by NPA.***

Keywords: Humanitarian mine clearance, manual scanning, metal detector, ground penetrating radar, radiometer, optical position monitoring system, data fusion

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## 1 INTRODUCTION

Humanitarian mine clearance is a complex task because mines are difficult to detect and may easily be confused with other objects commonly found in minefields. Indeed, anti-personnel (AP) mines are small and may contain only a very limited amount of metal, if any. Furthermore a large variety of mines may be found in an even larger variety of environmental conditions. Minefield characteristics such as the mine or soil types, area relief, mine depths in the ground, and mine density must be considered to define the most appropriate mine clearance tool and procedure. Due to the large variety of minefields, several tools are used for mine clearance. The most conventional ones are MDs, mechanical mine clearance machines, and dogs. No universal solution has been found yet and most probably none will be found in the near future. Hence the concept of a deminer toolbox is preferable.

The extensive use of MDs shows that there is a vast diversity of situations in which mine clearance organisations consider it to be suited for the task. A hand-held MD can be used in terrain difficult to access, where other techniques such as mechanical mine clearance tools would fail. Other advantages of the MD are its robustness, simple handling and maintenance, and its relatively low cost. The main problem is its high false alarm rate (FAR) due to the variety of non-mine metallic objects present in most minefields. Each false alarm must be treated as if it was a mine. This significantly reduces the clearing speed and thus increases the clearing costs and may reduce the concentration of the deminer and therefore increase the risk of an accident or of missing a mine.

Therefore, a hand-held search head that could be handled in a similar way as the MD, and which is able to detect all mines that a classic MD would detect while reducing significantly the false alarm rate, would be of great interest for the mine clearance community. The ability to extend the use of the system in situations where a hand-held detector is needed but MDs cannot be used, i.e. very low metal or pure plastic mines, and adverse soil conditions, would be a further considerable improvement. To reduce the false-alarm rate of MDs, more specific information on the buried objects is required. Thus more advanced processing of the MD signal and the use of additional sensors based on different physical principles should be added to the system.

The HOPE project was launched following these considerations. A multi-sensor hand-held prototype including a MD, a MWR and a GPR, to which an OPMS was added to provide imaging capabilities, was developed. The sensor selection is justified highlighting their complementarily and compatibility with other mine clearance constraints such as those linked with a hand-held detector. Typical objects are about 10 cm large and buried at a depth between 0 and 20 cm. Off-the-shelf sensors are not able to detect those objects and specific hardware had to be developed. Furthermore, to reduce the FAR, advanced processing of the sensor data was developed in order to gain as much information as possible on the detected object. It is shown that imaging provides significant valuable information. To derive images from an irregular scanning, a position monitoring system with high accuracy is needed. Here also, no off-the-shelf equipment met the system requirements and the OPMS was developed.

A photograph of the developed prototype in a typical operational posture is presented in Figure 1. It consists of the sensor head operated close to the ground, the back pack containing the electronics, a marker bar laid on the ground as a reference for the OPMS, and a remote Man Machine Interface (MMI). In section 3 the sensor selection is discussed. Hardware and software developments is briefly addressed in section 4. In section 5, the test campaigns are described. Finally, in sections 6 and 7, the system evaluation is presented and conclusions are drawn.

(a) The detector head and the backpack. (b) The detector head, the backpack (opened) and the marker bar. (c) The MMI notebook and the MMI screen.

**Figure 1 : The HOPE multi-sensor system and its various components**

## 2 THE HOPE CONSORTIUM

The formation of the consortium is presented in Figure 2. Vallon is the project coordinator. Partners on the last line are associated partners. Industrial partners are indicated in orange, research centers in blue, and NGOs are shown in green color.

