2

Research Challenges

James Trevelyan
The University of Western Australia
Australia

1. Introduction

Initial Approach

Research is seldom linear.

Often the objective is further than first expected. It can be like an unclimbed mountain peak, standing clear in a blue sky that seems just a short climb from the base camp. Yet as one climbs each ridge, only to find one has to descend another hidden defile to reach the next, the summit seems to recede into the distance, and may even be out of sight much of the time. One constantly changes direction. Precipices reshape strategy: obstacles that force new approach routes so obvious in hindsight. What seemed to be the summit at first turns out later to be only a shoulder on the mountain hiding a higher summit from view. Sheer faces and overhangs divert those seeking technical climbing challenges from the more distant summit. Early climbers may run short of supplies or endurance and give up, but may write their accounts and leave maps to guide others. They will have improved their climbing techniques and may go on climb other peaks. This analogy captures my own path through demining research.

My research would not have been possible without the support of many colleagues and students and the support of organizations in Australia, USA, Pakistan and Afghanistan.

1995 brought a chance meeting with Gen. John Sanderson, then Australian Chief of General Staff who had commanded the 1993 UN mission in Cambodia. He encouraged me to see if robotics could help with landmine clearance, perhaps a slightly easier challenge than shearing sheep had been (Trevelyan 1992). He opened doors to Australian military expertise evolved from experience in Cambodia and other UN peacekeeping operations.

With students I developed a suspended cable concept (Trevelyan 1996) but a visit to Pakistan forced a reality check. I came into contact with Australians working with UN mine clearance teams in Afghanistan who described apparently simple problems with heavy helmets and primitive tools for investigating metal detector indications. They also provided a detailed description of working conditions in Afghanistan which ruled out the naïve ideas developed in Australia.

I had to revise my approach route. Robotic solutions ultimately depend on mobility on the one hand, and sensing capabilities that offer a more efficient solution than brute force (Trevelyan 1997b). Resolving the sensing problem presented a triple obstacle: (a) intrinsic performance challenges associated with either low detection probability or high false alarm rate or both, (b) the likely cost which would influence the economic viability, and (c) my

limited experience and access to the appropriate expertise in these technologies. Sensing the explosive directly by electromagnetic or particle radiation methods (e.g. NQR, thermal neutrons, neutron backscatter), at the time, required a combination of high electrical power demand and operating times of several minutes to accumulate sufficient signal relative to background noise. These were expensive prospects. There were also lower cost indirect methods such as low frequency eddy current induction detectors, thermal infrared emissions from the ground, ground penetrating radar (GPR) and acoustic techniques. Since these methods detect ground anomalies that happen to be associated with landmines, they would also respond to other anomalies such as metal fragments and discarded trash, even tree roots, stones and ant nests in the case of GPR (Bruscini and Gros 1998).

I made a strategic decision to take a different route by exploring low cost improvements to the current manual demining methods (Trevelyan 1997a). A further factor in this decision was that many military-related research projects had started to pursue multiple sensing technologies with far more access to financial resources and expertise than I could reasonably hope for. On the other hand, it seemed that no one had thought of pursuing incremental improvements to methods already in use.

Fig. 1. Left: Prodding to investigate metal detector indication: Afghan deminers normally squat instead of the required prone position shown in this posed photo. Note the bayonet prodding tool and 1.5 kg military helmet with scratched visor. Right: Light weight helmet, visor, prodder with hand protection, and ballistic apron developed through research in Australia and Pakistan. The visor outer surface is protected by a replaceable scratch-resistant film. (photos: UN Mine Action Centre for Afghanistan, J. Trevelyan)

By the turn of the millennium this alternative approach had yielded significant progress. Working with a small Pakistan-based organization we produced improved head protection by adapting methods developed in Africa for producing better quality light weight protective visors (Trevelyan 2000a). By directly interacting with Afghan deminers in their own language we were able to devise low cost tools and solutions that suited their real working conditions and cultural sensitivies. Some tools could be locally manufactured, using imported components and materials. The work on visors added to pressure on

existing manufacturers to improve their products and lower their selling prices providing world-wide benefits to demining organizations. Development has been continued by others and improvements are still occurring (Figure 5).

A detailed investigation of technology needs led to the creation of a web-based resource providing background information and an extensive photograph collection on the technical challenges and needs associated with land mine clearance in several countries (Trevelyan 2000a). It was this investigation that led to the notion of a "no-mines" detector. Most researchers have attempted to provide deminers with an improved mine or explosive detector. By carefully analyzing interviews with many deminers and the agencies that support them, we built a strong case for developing technology to sense minute explosive traces. The absence of explosive traces would indicate that there was no need for costly demining over a reasonably large area, thus enabling the land to be released for agriculture or housing. Explosive detection dogs can provide one way to do this, but are still relatively expensive to operate, train and support.

