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Study on the State of the Art in the EU related to humanitarian demining technology, products and practice

EUDEM: The EU in humanitarian DEMining
Final Report

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GUIDANCE THROUGH THE DOCUMENT – STRUCTURE

1. INTRODUCTION

1.1. Framework in which the EUDEM project has been executed

Needless to say, the general public's awareness of the landmine problem has constantly grown in the last 5-10 years, and so has the response of the international community. Political activities have culminated in the signature in 1997 of the Ottawa ban treaty. At the convention, the European Union (EU) committed to reinforce its efforts in helping afflicted nations clear their land of these deadly weapons. Given the scale and complexity of the problem, it would be highly beneficial to ***increase the co-ordination for maximum efficiency***.

At the EU level, ***civil research*** activities have started within the High Performance Computing and Networking (HPCN) domain of the Information Technologies (IT) programme, to promote industrial R&D activities in Europe in support of humanitarian demining operations world-wide[1]. The aim is to bring advanced equipment to the field in 2-4 years to improve speed, cost and safety of demining operations.

Three ***ESPRIT[2] R&D*** projects started in early 1998 and *six* more in early 1999. These projects aim at *researching, developing and testing new systems for detecting anti-personnel landmines*. These R&D projects are supported by a set of activities carried out in common, which include testing and evaluation, surveys, and data collection. ***EUDEM is one of these support activities***.

Other projects, outside the ESPRIT programme, are also ongoing. A lot of initiatives are starting up, even if not necessarily in a well structured and optimal way, and *the overall European picture is not always clear*. This is where this study also wants to help by ***providing scientific and technical support to Community policies***, in addition to direct support to ongoing ESPRIT projects. This will hopefully help improving efficiency and reducing the duplication of efforts in R&D programmes on humanitarian demining at national and EU level.

1.2. What are the EUDEM goals?

The general purpose of the EUDEM project is ***to study the state of the art in the EU related to humanitarian demining technology***, products and practice. The detailed goals are as follows:

1. Establish a ***list of organisations to be consulted***, primarily industrial companies producing or developing equipment, used in humanitarian demining actions, and organisations performing or supervising humanitarian demining operations. Also include key research centres and university laboratories active in this field.
2. Set-up a ***public, detailed and open database*** (http://www.eudem.vub.ac.be/), to be filled in according to the information provided by individuals or associations actively involved in Humanitarian Demining, or feeling that their products/services/research topics stand a serious chance of being used in the field one day. The EUDEM database is meant to be a tool for understanding the state of the art in EU humanitarian demining technology, products and practice, facilitating strategic decisions and interactions between the various parties (industrial partners among themselves, researchers with deminers and industrial partners, etc.), and improving the flow of information.
3. Perform a ***survey*** of the identified organisations.
4. Summarise ***existing techniques***, and identify ***new technology*** developments, their state of maturity, and their potential impact on demining practice.

1.3. How did we achieve the EUDEM goals?

1. The following existing information sources have been exploited, to establish *an initial* ***list of organisations*** *to be contacted*:

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[1] See also the corresponding official Website at http://www.cordis.lu/esprit/src/hphdhome.htm.

[2] ESPRIT, the information technologies (IT) programme, was an integrated programme of industrial R&D projects and technology take-up measures managed by DG III, the Directorate General for Industry of the European Commission. It formed part of the EU's Fourth Framework programme, which ran from 1994 to 1998.

Internet: list of existing links and data bases
Internal list of persons and organisations, active in humanitarian demining, accumulated in previous VUB/EPFL projects
EU financed projects
Participants lists to well known conferences in the domain
Literature on the subject.

2. In parallel we defined the technical details of the database software and its contents, which in fact correspond to the two page *questionnaire* (see Annex 3), which was mailed to the organisations identified during the previous step. The ***EUDEM database*** was gradually populated during the survey, and *will remain an open working tool allowing updates and new entries* on a continuous basis.
3. The ***survey*** itself exploited a combination of literature review, telephone contacts, questionnaires, *face-to-face interviews*, and other methods. Information already entered into the database was used as a starting point whenever possible.
4. Selected organisations were visited (see Annex 4). *Persons active at an organisation level, or in demining practice and technical development were interviewed*. Also, some organisations not yet active in the field but showing relevant interest and/or innovative ideas were included.

1.4. Nature of this report

This report is complementary to the previously mentioned database; it contains an overview of the basic assumptions and methodology followed during the survey. It also provides a synthesis of the state of the art and of the general conclusions, which can be drawn at this stage. Its target audience is broad and includes the general public, managers, and decision-makers. Technically involved people might find detailed information, interesting views and comments on strategies for future activities in the summary reports of the personal interviews (see Annex 8). Although a case study on research projects in the US is included (see Annex 5), only the EU activities are covered in a systematic way.

The EUDEM database is a continuously updateable data repository, which can be used as a tool for active search and consultation of information provided by the organisations themselves. *The EUDEM database is accessible world-wide and not limited to organisations active in Europe.*

1.5. How was EUDEM perceived by the contacted actors?

Generally speaking, EUDEM was well regarded by most organisations included in the study. Although it was often pointed out during the interviews that making available an overview of the European humanitarian demining picture could be interesting, criticism was not completely spared. Demining NGOs and deminers see huge sums of money being spent on conferences, research and surveys. The latter is done supposedly on their behalf, and yet financial means to do what they are actually doing are extremely hard to find. The fact that the money for the two activity types does not necessarily come from the same sources seems difficult to understand for the affected and involved communities. Yet, it was admitted by several of the interviewees that there is a great need to collect data at supranational level in order to avoid duplication of efforts. A certain level of transparency into the “why” of surveys was demanded since this seemed to form an obstacle for voluntary participation.

2. METHODS

In making the selection of actors to be contacted, we tried to reach the whole spectrum in the EU. The database now covers a population that goes beyond the list of people that were directly contacted by us for making an entry. Apart from an announcement through the ARIS network, no other publicity was made, since the time frame of the EUDEM project was too short. In order to be useful for the humanitarian demining community, the database should *remain an open working tool allowing updates and new entries* on a continuous basis, even after termination of the EUDEM project.

2.1. Justification of the chosen database system

As already pointed out we wanted ***a public, detailed and open database***, in which each user could quickly set up an account in order to *create and modify his own entry*[3], as well as *carry out searches on the full database*. The

[3] Which we did ourselves whenever we received a filled in questionnaire on paper, but direct access was and is preferred.

basic idea was to make records containing at least some contact information and a short profile, with the possibility of adding more detailed information. The Web interface had to be simple and easily adaptable, preferably with the necessary administration facilities already available.

Given these constraints, the small data quantity requirements, and the short time frame for set-up – the database had to be up and running shortly after the study's start and before the mailing of the questionnaire – we opted for a public domain software package[4], ***DBMan*** v2.0. DBMan works on a simple text file (a flat ASCII file) and uses a number of Perl scripts to provide a Web interface to individual records. Administrative tasks (add/remove/modify/view records, or add/remove users for example) can be carried out, and there is no need for reprogramming.

2.2. The questionnaire for the EUDEM database

After the initial establishment of the list of organisations to be contacted, the second phase of EUDEM consisted of a mailing, which was carried out in three different parts. At first 110 organisations were contacted at the end of January (January 26, 1999). These organisations received a one-page accompanying letter and a ***two-page questionnaire*** (see Annex 3). The survey was divided in three different sections:

- PART I: **Identification Data** (mandatory reply, unless otherwise specified) – *Organisation name, type, contact person, staffing figure, involvement in demining and type of involvement;*
- PART II: **Structural data on the organisation type** – *Products/services/research topics, current activities, Specific technologies, etc.;*
- PART III: **Background data** on the organisations' partners and more specific information – *Comments, needs, references.*

The questionnaire is short and most questions can be answered by ticking boxes, to lower the threshold for participation. The deadline for filling out the questionnaires – either directly in the database or by mail/fax to the VUB – was placed on February 26 (one month after the initial mailing).

At the beginning of March a reminder was either e-mailed or faxed to 82 organisations that had not replied by then. In addition, another 58 organisations that were not contacted in the initial phase, including a number of organisations outside Europe, were contacted. The new deadline for all submissions was set for the end of March.

As already mentioned, plans exist to ensure that the EUDEM database will remain an open working tool allowing updates and new entries on a continuous basis, even after the termination of the current project.

2.3. Typical interview skeleton

An interview was always started by giving the interviewee a short introduction of what our survey consisted of, and for what purpose it will be used. Consequently, a brief overview of the interviewed organisation was asked for. This part was followed with an attempt to clarify the involvement in Humanitarian demining activities. A brief discussion was held on the past and current activities of the organisation. Most emphasis was placed during the interviews on ***the personal opinion of the interviewee*** with respect to a certain technology and/or practice.

When specific projects – not necessarily directly related to humanitarian demining – were discussed, we tried to identify the (i) **Project aims**, (ii) **Maturity** of the different technologies involved, and corresponding **Cost estimates**, (iii) **Testing** procedures, (iv) "**Transferability**" of the developed techniques to different aspects of humanitarian demining, (v) **Technical specifications** of the equipment, performances in certain circumstances, compatibility between different techniques, degree of success in the field, and (vi) **R&D activities and strategies**, research funding, commercial perspectives.

Whenever time was available, it was a pleasure to talk about diverse topics of interest in a non-structured way. Several examples can be found in the written transcripts of the interviews (see Annex 8).

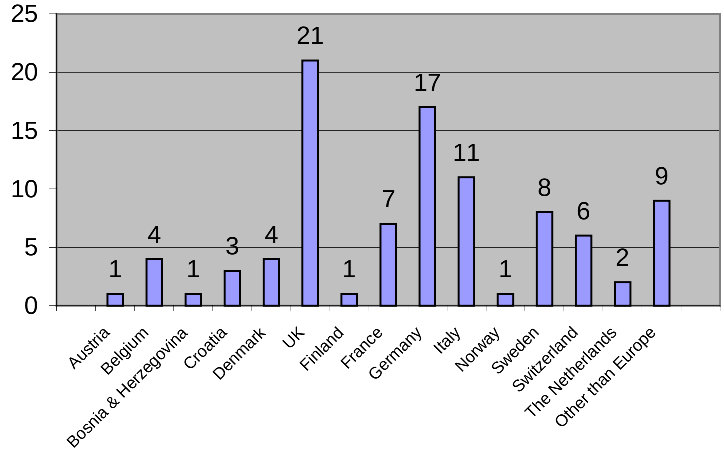
[4] See also http://www.gossamer-threads.com/scripts/dbman/index.htm.

3. THE EUDEM DATABASE: ANALYSIS OF THE CONTENTS

3.1. In general

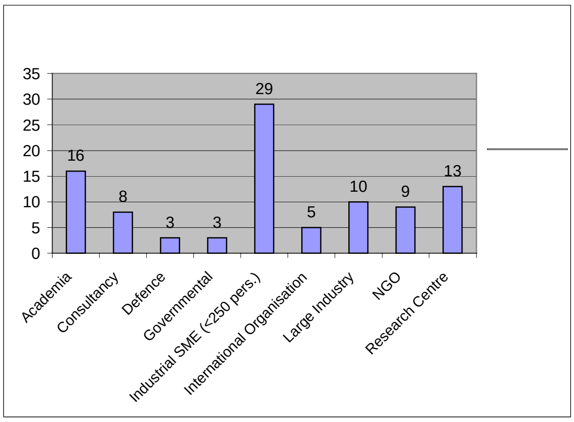
The overall response rate to the questionnaire has been very high. Out of the 168 contacted organisations, ***96 entries***[5] were made in the online database at http://www.eudem.vub.ac.be/, either by the organisation or by us when the questionnaire was received on paper.

The distribution of the database entries over the different countries reveals the highest score for the ***UK (21)***, followed by ***Germany (17)***, and ***Italy (11)***. For the Scandinavian countries, the highest score is found for ***Sweden (8)***. Note that also 9 entries of organisations from outside the EU have been registered.

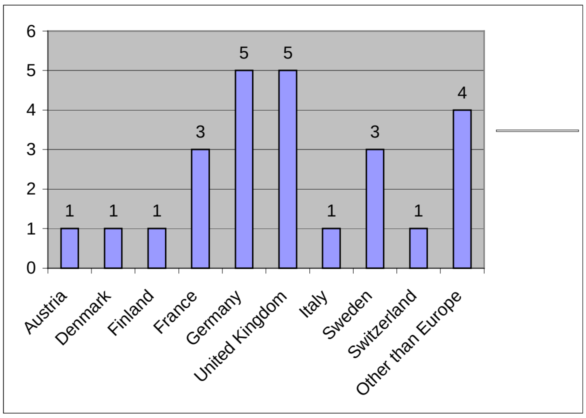


Graph 1. Distribution of entries in the EUDEM database over countries (total: 96)

The ***highest number*** of database entries clearly comes from ***Industrial Small and Medium Enterprises*** with less than 250 employees (Industrial SME (<250 pers.)) – see Graph 2. These are often not exclusively focussing their production on tools for humanitarian demining. Their willingness to participate in the EUDEM survey may also be explained by commercial agendas. The 8 entries labelled as "consultancy" in Graph 2 are small companies, mostly created by private consultants. In total, 31 organisations mention consultancy as one of their activities.



Graph 2. Distribution according to the organisation type



Graph 3. Distribution of INDUSTRIAL SME, according to the country of origin

The highest concentration of Industrial SMEs is found in Germany (5) and the UK (5), followed by Sweden, hosting 3 Industrial SMEs (See Graph 3).

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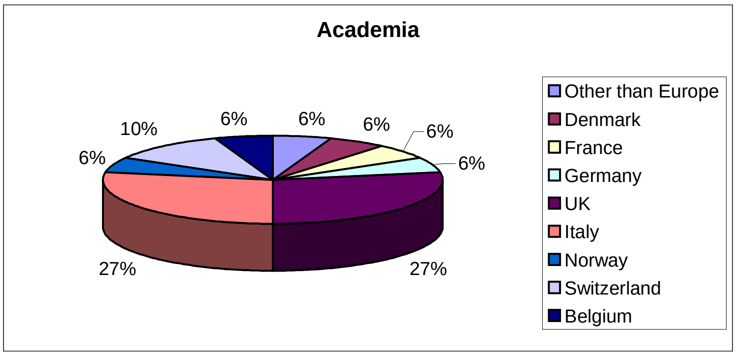
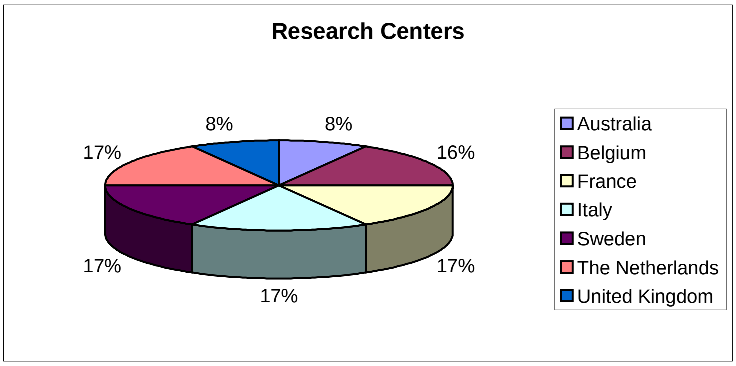
[5] The entries were taken into account for the extraction of statistics until the end of May 1999. Data entered after this date have not been considered.

Academia's (universities) take the ***second largest share*** of entries made in the database. This may be explained by their eagerness to participate in collaborative EU research and development projects, their policy of putting results in the public domain (e.g. publications, patents,…) and the less stringent constraints to protect their property rights. The densest concentrations of academic institutions involved in humanitarian demining are again to be found in the UK and surprisingly enough in Italy. They both count for 27% each of the academic organisations (which made an entry in the database) involved in humanitarian demining in Europe, or together for more than 50% of the total (see Graph 4; entries are shown in clockwise order starting from the top).



Graph 4. Distribution of Academic Institutions in the EUDEM database according to the country of origin

Besides universities, ***research centres*** have also made a large amount of database entries. The research centres in Europe are mostly located in four countries, namely Sweden, The Netherlands, France and Italy, followed closely by Belgium (see Graph 5; entries are shown in clockwise order starting from the top).



Graph 5. Distribution of Research Centers entries in the EUDEM database according to country of origin

Although we have made a distinction between universities and research centres, in practice both are often mainly/partly funded by the government, and hence it depends primarily on the countries' strategy for organising research whether a certain research activity is carried out in universities or in separate research centres. Graph 4 and Graph 5 show that ***the EU hosts a very large independent research potential, compared to the industrial involvement***.

3.2. Involvement in humanitarian demining

The 87 European organisations that filled in the field concerning the ***type of involvement*** in demining, are all mentioning ***mine detection***, either or not *combined with clearance/destruction and/or survey/mapping*. Out of the 87 organisations, 64 (i.e. 74%) declared to be involved in mine detection and the remaining 23 (i.e. 26%) mention a combined involvement in mine detection together with Clearance/Destruction and/or Survey/Mapping. Note that the manifest predominance of mine detection in the EUDEM database does not come as a surprise, because we have biased the survey towards that area of demining.

3.3. Technologies studied or developed in Europe

In this section, we try to give an interpretation of the database entries, with respect to the main foci of interest. The 9 organisations outside of Europe are not taken into account. Out of the 87 respondents in Europe (see Graph 1), only 70 have given information on technology studies. The numbers given in this section are only indicative, and should not be taken as absolute numbers.

We find the highest focus on the ***Ground Penetrating Radar*** (GPR) *technology*: 20 organisations declared to be working on or with GPR. The second highest score goes to the ***Metal Detector*** (MD), mentioned by 15 organisations. ***Infrared*** (IR) technology is mentioned in 6 entries distributed over different European countries. The 7 entries mentioning ***Dogs*** for mine clearance are also spread over the whole of Europe. Research on ***Nuclear Quadrupole Resonance*** (NQR) is conducted mainly in the UK at several institutes, at one organisation in Italy and one in Switzerland.

4. THE STATE OF THE ART IN EUROPE

This paragraph has been mostly drafted on the basis of the direct interviews carried out during the EUDEM study (the complete list of interviews is given in Annex 4, a summary of the interview contents can be found in Annex 8). The organisations and individuals we encountered include industrial companies, operators, key research centres, university laboratories and government agencies active in humanitarian demining, as well as some organisations not yet active in the field but showing relevant interest and/or innovative ideas. We concentrated mostly on detection, and partly on clearance and destruction equipment technologies; other aspects of the mine action process were partly investigated with the operators themselves, as well as with some government agencies. The organisations previously mentioned can be subdivided as follows:

ORGANISATIONS	TYPE	Interviews
Industry	Equipment manufacturers (for humanitarian demining)	6
Operators	R&D	9
	NGO	3
	MAC	4 (Geneva, Croatia)
	Commercial	2
Research centres	Supra-national	2 (ISL, JRC)
	National	7
University laboratories		4
Government agencies	MOD, Foreign Affairs, Development Aid	5

Table 1. Types of organisations and number of corresponding interviews

4.1. Current Equipment in the Field

4.1.1. Mine Dog Programs

Dogs can and are used to smell explosive vapours and/or traces, similarly to what is done at airports and in other security applications. Examples of application go back to the Second World War and in more recent times to the Vietnam War. Dogs were first employed for humanitarian demining in Afghanistan, which nowadays features one of the largest and most successful programs.