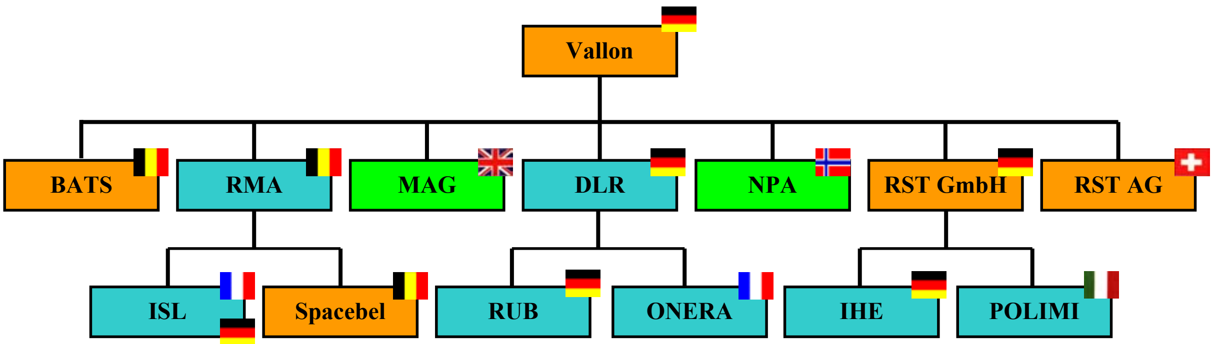



**Figure 2 : The HOPE consortium**

The main contribution of each partner may be summarized as follows:

- Vallon, RST and DLR developed the sensors, the MD, GPR and MWR, respectively. BATS was responsible for the embedded hardware.

- RUB, ONERA, IHE and POLIMI supported the GPR developments. RUB and ONERA worked for the radar signature modeling, IHE made the antenna design, and POLIMI investigated three-dimensional focusing techniques.
- MAG and NPA are potential end users; NPA set up the test sites in Sarajevo and provided the logistic support for the test campaign.
- RMA developed the OPMS, designed the software architecture, and implemented the MMI, the database, the MD advanced processing and the data fusion. Spacebel provided support for the software architecture design and ISL for the database, MD advanced processing, and fusion.

## 3 SENSOR SELECTION

The sensors must be selected to provide as much information as possible on the buried object to allow a significant reduction of the false alarm rate while keeping a very high detection rate. Due to the wide usage of the metal detector, it was decided to design a hand-held system to be operated in a similar way. To allow for a hand-held scanning, the volume and the weight of the selected sensors should be limited. Present metal detectors already show a very high detection rate and thus this sensor type was selected as the basic tool. Now the main objective is to reduce the false alarm rate. Therefore sensors that would allow the distinction between a mine and another metallic object, which would produce an alarm with a metal detector, were considered. Sensors that are able to detect pure plastic mines or low-metal mines in adverse conditions for the metal detector are interesting because they could increase the detection rate in non-cooperative soils, like conductive or magnetic soils, and provide a solution for the future if pure plastic mines become widely used.

A mine is characterised by one or several metallic pieces surrounded by a body. This body is partly filled with explosive and partly filled with air. The most direct indicator for a mine is the presence of explosive. Several principles can be used to detect the explosive and this is a subject of intensive research [4] but no explosive detection sensor seems to have reached maturity yet. Those sensors are usually quite slow and heavy and therefore they are usually seen as a confirmation device to use after a primary detection. In this scope, they could be used together with the HOPE system.

The mine body and its contents present a contrast against the environment with respect to many physical properties such as elasticity, thermal conductivity, thermal capacity, electrical permittivity, magnetic permeability and conductivity. Various sensors that are able to detect those contrasts exist but apart from the metal detector, none has reach maturity in the scope of mine detection. One may cite, infrared cameras, ground-penetrating radars, acoustic sensors. Intensive research is currently performed to adapt those sensors to the demining problem [5]. The GPR is amongst the most promising sensors because it is able to detect permittivity and conductivity contrasts. The explosive and air gaps contained in the mine bodies are such that in most soils a detectable contrast is expected. Besides the possibility to detect most mines including non-metal mines, in most soils, the GPR has the additional advantage of being able to provide three-dimensional images of the underground anomalies. Therefore a high discrimination power is expected from such instruments. GPRs are widely used in currently available multi-sensor detectors such as Hstamids and Gstamids [7]. Due to the high return of the soil-air interface, it is often difficult to detect surface-laid or shallow-buried mines. Therefore an additional sensor that would be dedicated to those surface-laid or shallow-buried objects was searched for.

An often-mentioned candidate for those mines is the infrared (IR) camera. The possibility to use an IR camera was considered but abandoned due to the low ground penetration depth. Apart from very favourable situations, IR cameras were not considered to add much useful information. Many non-mine objects do indeed also present thermal contrasts. The distinction can then only be based on the shape, but only lateral two-dimensional signatures may be obtained and thermal diffusion implies a significant blurring of the shapes and thus a weak discrimination power.

