1. Introduction

Since the mid 1990s considerable funding and effort has been invested worldwide in order to develop new technologies for humanitarian demining — with the aim of improving the productivity of present humanitarian demining methods while maintaining or increasing deminers' safety. During this time there has also been considerable investment of military funds in new sensing technologies that in some cases could also be applied to mine action. The change in the emphasis of the expected operational use of detection technology by military personnel — from, for example, combat minefield breaching to peace-keeping and peace-building operations — has also seen military detection requirements move to some extent towards those expected for humanitarian demining.

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

Although a host of physical principles have been investigated to detect landmines, only electromagnetic-based technologies, in particular enhanced metal detectors and ground penetrating radars, have seen significant advances and are being introduced into the field. Test results consistently confirm that some of these technologies can indeed increase the productivity of humanitarian demining, while at least maintaining the current high levels of safety. Several development groups have shown this is the case for the combination of a metal detector with ground penetrating radar (GPR). The first such combined system, the AN/PSS-14 (the military version), has now been fielded and others are expected to follow in the short term, such as the VMR1-MINEHOUND (see the corresponding descriptions).

1.1 Guidebook structure

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

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

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

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

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

Individual systems

Specific systems employing these techniques are then described in terms of the research/development programmes, the developers, the present specifications and available results. Where possible the *Guidebook* focuses on the most promising developments (high Technology Readiness Level — TRL — value, evaluated for HD applications, and recent systems), complemented by information on a few less mature systems, particularly when this was deemed necessary to illustrate a specific detection approach. The *Guidebook* does therefore contain details of: (i) technology which has now reached operational implementation stage, (ii) technology which is close to operational implementation, and (iii) prototype technology where substantial further engineering investment is required before reaching operational readiness.

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

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

Notes

A number of GPR systems presented here are components of multi-sensor systems. In this *Guidebook* we concentrate only on GPR while providing basic information on the other sensor/s used with it. Further information on metal detectors may be found in the *Metal Detectors and PPE Catalogue 2005* published by the GICHD and will not be reproduced here.

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

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

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

1.2 Technology Readiness Levels

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

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

TRLs range from a score of one which indicates the least ready for use — the basic physical principles have been noted and research can be started — to a score of nine which indicates successful operational deployment. The intermediate levels, two to eight, represent the different research, development and deployment phases as work progresses from research to the final product.

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

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

Related publications

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

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

Technology readiness table (adapted from (7))	
Technology readiness level	**Description**
1. *Basic principles observed and reported.* ❶●●●●●●●●	Lowest level of technology readiness. Scientific research begins to be evaluated for applications. Examples might include paper studies of a technology's basic properties.
2. *Technology concept and/or application formulated.* ●❷●●●●●●●	Invention begins. Once basic principles are observed, practical applications can be postulated. The application is speculative and there is no proof or detailed analysis to support the assumptions. Examples are still limited to paper studies.
3. *Analytical and experimental critical function and/or characteristic proof of concept.* ●●❸●●●●●●	Analytical studies and laboratory studies to physically validate analytical predictions of separate elements of the technology are undertaken. Examples include components that are not yet integrated or representative.
4. *Technology component and/or basic technology sub-system validation in laboratory environment.* ●●●❹●●●●●	Basic technology components are integrated. This is relatively "low fidelity" compared to the eventual system. Examples include integration of "ad hoc" hardware in a laboratory.
5. *Technology component and/or basic sub-system validation in relevant environment.* ●●●●❺●●●●	Fidelity of sub-system representation increases significantly. The basic technological components are integrated with realistic supporting elements so that the technology can be tested in a simulated environment. Examples include "high fidelity" laboratory integration of components.
6. *Technology system/ subsystem model or prototype demonstration in a relevant environment.* ●●●●●❻●●●	Representative model or prototype system, which is well beyond the representation tested for TRL 5, is tested in a relevant environment. Represents a major step up in a technology's demonstrated readiness. Examples include testing a prototype in a high fidelity laboratory environment or in simulated operational environment.
7. *Technology system prototype demonstration in an operational environment.* ●●●●●●❼●●	Prototype near or at planned operational system. Represents a major step up from TRL 6, requiring the demonstration of an actual system prototype in an operational environment, such as in an aircraft or vehicle. Information to allow supportability assessments is obtained. Examples include testing the prototype in a test bed vehicle.
8. *Actual technology system completed and qualified through test and demonstration.* ●●●●●●●❽●	Technology has been proven to work in its final form and under expected conditions. In almost all cases, this TRL represents the end of Demonstration. Examples include test and evaluation of the system in its intended detection system to determine if it meets design specifications, including those relating to supportability.
9. *Technology system "accredited" through successful mission operations.* ●●●●●●●●❾	Application of the technology in its final form and under mission conditions, such as those encountered in operational test and evaluation and reliability trials. Examples include using the system under operational mission conditions.