Dog training is extremely difficult and time-consuming, and lasts up to 3 years. Two dog-training centres were visited, one hosted by the Swedish Army and a commercial one, also located in Sweden. The training in the country of origin is essential and should be continued in the country where the dog has to work to ensure the adaptation to different working, soil, vegetation and weather conditions and also to a new local handler. The handler and the dog form the demining “system” and cannot perform well without perfect matching.

The price of a good dog is very high. Other ***limiting factors*** are unfavourable climatic conditions (such as excessive heat, too much wind or wind coming from the wrong direction), thick vegetation, as well as dense and/or mixed (AT and AP mines) minefields that can confuse the dogs. Daily working hours are also relatively short, but dogs can easily cover several thousand square meters per day (figures vary sharply).

The use of dogs is far from being a perfect science, and the detection rate (efficiency) of a dog-handler pair is subject to rather wild guesses. Nevertheless, well run dog programs are nowadays generally accepted by most humanitarian demining organisations for ***area verification*** (e.g. *Quality Control* after mine clearance activities) and ***minefield delineation*** (i.e. *area reduction*). For these applications, important time gains are obtained compared to manual clearance. The use of dogs for individual mine detection is somewhat more controversial (although examples exist: e.g. rescue operations, mine clearance in Afghanistan). In general, mine dog programs seem to be expanding (see for example the Swedish contribution to the establishment of a program in Cambodia). Handicap International estimates that *less than 500 dogs are currently in use world-wide*[6].

Intensively discussed issues are ***the lack of coherent and universal testing protocols*** *for dogs and the insufficient local training for the dog and its new handler. The systems differ from organisation to organisation. An important discussion point is also the lack of agreement on a Standard Operating Procedure (SOP).* A number of scientific studies (e.g. FOA in Sweden) try to clarify what dogs actually detect (minute amounts of explosive, or a composite odour in higher concentrations, etc.).

An ***excellent report*** has been published by Handicap International on the subject: "The use of dogs for operations related to humanitarian mine clearance", (2nd quarter of) 1998, ISBN 2-909064-33-6, 229 pp, ed. by Chris Horwood, Bill Howell, Robert Keeley, Dr. Jean-Baptiste Richardier.

4.1.2. Manual Demining

Detection and clearance in Humanitarian Demining very often rely on manual methods as the *primary procedure*. The problem resides primarily in the detection phase: once a mine has been found, deminers know well how to remove it or blow it up[7]. When operating in this way *the detection phase still relies heavily on metal detectors*, whereby each alarm needs to be carefully checked until it has been fully understood and/or its source removed. This is normally done visually, and by *prodding and excavating* the ground. Sometimes this is the only way to explore the ground, for example when the area is saturated with metallic debris or when the soil is too conductive or magnetic.

Unfortunately, metal detectors cannot differentiate a mine or UXO from metallic debris. In most battlefields, but not only there, the soil is contaminated by large quantities of shrapnel, metal scraps, cartridge cases, etc., leading to between 100 and 1,000 ***false alarms*** for each real mine. Each alarm means a waste of time and induces a loss of concentration. When manual methods follow other procedures, such as mechanical clearance, constraints on the need to check each alarm are often somewhat relaxed**.**

We have not gone into the details of ***incremental improvements*** to the current field procedures, and we left aside the discussion of SOPs and the specific procedures to take care of intelligent devices, booby traps, vegetation cutting, trip wires, etc. We would like, however, to point out the importance of continuous developments to improve several pieces of equipment (e.g. protection items, more effective prodding and excavation tools, or vegetation cutting equipment) that, far from being spectacular, can make a difference in the field and bring ***real short term added-value***.

4.1.3. Metal Detectors

The detectors we are considering here are electromagnetic sensors exploiting low frequency electromagnetic fields up to some hundred kHz roughly. These sensors are capable of *detecting metallic objects buried in the ground at shallow depth*, whilst indirectly providing "limited" information on their nature (depth, shape, size, etc.). Proximity of the sensor to the surface is usually required.

Magnetic Devices

Magnetic devices rely on the influence of nearby ferromagnetic objects, either via induced or via residual magnetisation, on top of the Earth magnetic field. They are called ***magnetometers***, or ***gradiometers*** when used in a differential arrangement. These very sensitive devices are usually employed to detect large ferromagnetic objects such as UXO and can be effective at depths of several meters, but do not react to non-ferromagnetic targets. They are only used in humanitarian demining when a real need exists (e.g. deeply buried UXO).

"Metal Detectors" (Electromagnetic Induction Devices)

Electromagnetic induction devices, which are often referred to as "metal detectors", are active devices capable of detecting tiny amounts of metal (from a fraction of a gram onwards) at shallow depths. They are still to the best of our knowledge, apart from dogs, *the only detectors really being used in the field*, and are probably going to remain in use for some time. Frequency Domain systems have often represented the choice because they seem to work well especially for very small and nearby objects, but they are being more and more challenged by

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[6] Ben Lark, Proceedings, Demining Technologies - International Exhibition, Workshops and Training Courses, A. Sieber (Ed.), 29 Sept. – 1 Oct. 1998, Ispra (VA), Italy, p 101, EUR 18682, 1998.

[7] Which does not mean that new, cheaper and/or safer disposal methods are not welcome as part of the overall demining tools.

pulse systems, and not only where ground conditions are severe (e.g. sea-water or laterite soils, see Explanation Box).

European metal detector manufacturers are well established at international level and include *Ebinger, Förster and Vallon in Germany, Schiebel in Austria, and Guartel in the UK*. Most of these companies are small, and jealously guard the secrets of the trade; technical and scientific documentation has unfortunately been rather rare up to now. Production has been in general mostly geared towards the military market. Recently several systems that take into account the humanitarian demining needs have seen the light. Metal detectors designed for humanitarian demining usually share the following characteristics:

- **Weight**: less than 2 kg. **Price**: in the 2000-4000 EURO range.
- **Size**: round, oval or rectangular head. In the former case the diameter is between 20 and 30 cm, to achieve sufficient depth and a reasonable scanning surface and speed.
- **Operating depth**: shallow, i.e. from flush (even with the surface) down to about 10-15 cm for minimum-metal mines, 20-30 cm for mines with an appreciable metallic content, and about 50-70 cm for large metallic objects such as UXO or metallic mines.
- **Electrical/Mechanical**: capable of working with standard cell batteries for a long time (tens of hours), and usually simple to use. Many demining teams pay more attention to the ergonomics rather than to the pure performances of the detector itself.
- **Output**: normally an audio signal, usually already the result of extensive internal data processing**,** from which an experienced operator can make some qualitative statement on the target and its position. *When using manual methods as the primary procedure,* ***each*** *alarm is carefully checked* until it has been fully understood and/or its source removed.

To the best of our knowledge no current metal detector for humanitarian demining applications delivers some quantitative information on the object under analysis. This is astonishing at first view, since there are other disciplines like Non Destructive Testing where this is the case. It can probably be explained by the urgent priority to enhance detection performance through better background rejection (i.e. reduction of the metal detector false alarm rate) and achieving higher sensitivity, as well as by the need of being very precise whilst usually not having any a priori information on the object under analysis.

A few large coil metal detectors, by Ebinger and Vallon for example, have been manufactured for the detection of larger metallic objects such as metallic mines or UXO. They can for example be employed as an alternative to magnetometers for the detection of ordnance that is not too deeply buried, or in cases where magnetometers can not be used (magnetic soil).

Metal Detector Arrays

Most metal detector arrays, normally one to several meters wide, are derived from commercially available metal detector technology and are *usually employed for vehicle platforms to rapidly scan large areas*. Some of them can deliver information not only on the location of metallic objects but also on their depth and their approximate size, for example in the form of an "equivalent object volume" (which can be used to reduce the number of false alarms when looking for UXO for example). Some systems do also employ a special suspension system to make sure that the detectors are always parallel to the surface, and that a constant height is maintained.

European manufacturers include Förster (working within the ESPRIT LOTUS project), TZN and Vallon in Germany, as well as Schiebel in Austria. Förster is working on an extension of its portable MINEX 2FD two frequency continuous wave technology, using one large rectangular transmitter coil and 7 staggered (i.e. partially overlapping) differential receiver coil pairs; the final system should not be too expensive. TZN is a relative newcomer to the field, and is now commercialising the AMOS Unexploded Ordnance Detection System, which uses pulse induction and features a double layer coil system. Vallon and Schiebel arrays have been on the market for some time, whereby the Schiebel VAMIDS (Vehicular Array Mine Detection System) has been used in a number of projects; it employs combinations of 1 m wide flexible or rigid segmented arrays containing eight individual sensors.

Apart from the use in combination with other sensors, metal detector arrays can be used on their own, possibly for *Quality Control applications*, and the set-up/maintenance of a *data archive* in order to compare previously executed searches with new searches[8] (suggestions by TZN). *Applications on road and road verge, or in combination with a magnetometer for the detection of UXO are* also feasible (suggestions by Förster). They obviously strongly depend on the end user and its SOP.

EXPLANATION BOX

Metal Detectors (Electromagnetic Induction Devices)

Metal detectors (MDs), actually electromagnetic induction devices, are usually composed of a search head containing one or more coils carrying a time-varying electric current. The latter generates a corresponding time-varying magnetic field. This primary field reacts with the electric and/or magnetic properties of the target (the soil itself or any metallic object), which responds to it by generating a secondary magnetic field. This effect links back into the receiver coil(s) in the search head, where it induces an electrical voltage which is detected and converted, for example, into an audio signal.

The secondary field depends, both temporally and spatially, on a large number of parameters such as the distance, material type, orientation, shape and size of the buried object, but target characterisation is very difficult in the general case. The secondary field is due to eddy currents, which are induced by the primary field in conductive materials. Low conductivity metals, such as some alloys and stainless steel, are in general more difficult to detect, whereas the detector's response is magnified for ferromagnetic objects (induced magnetisation).

In the case of a circular coil of radius R for example, the primary field behaves at a distance z on the coil axis as $R^2/(R^2+z^2)^{3/2}$, i.e. decreases with the cube of the distance far away from the coil. Given that the secondary magnetic field has to "propagate" all the way back to the receiver coil(s) it is not surprising that the "art" of building metal detectors consists, in a certain sense, in discriminating small target signals from background signals. Smaller coils provide better sensitivity (at closer ranges, $z \approx R$) and spatial resolution, but do not allow going as deep, and scanning as fast, as the larger ones.

Frequency Domain (Continuous Wave) Metal Detectors

Metal detectors can be subdivided in Frequency Domain, or Continuous Wave (CW), and Time Domain, or pulse, systems. Frequency Domain instruments make use of a discrete number of sinusoidal signals, very often just one. They can employ separate transmit/receive circuits, measuring the (small) change in mutual inductance between the transmit and the receive coil(s) caused by the presence of metallic or magnetic objects.

Information on the target's nature is contained in the amplitude and phase of the received signal, as the detector approaches the target. Measurements carried out in background conditions can be used to reject part of the background signal itself, especially in areas in which the detector's performance would otherwise be seriously degraded, such as sea beaches (sea-water is conductive) or strongly mineralised regions, which can be conductive or iron rich. Generally speaking, background rejection is more difficult in heterogeneous areas.

Time Domain (Pulse) Metal Detectors

Time Domain, or "pulse", instruments work by passing pulses of current through a coil (typical repetition rate of the order of 1 kHz), taking care of obtaining a high slew rate to minimise the current switch-off transient time (a few μs). Eddy currents are thus induced in nearby conductive objects and their exponential decay with time is observed. A Time Domain metal detector measures how quickly the momentarily generated magnetic field breaks down, which happens to be slower in presence of metal.

The eddy current decay time constant itself, some hundred μs, depends (predominantly) on the target's conductivity, permeability and size. Low conductivity background and nuisance items, such as seawater for example, have a very short decay time. A pulse detector, which is tuned to sample only a specific portion of the received signal, can therefore be "easily" made insensitive to them by an appropriate choice of the delay (some tens of μsec) between the time of switch-off and the sample acquisition. A similar argument applies to purely magnetic but non-conductive targets, which are magnetised by the transmit pulse but demagnetise just as promptly after switch-off.

A pulse systems is therefore the detector of choice when it comes to working in seawater or strongly mineralised soils (containing for example bauxite, laterite, magnetite or magmatite, which are conductive and/or magnetic) as found in parts of Cambodia, Mozambique and Angola. On the other hand, at least up to some time ago, overall sensitivity was probably low in comparison with Frequency Domain detectors, and there were problems in finding low conductivity metallic object such as those made of stainless steel.

Given that the transmit and the receive phase are temporally separated, pulse detectors can use one and the same coil for transmitting and receiving; the decoupling of the two phases also allows to work with high power, and therefore to go deeper. Power consumption might obviously become an issue.

4.1.4. Mechanically Assisted Demining

[8] Recording the data might in fact be useful in case of controversy at a later stage, i.e. after clearance, for "going over the books" easily.

A number of machines have been tested during the past years, partially adapting them from military designs. The general trend goes from "mechanical demining" towards "mechanically assisted demining", adaptable to local circumstances. Without pretending to be exhaustive, the following systems are currently used (see *Humanitarian Mine Action Equipment Catalogue 1998/1999, German Federal Foreign Office* – second draft):

- **Vegetation cutters**: in many countries, and not only tropical ones, vegetation is a large problem and its removal (mine detectors have to be used in close proximity to the soil, and tripwires have to be detected) can take up a substantial fraction of the time. Vegetation cutters are used by several organisations to accelerate manual clearance and the work of sniffing dogs. In their simplest form they consist of adequately modified commercial devices (e.g. tractors or excavators).
- **Mine Clearing Flails:** clearance machine hitting and milling the ground with a series of flails (long chains with clearing elements, similar to hammers, attached to them). The flails are attached to a rapidly rotating drum, and *detonate the mines or break them apart*. Such systems have been in use for years for military applications, and a number of units have also been produced and tested during the last years for humanitarian demining. European producers include Aardvark in the UK, Hydrema in Denmark, Patria Vehicles in Finland, Technopol in Slovakia. Prices start from about 500 k EURO, and the systems are rather large, at least 15-20 t. Clearance depth is usually adjustable, and there is a trade-off between depth and forward speed. Several machines are in use, for example with NPA in Angola.
- **Mini Flails:** a smaller version of the flail system just described, with correspondingly reduced price and maintenance cost, designed in particular for vegetation clearance (see also the *Vegetation cutters* described above). Some systems should also be able to clear (shallow) landmines. Much development work is still going on (e.g.. in the UK at the Warwick University); some systems are operational (e.g. the Croatian MV2).
- **Earth Tillers**: rather large and bulky clearance machines employing one or more rotating horizontal drums with special teeth, capable of tilling the soil to a variable depth, detonating or disrupting mines as they move on the field. Weight is usually at least 30-40 t (some machines have been built around a tank chassis), and prices go from 1 M EURO upwards. European producers include amongst others MaK (Rhino system) and Krohn in Germany, Bofors (Mine-Guzzler) in Sweden. Some systems might be in use or being tested.
- **Wheel Shovel** (e.g. HALO Trust in Afghanistan) based systems for digging up mines that will be manually cleared afterwards, for the excavation and inspection of (urban) rubble, also for roads (road grader). A mesh basket is fitted over the shovel, which then shakes out the rubble; large ordnance and mines will remain held by the mesh in the bucket.
- **AP Mine Sifter** (e.g. MgM Foundation in Angola): a drum is used to pick up the contaminated soil; it then closes and rotates, and the loose soil falls out. The remaining debris can be visually inspected.
- **Mine Protected Vehicle**: MPVs are vehicles designed to resist AP and AT mine explosion. They can be modified, for example by replacing the tyres with large steel wheels or attaching devices such as steel disc roller sets, for mine clearance (e.g. Mechem - South Africa, also used in Croatia).

Concerning the mine clearing vehicles in particular, one can say that usually the machines have to be backed-up by some manual method (full detection drill or visual inspection), dogs or a second machine in order to guarantee a satisfactory overall clearance rate. These systems are *employed for mine verification and area reduction tasks as well as clearance of actual minefields*. They are mostly used in wide areas (not in dense forests), and roads. Large mechanical systems, in particular the flail and tiller machines, do require substantial investments, not only for machine costs but also for logistics and maintenance, and can actually only be employed on a fraction of the total mined areas.

Environmental effects, such as erosion and soil pollution due to exploded mine residuals, have not always been duly studied. A confidential study on the effects of mechanical clearance on the natural ecosystem has been carried out in Norway. More emphasis should be attributed to this specific aspect of demining.

More information on Mechanically Assisted Clearance is available in the summer issue (June/July 1999) of the Journal of Humanitarian Demining (published by the Mine Action Information Center at the James Madison University, see http://www.hdic.jmu.edu/hdic/journal/3.2/), as well as from the ongoing study on Mechanical Support to Demining by Handicap International.

4.2. Emerging Sensor Technologies

Needless to say, *the detection capability, and corresponding false alarm rate, are only two of the many parameters that have to be considered.* Others, will also strongly determine if the system will ever be fielded, e.g. *importance of the target application, cost, size, complexity, penetration depth, simple and/or user friendly man machine interface (MMI), etc*. The risk of R&D is, as Colin King once put it, to devise systems which "work best where they are least useful".

4.2.1 Enhanced Metal Detectors

These detectors have indeed become more and more refined and sensitive over the years. Although it has often been said that they have reached their limits, there are still opportunities for ***improvement in background rejection***, helping in difficult soil conditions, and perhaps in ***sensitivity***. Developments are ongoing, and partly financed by current EC R&D projects.

Next in the line of "realisable" items is probably the determination of the ***object's depth***. It could be delivered for example either by scanning the detector across the object and analysing the width of the response (or other parameters), or by taking at least two measurements under different conditions, for example by using two overlapping coils which is probably easiest. Some of these techniques are in use for Non Destructive Testing applications and UXO localisation.

Giving an estimate of the ***object's size*** is next in the wish list. In principle the object's size should represent an interesting piece of information, although opinions diverge. One way of estimating the size of an object could consist in measuring the magnetic field over an area in order to try to calculate the object's magnetic dipole moment (typically using a simple, dipolar model), that gives an indication of its "magnetic" volume. Another way is to try to extract the information from the time behaviour (the pulse shape) of the received signal in a pulse detector for example. Again, technical feasibility as well as applicability in the field and sources of errors have to be very carefully studied. This development is also being looked into but is probably rather tough: a detector's response contains a lot of information on the target, but depends on a series of parameters as well.

Another approach is to generate an ***image***, for example by scanning a single sensor over a surface. Resolution enhancement techniques such as deconvolving the detector's intrinsic response might also be tried. Whether this approach will be practically applicable in the field, from the point of view of the resulting resolution, scanning speed and cost for example, remains to be demonstrated. Imaging activities seem to be still at the research level.

Another interesting line of research is to investigate how concepts from ***low-power electronic design*** can be used to *increase autonomous operation time* (e.g. proposals exist for systems that are (partially) powered by movement).

Other hardware improvements have been suggested, such as sensors other than the ordinary coils currently used in metal detectors, for example *giant magnetoresistive elements*, or *miniature fluxgate elements*. They are expected to be broadband and provide better spatial accuracy; the construction of linear or bidimensional arrays should also be possible, delivering some kind of localised image of the soil metallic/magnetic contents. On the other hand their overall sensitivity is likely to be smaller, which might very well discourage their use for certain applications (their use might for example be envisaged for the detection of UXO or mines with a relevant metal content, but not for minimum metal mines).