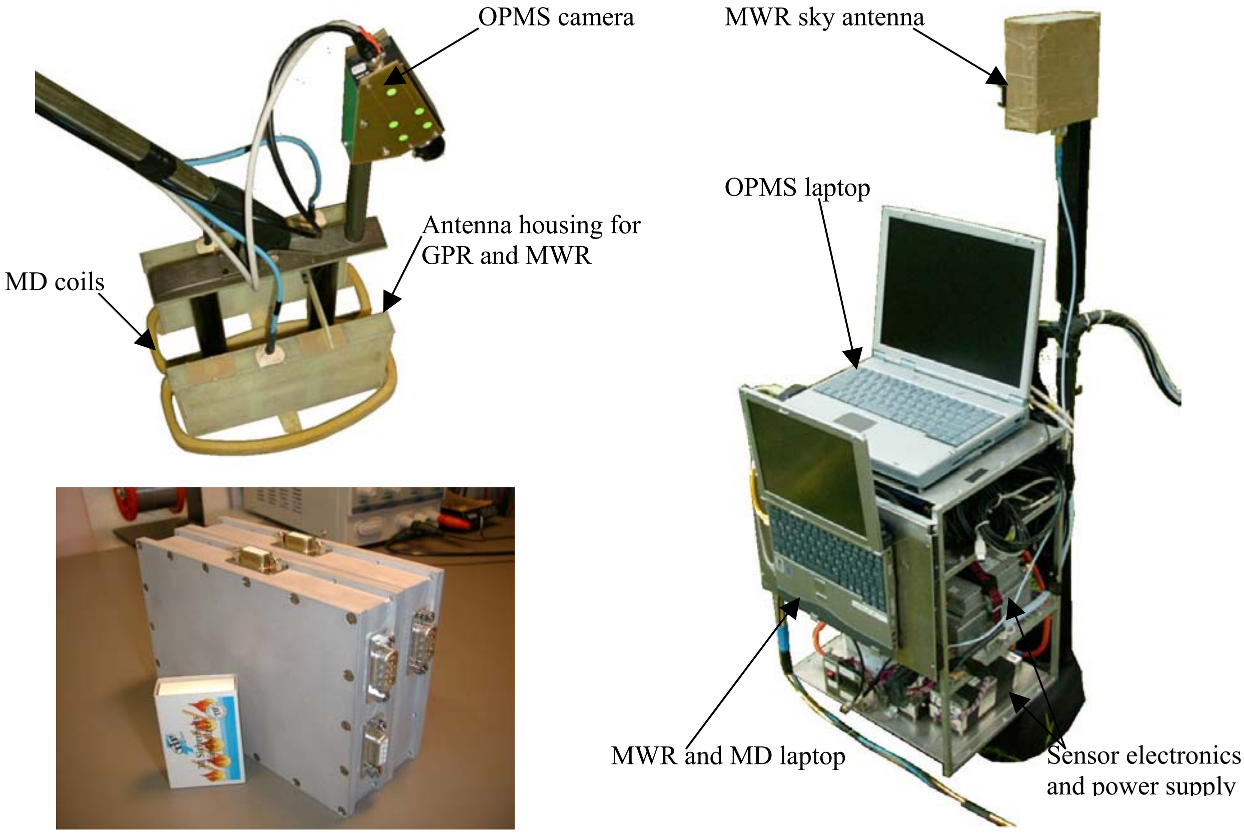
Another promising candidate is the MWR. Due to penetration depth constraints both the GPR and the MWR should be used in the same frequency range below 10GHz of the electro-magnetic spectrum. The final frequency range was chosen as a compromise between an adequate ground resolution, which can be obtained easier for higher frequencies, and a sufficient soil penetration achievable at the lower frequencies. Thus a frequency range of about 1-6GHz was selected, which allows to use the identical antennas for both sensors to avoid extra volume and weight. This is clearly an advantage of the sensor suite selected in the scope of a hand-held system.

The selected sensors - MD, GPR and MWR - deliver complementary information although they all work in the electro-magnetic spectrum. The metal detector works at very low frequencies of up to a few tens of kilohertz where the propagation effects may be neglected and the target is in the near field of the detector. It can detect conductive and magnetic materials. Although most commercial MDs do not include any discrimination capabilities discrimination should be possible through advanced processing, especially if, as in the HOPE project, a position monitoring system is available. The GPR and radiometer work at microwave frequencies where the electric permittivity contrast may also be detected. The GPR radiates electromagnetic signals and objects may be missed close to the surface where a strong direct return of the soil surface is superimposed to the target's signature. The radiometer only receives thermally generated radiation and thus is not sensitive to this problem.