It is interesting to see that *for most of these activities there does not seem to be a clear cut opinion neither on the technical aspects (realisable or not) nor on the actual applications and utility in the field.*

4.2.2. Passive Microwave Radiometers

Passive radiometers working in the microwave range of the electromagnetic spectrum have been suggested in particular for the detection of mines placed on the surface (but covered with light vegetation for example) or shallowly buried mines (some cm). The actual maximum detection depth is a strong function of the frequency being used, soil humidity and conductivity, material type (metal or plastic) and size (AT *vs.* AP Mine for example). Increasing the frequency, results in better spatial resolution, but soil penetration can be drastically reduced (especially for wet soils); the trend has been therefore towards lower operating frequencies, say below 10 GHz. We are referring here to close-in detection; distant detection of larger objects on the surface seems possible too, using millimetre wave devices (i.e. working at higher frequencies, for example 94 GHz).

Metallic targets do indeed 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 radiation depends therefore almost entirely on its physical temperature, whereas metal radiation depends mostly on the reflection of the low-level radiation from the (cold) sky which "illuminates" it. It is possible to measure this contrast between the "warm" ground and a "cold" mine (both temperatures as seen in the microwave band) using a passive radiometer; the latter basically consists of a receiving antenna measuring the microwave radiation coming from an object and functions like a microwave band power meter. The detection of plastic targets is also possible but more difficult, given that they produce a much smaller ΔT (temperature difference) than the metal objects (they have much lower reflectivity and transparency to radiation rising from below them).

Passive microwave radiometers are simpler devices than the Ground Penetrating Radar and should suffer less from clutter problems. In principle it should be possible to build man portable systems using rather low cost materials. Like many other sensors, they could be scanned over the ground to generate bidimensional images, with best results in dry soils, and for metallic targets and/or large objects.

Work on passive microwave radiometers is also being looked into within current EC R&D projects (e.g. by ERA in the UK, DLR in Germany and Thomson-CSF Detexis in France), usually in conjunction with a Ground Penetrating Radar that might have problems with the detection of surface or shallowly buried objects. It will be interesting to verify if there are some applications where microwave radiometers can be used on their own.

4.2.3. Infrared (IR)

Infrared (IR) cameras are passive devices sensitive to radiation in the infrared part of the spectrum (i.e. basically to the physical temperature of a body). They are capable of detecting under some circumstances *mines on the surface as well as buried mines*. The detection of buried objects might seem rather surprising, given that IR rays do not penetrate the ground and that it is therefore not possible to measure directly the temperature of a buried mine. What happens is in fact that mines do retain or release heat at a different rate than their surroundings. During natural temperature variations of the environment it is therefore possible, using IR cameras, to *measure the thermal contrast between the soil over a buried mine and the soil close to it*. The devices of potential interest do normally operate in the 3-5 µm and 8-12 µm atmospheric windows[9], corresponding respectively to Medium Wave IR (MWIR) and Long Wave IR (LWIR).

When the previously mentioned thermal contrast is due solely to the presence of the buried mine (alteration of the heat flow) one speaks of a *volume effect*. When it is due primarily to the disturbed soil layer above and around the mine (resulting from the burying operation) one speaks of a *surface effect*, which can be detectable for some time (say weeks) after burial and which enhances the mine's signature.

Note that rather sensitive cameras have to be employed, with sufficient spatial resolution; the maximum burial depth that still allows detection, is estimated at 10-15 cm. In addition, results obtained with passive infrared imagery can ***depend*** quite heavily on the ***environmental conditions*** and there are crossover periods[10] (typically in the evening and in the morning) when the thermal contrast is negligible and the mine practically undetectable. Other problems are due to the target object's history, uneven surfaces, clutter and vegetation (which cause a number of secondary effects). *It remains to be seen if this heavy dependency on external conditions can be overcome in practical applications*, possibly enhancing the detection techniques. Two major approaches have been studied to enhance detection efficiency:

- The analysis of IR image sequences, showing the dynamic scene behaviour after or during time variant heating (e.g. solar illumination), as studied at VUB in Belgium, and BGT in Germany.
- The exploitation of an extra physical parameter, namely the polarisation of the IR radiation reflected and emitted by man-made objects, as studied at DERA in the UK, Thomson-CSF Detexis in France and Daimler Benz in Germany. A periodical image sequence can be obtained by continuously rotating the polarisation orientation.

Both methods are creating augmented contrast between the natural environment and man-made objects, by analysing *sequences* of images and combining them into one or a few parametric images.

Infrared systems have been and are being intensively investigated by a number of companies and research centres for defence applications, in particular for the *detection of mines and minefields* (mostly AT mines) *from airborne platforms*, and for the *stand-off detection from vehicles*, typically on roads and tracks again for AT mines. The only EC ESPRIT project which makes use of IR sensors is the LOTUS project (multisensor remote

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[9] The atmosphere is transparent to infrared radiation in these wavelength bands.

[10] When the soil above a mine changes from hotter than the surrounding soil to colder (thermal inversion), or vice versa.

controlled vehicle); IR sensors have also been used in the EC DG VIII pilot project "Airborne Minefield Detection in Mozambique". In Europe we have not encountered activities using this type of sensor for man portable applications.

Direct measurements can be coupled to ***thermodynamic soil modelling*** programs, with models describing the heat transfer in the mine and the ground, as well as the heat exchange between ground and atmosphere. Depending on the model's sophistication level they can simulate not only the heat flow in the ground but also the moisture flow. This type of study should allow predicting where and when the detection can be performed (FOA in Sweden is among the institutions working on this).

What speaks in favour of IR systems is their ***imaging capability*** (large field of view), and the recent technological progress yielding cheaper, more sensitive and larger sensor arrays moving towards an imaging quality comparable to current commercial digital cameras operating in the visible spectrum. High-end cameras are usually cooled so that the sensing element works at low temperature for maximum sensitivity; they are still rather expensive. Small, uncooled cameras are also starting to be industrialised and are definitely cheaper, but a factor 5-10 less sensitive.

4.2.4 Multi-spectral Imaging Systems

In reconnaissance applications based on imaging sensors, for example minefield detection using airborne systems, it can be difficult to differentiate the mine from the background due to low contrast and the presence of highly textured backgrounds. Multispectral techniques can be used since they provide more information than images from common broadband cameras. The multispectral systems themselves operate over several wavelength bands, e.g. from ultraviolet to visible and thermal infrared (0.2-14 μm). Surface laid and buried mines can be found due to contrast variations in the collected multidimensional image. FOA in Sweden is investigating multispectral analysis for mine detection and minefield delineation. Note that *multispectral imaging has the advantage of measuring different physical parameters simultaneously, and without major spatial co-registration problems*.

4.2.5 X-ray Backscatter Techniques

Backscattered radiation is detected during active illumination of the ground with X-rays, and basically determines whether or not an object is made up predominantly of light chemical elements (i.e. low atomic number Z). The technique is intended for real-time detection of AT mines. The system is said to be able (Thomson-CSF Detexis in France) to produce a 2D image with a resolution of some cm. Potential problems come from shallow penetration, system complexity, sensitivity to soil topography, sensor height variation, and safety aspects due to the use of ionising radiation. Outside Europe, research on the subject has been carried out during the last decade in particular by the University of Florida, mostly for defence applications. X-ray backscatter techniques are also used in geological studies.

4.2.6 Ground Penetrating Radar (GPR)

Background

Ground Penetrating Radar (GPR) has been in use for at least 15-20 years in civil engineering, geology and archaeology for the detection of buried objects and soil study. The detection of landmines has been a subject of interest, in particular due to the radar's potential for the detection of plastic mines. Today a very large number of organisations over all of Europe are working on different parts of GPR systems, and amongst the sensors encountered, *GPR is probably the most studied*.

GPR works by emitting an electromagnetic wave into the ground, rather than in the air as in most 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[11]. Buried objects, as well as the air-ground interface, cause reflections of the emitted energy, which are recorded by a receiver antenna. The antenna is indeed one of the crucial parts of the system. Most systems are low power ones and do not present any danger to the operator.

GPRs can be subdivided into four categories, depending on their operating principle. The first type is a *time domain* GPR with an *impulse system*, where the emitted pulse has a carrier frequency, modulated by a square envelope. This type of device operates in a limited frequency range, and has in most cases a mono-cycle pulse.

[11] At 1 GHz, a frequency similar to the one used for mobile phones, electromagnetic waves have a wavelength of 30 cm in air and of about 10-15 cm in the ground.

The second type of *time domain* GPR is the so-called *Chirp Radar*, which transmits a pulse-train waveform where the carrier frequency of each pulse is rapidly changed across the pulse width. *Frequency domain* GPRs transmit a signal with a changing carrier frequency over a chosen frequency range. This carrier frequency can be 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 terminology *Ultra Wide Band (UWB)* GPR is used for a system having a fractional bandwidth, which is larger than 25%.
What particularly matters for detection is the difference between the electromagnetic properties of the target (in particular its dielectric constant) and those of the ground. The amount of energy reflected obviously depends also on the object's size and form, which is a prerequisite for reliable detection of small AP mines. Spatial resolution depends on the frequency used, and the resolution needed to cope with the small objects considered enforces the use of wide frequency bands (some GHz)[12], with the higher frequencies being limited in penetration depth. Microwaves are indeed strongly attenuated by certain types of conductive soils, such as clay, and attenuation increases with frequency. Wet clay in particular provides an extremely tough environment (penetration is very poor).

System Configuration
GPR systems for landmine detection are either designed *to provide detection warnings* (e.g. an audio signal as in MDs), or *to produce image data*.

In the first case, adequate signal processing should extract information on the target object from the return signal. The final aim is to detect the targets and, if possible, classify them[13]. The main problem is understanding if and how such information can be extracted in a usable and robust way, in particular if invariant features do exist (independent of target orientation and depth, soil type, etc).

In the second case, the area scanning should either be controlled or tracked so that the radar's pose is known for each of the acquired signals (in real time if necessary). Designing a *tracking system*, in particular for a handheld probe, is a complex task due to the required precision level and the area coverage. Several types of images representing the spatial structure of the measured data can then be produced, for example vertical slices (so called B-scans), horizontal slices (C-scans), or full 3D volume representations. The wavelength of the GPR radiation is comparable to the target object size (centimetres or tens of cm). *A radar image has therefore* a *totally different nature than an optical image* (lower spatial resolution, "fuzzy" aspect due to complex interaction of the emitted signal with the target objects, particular noise patterns due to scattering). In addition, GPR antennas normally have a wide beam pattern, which degrades the spatial resolution unless appropriately corrected.

The ***imaging approach*** is appealing, but it requires a good analysis of scanning time, data processing, scene reconstruction, processing power and visualisation. Scanning time performance is less stringent for humanitarian demining than for military applications. Moreover using GPR arrays reduces the scanning time at the cost of increased processing complexity. Typical data *pre-processing* components are: regridding of the measured data to the image grid, clutter removal, correction of the varying distances between the antenna and the ground, pose correction (note that these pre-processing steps are also used when the GPR is configured as a detection warning device without imaging). Scene reconstruction for visualisation of the underground requires solving an ill posed mathematical inverse problem, which is a non-trivial numerical problem that cannot be solved without sufficient processing power. Direct feature extraction from the measured data followed by classification based on the extracted features is an approach, which does not necessarily require the scene to be reconstructed from the measured data. *Visualisation can either be an image of the reconstructed scene, the pre-processed data in the form of C-scans, or an image of the classification results.*

European R&D
Nearly all EC ***ESPRIT*** projects on humanitarian demining are working on GPR systems, mostly for ***handheld applications***. Results are expected within 1 to 3 years. Despite the 20 years of GPR experience in civil engineering, geology and archaeology, we should be careful not to be overoptimistic concerning the development times for GPR mine detection systems. In the former applications, GPR systems are used by specialists of visual GPR image interpretation, and for large objects the detection heavily relies on spatial correlation. For mine detection, however, small AP mines have to be detected in the presence of a complex

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[12] The shorter the pulse or the wider the bandwidth, the better the spatial resolution.

[13] Detection means telling that "there is something", classification means telling what it is (in the simplest case something like "dangerous, not dangerous, do not know", ideally something like "a stone, mine type A, mine type B, etc.").

underground (e.g. inhomogeneities, irregular surfaces, etc.). Providing light, user friendly and affordable systems with sufficient autonomy (prices of commercial equipment are gradually decreasing but still about a factor 5-10 higher than metal detectors) is also a main technical challenge. Tests in the field by end users should assess real system performances and limitations.

Vehicle mounted GPR systems are also under study for application on roads and tracks, usually with the main target of detecting AT mines or UXO (which should facilitate the task compared to the detection of AP mines). During the interviews two types of systems were mentioned, (i) an array antenna mounted in front of the vehicle to ensure sufficient coverage, combined with imaging techniques, and (ii) a forward looking UWB radar combined with analysis of target traces formed by the forward vehicle motion. One ESPRIT project, LOTUS (start: January 1999, duration: 3 years), investigates a vehicular approach, and several other efforts are ongoing at national level, mainly for defence applications. The latter might partially have an impact on the humanitarian demining scenario. Some *Quality Assurance/Quality Control applications* have also been suggested, for example road survey after clearance, and the establishment of records describing the history of the clearance task, in order to compare previously executed searches with new searches and to eliminate controversy after clearance[14].

In *several domains other than demining high tech GPR-like developments are ongoing*, e.g. the modulated microwave array antennas ("retinas") and corresponding tomographic, real time image reconstruction, as pioneered by SATIMO in France. Even without a specific programme targeted at humanitarian mine detection, it is useful to closely monitor these developments, so that specific humanitarian demining tests can be carried out once the technology is mature.

4.2.7 Bulk Explosive Detection Systems

Techniques that detect the explosive itself, in bulk form, should not be confused with trace explosive detection such as carried out by sniffing dogs.

Nuclear Quadrupole Resonance (NQR)

Nuclear Quadrupole Resonance (NQR) is one of a few techniques capable of detecting the explosive in bulk form. Contrary to what its name might indicate, *NQR does not use radioactive sources nor produces any form of harmful radiation*. Instead it uses radio waves, somewhat higher in frequency than those of a pulsed metal detector.

NQR has been described as "an electromagnetic resonance screening technique with the specificity of chemical spectroscopy". It relies upon the resonant response of certain nuclei possessing electric quadrupole moments. It is being developed in particular for airline security applications, and has the fundamental advantage of not needing an external (static) magnetic field, like Nuclear Magnetic Resonance (NMR). Problems are due in particular –as in most other sensing techniques for landmine detection – to the need for a one-sided (remote) implementation (it is impossible to put parts of the sensor on "the other side of the object"). *Encouraging results have been obtained with RDX. Increasing the signal to noise ratio for TNT*, used in the majority of mines, *is therefore one of the priorities in current research*.

Similarly to metal detectors, the generated and the received field decay very quickly with distance; detection depth will be limited (depending on the type and amount of explosive, and the measurement time – typically seconds to tens of seconds) and the equipment will have to be used in close proximity to the ground.

Concerning Europe, NQR for landmine detection has been intensively researched in the UK in the context of defence applications, in particular at King's College in London (KCL) under sponsorship of DERA, at DERA itself and at ERA Technology (especially equipment manufacturing). No currently ongoing ESPRIT project covers NQR research. Whether there are at present any plans - apart from those of KCL - to transfer this know-how to humanitarian demining, is unknown to us. R&D was also carried out in the former Soviet Union, in Kaliningrad, already at the time of the Afghanistan War. In this case, present efforts are likely to depend strongly on the funding situation.

NQR systems are most likely to be used in combination with other sensors as *confirmatory devices*. The estimated cost is 5-10 times the price of current metal detectors.

[14] As suggested by Mine-Tech (Zimbabwe) and TRICON (Germany) during informal discussions at a conference in 1998.

Finally, let us point out the *activities on handheld and vehicle mounted NQR systems*, currently being carried out in the US by Quantum Magnetics, under sponsorship from DARPA, the U.S. Marine Corps System Command and the U.S. Army. Initially aimed at military systems, these activities now seem to be extended to humanitarian demining.

Thermal and Fast Neutron Analysis (TNA & FNA)

Background

There are several neutron-based techniques for detecting explosives in bulk form. All systems are composed of at least a *neutron source* – continuous or pulsed, emitting in bursts – to produce the neutrons that have to be directed into the ground, and a *detector* to characterize the outgoing radiation, usually gamma rays[15], resulting from the interaction of the neutrons with the soil and the substances it contains (e.g. the explosive). Amongst the generic neutron-based explosive detection techniques we have Thermal Neutron Analysis and Fast Neutron Analysis (a number of derivatives thereof do exist), which are described in the Explanation Box.

- **Thermal Neutron Analysis** (TNA) is probably the "easiest" and cheapest among the neutron-based techniques. It features *high sensitivity to nitrogen* concentration. On the other hand it is relatively slow, and is usually not suited for operation in real-time, like conventional metal detectors (second or even minute response times).
- **Fast Neutron Analysis** (FNA) has the potential of delivering better results than TNA, because it is *sensitive to nearly all elements in explosives* and opens the possibility of identifying the substance under analysis, but is usually far more complex and expensive. Note that in using pulsed FNA, (pulsed) TNA comes in "automatically" (TNA gamma rays can be detected after each pulse).

The *gamma ray detector* is a key element of the system. According to the requirements its complexity can range from a simple counting device (registering only the amount of gamma photons) to the measurement of the energy (essential for chemical characterisation). A system with a pulsed source could in principle also deliver some timing information, from which the spatial position of the source of outgoing radiation can be determined. Such a system would therefore be able to determine the type of substances, where they are situated, and therefore generate an image.

System Configuration

Neutron analysis systems could typically be combined with other sensors, and used in a confirmatory role. Amongst the drawbacks of neutron based systems we find usually system complexity and cost, radiation hazard, system weight (especially due to heavy shielding), power requirements. Depth of penetration also has to be carefully assessed, as well as minimum amount of detectable explosive. It remains to be established if such a system will be practical and fieldable, if the added performance will be sufficient to justify the extra costs, and if improvements can be obtained in special applications[16]. Some FNA based systems are in use for the detailed discrimination of ordnance containing explosives, inert substances and chemical warfare agents, whereby the corresponding companies mostly provide a service rather than sell a product.

European R&D

Nuclear sensor systems are studied and designed, notably in France (EPPRA, SODERN), Germany (I.U.T.), Italy (INFN), Russia and the US.

Problems for landmine detection include: the need for a one-sided sensor configuration, operator security, equipment portability, and limited soil penetration of particles/radiation. To the best of our knowledge, no one has yet produced a fieldable and effective system for humanitarian demining applications. EPPRA (France) is working on neutron based techniques within the EC MINESEYE project. INFN (the Italian National Institute of Nuclear Physics) is engaged in an internal collaborative research program, called EXPLODET (EXPLOsive DETection), over the period 1998-2000. The involvement of other organisations with the necessary background is likely to be strongly dependent on the financial resources made available. Note that INFN includes in its project budget about 25 kEURO exclusively for material costs associated to a TNA system that is probably the "easiest" among the neutron based systems. FNA systems are likely to be much more expensive.

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[15] Gamma rays are similar to X-rays, but of higher energy, and are emitted in radioactive decays and reaction between nuclei.

[16] TNA sensors have been tested for example for the confirmation of the presence of AT mines on roads.

EXPLANATION BOX

Thermal Neutron Analysis (TNA) relies on the elevated nitrogen concentration of most commonly used explosives, and is based on the detection of characteristic gamma rays emitted by the nitrogen nuclei in thermal neutron capture reactions. The thermal (i.e. slow) neutrons themselves can be produced by slowing down fast neutrons from low cost, small radioisotopic sources, such as ^{252}Cf (Californium-252), or from portable electronic neutron generators[17] (e.g. small accelerators of the electrostatic Deuterium-Tritium or plasma-focus type). The "slowdown" takes place in a specially designed "moderator", or in the target substance itself (the earth and the explosive in our case).

Fast Neutron Analysis (FNA) is based on the interaction of fast neutrons, mostly inelastic neutron scattering, with the nuclei of interest. During this process the high energy neutrons put elements in an excited, short lived state, in particular Carbon, Nitrogen and Oxygen of explosives and soils, by hitting their nuclei. The nuclei return to their initial state by emitting gamma radiation, whose energy distribution, or spectrum reflects the, chemical characteristics of each nucleus. In other words, by characterising 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 – in order to determine the type[18] of substance under analysis (all explosives are composed of Carbon, Nitrogen, Oxygen, and Hydrogen that is not detectable by pure FNA).

Neutron backscattering is a different technique, where slow neutrons coming back in the direction of the source are detected, providing a measure of the hydrogen content of the material. Neutron backscattering is probably the simplest technique, but seems likely to only work in dry or slightly humid environments.

Note that the International Atomic Energy Agency (IAEA) in Vienna has quite recently started a **C**o-ordinated **R**esearch **P**roject (CRP) on the ***Application of Nuclear Techniques to Anti-Personnel Landmine Identification.*** "The main objective of this CRP is to apply this knowledge to humanitarian demining and to make already existing prototype instruments ready for field deployment. The output of the CRP will be a report that describes the state of the art of nuclear techniques for identification of antipersonnel landmines. These research results will be made freely available for use by scientists and organisations involved in research, development and use of equipment for post-conflict humanitarian demining." More information is available from the Scientific Secretary, Ulf Rosengard (email: u.rosengard@iaea.org, phone: + 43 1 2600 21753).

4.2.8. Trace/Vapour Explosive Detection Systems

We already discussed the use of dogs (see 4.1.1. Mine Dog Programs) and pointed out their importance in particular for verification and area reduction purposes (i.e. when the focus is on verifying that a given area is mine/explosive free or not). Research on sniffing dogs and how to complement or replace them with adequate sensors is scarce in Europe, compared to the effort put into other sensors (most notably GPR). *More precise and clear quantitative information seems strongly needed.*

One way of approaching the problem is to *increase our knowledge on how exactly dogs work*, i.e. how (using also other senses?) and what exactly they detect and in which concentration (explosive vapours or other substances leaking from the mine or from its surface, trace particles deposited in and on the soil around the mine). Another way, complementary to the first, is to *study the different processes between explosives and the environment*, in particular the migration of explosives, leaking from a mine, in the soil and in the air. Long term research of this kind is carried out for example at FOA in Sweden.

Sensor systems for field application should have an appropriate ***sampling system*** (of the air or the soil), possibly including filtering to increase concentration. Up to now it seems that sensors either have a too low sensitivity, are too slow or too large to be used in field applications.

Note the existence of a large *three year project*, started in 1997 by DARPA (the US Defense Advanced Research Projects Agency) and funded at the 25 million US$ level, aimed at developing an electronic dog's nose that can be used reliably in the field (see also http://www.darpa.mil/DSO/rd/Applied/UXO/index.html). If and when the results of this project will be made available to the humanitarian demining community remains obviously to be seen.

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[17] One of their advantages is not to be radioactive when switched off (a source is always radioactive).

[18] Examples of chemical compositions: TNT is $C_7H_5N_3O_6$, RDX is $C_3H_6N_6O_6$.

Biosensor
The "biosensor" program of the Swedish Biosensor Applications AB (http://www.bioapp.se/), formerly a company of the Bofors group, seems to be one of the very few in Europe targeted specifically at humanitarian demining applications, and perhaps the most advanced (work has been ongoing since 1995).

Biosensor systems are used to develop portable vapour detection systems, sometimes also called "artificial dog noses". The collection system collects air and the air sample passes a filter which absorbs the molecules of the target substance. The filter is purged of its contents and the collected molecules are dissolved in a fluid, the collection system concentrating a sample of 100 litres of air to 10 microlitres of liquid. The system also minimises the risk of contamination through its automatic clearing process. The droplet obtained in this way is then brought into contact with the actual biosensor, a piezoelectric crystal (actually a Quartz Crystal Microbalance), whose surface is covered by an antibody reacting with the molecules of TNT. The antibodies detach themselves from the sensor, whose variation in oscillating frequency is then measured.

Highly selective, sensitive, portable systems are under development, and a prototype for TNT will be tested in minefields in 1999 and cross-checked with a dog based detection scheme (typically MEDDS employed by the South African Mechem). These systems could be used for verification and area reduction purposes. The quartz crystal has to be reloaded or changed after a few positive answers. So far research has mostly concentrated on the detection of TNT; this also implies that, given the antibodies' specificity, the system will not detect other explosive substances. Therefore, even if TNT is present in most mines, the development and the application of antibodies for PETN and RDX are under investigation. Overall detection time is of about 2-3 minutes at present, and projected cost between 15 and 25 k EURO.

Ion Mobility Spectrometer (IMS)
The Ion Mobility Spectrometer (IMS) is a detection system capable of identifying and quantifying chemical vapours in minute traces. Its strong points are ease of use, speed of analysis (quick answer), sensitivity (capable of measuring tiny quantities) and specificity (capable of differentiating well between substances). As usual, it is difficult to speak about detection limits, but *an IMS is believed to be up to 1000 times more sensitive than a mass spectrometer*, with relative detection limits (concentrations) at least in the ppb[19] range, corresponding to an absolute quantity of picograms (10^{-12} g) for some substances.

An IMS delivers as output a current value *vs*. a drift time, whereby the drift time allows identifying the substance, and the current is a measure of its quantity. IMS makes use of the different mobilities of ionised species in gases. Molecules enter the ionisation region in ambient air via an inlet membrane, where they are ionised by means of UV radiation or beta particles. Short periodical pulses on a shutter grid allow the produced ions to move into the drift tube, where different charged particles drift according to their specific velocities, arrive at characteristic times at the collector electrode and cause current pulses forming the IMS spectrum. The drift time depends on the ion mass and on its molecular structure, and allows the identification of the substance. The presence of several kinds of compounds in the probe sample results in an increased complexity of the ion mobility spectra, which often can not be interpreted exactly.

An IMS system has been for example developed by IUT in Germany (other manufacturers might be offering similar pieces of equipment) as a commercially available system, with a weight of about 6 kg and prices starting from 30 kDM. It is portable, can operate in field conditions from a battery pack for 6-8 hours, and measures signals quasi-continuously (near real-time) all 2-30 s. Note that a conceptually similar IMS system, the IONSCAN, is currently being developed and tested by Barringer in the US for the NVESD (US Army Night Vision Laboratories) in Fort Belvoir, VA, for the detection of landmines.

4.3. Multi-sensor Systems

A number of ongoing research projects are aimed at *combining several sensors in order to exploit complementary information* (each sensor measures different physical characteristics), and to enhance detection and even classification. Sensor fusion should guarantee that the multi-sensor system at least retains the probability of detection of each single sensor, and moreover reduces the false alarm statistics.

Since the objective of these systems is mine identification, it is important to take into account the relative strengths and weaknesses of the sensors, as well as the environmental conditions (e.g. type of soil, clutter,

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19 Parts per billion, i.e. capable of detecting the presence of 1 molecule in 10^9 (= 1 billion).

humidity and vegetation) in which each sensor may be used. *The ultimate goal would be to* ***fully integrate individual sensors***, physically as well as from the point of view of data fusion. Physical integration requires close collaboration between the manufacturers of individual pieces of equipment, to ensure technical compatibility and to avoid cross talk and measurement ambiguity due to spatio-temporal misalignment. This is probably easier to achieve than full data fusion (see 4.3.1 Data Fusion Methods).

To avoid full data fusion, *easier solutions are being investigated*, such as using one of the sensors as ***primary detector*** (typically the metal detector) and another as a ***confirmatory sensor*** (e.g. a GPR or an explosive detection system), possibly leaving the final decision to the operator. This can simplify to a great extent system design and analysis, and in a certain sense comes closer to current operational procedures, where "sensors" (metal detectors, manual prodding, sniffing dogs) are used sequentially. Generally speaking, in all systems an experienced operator is crucial for the overall performance.

Multi-sensor system design and data fusion are fashionable research topics, nowadays. The underlying rationale for this interest is that exploitation of different sensing principles leads to more reliable detection/classification results by combining different pieces of incomplete or imperfect information. *The risk of this approach is that combining insufficiently mature sensors yields an even more complicated problem than pushing individual sensor technologies up to their intrinsic physical detection limits.* This implies that research and development of single-sensor data processing and pattern recognition techniques for mine detection/classification should be continued, and that multi-sensor system design should carefully take into account the requirements of the target application, the operational procedures and the complementary properties of the sensing principles.

During our interviews we came across the following multi-sensor combinations: (i) MD, GPR, (ii) MD, GPR, microwave/millimetre wave radiometer, (iii) MD, IR, GPR, (iv) MD, GPR, NQR, (v) MD, GPR, Vapour/trace explosive detection, (vi) MD, FNA.

4.3.1 Data Fusion Methods

The choice of a method for merging data in a multi-sensor system depends mostly on the data format of the signals, which can be a 2D image (e.g. IR), a 1D time series (e.g. GPR), or a scalar value which expresses the detection of the presence of explosive or metal for example. Three different types of *data fusion architectures* can, in principle, be used:

- **Pixel level fusion**: multiple images are combined to a single image, and each location in the combined image has an associated vector of measurements from each of the sensors. The new image is then processed by an algorithm such as target detection/recognition that simultaneously operates on the vector values. The problems of putting pixel level fusion into practice are due to the differences in field of view, in sensor orientation (e.g. forward looking, downward looking), in resolution, and in data format.
- **Feature level fusion**: features are extracted from each of the sensor data, followed by a registration step, usually carried out at the level of regions of interest or image segments containing more than one pixel. Such a co-registration of features from individual sensors is often easier to achieve than pixel level fusion. A detection/classification algorithm can then be applied on the combined feature vector characterising a region of a certain spatial extent.
- **High-level data fusion**: 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. Because the sensors have very different data characteristics, this kind of data fusion is probably the most accessible for a mine detection system.

The EU LOTUS and HOPE projects are studying, amongst others, data fusion techniques. The HOM-2000 project in the Netherlands has also scheduled data fusion for handheld and vehicle based systems in its starting second phase.

4.3.2 Handheld Systems

Multi-sensor systems can be made portable, similarly to currently used metal detectors. The human operator is indeed still difficult to surpass when it comes to taking analytical decisions in a complex environment, and there will always be situations where portable equipment is needed. Problems lie in producing affordable (5-10 times the cost of an individual high-end metal detector?), compact and lightweight systems, with sufficient autonomy, improved productivity (reduced false alarm rate), ease of use (ergonomics), and overall performances justifying the price.

Most handheld multi-sensor systems include a metal detector in their set-up. Most of the mines still contain some metal, even if sometimes in reduced quantities. In addition, metal detectors are still the only sensors really used in demining practice. Their inclusion should therefore facilitate the transition from single sensor to multi-sensor systems and guarantee system acceptance.

Ground Penetrating Radar is also well positioned in the list of preferences, followed by bulk explosive detectors (e.g. NQR) and vapour trace detectors. Other sensors being studied are infrared devices, which have the potential of detecting the object from a standoff position (e.g. mounted on the protection helmet of the operator). Microwave radiometers can be particularly useful for the detection of surface or shallowly buried objects, where radar might have problems.

4.3.3. Vehicle Platforms

Vehicle platforms are typically used for rapid surveying of large areas, in particular roads or moderately off-road areas. Sensor choice as well as sensor performance are usually not constrained by power and computational requirements. Sensor arrays are usually employed. Position tracking equipment and platform stability control systems are also extremely important. Usually a combination of forward looking (e.g. IR, visual, multispectral cameras, UWB radar) and downward looking sensors (e.g. GPR array, MD array) are used. Near “real-time” processing and decision taking might be necessary at high vehicle speeds. In some cases remotely controlled vehicles are used.

Most of the encountered vehicle based projects are military oriented, apart from the EC LOTUS project.

4.4. Technological Maturity

From the discussion during the interviews, the EUDEM database, the bibliographic analysis of the state of the art, and the equipment specifications provided by the manufacturers, we have tried to make *some inferences about the maturity of the mine detection technologies described above, as well as their cost*. The resulting list is undoubtedly subjective, and open for criticism, because (i) we must rely on indirect evidence due to the absence of well established definitions of equipment performance, (ii) most of the results of independent performance tests are not publicly available, (iii) we have not conducted performance tests ourselves, and (iv) we do not share the practical experience of deminers working in the field.

Technological maturity should be interpreted as a qualitative measure expressing a mixture of the:

- State of advancement of the R&D;
- Demonstration of detection capabilities useful for humanitarian demining;
- Demonstration of building a practical system.

Cost includes technological cost only, i.e. does not take into account the actual productivity in the field. Needless to say, innovation can very well come from technologies other than the ones listed below, for example other trace explosive sensors, or acoustical/seismic detection systems, etc.

Sensor technology	**Maturity**	**Cost**	**Comments**
Dogs	H	H-HH	Used in practice
Prodding/Excavation	H	LL	Used in practice
Magnetic devices	H	M	Used in practice (Magnetometers, Gradiometers)
Metal detectors	H	L	Used in practice
Metal detector Array	H	H-HH	(Used in practice?)
Passive mm wave	L-M	HH	EU HOPE project claims low cost Handheld multisensor probe including radiometer
mm wave radar	L	HH	Cost figure based on lab equipment
Passive infrared	M-H	H	Cost is decreasing
Polarised infrared	M	HH	
Multispectral	L	HH	
Ground Penetrating Radar (GPR)	H	M-H	
Ultra-wideband radar (UWB)	L-M	H-HH	
GPR Array	M-H	HH	
Nuclear Quadrupole Resonance (NQR)	M	H	
Thermal Neutron Analysis (TNA)	M	HH	
Fast Neutron Analysis (FNA)	L-M	HH	
Ion Mobility Spectrometer (IMS)	M	M-H	
Biosensor	M-H	M	

Table 2. (Qualitative) Maturity and Cost evaluation for the previously mentioned technologies. Maturity indication ranges from Low (L) to Medium (M) up to High (H); Cost indication uses L ≈ 4000 EURO (price of a high end metal detector), M ≈ 2 to 5 times L, H ≈ 5 to 10 times L, and HH >10 times L.

4.5. EC projects

The following table very briefly summarises the largest European R&D projects on humanitarian demining, as well as some primarily defence oriented projects. More details are usually available in the interview reports (for the EC projects see also http://www.cordis.lu/esprit/src/hphdhome.htm).

Project	Prime contractor	Sensors	Start	Duration, Partners*	Comments
GEODE	Dassault	pulse GPR (EMRAD), FMCW GPR? (ELTA) + MD (Förster) + IR (Marconi)	Jan. 98	15, 4P + 2A	Vehicle
MINEREC	EMRAD	GPR (EMRAD)	Jan. 98	18, 2P	GPR array, real time
Airborne minefield detection in Mozambique	ITC	ZeissLMK2000(optical), LeicaRC30(optical), VOS80C(digital), ReconCA860(thermal), AES-1(SAR)	Feb. 98	18, 12P	Pilot project EC DG VIII + some EC countries
HOPE	Vallon	pulse MD (Vallon) + stepped frequency (imaging) GPR (RST) + radiometer (DLR)	Jan. 99	24, 7P + 7A	Portable
PICE	Celsius Tech	pulse MD (Schiebel) + stepped frequency (no imaging) GPR (Celsius Tech)	Jan. 99	24, 5P + 4A	Portable
INFIELD	Detexis	pulse GPR (ERA) + continuous wave MD (Ebinger) + radiometer (ERA?)	Jan. 99	18, 3P + 1A	Portable
LOTUS	Detexis	pulse GPR (EMRAD) + MD (Foerster) + IR (Marconi)	Jan. 99	36, 4P + 1A	Vehicle
DEMINE	TUI	GPR (all)	Feb. 99	24, 6P	GPR only
MINESEYE	EPPRA	neutron (EPPRA) + digital MD (?)	Feb. 99	30, 5P	Portable, vehicle
HOM2000	TNO	GPR, MD, IR, …		National Dutch project	Mostly Hum. Dem.
HUDEM	RMA	GPR, MD, IR, robotics, …		National Belgian project	Purely Hum. Dem. mostly academia
-----------	FOA	GPR, MD, IR, multi-spectral, explosive det. …		National Swedish project	Mostly Hum. Dem. Portable, Airborne
EXPLODET	INFN	TNA, FNA	1998	36, 10P	Purely Hum. Dem
(several projects)	DERA	GPR, UWB, MD, IR, pol. IR, NQR, mm wave, …		UK MoD sponsored	(nearly entirely) Defence: Portable, Vehicle, Airborne
MMSR, DMH	MaK, BGT (?)	GPR, MD, IR, multispectral, …		German MoD sponsored	Defence: Vehicle, Airborne
(several projects)	Detexis?	GPR, MD, IR, …		French DGA sponsored	Defence: Vehicle, Airborne

Table 3. Largest European R&D projects on humanitarian demining, as well as some defence oriented projects.

NOTE: DERA: Defence and Research Evaluation Agency (UK), Detexis: Thomson-CSF Detexis, FOA: Swedish Defence Research Establishment, INFN: Italian National Institute for Nuclear Physics, RMA: Royal Militay Academy (Brussels), TNO: Netherlands Organisation for Applied Scientific Research, TUI: Techn. Universität Ilmenau (Germany).
*: P: Partner, A: Associate.

5. SMALL SCALE ANALYSIS OF ONGOING GOVERNMENT FUNDED R&D PROJECTS IN THE US

The current paragraph is the summary of a report made by John Brooks, on behalf of the EUDEM project. It is mainly centred towards military R&D projects with some focus on humanitarian demining.
The goals of the US survey were to determine the current state-of-the-art of US military and humanitarian demining technologies related to the detection and classification of anti-personnel land mines (APLs). The US Army-funded programs were investigated; the many US Navy programs were not. It is interesting to note that a co-ordination office, JUXOCO, was established to provide co-ordination for all Department of Defense (DoD) UXO programs; it serves as a ***repository of data collected at US test facilities***. All test data involving UXO and mine detection/clearance is linked to the JUXOCO web site, http://www.uxocoe.org/index2.htm.

For the EUDEM survey, three US ***GPR programs*** were reviewed; the Ground-based STAnd-off Mine Detection System **(GSTAMIDS)**, the Hand-held STAnd-off Mine Detection System (HSTAMIDS), and a developmental short-pulse hand-held GPR designated as the BRTRC/Wichmann radar. In general, the tendency to employ stepped-frequency modulation is consistent between the three main programs; the BRTRC/Wichmann radar uses a more conventional short-pulse modulation, albeit a very wideband pulse, ca. 5 GHz.