## 4 HARDWARE AND SOFTWARE DEVELOPMENTS

As already mentioned, except for the MD, no off-the-shelf sensors are suited for the demining problem which has very specific requirements. Therefore, dedicated sensors taking into account the specifies of the demining problem were developed by the consortium. An improved MD that allows for a higher sensitivity and more advanced signal processing was also developed. As for the sensors, no off-the-shelf positioning system could be used and the OPMS was developed.

Due to space restrictions, the hardware development can not be presented in this paper and only some illustrative photographs are presented in Figure 3. The interested reader can consult [2][3][8]-[11].



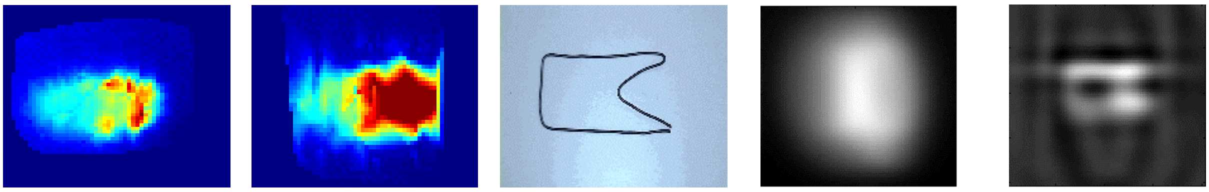

Top: HOPE head (a) and

bottom: GPR electronics box (b)

(c) MWR backpack

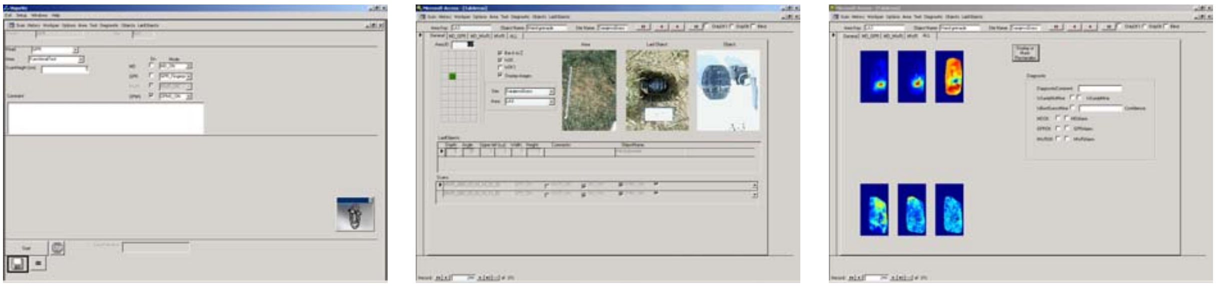
**Figure 3 : HOPE hardware illustration**

On the software side, advanced signal processing was implemented including imaging with the various sensors and focusing algorithms for the MD and GPR. Due to space constraint this advanced processing can not be presented in this paper. As an example, a raw MD images computed from a manual scanning and the MD focusing is illustrated in Figure 4. More information may be found in [1][8]-[11]. A specific MMI shown in Figure 1c and a database illustrated in Figure 5 were also developed to control the data acquisition, to store the acquired data in an ordered manner, to visualize the results and to perform the blind test evaluation.



(a) Shallow metallic sphere | (a) Shallow barbed wire | (c) picture of the object | (d) raw MD image | (e) focused image

**Figure 4 : MD imaging (a) (b) from manual scanning – (c)-(e) from regular scanning of an open flag shaped wire 8X16cm, 4 cm deep**



(a) Sensor control and meta-data encoding window | (b) meta-data display window | (c) Interpretation window including images created from sensor data

**Figure 5 : HOPE database**

## 5 TEST CAMPAIGN

To evaluate, validate and improve the single sensors and the combined system, several tests were performed. Photographs of the test sites may be seen on Figure 6. Laboratory tests of individual components and of the whole system were performed at the partner premises. First trials on foreign artificial mine fields have been performed at the JRC test facilities in ISPRA, Italy, where an X-Y table was available to perform a regular scanning. Additional test campaigns took place in Sarajevo, Bosnia, where the full detector including the positioning system was tested in the aspired manual scanning operation.

The JRC test site is described at the JRC web site [6]. It is composed of an outdoor test lane about 80m long and 5.7m wide. The lane is separated into several areas with various soils amongst which we scanned the areas number 1 to 4, and 7, corresponding to loamy soil, sandy soil, pure sand, and ferromagnetic soil. Each area has the same layout and contains mine simulants, non-mine objects and reference objects at various depths ranging from 0 to 15 cm. Mine simulants are of various size ranging from about 5 to 10cm and have a low or high metal content.