EMI (**E**lectro**M**agnetic **I**nduction) has been used with some success for the detection of buried metallic UXO and mines. The principle is based on transmission of a wideband electromagnetic waveform. The resulting field induces a secondary current in the earth as well as in any buried objects. A receiving coil senses only the weak secondary field returned from the earth and buried objects.

The US requirement for **HSTAMIDS** is a probability of detection, Pd, of a mine to be 0.80 (i.e. a clearly military oriented specification; Annex 5 explains how this Pd is defined); the best performance with trained contractor personnel was 0.70, and the average performance using military personnel was only 0.30. Such performance has led to an 18-month extension of the HSTAMIDS program. Two systems of different vendors are briefly analysed in Annex 5

The Airborne STAnd-off Mine Detection System **(ASTAMIDS)** was a program developed to locate minefields, and used an IR sensor as the primary queuing sensor. ASTAMIDS failed to meet US Government specifications due to the poor performance of the IR sensor. The program has been realigned to study other options; the program is now called the Light Airborne Mine Detector (LAMD). No specific information regarding the failure has been made available at the time of the report.

As a conclusion, one can say the US Army demining technology program is maturing, with some erratic programmatic behaviour due to lack of clear success of any single or group of technologies. The 18 month delay in HSTAMIDS and the restructuring of ASTAMIDS are clear evidence of this. The progress of GSTAMIDS is promising. The lack of a consistent methodology for performance evaluation and system comparison leads to a "floating baseline" for competing systems to meet (see Annexe 5).

6. CONCLUSIONS AND DISCUSSIONS

To guide the reader through the conclusions, we have classified them in 3 categories: ***Policy*** (related to organisational and co-ordination aspects), ***Practice*** (related to currently used demining technology and procedures), ***Technology*** (related to R& D for new technologies, specification of equipment and testing).

6.1. Policy

– EQUIPMENT PROCUREMENT (AGENCY):

Several NGOs have stressed the need for new technology to speed-up current demining procedures, but they are often reluctant to invest in it, since (i) every particular local circumstance requires specific logistics, campaign organisation and equipment, (ii) as a consequence not all existing equipment is continuously in use, and (iii) the investment in equipment maintenance is too high. In this respect the concept of a supranational Equipment Procurement Agency, acquiring, organising and maintaining a ***central pool of equipment*** (technical toolbox), which could be called upon by the deminers following e.g. a leasing formula, could indeed form the basis of a solution to meet the market requirements. Work on setting up such an Agency is currently ongoing, with discussions involving (at least) the JRC in Ispra and the Geneva International Centre for Humanitarian Demining at the European level. The same concept should also be valid for currently available but expensive equipment (e.g. machines and dogs).

– MINE CLEARANCE FUNDING:

Although it is recognised that the EU should play a coordinating role in mine action programs, there is a generalised criticism by the *NGO end users* of the current EU way of working. Main recommendations for better operational functioning include ***shortening the delay in funding, reducing the amount of bureaucratic procedures and limiting the fragmentation in too many EU divisions*** with *insufficient coordination*. It should be generally accepted that mine clearance needs a continuous security of funding, because it is a long-term process, and not a short-time emergency action.

– PUBLIC INTEREST:

Public interest changes quickly, leading to inefficient usage of funds. This has caused the shift of campaigns from Bosnia, where the mine problem still persists, towards for example, Kosovo. Working NGOs had to change their policy at several other occasions, simply because they depend on the demands of their donors. Although the public interest, highly influenced by the mass media, has placed the mine issues lower on the problem agenda, compared to other international issues, the international community should not forget its responsibility.

– INFORMATION SHARING:

Apart from the normal protections of industrial property rights, we have found ***many government-funded projects for humanitarian demining purposes, which are not releasing any of their results in the public domain.*** This is a major impediment to progress, historically resulting from the early military involvement in the domain. Many classified NATO reports for example could bring a breakthrough in the development of new technology, the assessment of usefulness of certain techniques and the standardisation of testing protocols. Seeing Humanitarian demining as an urgent problem (see the signed Ottawa treaty), the release of this information should be a major and priority topic for the political agenda. ***Information sharing between publicly funded military- and civilian projects should be a bi-directional process.***

– EUDEM DATABASE:

The EUDEM database is an attempt to give ***an overview of the European offer within the field of humanitarian demining.*** Its goals can only be realised if updates and the possibility for new entries are guarantied on a continuous basis. Under these conditions, it could serve as a common data repository and a practical search tool for all actors in the demining sector, simplifying contacts and *favouring joint efforts to solve a joint commitment*. Maintaining the availability of the EUDEM data base requires a (small-scale) effort, continued over a number of years. More generally speaking, a lot of information sources on humanitarian demining can be consulted via the internet, but most of them are repeating the same things, and many of them are unreliable with respect to the information content and should be interpreted with care. This is of course a basic characteristic of the internet, but nevertheless we think that a reliable information dispatcher (e.g. JRC) could be beneficial to structure the fragmented information, to guarantee its reliability or at least mention its origin.

6.2. Practice

– INCREMENTAL IMPROVEMENTS TO CURRENT FIELD PROCEDURES:

At several occasions during the EUDEM survey, the importance of continuous developments was stressed to improve several pieces of equipment (e.g. protection items, more effective prodding and excavation tools, or vegetation cutting equipment) that, far from being spectacular, can make a difference in the field and bring ***real short term added-value***.

– MINE DOG PROGRAMS:

Although the use of dogs is rather far from being a perfect science, well-run dog programs have apparently managed to convince more than one sceptic deminer. The use of dogs is therefore nowadays generally approved by most humanitarian demining organisations for area verification and minefield delineation purposes (area reduction), which allow important time gains compared to manual clearance operations, and quality control after mine clearance activities. Detection of minimum metal mines is possible and particularly appreciated. Individual mine detection during clearance operations is somewhat more controversial. In general mine dog programs seem to be expanding.

Heavily discussed issues are the lack of coherent and universal testing protocols for dogs and sufficient local training for the dog and its new handler. There seems to be little agreement on a Standard Operating Procedure (SOP). A number of studies are also underway to establish what dogs actually detect and how.

– MECHANICAL SYSTEMS:

An evolution is observed from ***mechanical demining*** towards ***mechanically assisted demining*** adaptable to local circumstances. Concerning the mine clearing vehicles in particular, one can say that the machines have usually to be *backed-up* by some manual method. These systems are employed for mine verification and area reduction tasks, as well as clearance of actual minefields. Large mechanical systems do require substantial investments (machine costs, logistics, and maintenance), and can actually only be employed on a fraction of the total mined areas. ***Environmental effects have not always been sufficiently studied***. Several *specialized pieces of equipment* are also being used, for example to *clear vegetation* and tripwires, to accelerate manual clearance or the use of dogs.

– HUMANITARIAN VERSUS MILITARY OBJECTIVES:

It is important to understand the extent to which the design of mine detection and minefield delineation technology is based on military operational doctrine, compared to humanitarian or post-conflict requirements***. For the latter the needs of real time operation and testing following military practice are not so relevant***. Hence objectives as *acceptance* and *ergonomy* adapted to usage by indigenous deminers and NGOs, as well as *increased performance in sensitivity at a reasonable False Alarm Rate* should be emphasized.

6.3. Technology

– INPUT FROM OTHER DOMAINS:

It is well recognised how ***military procedures and technology*** have influenced, through a relatively long process of adaptation, the field of humanitarian demining, but ***other domains are also providing new insights***, like non destructive testing, signal/image processing, remote sensing, Geographic Information Systems, medical imaging, etc. These other domains were included in our study, containing the list of actors claiming to develop new technological applications, but admitting not to be active yet in humanitarian demining. In our opinion, it is useful to closely monitor these developments, so that specific humanitarian demining tests can be carried out once the technology has reached maturity in other application domains.

– EXISTING VS. NEW TECHNOLOGIES:

Several end-users and national demining campaign sponsors brought up that less emphasis should be put on development of new technologies. The "*improvement of existing technology will resolve the problem faster*", so that the political commitments of a mine free world within 10 years could be achieved. This (perfectly understandable) attitude towards new technologies is also observed in other professions (e.g. health care and medicine), where fast and critical decisions need to be made. It can partly be explained by a preference to use an imperfect technique whose limitations are well-known as compared to a new technique with better performances that is not fully trusted yet.

It is recognised, on the other hand, that the progress made with present techniques will not enable the 'current people in the field' to meet the Ottawa requirements. ***Faster and safer technologies*** are badly needed. The discussion on this issue is ongoing, and the many visions do not always coincide.

Following the same line of discussion, one should not forget that in the framework of the Ottawa convention every mine has to be identified as a 'real potential killer'. In practice however, when priority areas are defined and the ***remediation strategy is adapted to the urgency*** (e.g. fencing instead of clearance) only a fraction of the millions of mines spread out over the world are causing an immediate threat. Adapting the remediation strategy to locally defined priorities was mentioned by many government agencies. The need for ***complete solutions, taking into account all economical, rebuilding, psychological, cultural and environmental aspects*** was stressed by many NGOs – *Mine Action is indeed not only about demining*.

– (GLOBAL) R&D TRENDS:

Much of the R&D effort for humanitarian demining has indeed gone towards the **detection of individual mines** (usually close-in techniques mainly for blast mines rather than stand-off techniques for fragmentation or bounding mines). Two approaches seem to be followed, (i) either the combination of different sensors in one unit (***a multi-sensor system***), more performing but at the same time more complex and difficult to characterise, and (ii) the ***combination of a detection sensor*** (usually the metal detector) ***with a confirmation sensor*** such as NQR or neutron based techniques for bulk explosive detection, or sometimes the GPR.

Some research is also currently underway on **wide area confirmation methods**, for example airborne minefield delineation or explosive vapour/trace detection (e.g. biosensors) to complement or replace dogs, in order to save precious time by concentrating on areas which really need to demined. The amount of such research is nevertheless rather small in the civil sector, compared to the importance of the subject, and compared to the effort put into other sensors (most notably GPR). This might change in the near future, especially concerning the detection of explosives.

The use of sensors for **specialised applications** (e.g. ***Quality Assurance*** in some scenarios) has probably not yet received sufficient attention (see comments in the GPR and metal detection sections, 4.2.6 and 4.1.3).

Evolution should be governed by the following set of keywords (NPA): ***"Safer, Faster and Cheaper".***

– SENSOR TECHNOLOGY MATURITY:

A summarising view on the maturity of mine detection technologies is undoubtedly subjective and open for criticism. Taking into account that (i) we have to rely on indirect evidence due to the absence of well established definitions of equipment performance, (ii) most of the results of independent performance tests are not publicly available, (iii) we have not conducted performance tests ourselves, and (iv) we do not share the practical experience of deminers working in the field, we nevertheless think that ***Table 2 in 4.4 is useful in fixing the large tendencies in technology maturity and equipment cost***.

Ground Penetrating Radar is undoubtedly the most popular sensing principle for R&D in humanitarian demining. The new developments in metal detection try to extend target detection towards target depth, volume, and shape estimation as well as imaging. Microwave radiometers could be complementary to GPR for imaging and detection of buried mines at shallow depths. IR sensors will probably always require a physical reasoning from the operator to yield good results. Image sequence analysis is a good candidate for boosting op IR imaging performances for the detection of man-made targets. The techniques mentioned above rely on the detection of an *indirect* parameter or pattern (e.g. temperature difference, dielectric constant, reflection coefficient..) from which subsequently the presence of a mine is inferred. Direct detection of explosives and/or analysis of its composition are achieved by bulk and vapor trace detectors. The latter are perceived as potentially important developments.

– DETECTION AND NEUTRALISATION (AN INTEGRATED APPROACH):

In the surveyed research programs, a tendency is observed to ***combine the detection and neutralisation phases of demining***. It is clear that this is motivated by the urge to speed-up the process. In this area, compound vehicular platforms are being developed for detection, marking and neutralisation. Particular to humanitarian demining, real time operation is a less stringent requirement than for military applications.

– INFORMATION TECHNOLOGY:

Geographic Information Systems (GIS) are recognised as useful tools for managing, planning, monitoring and designing solutions concerning global infrastructure and environmental issues. For demining only, it is often perceived as being too complex to put into practice. Nevertheless at several occasions, situations were encountered where the transmission of information between different demining organisations, working in the same geographic area, caused uncertainty about the work already carried out and lead to duplicated efforts. ***Supranational incentives and co-ordination could avoid the reluctance to share information, help in simplifying the user interface and standardising products. Low cost and commercially available technology for localisation*** (e.g. differential GPS, Glonass, and other forthcoming satellite networks), used in conjunction with GIS and wireless communication could provide objective and easily collectable data on minefield areas. Training, education and demonstrations could achieve promotion for the wide spread usage of these technologies. The know-how, if not available already, is certainly not too complex to acquire. Adequate ***maps*** (cartography) are also badly needed in a number of circumstances.

– NEW CONCEPTS FOR USING ANIMALS AND PLANTS:

At the conceptual level, some attempts to introduce really new technologies in the field of humanitarian demining have been noticed (e.g. extension of the detection by animals to other types of animals than solely dogs - cockroaches, rats, fluorescent wasps, plants that change colour when they come into contact with explosive molecules). These imply a complete change of attitudes and ways of working. The more conservative end users are reluctant to even consider these new concepts.

– AIRBORNE MINEFIELD DETECTION / REMOTE SENSING:

The role of *remote sensing vs. ground based methods* has not yet been fully identified. For airborne minefield detection on realistic surfaces (100 up to 1000 km^2), ***terabytes***[20] ***of digital data have to be analysed***. Setting-up a measurement campaign is a complex and expensive operation. Although for civilian applications on-board processing might not be a primary requirement, even off-line analysis requires huge computing facilities. The development of remote sensing systems has been primarily done in the military context, results are often not publicly available, and it is unlikely that these systems will be operational for civilian applications in the near future. Several platforms have been tested, like airships, aircrafts, drones, and helicopters. The ***privileged sensors*** are the ***optical*** and the ***IR imager***, although ***UWB-SAR*** seems to yield promising results for the future. On certain soil types and non-densely vegetated areas the airborne minefield delineation results are reported to be successful (e.g. deserts). In our opinion, ***aerial photographs might be useful, as pictorial information for end users*** to help understand the structure of the local terrain.
Change detection by analysis of satellite data is ongoing and could be attractive as a supplementary exploitation of commercial satellite image dissemination.

– SIGNAL AND IMAGE PROCESSING

During the EUDEM survey, it became obvious that it is much easier to gather information about the physical properties and principles of demining equipment, than about the signal processing architecture inside the equipment. Almost no precise information could be obtained about the actual algorithms for clutter rejection, feature extraction, and classification. ***In this area there is clearly an important task for universities and research centres publishing in the public domain.*** Several levels of data fusion have been defined in 4.3.1. No concluding results could be found, at this stage. Besides continuation of the data fusion efforts, also further developments on pushing the full single sensor systems (physical set-up combined with appropriate signal processing) towards their intrinsic physical detection limits.

– SIGNATURE DATABASE:

Due to the accepted high clearance rate (99.6 %) required for civilian applications, equipment evaluation and detection algorithms should inevitably be tested on an independent (i.e., different from the learning set used for designing the algorithms) and large data-set. Moreover it appears that the signal processing is highly dependent on the particular sensor implementation and the measurement conditions. This means that *local detection circumstances* (e.g. environmental factors such as humidity, soil type, vegetation, temperature), *data acquisition protocol* (e.g. sensor height, scanning type,…) and *object related parameters* (e.g. mine type, depth, orientation) have to be taken into account. At this moment, only fragmented pieces of information exist (e.g. MACADAM, EPFL, VUB,…). ***To build a useful signature database is a major enterprise requiring a well-defined methodology and sufficient funding***. A supranational initiative is recommended, which is currently being prepared under the co-ordination of the JRC.

– TESTING AND EVALUATION:

The implementation of ***specifications for testing protocols*** is again a supranational mission. The existence of several *ad hoc* protocols is a well-known fact after this survey, but they remain proprietary information, which is inaccessible for the research community. Annex 5 points out for example that probability of detection and probability of false alarm are useless specifications without at least a clear explanation of the methods used to determine the performance.
In order to test or to compare new technologies that are in the phase of development or have been developed, a possibility should exist to *gain confidence by application on the field*.

[20] 1 Terabyte = 10^{12} bytes = 1000 Gigabytes (one CD-ROM contains about 0.65 Gigabytes).

The establishment of a joint working group, focussing on the development of testing methodologies and the design of standards for sensor and system assessment, is currently ongoing. At the European side, the existing CADMOS[21] workgroup, promoted by JRC, acts as the core group. The demining community would appreciate dissemination of the current status and intermediate results. Work is also being done at international level to set up ***an international network of test, evaluation and certification centres***.

– USER REQUIREMENTS / EQUIPMENT CERTIFICATION:

The problem of defining precise requirements, i.e. of some authority(ies) clearly stating what is required for which type of application – especially concerning sensors – and how to measure it, has been raised by several industrial companies. Ongoing efforts to come up with ***Statements of Operational Requirements*** (SOR), sort of catalogue of end user needs ("wish lists"), and related ***Statements of Equipment Requirements*** (SER) (the technical specifications for equipment to address the users' needs) are certainly a step in the right direction. These are likely to be country dependent, but a standardisation effort will be made. Work is ongoing, in Europe, at JRC and the Geneva International Centre.

This information, perhaps together with examples of how demining is actually carried out (e.g. taken from the end users' Standard Operation Procedures, or SOP), should according to us reach all interested parties in a timely and precise manner. This could be for example in the form of a newsletter, or a simple reference to an updated Web page. Tightly coupled to this is a demand, expressed by some, for ***certification of equipment*** developed by industry and R&D centres to ensure conformity with the user needs and suitability for the application in question[22].

The current report is a summary of the state of the art in the EU related to humanitarian demining technology, products and practice. Sometimes the conclusions reflect personal opinions of the authors, and some of them had to be simplified leaving out nuances in order to make their message clear. For detailed information and the origin of the individual conclusions, the reader is referred to the substantial amount of information coming from different sources in the Annexes of the report.

[21] Committee of Advisors: Detection of Mines based on Operational Standards.

[22] This point is obviously related to the question of who is responsible in case of system error or failure.