In Sarajevo, two test sites were set up by NPA, one with gravel and the other with grass. Both test sites are divided into two areas: one aspired for a learning procedure of the system, and another one to perform a blind test. Both consist each of 50 to 100 single small areas of 1m by 0.5m in size. In each small area, no, one or two objects are buried. For the learning area, the position and characteristics of the buried objects was available to the HOPE team, but not for the blind test area. All objects buried in the Sarajevo test site originate from actual mine fields in Bosnia and Herzegovina. The mines are real ones and contain explosives. Only the detonators have been deactivated. All false targets or unexploded ordnance (UXO) was found in actual mine fields before. In that sense, the objects used in Sarajevo are the most realistic ones.

(a) Ispra test facility

(b) Ispra – HOPE head on gantry

(c) In lab manual scanning

(d) Sarajevo grass test site

**Figure 6 : HOPE test sites**

## 6 SYSTEM EVALUATION

As a first evaluation, a blind test was performed using the data collected in ISPRA where a regular scanning was performed by means of a gantry. Images from the test set have been presented in a random order to the person doing the test who has to classify the object. Typical classes used were *No Metal*, *Sphere*, *Barbed Wire*, *Can*, *Surely A Mine*, and *Don't Know*. The results were compared with those that would be obtained by a conventional standalone metal detector, i.e. an alarm when, and only when metal is present, in order to estimate the improvement of the HOPE detector in the detection probability and the false alarm rate.

A significant improvement of the false alarm rate was observed. Up to 62% of non-mine metallic objects for which a conventional MD would produce a false alarm were correctly identified as non-mine objects. Typically all barbed wires and cans were correctly detected and identified

The detection probability has decreased because two mines were confused with barbed wire. This decrease, though reasonable, is clearly unacceptable for a commercial product. Nevertheless we believe that this is not due to a conceptual problem of the approach but to the marginal use of the non-MD sensors and to the absence of advanced processing - up to now only raw images were used. Even so, the results demonstrated the potential of imaging and of the multi-sensor concept.

The results obtained during the HOPE project are quite encouraging, although many of the ambitious goals have not or only partly been achieved. At the best knowledge of the consortium, this was the first time high-resolution registered images could be obtained from a manual and thus irregular scanning using a multi-sensor system. All sensors and the OPMS gave very promising results. However several problems remain and should be solved before the real performance of the system can fairly be evaluated.

The prototype was very useful to detect mainly many previously unknown problems and to understand them. Clear plans of the next generation system have been discussed inside the consortium after discussion with the end-user whose contribution was of utmost importance. Solutions for the most problems have been proposed and we are now in a good position to start the development of an operational product.

The reaction of the end-user, represented by NPA, to the system was quite encouraging. They were very interested by the potential false-alarm-rate reduction that the operational system could provide. They operated the system and felt that this prototype was not too far from an operational product and they showed a big enthusiasm for such an operational system. Furthermore they are willing to make the adaptation to their operational procedures which such a system could require.

## 7 CONCLUSION

A novel multi-sensor mine-detection system for a hand-held use has been developed, explored, and tested within the HOPE project. It consists of three sensor types – a metal detector, a ground penetrating radar, and a microwave radiometer – and an optical position monitoring system to allow imaging of an observed scene. The main goal of the system is the reduction of the false-alarm rate, which is high for classical stand-alone metal-detector operations, while the detection rate should be kept close to 100%. By using advanced data processing like imaging and data fusion the system was found to be able to approach the ambitious goals. As inescapable within highly demanding requirements and tightly attached time constraints, the single sensors and the final combined system are still facing some problems, which presently keep away the device from an operational status. Those problems, prohibited a fair evaluation of the system. Solutions for the most problems have been proposed and discussed with the end user and we are now in a good position to start the development of an operational product.

The prototype, even with the above-mentioned limitations, was very useful to demonstrate the concept. At the best knowledge of the consortium, this was the first time high-resolution registered images could be obtained from a manual and thus irregular scanning using a multi-sensor system. The system was operated in the field by the end-user which were really positive about it. It turned out that the operational procedures should be adapted to use the HOPE system but the end users did not find any major problem for this. Although limited, the first evaluation showed that indeed imaging, advance sensor data processing and data fusion brings quite valuable information that serve the system's main objective of false alarm reduction.

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