7. LIST OF ANNEXES

Annex 1: Existing information sources and databases exploited as “starting points”
Annex 2: List of received documents
Annex 3: Questionnaire for the survey
Annex 4: Chronological Overview of interviews carried out
Annex 5: The case study done in the US
Annex 6: Some links to General Information and more Technical Information on Humanitarian Demining, alphabetically sorted
Annex 7: Co-ordinates of the organisations that were contacted for the survey
Annex 8: Face to face interviews in chronological order.
Annex 9: EUDEM data base listing

8. GLOSSARY

Sources:
http://www.hdic.jmu.edu/hdic/category/
http://www.demining.brtrc.com/policy/publicpolicy/intragny/summary.htm

Term	Definition
Anti-personnel Landmine (APL)	The term "anti-personnel landmine" means any munition placed under, on, or near the ground or other surface area, either placed by humans, or delivered by artillery, rocket, mortar, any similar means, or dropped from an aircraft and which is designed, constructed or adapted to be detonated or exploded by the presence, proximity, or contact of a person. The term "anti-personnel landmine" does not include command detonated Claymore munitions. (Leahy Amendment, signed into law February 12, 1996, "Moratorium on Use of Antipersonnel Landmines," section 583)
AP Mine Sifter	A drum that picks up the contaminated soil, closes and rotates until all loose soil falls out. The remaining debris can be visually inspected.
ARIS network	A European Network of Excellence on “Action for Research and Information Support in Civilian Demining”, co-ordinated by JRC
Biochemical Neutralization	Some organisms feed on certain elements of explosive chemicals, thus rendering them inert, and therefore could theoretically be used in demining.
Biosensor	Animals (dogs, pigs, rats) can be used as biosensors but the term can also refer to other new artificial vapour-analysing technologies such as artificial olfactory systems which analyse air particles for trace elements of explosive vapours.
Bounding Mine	A fragmentation anti-personnel mine that employs a primary charge to elevate the mine to a predetermined height before the main charge is initiated. Set off by either trip wire or pressure and, unlike blast and simple fragmentation mines, is designed to kill rather than maim. Sometimes nicknamed "bouncing Betty."
Check Clearing	When little or nothing is known about the mine situation in a given area, the area has to be check-cleared to establish whether it is mined and warrants a full fledged mine clearing operation.
Clutter	Interfering echo's in a radar signal caused by reflection from objects other than the target
Command-destructing Mine	A mine that can be detonated by a remotely delivered command.
Countermine	Military operations concerned primarily with rapid breaching of mined barriers rather than mine clearing through the use of ploughs, rollers, flails, etc., and not concerned with area clearance.
Demining	The complete removal of all landmines from an area in order to safeguard the civilian population. (*Hidden Killers*, 1994)
Demining Debt	Used to describe the phenomena occurring when the uncleared landmines proliferate at a rate faster than adequate funds and technologies allow for as a rate of clearance.
DoD	Department of Defence
Earth Tiller	Horizontal steel beam mounted with teeth tilling the soil up to a depth up to 50 cm, whilst travelling, detonating or disrupting mines

Electromagnetic Induction (EMI)	The process by which a current flowing through a primary coil produces a secondary current in a conductive medium
Environmental Restoration	The process of cleaning up areas that have experienced military action or armed conflict eliminating munitions, explosives, and harmful by-products to restore the area to peaceful civilian pursuits.
EOD	Explosive Ordnance Disposal
False Alarm Rate	The rate of alarms generated by other phenomena than the target objects which have to be detected
Flail	Rotary flail devices are typically composed of cylindrical drum structures housing a collection of chains on a horizontal bar which, hitting and milling the ground to detonate the mines or break them apart
FNA	Fast Neutron Analysis is based on the interaction of fast neutrons with the nuclei of interest. During this process the high energy neutrons put elements in an excited, short lived state, in particular Carbon, Nitrogen and Oxygen of explosives and soils, by hitting their nuclei. The nuclei return to their initial state by emitting gamma radiation, whose energy distribution is chemically characteristic of each nucleus. By characterising 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 – in order to determine the type of substance under analysis
Fragmentation Mine	An antipersonnel mine laying above the ground and usually employing either a packing of fragments, steel balls, or pellets, or a segmented outer casing which is dispersed by the force of the explosion and becomes the primary cause of injury to the victim.
GIS	Geographic Information System
GPS	Global Positioning System
GPR	Ground Penetrating Radar
Horizontal Action Mine	Mine designed to produce a destructive effect to one or more targets in a variable direction approximately parallel to the ground. Also called an aim controlled-effect mine (ACEM).
Humanitarian Demining	The safe, effective, and cost efficient clearance of landmines from land and littoral areas in order that life can return to normal.
IMS	Ion Mobility Spectrometer
Indiscriminate Effect	Problems posed by landmines even when the combatants make a good faith effort to distinguish between military targets and civilians; because of the inherent time lag between the laying of mines and their explosion, mines often present an indiscriminate danger far into the future.
Infrared (IR) technology	Technology based on electromagnetic waves in the infrared spectral region, lying outside the visible spectrum at its red end
International Organisations (IOs)	Organisations with a global charter and influence such as the United Nations and International Committee of the Red Cross.
JRC	Joint Research Centre of the European Commission
JUXOCO	Joint Unexploded Co-ordination Office, the US government office responsible for all army counter mine programmes, including humanitarian demining programmes
Landmine	Any munitions designed and manufactured to be detonated after it has been laid by the presence, proximity, or contact of a person or vehicle. (*Hidden Killers*, 1994)
LWIR	Long Wave IR (8-12µm)
MD	Detector to detect metallic objects
Mine Action	In principle, includes more than mine clearing and mine awareness campaigns and is designed to mitigate the effects of landmines prior to the beginning of clearance operations.
Mine Action Center (MAC)	A host nation structure for carrying out mine awareness campaigns, conduct reconnaissance, collects and centralizes mine data
Mine Awareness Training	A program to assist host nation governments, international organisations, and non-governmental organisations to train local populations to deal with landmines until mines can be permanently removed. The program minimises the danger of uncleared mines by training host nationals in mine detection, identification, marking, avoidance, reporting, mapping, rudimentary extrication, and first aid skills.
Minefield Density	The average number of landmines detected per square meter of minefield or the number of mines in a known "pattern."

Mine Protected Vehicle (MPV)	Vehicles designed to be protected against AP and AT mines.
Microwave	A comparatively short electromagnetic wave, typical wave lengths between 1 cm-1 m
Millimeter wave	Frequency between 50-180 GHz, i.e. wavelength between 6 mm-1.7 mm respectively
MoD	Ministry of Defence
Multi-sensor Mine Detector	Detection using combinations of technologies such as magnetic, infrared, microwave, chemical, radar and biosensor detectors to correlate their respective accuracy's into a more accurate detection.
MWIR	Medium Wave IR (3-5µm)
Non-governmental Organisations (NGOs)	Transnational organisation of private citizens that maintains a consultative status with the Economic and Social Council of the United Nations. Non-governmental organisations may be professional associations, foundations, multinational businesses, or simply groups with a common interest in humanitarian assistance activities (development and relief).
Non-reconstitutable Mine	A self-deactivating, self-neutralising, or command-neutralising mine that cannot be reactivated by means available outside its manufacturing plant or comparable facility.
NMR	Nuclear Magnetic Resonance: the magnetic resonance of an atomic nucleus
NQR	Nuclear Quadrupole Resonance: an electromagnetic resonance screening technique for the detection of explosives in bulk form, relying upon the resonant response of certain nuclei possessing electric quadrupole moments
PETN	Pentaerythritol tetranitrate ($C_5H_8N_4O_{12}$) is one of the strongest known high explosives. It is primarily used in booster and bursting charges of small calibre ammunition, and in upper charges of detonators in some landmines and shells.
Probing	See prodding
Prodding	Location of individual mines by prodding the ground with a thin rod or blade inserted at an angle every 4-5 cm (i.e., 400-600 prodding actions every square meter).
RDX	(Cyclotrimethylenetrinitramine, $C_3H_6N_6O_6$) Hexogen, or Cyclonite, RDX is considered one of the most powerful military high explosives. Sometimes used in mines together with TNT (Composition-B).
R&D	Research & Development
ROC	Receiver Operating Characteristics
Safety Distance	Distance to be maintained at all times between deminers; usually 50 meters between teams and 5 meters between members of the same team.
Self-deactivating Mine	A mine that automatically renders itself inoperable by means of exhaustion of a component of the mine that is essential to the operation of the mine.
Self-destructing Mine	A mine that automatically destroys itself by means of an incorporated mechanism.
Self-eliminating Mine	A mine that is self-destructing, self-deactivating, and cannot be reconstructed..
Self-neutralizing Mine	A mine that automatically renders itself inoperable by means of an incorporated mechanism.
SAR	Synthetic Aperture Radar
SER	Statements of Equipment Requirements
SOP	Standard Operating Procedure
SOR	Statements of Operational Requirements
Sub-Surface Clearance	Mine clearance is categorised by depth; in this case, the ground has to be searched for mines to a depth of 200mm, the layer where antipersonnel mines are found.
TNA	Thermal Neutron Analysis: features high sensitivity to nitrogen concentration and low cost. On the other hand it is relatively slow, and is usually not employed in a real-time mode, like conventional metal detector for example, but used as a confirmatory device targeted at the verification of suspected spots.
TNT	(2,4,6-) Trinitrotoluene (also Trotyl), most common explosive in landmines ($C_7H_5N_3O_6$)
UWB	Ultra-wideband radar
Unexploded Ordnance (UXO)	Any mass-produced explosive munitions that have failed to function fully as designed.

Vegetation Cutter	Machine designed for clearing vegetation and tripwires as a precursor to accelerated manual clearance
Wheel Shovel	Wheel Shovel (e.g. HALO Trust in Afghanistan) based systems for digging up mines that will be manually cleared afterwards, for the excavation and inspection of (urban) rubble, also for roads (road grader). A mesh basket is fitted over the shovel, which then shakes out the rubble; large ordnance and mines will remain held by the mesh in the bucket.
X-ray back scatter	The scattering of X-ray radiation in a direction opposite to that of the incident radiation, due to reflection on particles of the medium traversed.

ANNEX 1. EXISTING INFORMATION SOURCES AND DATABASES EXPLOITED AS "STARTING POINTS"

- *Internet*: list of links and databases:
  - DeTeC (http://diwww.epfl.ch/lami/detec/minelinks.html);
  - MgM Foundation Web site (http://www.mgm.org/);
  - Lawrence Livermore National Lab's "Who's Who" (http://www.llnl.gov/landmine/landmine_whos_who.html);
  - HDIC Demining Organisation Directory (http://www.hdic.jmu.edu/hdic/exchange/database/);
  - CARE (http://www.care.org/newscenter/landmines/ngoland.html);
  - JMU Humanitarian Demining Information Center (http://www.hdic.jmu.edu/hdic/exchange/ngo/).

- *Internal lists* of persons and organisations active in humanitarian demining, accumulated in previous projects, and other lists:
  - Internal EPFL;
  - Internal VUB (also in relation with ongoing projects);
  - US State Department "Hidden Killer'98" report (http://www.state.gov/www/global/arms/rpt_9809_demine_toc.html)

- *EU financed projects*, in the research as well as the clearance area:
  - List of projects and contact points: projects from DGIII(ESPRIT)/DGXIII: http://www.cordis.lu/esprit/src/hphdhome.htm
  - For technology projects from DGVIII, Mr. Cervone / DGVIII;
  - ARIS Network of Excellence (NoE) on Humanitarian Demining (http://www.at.sai.jrc.it/aris/);
  - DGIA, DGIB - Mr. Cervone;
  - DGVIII: airborne minefield detection.

- List of participants to well known conferences in the domain:
  - JRC workshops;
  - Edinburgh 96-98 (EUREL International Conference on The Detection of Abandoned Landmines);
  - Other (ex. conferences on mechanical demining in Germany & Toulouse).

- Literature on the subject (survey papers for example).

ANNEX 2. LIST OF RECEIVED DOCUMENTS, PUBLICITY BROCHURES, AND OTHER INFORMATION SOURCES

(1) Andrews A.M., George V., Altshuler T.W. & Mulqueen M. Results of the Countermine Task Force Mine Detection Technology Demonstration at Fort A.P. Hill, Virginia, March 18-22, 1996
(2) Rotondo F., Altshuler T.W., Rosen E., Dion-Schwarz C & Ayers E. Report on the Advanced Technology Demonstration (ATD) of the Vehicular Mounted Mine Detection (VMMD) Systems at Aberdeen, Maryland, and Socorro, New Mexico, Virginia, 1998
(3) JUXOCO (Joint Unexploded Ordnance Coordination Office). Hand Held Metallic Mine Detector Performance Baselining Collection Plan, Fort A.P. Hill, Virginia, 1998
(4) Tantum S.L. & Collins L.M. Detection and identification of mines using signals from Wichmann/BRTRC Antenna: a preliminary report, Duke University.
(5) Carin L. & Baum C.E. Wideband Time- and Frequency-Domain EMI: Phenomenology and Signal Processing, Duke University
(6) Khadr N., Barrow B.J., Bell T.H. & Nelson H.H. Target Shape Classification using Electromagnetic Induction Sensor Data, Arlington.
(7) Kaczkowski P.J. Pulsed Electromagnetic Induction (PEMI) for UXO Discrimination in JPG Phase IV – Preliminary Results, University of Washington.
(8) Arcone S.A., Delaney A.J., Sellmann P.V. & O'Neill K. UXO detection at Jefferson Proving Ground Using Ground-Penetrating Radar, UXO Forum '98, Anaheim, California, 1998
(9) Wichmann G. Research and Development on the Field of Mine Detection, 1996
(10) DFID Background Briefing. Humanitarian mine action, a progress report, February 1999
(11) Andrews A.M., Altshuler T.W., Rosen E.M. & Porter L.J. Performance in December 1996 Hand-Held Landmine Detection Tests at APG, Coleman Research Corp. (CRC), GDE Systems, Inc. (GDE), and AN/PSS-12, IDA, March 1996
(12) Carin L., Geng N. & McClure M. Ultra-Wideband Synthetic Aperture Radar for Mine Field Detection, Duke University, Durham
(13) Arnsfelt A.B., PL Brake. Innovative environmental inventions.
(14) Hydrema Publicity Brochure on Mine Clearing Vehicles
(15) Vallon Publicity Brochure on MDs
(16) CAT Publicity Brochure on Multisensor Mine Detecting System
(17) Zanzi L, Moscon A & Valle S. Processing Strategies for the Application of the GPR Technology to Humanitarian Demining, Milano, Italy
(18) DEMEX Publicity Brochure on Environment Dynamics Recovery
(19) Naz P., Bobin L., Christnacher F & Parmentier G. Détection acoustique et sismique d'objets enfouis, ISL
(20) SODERN Publicity Brochure on Neutronics
(21) Universität Tübingen Publicity Brochure
(22) IUT Publicity Brochure on Ion Mobility Spectrometry
(23) FGAN Publicity Brochure on Research Fields and organisation
(24) TZN Publicity Brochure on Mobile Mine Detection and Clearance Device
(25) ABC Publicity Brochure
(26) LETI Publicity Brochure on Magnometer Technologies
(27) CEA-LETI Publicity Brochure on X-Technologies
(28) Cacciabue P.C. (ed.). Human Factors Research Activities, Annual Report 1998, JRC, Ispra, 1998
(29) SATIMO Publicity Brochure on Electromagnetic Field Measurement Systems
(30) AA Publicity Brochure on Leben Ohne Minen: Der Ottawa Vertrag- Eine Herausförderung für die Zukunft.
(31) AA Report on Humanitarian Mine Action, 1998
(32) Busch OTL. Humanitäres Minenräumen in Afghanistan, Bonn, June 1999
(33) Padova University Publicity Brochure on the Explodet Project 1998 Progress Report
(34) Bach P, Le Tourneur P., Poumarède B & Brette M. Detection of Abandoned Land Mines Using Neutron Interrogation. International Conference Edinburgh, UK 1996.
(35) Bach P., Ma J.L, Froment D. a J.C. Jaureguy. Chemical Weapons detection by fast neutron activation analysis techniques.
(36) Vettèse F., Asselineau B, Dhermain J, Antonot B & Bach P. Neutron activation analysis techniques to identify arsenic in chemical weapons, Sweden, June 1995.
(37) SODERN Publicity Brochure on Mines detector using neutron interrogation
(38) General Engineering Anchor Group Publicity Brochure on GIS for demining
(39) ABC Publicity Brochure on Humanitarian Demining
(40) BICAT Publicity Brochure on Recycling of Demolition Debris with Hidden Explosives

(41) Aardvark Publicity Brochure on Mechanical Minefield Clearance System
(42) Hydrema Publicity Brochure on Mine Clearing Vehicle
(43) Handicap International-MAG-NPA. Publicity Brochure "Portfolio of Mine Related Projects 1998
(44) Busch OTL Slides on Close-in Detection & Remote Sensing System
(45) AA Humanitarian Mine Action Equipment Catalogue 1998-1999
(46) NPA Brochure: Mines, the Silent Killers
(47) Hundskolan Publicity Brochure
(48) Hundskolan Video
(49) Celsius Mine-Guzzler Video
(50) Celsius Publicity Brochure on Mine Guzzler & Technical Description
(51) Ixtrem Publicity Brochure on Electromagnetic Detectors
(52) DLR print out CD-rom
(53) TNO year report 1998
(54) Vallon Publicity Brochure on Metal Mine Detectors
(55) Aardvark Beating the land mine video
(56) Hydrema Publicity Brochure on Toolbox Concept
(57) AA slides on Toolbox approach
(58) ICRC Overview 1998
(59) Schiebel Publicity Brochure on All Terrain Mine Detector
(60) HOM2000 Publicity Brochure

ANNEX 3. QUESTIONNAIRE FOR THE SURVEY

EUDEM Research Survey

Questionnaire for a survey: EU-project on DEMINING organisations

PART I: Identification Data (required unless otherwise specified)

Organisation Name: «Institute» - «Dept»

Organisation Type (please cross out and/or complete):

- ❑ Industrial SME (<250 pers.)
- ❑ Large Industry
- ❑ Research Centre
- ❑ Academia
- ❑ Defence
- ❑ Other Governmental
- ❑ NGO
- ❑ International Organisation
- ❑ Other, please specify: ……………………………………..

Contact Person, «Title» «First_name» «Family_Name»,
Function within Organisation: ………………………………

Address (Street, no., Postal Code, City, Country):
«Address_1»
«Address_2»
«city»
«Country»

Telephone/Fax no. T«Tel» F: «Fax».

E-mail (if available): «Email»

Address of the Web site(s) (if available): «Homepage»

Affiliation or Branches in other Countries (if applicable) to be listed below:

Total no. of Staff Members working in the entire Organisation:

No. of Staff Members in activities directly related with Demining:

Involvement in Demining (please cross out and/or complete):

- ❑ Mine Awareness
- ❑ Victim Assistance
- ❑ Survey/Mapping
- ❑ Detection
- ❑ Clearance/Destruction
- ❑ Other, please specify:………………………………….

Type of Involvement (please cross out and/or complete):

- ❑ Consultancy
- ❑ Education/Training
- ❑ Equipment Manufacturing
- ❑ Demining Campaigner/Organiser
- ❑ Other, please specify:………………………………….

PART II: Structural data on the organisation type:

Products/services/research topics (if any) offered/handled by your organisation:

Please list **five** keywords to summarise your activities:

- …………………………….. -…………………………….. - ………………………………
- …………………………….. -……………………………..

Current activities, described in an abstract of not more than 10 lines:

Financial support sources (if any) actually involved in these activities:

Specific technologies currently being used or considered for the future:

Solutions which have been used in the past, but have been discarded, and why:

PART III: Background data on the organisations' partners and more specific information:

Partners (if any) involved in current (C) or past (P) activities:

Comments (C) or needs (N) that you would like to share with us:

Please list references***** on your activities (articles, brochures, books with results, activity reports, yearbooks, …) which you judge to be relevant:

Are you interested/willing to have further contacts and/or visits?

❑ Yes
❑ No

*****Please send us a copy of your reference material together with the completed questionnaire or by separate mail to the following address:

Karin De Bruyn
EUDEM Survey Project-Vrije Universiteit Brussels
ETRO Dept., Fac. of Applied Sciences
Pleinlaan 2
B-1050 Brussels, BELGIUM

ANNEX 4. CHRONOLOGICAL OVERVIEW OF INTERVIEWS CARRIED OUT

During EUDEM 49 main players, active in several aspects of demining/mine action, were personally visited in 10 European countries. The following visits and interviews were carried out in chronological order:

Organisation	Full Name	Place	Country	Date
IDS	Ingegneria dei Sistemi	Pisa	Italy	14/1/1999
JRC	EC Joint Research Centre	Ispra, Varese	Italy	15/2/1999
Politecnico di Milano		Milano	Italy	16/2/1999
INFN	Istituto Nazionale di Fisica Nucleare	Padova	Italy	16/2/1999
ABC	Appalti Bonifiche Costruzioni	Firenze	Italy	17/2/1999
Marconi SpA	(now Marconi Communications)	Genova	Italy	18/2/1999
ICRC	Intnl. Committee of the Red Cross	Genève	Switzerland	3/3/1999
GICHD	Geneva Intl Centre for Hum. Demining	Bern & Genève	Switzerland	15/3&3/6/1999
Alain Priou	**contribution by e-mail**	Univ. X Nanterre, Paris	France	18/3/1999
DGA	Délégation Générale pour l'Armement	St. Cloud, Paris	France	23/3/1999
Handicap International		Lyon	France	23/3/1999
ONERA		Toulouse	France	24/3/1999
SATIMO		Courtabœuf, Paris	France	24/3/1999
ISL	Institut de Saint-Louis	Saint-Louis	France	24/3/1999
CEA-LETI		Grenoble	France	25/3/1999
EPPRA		Palaiseau, Paris	France	26/3/1999
SODERN		Limeil-Brevannes, Paris	France	26/3/1999
MoD	UK Ministry of Defence	London	United Kingdom	30/3/1999
DERA	Defence Research & Evaluation Agency	Chertsey	United Kingdom	30/3/1999
HALO Trust		Glasgow	United Kingdom	31/3/1999
BGT	Bodenseewerk Gerätetechnick	Ueberlingen	Germany	21/4/1999
Vallon GmbH		Eningen	Germany	22/4/1999
Universität Tübingen		Tübingen	Germany	22/4/1999
Institut Dr. Förster		Reutlingen	Germany	23/4/1999
FGAN/FOM	Research Establishment for Applied Science	Tübingen	Germany	23/4/1999
TZN		Unterlüss	Germany	3/5/1999
IUT	Institut für Umwelttechnologien	Berlin	Germany	4/5/1999
DEMEX	(Consulting Engineers)	Copenhagen	Denmark	5/5/1999
A/S Hydrema		Støvring, Aalborg	Denmark	5/5/1999
DTU	Technical University of Denmark	Lyngby	Denmark	6/5/1999
Ole Nymann, CAT		(Lyngby, see above)	Denmark	6/5/1999
FOA	Swedish Defence Research Est.	Linköping	Sweden	10/5/1999
Biosensor Applications AB		Oerebro	Sweden	11/5/1999
Bofors AB		Karlskoga	Sweden	11/5/1999
Celsius Tech		Järfälla, Stockholm	Sweden	12/5/1999
Landmacht	Dutch Ministry of Defence	Den Haag	The Netherlands	18/5/1999
TNO	Netherlands Organisation for Applied Scientific Research	Den Haag	The Netherlands	18/5/1999
NPA	Norwegian People's Aid	Oslo	Norway	20/5/1999
Swedish Armed Forces Dog Training Center		Stockholm	Sweden	20/5/1999
Humanity Dog		Kramfors	Sweden	21/5/1999
UN MAAP and CROMAC	UN Mine Action Assistance Programme, CROatian MAC	Zagreb	Croatia	24/5/1999
MECHEM operations		Gospic, Licki Osik	Croatia	25/5-26/5/1999
A.B.C.D. operations		Slavonski Brod	Croatia	27/5/1999
Tamar operations area	[ops had not yet started]	Kusonje	Croatia	27/5/1999
CROMAC Scientif Council		Zagreb	Croatia	28/5/1999
King's College London	**[written contribution]**	London	United Kingdom	5/1999
JRC	EC Joint Research Centre	Ispra, Varese	Italy	14/6-16/6/1999
German Federal Foreign Office		Bonn	Germany	25/6/1999
DLR	Deutsches Zentrum für Luft- und Raumfahrt	München	Germany	25/6/1999

ANNEX 5. THE CASE-STUDY DONE IN THE US

The study was carried out by John Brooks, on behalf of the EUDEM project.

1. Introduction.

This report summarizes the results of a series of telephone and personal contacts made with US Government and industry representative in various areas of unexploded ordnance (UXO) and land mine detection and remediation. **Table 4** at the end of this report lists the names and affiliations of all key personnel contacted. The goals of the survey were to determine the current state-of-the-art of US military and humanitarian demining technologies related to the detection and classification of anti-personnel land mines (APLs). US Army-funded programs were investigated; the many US Navy programs were not, due to the general nature of humanitarian or post-conflict demining. All information herein is current as of 01 March 1999.

1.1. Approach

The approach to the survey was two-fold; telephone contact and personal contact. Every effort was made to contact the program manager for each on-going technology development effort. In general, they were responsive to my inquiries, but declined to provide specifics of any signal processing. In almost all cases, they referred me to the Government Contracting Officer's Technical Representative (COTR) at Ft. Belvoir.

Upon contacting each individual, I explained my relationship to the EUDEM; in addition, I informed each individual that all information provided by them could be used in published documents; thus, any proprietary or confidential information was to be excluded. However, within this report, I have at times made judgements of sensor configurations and performance based on deriving or extrapolating from personal observations of equipment. This is particularly the case with the GDE version of the HSTAMIDS, where I have made inferences of system configuration based on personally handling the device, and discussions with US Government personnel.

On 24 and 25 February 1999, I met with representatives of the US Night Vision Electronic Sensors Directorate (NVESD) and the Joint Unexploded Ordnance Coordination Office (JUXOCO). NVESD is the designated US Government office of responsibility for all Army countermine programs, including humanitarian demining programs. JUXOCO was established to provide a coordination function for all Department of Defense (DoD) UXO programs; it serves as a repository of data collected at US test facilities such as Ft. A.P. Hill, Aberdeen Proving Ground and the Jefferson Proving Ground (JPG). All test data involving UXO and mine detection/clearance is linked to the JUXOCO web site, http://www.uxocoe.org/index2.htm. JUXOCO is also referred to as the Joint UXO Center of Excellence, abbreviated JUXOCOE. In this report, JUXOCO, UXOCOE, UXOCO and JUXOCOE may be used interchangeably.

1.2. Previous Surveys and Workshops

JUXOCOE held a series of workshops to investigate various technical approaches to detecting UXO. Due to the volume of information, the links to those workshops are provided.

General: http://www.uxocoe.org/index2.htm
Aided Target Recognition:
http://www.denix.osd.mil/denix/Public/News/UXOCOE/Documents/Atr/atr1.html#Technology%20Limitations
Other Technologies: http://www.denix.osd.mil/denix/Public/News/UXOCOE/Documents/Other/other1.html
Magnetometry: http://www.denix.osd.mil/denix/Public/News/UXOCOE/Documents/Magnetometry/mag2.html

1.3. Comments on Military vs. Humanitarian Design

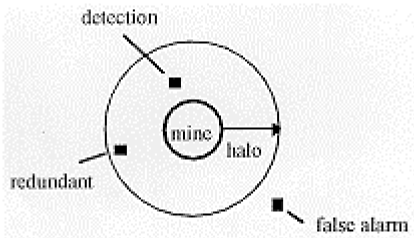
Because the vast majority of funding for US demining technology is derived from the US Department of Defense (DoD), it is therefore necessary to understand the extent to which the design of such systems is based on military operational doctrine compared to humanitarian, or post-conflict doctrine. This influence is manifested in two ways; the requirement, stated by US Government program managers, to locate the mine "in real time" and also the fact that all developmental devices are tested by military engineers using military practices. The first requirement results in a development path that does not permit the exploitation of several processing methods which, for example, generate an image of the target following the scanning of an area of interest. The current prototype models (CRC, GDE) Hand-Held STAnd-off Mine Detection System (HSTAMIDS) are scanned over an area of interest and the possible presence of a mine is indicated by a simple audio tone at the time the sensor is passed over the mine; thus, only the received energy and possibly the duration (an indication of physical size of the target) are used as classification features. The practice of military personnel testing the devices leads to designs which may not be ergonomically suited to indigenous deminers in such places as Cambodia and Angola;

acceptance of the devices by those deminers and the corresponding Non-Governmental Organizations (NGOs) is thus problematical.

1.4. Comments on Performance Measures

As a framework for the discussion in the following sections, it is instructive to assess the way in which field tests in the US have been conducted and evaluated. In particular, whether a contractor "wins" or "loses" a competition is based almost entirely on how that contractor scores in the area of "probability of detection (P_d)" and "probability of false alarm (P_{fa})" and the resulting receiver operating characteristic (ROC) curves. Three specific reports are of note (Andrews, et.al.(1), Rotonso, et. al.(2), Draft JUXOCO Report (3)). Each report has different criteria for measuring P_d and P_{fa}, so it is not possible to compare various systems from one report to the other, nor is there any firm "standard" measure of performance.

The first report describes a series of tests conducted in March 1996 of both vehicular and hand-held demining systems. The vehicular systems were represented by Geo-Centers, SAIC, IAI Elta and GDE Systems. In this report, a valid target is declared if it is detected anywhere within the bounds of the mine, and also 0.5 m outside the mine boundary; in other words, the mine is surrounded by a "halo" which is 0.5 m larger than the mine itself (Hand-held systems were evaluated with a 0.15m halo):

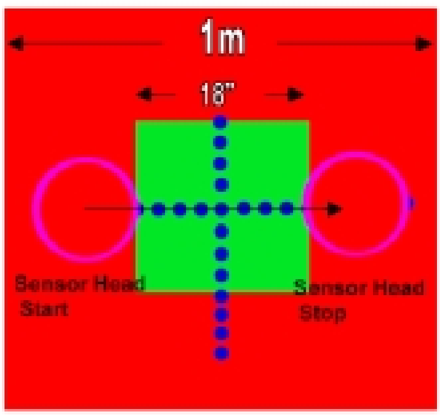


Thus, any signal that exceeds some threshold within this large ring is considered to be a valid mine detection. Additional detections within the halo are considered to be redundant. The second report describes a series of tests conducted at Aberdeen and Soccoro sites two years later than the first report. The systems in this report are from CRC, GDE, EG&G, GeoCenters and Computing Devices of Canada. In the second report, *the halo is extended to 1.0m*. This automatically increases the chance that a "detection" will be declared a mine (and thus ensuring a higher "score" for the device,) even though it may have been produced by a non-mine object.

In both the above reports, the ROC is generated by assuming Gaussian statistics for both clutter and mean-shifted Gaussian for target + clutter. This seems to imply that the mean clutter is statistically different from the target; this is not the case in practice. Perhaps a better measure of performance under the Gaussian assumption would be a test of variance, or an assumption of Rayleigh-Rice statistics common to radar signal processing practice.

The third report is a draft test plan for the HSTAMIDS tests. In this report, the test area of size 49m x 20m is divided into 980 squares, each 1 m in length. 880 squares contain various clutter targets, and 100 squares contain mine targets. The center of each grid square is scanned once vertically and once horizontally as shown in the following figure, extracted from the test plan:

Fig. 6 Data Collection Template and Sensor Head Positioning Technique



This methodology permits a more consistent measure of assessing detector performance. It should be noted, however, that this test approach still involves the use of a single scan in any one direction over the target. No images are created. The results of this test methodology was used by Duke University to assert "100% Correct" classification of a number of minimum-metal APLs with the Wichmann/BRTRC antenna (4).

The above discussion points out the need to develop a consistent method, and a mathematically sound procedure for assessing and comparing system performance; it also indicates that reports of a certain system achieving a specific level for P_d and P_{fa} needs to be accompanied with a clear explanation of the methods used to determine the reported performance.

1.5. Summary of Technology Issues

RADAR (GPR)

For this survey, three US GPR programs were reviewed; the Ground-based STAnd-off Mine Detection System (GSTAMIDS), the Hand-held STAnd-off Mine Detection System (HSTAMIDS), and a developmental short-pulse hand-held GPR designated as the BRTRC/Wichmann radar. In general, the tendency to employ stepped-frequency modulation is consistent between the three main programs; the BRTRC/Wichmann radar uses a more conventional short-pulse modulation, albeit a very wideband pulse, ca. 5 GHz.

Although no specific information was obtained regarding signal processing methods and algorithms due to company proprietary considerations, a review of applicable published literature and discussions with US Government personnel revealed that, in general, the features used for classification are rather simple, including the statistical mean and variance of the returned signals under the assumption of a Gaussian distribution for noise. This may explain the poor performance of the HSTAMIDS candidates to date. The US requirement for HSTAMIDS is a probability of detection, Pd, of a mine to be 0.80 (see Section 1.1); the "halo" for handheld system tests is 15cm); the best performance with trained contractor personnel was 0.70, and the average performance using military personnel was only 0.30 for min-metal APL. Such performance has led to an 18-month extension of the HSTAMIDS program.

ELECTROMAGNETIC INDUCTION (EMI)

EMI has been used with some success for the detection of buried metallic UXO and mines (5) One EMI system which has been used in these tests is the Geophex GEM-3 (8). The GEM-3 is a prototype wide-band frequency-domain EMI sensor. The GEM-3 uses a pair of concentric, circular coils to transmit a continuous, wideband, digital electromagnetic waveform. The resulting field induces a secondary current in the earth as well as in any buried objects. The set of two transmitter coils has been designed so that they create a zone of magnetic cavity at the center of the two coils. A third receiving coil is placed within the magnetic cavity so that it senses only the weak secondary field returned from the earth and buried objects.

INFRARED (IR)

The Airborne STAnd-off Mine Detection System (ASTAMIDS) was a program developed to locate minefields, and used an IR sensor as the primary queuing sensor. ASTAMIDS failed to meet US Government specifications due to the poor performance of the IR sensor. He program has been realigned to study other options; the program is now called the Light Airborne Mine Detector (LAMD), according to NVESD and JUXOCOE personnel. No specific information regarding the failure has been made available at the time of this report.

2. Vendor Specifics

2.1. HSTAMIDS

The Government Contracting Officer's Technical Representative (COTR) is Mr. Mark Locke, 703-704-2418, mlocke@nvl.army.mil.

The HSTAMIDS program consists of working prototypes from Coleman Research Corp. (CRC) and GDE Systems. When controlled tests were conducted at Yuma Proving Ground, both "expert operators" (contractor personnel) and military operators used the systems. The expert operators managed to achieve a probability of detection (Pd) of about 0.70, whereas the military operators achieved only about 0.30 Pd. The objective goal for HSTAMIDS is to achieve a Pd of 0.80, so the HSTAMIDS program has been extended for 18 months, with additional tests to be conducted in march-April 2000.

A detailed summary of additional tests of the two HSTAMIDS competitors in Dec. 96 is attached (9), and is also available at http://www.denix.osd.mil/denix/Public/News/UXOCOE/Documents/Ida/ida1.html.

The following, extracted from the report, summarizes the performance of the two systems:

"The two contractor systems exhibited similar performance to the AN/PSS-12 for AT/Metal, AP/Metal, and AP/LowMetal. For AT/LowMetal and AT/NonMetal, both systems outperformed the AN/PSS-12. Finally, the CRC system exhibited a slight statistically significant improvement over the AN/PSS-12 for AP/NM, whereas the GDE system did not exhibit a statistically significant increase in performance, as determined from the upper limits on the confidence intervals calculated using a binomial detection process. The following summarizes the results:

	GDE			*CRC*			*AN/PSS-12*		
Mine Type	*FAR* (m^{-2})	P_d	*SNR*	*FAR* (m^{-2})	P_d	*SNR*	*FAR* (m^{-2})	P_d	*SNR*
AT/M	0.50	0.97	8.3	0.67	1.00		0.56	1.00	
AP/M	0.50	0.97	9.2	0.67	0.93	7.9	0.56	0.97	9.1
AT/LM	0.50	0.90	6.7	0.67	0.97	7.9	0.56	0.67	3.5
AP/LM	0.50	0.66	5.1	0.67	0.69	4.9	0.56	0.67	5.0
AT/NM	0.50	0.91	6.9	0.67	0.89	6.1	0.56	0.34	-1.7
AP/NM	0.50	0.32	1.1	0.67	0.46	2.4	0.56	0.20	-1.9

- "Both the GDE and CRC systems provide increased capability over the AN/PSS-12. This is particularly true with regard to the detection of AT/LM, AT/NM, and potentially for AP/NM mines. Regardless of the improved performance of the contractor systems relative to the AN/PSS-12*, both performed poorly when attempting to detect AP/LM and very poorly when attempting to detect AP/NM mines*. (emphasis added by JWB)

- "Detection of NM mines by the AN/PSS-12 -- which does not have the capability to detect nonmetallic objects -- indicates that visual cues may have influenced the test results.

- "Probabilities of detection in the current test are somewhat lower than have been achieved by the same systems in previous tests. This may be attributable to operation of the equipment by soldiers rather than contractor personnel; it may also be due to differing clutter environments, target populations, and natural geology. "

Neither of the HSTAMIDS devices produce any type of image. In operation, the sensor is scanned by hand and an audio and visual indication alert the operator to the presence of an anomaly; the radar sensors can be considered to be adjuncts to the MD sensor in both cases.

GDE:
Program Manager : Mr. Bob Penninger, 619-675-2605

Mr. Penninger declined to provide any details of the GDE version of HSTAMIDS, other than to volunteer that the modulation scheme is a stepped frequency approach. NVESD has a working prototype of the GDE HSTAMIDS; a physical inspection of the GDE device reveals that the antenna assembly is probably of a patch design. There are two painted rings on the top of the antenna assembly, and an oval-shaped drawing; each figure is offset to denote the locations of the metal detector loop, a wide-band RF antenna and possibly a narrow-band, high-frequency RF antenna. According to NVESD personnel, the fact that the three sensors are not coaxial, the possible detection of a target can lead to confusion in target registration. The higher frequency antenna is probably designed to permit better discrimination of small targets. The hand-held sensor is augmented with a helmet-mounted IR camera, as is the CRC model.

CRC:
Program Manager: Dr. Bill Steinway, Bill_Steinway@mail.crc.com

The CRC version of HSTAMIDS is a stepped-frequency GPR operating (according to contractor-provided information) in 128 discrete frequencies from ca. 900 MHz to ca. 2750 MHz; a single scan through these frequencies is called a "frequency packet" and 78 packets are transmitted per second. Thus, each frequency dwell has a nominal 100 microsecond duration, with a nominal 14 MHz frequency separation. The current version has 2 receive and 2 transmit antennas; however, the newest version for evaluation will have a single transmit antenna and 2 receive antennas.

2.2. GSTAMIDS:

GSTAMIDS is now undergoing proposal evaluation for EMD (PE 6.4) so all discussions about the current program are prohibited until after 01 April 1999. Government Contracting Officer Technical Representative (COTR) for preceding program is Peter Howard, 703-704-2636, phoward@invel.army.mil. Test reports on previous GSTAMIDS devices are referenced in (6) and (7), and the following comments are derived from those reports.

Although not explicitly a part of the GSTAMIDS program, the Boom-SAR (10) has been used to outline minefields. The reference indicates reasonably good agreement between simulation and experiment.

EG&G:

POC: Jory Cafferky, 505-998-0677, caffej@egginc.com, http://www.eoir.com/uxo/eg&g.htm

The August 1997 EG&G data collection was performed to test the ability of the EG&G VMMD Radar System to locate buried mines. The EG&G radar system is comprised of nine transmitter/receiver pairs each 35cm apart, 1 foot off the ground, and pointed at a 45 degree angle with respect to the ground.

GEO-CENTERS, INC.

POC: Thomas Gorman, 617-964-7070, tomgorman@tech.geo-centers.com,

Geo-Centers GSTAMIDS consists of a vehicle-mounted GPR and IR sensors. The forward looking IR sensor consists of a 3-5 mm Amberview camera that provides a 14 bit, 256 by 256 pixel, video image every 2 seconds. The GPR system is mounted 50 cm. above the ground. The 80 cm. wide multi-antenna (four transmit, four receive) ground-penetrating radar array, termed a Focused Array Radar (FAR), focuses and sweeps energy into the ground to detect buried objects. This GPR operates in a frequency range of 700-1,300 MHz. The focused GPR array is described at http://www-dsed.llnl.gov/documents/em/sdndarpa96/sdndarpa96.html, "LLNL DARPA Mine Detection Field Experiment using RF."

2.3. BRTRC/Wichmann

Fred Clodfelter, 703-205-1535, fclodfel@brtrc.com, http://www.brtrc.com/:, described briefly a cooperative agreement between BRTRC and Guenter Wichmann whereas BRTRC builds a GPR using the Wichmann antenna. The antenna is claimed to minimize ground clutter and is the key component; the antenna has an upper frequency of ca. 5 GHz. And employs a simple pulse.

Subsequent to the visit to JUXOCO, a report dated 1996, entitled "Research and Development on the Field of Mine Detection" by Guenter Wichmann, DTIC AD AD-A325 260, available from the Defense technical Information Service (DTIC), http://www.dtic.mil/dtic/ This report describes an antenna design which is capable of transmitting a sub-100ps pulse with little reflection, at the cost of very high attenuation and low output power of 10mW.

Prof. Leslie Collins, Duke University, 919-660-5260, lcollins@ee.duke.edu, performed a study of the BRTRC/Wichmann radar data set and claims "100% Correct Identification"[VIII] of a number of APLs, including PMA-3, M-14 and VS-50. This research was supported by JUXOCOE. The briefing is included in this report[4]. A telecon with Prof. Collins on 01 March 1999 indicated that she used a very small data sample, so the results and claims are not conclusive. The analysis of the data followed in part the Generalized Likelihood Ratio Test (GLRT). The BRTRC/Wichmann antenna is a ca. 0.5m linear array of eight transmit/receive antennas sample the surface about every 10cm.

2.4. ASTAMIDS:

According to Mr. Locke of NVESD and Dr. Altshuler of DARPA, the ASTAMIDS program failed to pass the previous milestone and the program has been returned to the tech base, i.e., back to R&D (PE 6.2). The system failed due to the inability of the IR sensor to reliably detect mines at a distance. The program has now been renamed the Light AirBorne Mine Detector (LAMD).

2.5. Acoustic/Laser Device

Prof. James Sabatier, 601-232-5404, sabatier@olemiss.eduu, has a news release at http://www.olemiss.edu/news/newsdesk/story438.html which also claims "100% Correct Identification" of a number of APL and ATL at Ft. A.P. Hill tests in 1998. He explained to me that the system works by scanning a laser beam across a suspect area while exciting seismic waves over the area. The laser is claimed to be able to permit the detection of the mines. Works poorly in vegetated environments.

2.6. DARPA Dogsnose/NQR Program

Details of the DARPA chemical detection and nuclear quadrupole resonance (NQR) programs are described at http://www.darpa.mil/dso/rd/Applied/UXO/index.html No additional comments are offered here.

3. Conclusion

The US Army demining technology program is maturing, with some erratic programmatic behavior due to lack of clear success of any single or group of technologies. The 18-month delay in HSTAMIDS and the restructuring of ASTAMIDS are clear evidence of this; however, the enthusiasm for continuing is encouraging, as the US clearly recognizes the need for a solution to the mine detection problem. The progress of GSTAMIDS is promising.

The lack of a consistent methodology for performance evaluation and system comparison leads to a "floating baseline" for competing systems to meet.

Table 4. Personnel Contacted

Contact	Company/Org.	Phone	Title	E-mail Address
Fred Clodfelter	BRTRC	[1] 703-205-1535		fclodfel@brtrc.com
Roger Rogowski	BRTRC/Wichmann	[1] 703-205-1544		rogowski@brtrc.com
Dr. William Steinway	Coleman Research ...	[1] 407-352-3700	PM, CRC HSTAMIDS	Bill_Steinway@mail.crc.com
Thomas W Altshuler	DARPA	[1] 703-696-0222	PM, DARPA APL Alternatives	taltshul@ida.org
Regina Dugan	DARPA	[1] 703-696-2296	PM, DSO Dogsnose Program	rdugan@darpa.mil
Leslie M. Collins	Duke University	[1] 919-660-5260	Professor	lcollins@ee.duke.edu
Stacy L. Tantum	Duke University	[1] 919-660-5262		slt@ee.duke.edu
Jory Cafferky	EG&G/GSTAMIDS	[1] 505-998-0677	PM, GSTAMIDS	caffej@egginc.com
Bob Penninger	GDE Systems	[1] 619-675-2605	PM, GDE HSTAMIDS	
Thomas Gorman	Geo-Centers	[1] 617-964-7070	PM, GSTAMIDS	tomgorman@tech.geo-centers.com
Tom McNiff	GEO- Centers	[1] 703-764-3298		tommcniff@aol.com
Ron Kelly	Jaycor	[1] 703-847-4006	PM, Jaycor Stand-off Detector	rkelly@jaycor.com
Mike Jennings	JPO/MCM/ACTD	[1] 703-704-1032	Director, Army ACTD	mjenning@nvl.army.mil
Amber Kasbeer	JUXOCOE	[1] 703-704-1838	PM, Air Force UCOCOE	akasbeer@nvl.army.mil
Dick Weaver	JUXOCOE	[1] 703-704-1090	Director, JUXOCOE	dweaver@nvl.army.mil
Beverly Briggs	NVESD	[1] 703-704-1073	PM, DoD Hum. Demining Progs	
Zenon Derzko	NVESD	[1] 703-704-3236		zderzko@nvl.army.mil
Peter Howard	NVESD	[1] 703-704-2636	COTR, GSTAMIDS	phoward@invel.army.mil
Christine Lee	NVESD	[1] 703-704-1842		clee@nvl.army.mil
David Lee	NVESD	[1] 703-704-1063		
Mark Locke	NVESD	[1] 703-704-2418	COTR, HSTAMIDS	mlocke@nvl.army.mil
Harvin McFaddin	NVESD	[1] 703-704-2434		hmcfaddi@nvl.army.mil
Kurt Montavon	NVESD	[1] 703-704-1381		kmontavo@nvl.army.mil
Dennis Reidy	NVESD	[1] 703-704-1097	Test Site Coordinato	dreidy@nvl.army.mil
Ron Rupe	NVESD	[1] 703-704-2442	Project Engineer, ASTAMIDS	
Kelly Sherbondy	NVESD	[1] 703-704-2448	Director, MCM R&D	ksherbon@nvl.army.mil
Anh Trang	NVESD	[1] 703-704-2456		atrang@nvl.army.mil
Edmund Zacharkevics	NVESD	[1] 703-704-1609		ezachark@nvl.army.mil
Doug Sherburne	NVESD (Camber, Inc.)	[1] 703-704-1026		dsherbur@nvl.army.mil
Peter Ngan	NVESD Countermine	[1] 703-704-2430		pngan@nvl.army.mil
Phil Purdy	Office of Naval Res...	[1] 703)704-1975	PM, ASTAMIDS	jppurdy@nvl.army.mil
James Sabatier	University of Mississ...	[1] 601-232-5404	Sr Research Scientist,NCPA	sabatier@olemiss.eduu
Jim Keller	University of Missour...	[1] 573-882-7339	Researcher, Fuzzy Logic	keller@cecs.missouri.edu
James Harvey	US Army Research ...	[1] 919-549-4244	PM, Demining MURI	harvey@aro-emh1.army.mil
Guenter Wischmann	Wichmann			Roentgenstrasse 38, Heidelberg

4. References

[1] A. Andrews, *et. al.*, *Results of the Countermine Task Force Mine Detection Technology Demonstration at* [For] *A.P. Hill, Virginia, March 18-22, 1996*, IDA Report P-3192, July 1996

[2] F. Rotondo, *et. al.*, *Report on the Advanced Technology Demonstration (ATD) of the Vehicular-Mounted Mine Detection (VMMD) Systems at Aberdeen Maryland and Soccoro, New Mexico*, IDA Report D-2203, October 1998

[3] Draft UXOCO Report, *Handheld Metallic Mine Detector Performance Baselining Collection Plan, Fort AP Hill, Virginia*, May 1998 to November 1998

[4] S. L. Tatum, L. M. Collins,"Detection and Identification of Mines Using Signals From the Wichmann/BRTRC Antenna: A Preliminary Report," undatae briefing

[5] L. Carin, C. Baum, *Wideband Time and Frequency-Domain EMI: Phenomenology and Signal Processing*, Undated

[6] N. Khadr, H. Nelson, *Target Shape Classification Using Elecgtromagnetic Induction Sensor Data*, Undated

[7] P. Kaczkowski, *Pulsed Electromagnetic Induction (EMI) For UXO Discrimination in JPG Phase IV-Preliminary Results*, Undated

[8] L. Collins, P. Gao, " Statistical Signal Processing for Demining: Experimental Validation Progress Report I: Signatures of Land Mines in Soil and in Air: Are They Different? What are the Characteristics of the Sensor Noise?," Duke University, August 1998

[9] A. Andrews, *et. al.*, *Performance in December 1996 Hand-Held Landmine Detection Tests at APG, Coleman Research, Corp. (CRC), GDE Systems, Inc. (GDE), and AN/PSS-12*, March 1998, IDA Report (Unk)

[10] L. Carin *et. al.*, *Ultra-Wideband Synthetic Aperture Radar for Mine Field Detection, Undated*

ANNEX 6. SOME LINKS TO GENERAL AND MORE TECHNICAL INFORMATION ON HUMANITARIAN DEMINING

This information is complementary to the one already provided in Annex 1: Existing information sources and databases. Please check in particular the pages at http://diwww.epfl.ch/lami/detec/mine10links.html, http://diwww.epfl.ch/lami/detec/mine10links.html and http://etro.vub.ac.be/~eudem/eudemlinks.html

- A Summary of Land Mine WWW Pages: page with a load of links.
- Australian Specialist Dog Sections
- Canadian International Demining Center
- Canadian International Demining Center - bilder
- Countermine Solutions (Canadian Defence R&D)
- Countermine solutions: Very interesting, clear and down to earth overview of the long Canadian experience in the field of "Countermine" Information, Detection, Neutralization and Protection
- Danish Demining Research Forum
- DARPA DogsNose (Chemical Signatures, Trace Explosive Detection): DARPA's 3 year, 25 M$ program, on the detection of landmines via their chemical signatures, inspired by the dogs' remarkable capabilities (http://web-ext2.darpa.mil/DSO/solicitations/index.html). See also the impressive Knowledge Warehouse (bibliography on the vapor detection of landmines), and the "older" database at http://eagle.sysplan.com/Info/LandMine/index.html
- DefenseLINK News: HUMANITARIAN DEMINING ON THE INTERNET
- Demining in Cambodia
- Demining Project, Information Search Strategy
- Demining Research at UWA (University of Western Australia, James Trevelyan): Excellent site on incremental, "down to earth" research projects (short term practical improvements), photograph gallery, Australian links (http://www.mech.uwa.edu.au/jpt/demining/Default.html).
- DeTeC - Demining Technology Center in Lausanne: This page contains a LOT of links on other sites, but also to all the technical ones by the producing companies. Situated at the Demining Technology Centre - frequently updated: http://diwww.epfl.ch/lami/detec/mine10links.html:
- DHA-Online - Uganda - Demining Information
- E.S.R.I. (ArcInfo)
- FHF´s Hemsida: The Swedish military doghandler's association presents itself.
- Gazette - special Phototour in Bosnia
- Geneva International Centre for Humanitarian Demining: Information Management System for Mine Action; annual meetings for mine action managers and other stake-holders; training courses for mine action managers and information technology specialists; Technical studies (staff: 12-15 from the beginning of 1999) (http://www.gichd.ch/).
- GTD: A Spanish Company, EUREKA ANGEL project
- Guartel Ltd.: Maunfacturer of Metal Detectors.
- Guides | Landmines (OneWorld):Excellent source of information on the landmine problem (http://www.oneworld.org/guides/landmines/front.html).
- Handicap International
- HDIC Demining Category Pages
- Heartlands Group Ltd.: A UK-based Company
- Hemvärnshundar: Home Guard Norra Hälsingland presents itself in Swedish.
- http://www.mech.uwa.edu.au/jpt/demining/minefields
- http://etro.vub.ac.be/~eudem/eudemlinks.html: some links established in regard to the EUDEM project
- http://etro.vub.ac.be/minedet: ETRO/VUB web site on the research activities related to demining
- Humanitarian demining
- Humanitarian Demining Equipment Catalog MEDDS K-9 Detection: Humanitarian Demining Catalog - Mine Detection Dogs

- Humanitarian Demining Equipment Catalog, Free-leach K-9 Detection: Humanitarian Demining Catalog - Mine Detection Dogs free-leash search.
- Humanitarian Demining K-9 Program: Humanitarian Demining K-9 Program
- Humanitarian Demining Technology Development Programme (The Development Technology Unit (DTU) - Univ. of Warwick): Excellent effort, especially in the field of humanitarian land-mine clearance and the design of demining equipment and protective clothing for production in poor countries (http://www.eng.warwick.ac.uk/dtu/mines/)
- Humanitarian Demining: Esprit evaluates R&D proposals, plus other news
- Infinia: A Croatian Mine Clearance Vehicle Design (BAD LINK)
- International Campaign to Ban Landmines Winner of the 1997 Nobel Prize in Peace
- International Red Cross on humanitarian demining: web site of the international Red Cross
- Internet Petition to Ban Landmines in Memory of Diana
- IS Robotics: Counter mine and reconnaissance projects.
- Jan Bildtgårds hemsida: Swedish Policedogs site in english.
- JMU Humanitarian Demining Information Center Pages: HDIC at James Madison University: Center of Excellence in information collection, analysis, processing and dissemination (http://www.hdic.jmu.edu/hdic/demining.htm).
- K9 - Police Dog Homepage: The original Canadian site
- K9 - US Polishund hemsida: Swedish version of a good canadian site. Good own links.
- Kurd Web Minelinks
- Land Mine Awareness Education: Lots of information and practical descriptions as well as reports on Mine Awareness
- Landmine Ban Treaty Agreed in Oslo - Norway
- Landmines - NGO Committee on Disarmament: Info on international efforts to control and eliminate landmines (http://www.igc.apc.org/disarm/landmine.html).
- Landmines - the hidden enemy
- Landmines explosions-photogallery
- LANDMINES: Support to EC Humanitarian Demining R & D
- Landmines: What is Schools Demining Schools
- LANDMINES:EC Humanitarian Demining Web Site)
- Lawrence Livermore National Labs: Impulse Radar
- Linkpage: Peace & Security: Several links on land mines as well as other armed conflict pages
- Mark Daltons Summary of Land Mine WWW pages: Another "loads of links" page Menschen Gegen Minen: MGM, a large humanitarian group, with lots of links. The Humanitarian Foundation of People against Landmines. Addresses, links, online forum and much more.
- Midas Data Systems: Orbis, the Minefield Data Administration System
- Mine map over Sarajevo
- Minerats: Anti-personnel mine clearance robots.
- Mines and Minefields - Defining the Problem (Univ. of Western Australia)
- MineWeb Home Page
- MINWARA - The Mine Warfare Association
- Nordiska Polishundsidor: Police dog and Policedog handlers sites from all nordic countries.
- Norwegian People's Aid: Mines: The Silent Killers: The Landmine Problem and NPA's humanitarian demining concept/activity. One of the leading NGOs in Humanitarian Demining (http://www.npaid.no/mines/).
- OAO Robotics: Various teleoperated designs
- Oneworld: Contains photographs, video clips, and soundtracks
- Operation Landmine (from the Operation USA NGO): Focus on conversion of advanced American technology to the detection and destruction of AP landmines (overview of detection technologies etc.)
- (http://www.opusa.org/opland/index.html)
- Operation USA K-9
- Oxfam
- Peace and disarmament: Land mines - Canadian Forces College
- Pictures from Bosnien
- Pictures from Zagreb
- Princess Diana, 1961-1997

- (Review) C&EN 970310 - LAND MINES: Horrors Begging for Solutions: Excellent review article on (chemical) detection methods. Interviews, glossary (http://pubs.acs.org/hotartcl/cenear/970310/land.html).
- Ronco Consulting Corp.: International Demining Consultants
- Safe-Lane:Live coverage of the Treaty Signing Conference in Ottawa December 2-4 as well as other information on the issue - this site also contains a nice thematically sorted link page.
- Schiebel: An Austrian mine clearance company
- Second International Conference on the Detection of Abandoned Land Mines: By Institution of Electrical Engineers
- The Cambodian Mine Action Centre: Cambodia's National Humanitarian Demining Organization.
- The International Campaign to Ban Landmines
- The Mines Advisory Group: One of the leading NGOs in Humanitarian Demining, with activities in North Iraq, Cambodia, Angola and Laos (others planned) (http://www.oneworld.org/mag/).
- The MineWeb: U.S. State Dept. Info on Bosnia.
- The Warchild Landmine Programme
- Trondheim Politi's tjenstehundklubb: Trondheims Policedogs presents itself in Swedish.
- U.S. Navy: Various designs for robotic countermining vehicles.
- UN information about Mine detection dogs
- United Nations Demining Database: Conference information, world reports, some links, UN Mine Action Policy, Points of Contact, Demining Programmes, Casualties and Incidents Reports from around the world, Landmines Magazine, International Mine Clearance Standards (http://www.un.org/Depts/Landmine/).
- United Nations Institute for Disarmament Research
- United Nations Landmine Conference, Geneva
- United Nations on humanitarian demining
- United States Army: Extensive list of available and prospective technologies.
- University of Alberta: A mechanical means of land mine detection.
- University of Florida: X-ray backscatter
- University of Western Australia: Many Different Projects
- UXB International: An American UXO Disposal Company
- UXOCOE (Unexploded Ordnance Center of Excellence): Aims: to build a cooperative multinational effort to share expertise, data and test sites; to build and maintain a UXO detection and clearance database; to standardize target UXO (including land mines); establish benchmarks, metrics, milestones and deliverables. Work your way especially towards the huge SIGNATURE DATABASE and a number of interesting documents (http://www.denix.osd.mil/denix/Public/News/UXOCOE/uxocoe.html).

Vietnam Veterans of America Foundation: International humanitarian, advocacy, and educational organization dedicated to assisting the victims of war. Played pivotal role in international campaign to ban landmines (http://www.vvaf.org/). Excellent Landmine Library - Resource List at http://www.vvaf.org/library/resource_list.html.

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