Analysis of accident reports compiled by the Afghanistan Mine Action Centre provided the stimulus to develop prodding tools with hand protection (Trevelyan 2000a). Most accidents were associated with prodding: investigation of metal detector indications usually by using a bayonet to dig through and clear soil to locate the source of the indication. Facial and eye injuries were common resulting in blindness because deminers did not have visors in place at the time. The visors were attached to heavy and uncomfortable helmets and the visors made from polycarbonate had became scratched, obscuring clear vision, so deminers worked with their visors raised or even took off the helmets. Accidental triggering of blast mines by prodding also resulted in major trauma to the hand holding the prodder, but otherwise only temporary deafness and superficial grazing injuries. Light weight scratch-resistant visors and hand protection for prodders could eliminate both problems, as detailed by Trevelyan (2000a). A relatively light weight apron could greatly reduce grazing from secondary fragmentation while still permitting deminers to work in their favoured squatting position (Trevelyan 1999).

Efforts by the Afghan demining NGOs such as Afghan Technical Consultants to reduce the incidence of accidents were so successful that the need for protection was greatly reduced (Trevelyan 2000b).

Careful analysis and measurement of the actual time required for deminers to investigate and locate metal fragments with metal detectors and prodders revealed that deminers work much faster and more reliably than many had thought possible, even with primitive tools (Trevelyan 2002; Trevelyan 2004). This work showed that advanced technology mine detectors were unlikely to be cost effective except in certain locations.

2. Evolution of Landmine Clearance Techniques

Removing landmines is difficult. It is important to distinguish between humanitarian mine clearance and military mine clearance methods (sometimes called "breeching"). Military mine clearance has to work fast, in all conditions (even under fire), and therefore it is unrealistic to aim for 100% clearance. In humanitarian operations there is less time pressure and work can be suspended in unfavourable conditions, and the aim is 100% clearance to a depth considered to be practical in given working conditions. Recent political expectations of low casualties often demand very high clearance standards even in military operations.

Humanitarian mine clearance typically starts years, perhaps decades after the mines were laid. The mines lie buried or hidden from view. They deter people from entering the land so vegetation often grows thickly. Drainage systems rapidly become clogged denying access in wet conditions.

The traditional "manual" method for removing landmines has been to use a metal detector to locate metal fragments close to the ground surface and then to carefully check each metal fragment to see if it is associated with a mine or explosive device. Any tripwires and vegetation have to be removed, with great care, before a metal detector can be used. In many areas deminers have to investigate hundreds or thousands of metal fragments for every mine found. Manual mine clearance also requires careful organization and marking of the ground to ensure safety and thorough clearance. Currently it is still the method that guarantees the lowest risk of residual mine contamination but it is expensive, typically costing US$1 - $5 /m².

Fig. 2. Typical ruined house overgrown by vegetation in a village in northern Croatia, possibly containing mines or booby traps. The entire village population was forced to leave in 1991 and the houses were looted and intentionally severely damaged. Vegetation problems like this must be taken into account in considering practical mine and unexploded ordnance (UXO) clearance devices. August 1999 (photo: J. Trevelyan)

Armoured mine clearance machines using hammers mounted on the end of rapidly spinning chains (flails) first appeared in the 1940s but have not been able to neutralize mines with sufficient reliability for most humanitarian applications (GICHD 2004).

In the late 1990s commercial mine clearance organizations operating in thick vegetation in Bosnia Herzegovina and Croatia realised that flails spinning just above the ground could rapidly remove vegetation and trip wires to prepare the ground for manual clearance, often assisted by mine detection dogs. Clearance costs have been reduced by up to 80% (particularly in thick vegetation) using different combinations of machines, detection dogs and manual clearance.

Ground milling machines use metal drums studded with hard cutters that shred buried objects. They require more power than flails but can operate with greater levels of reliability. Both flails and ground milling machines have been extensively used in Croatia to recover large areas of formerly productive agricultural land. Both kinds of machines can withstand a limited number of anti-tank (AT) mine and moderate size UXO explosions before main bearings and other components need to be replaced.

Naturally, machines operate best on flat or gently sloping ground that is also the land that is most valuable for agriculture and human habitation. Thick forest and mountainous terrain still requires traditional manual clearance and in most countries will not be cleared of mines for a long time, if ever.

Fig. 3. Flail machine using hammers on the ends of spinning chains to clear vegetation and tripwires. This machine will also detonate a proportion of buried mines (inset). (photos: Scanjack AB, Sweden)

Mechanized clearance methods continue to evolve with improvements to machines and techniques. Machines can be used for survey, risk assessment and risk reduction tasks to help determine the need for more expensive manual clearance methods. Mine action programs are gradually shifting from an emphasis on total clearance in the 1990s to one of progressive prioritized risk reduction involving a series of measures including high security fences, mechanized survey and risk reduction methods and selective manual clearance (GICHD 2005a, part 4). Protective measures applied to agricultural machinery offer cheaper alternatives in low AT risk areas (Trevelyan et al. 2002).

3. Evolution of Demining Research Priorities

Unlike mountain climbing, researchers in demining have had to contend with shifting objectives. A combination of slow progress with research, political developments, and changes in public perception has changed research priorities over a relatively short time-scale and it is valuable to reflect on this. By far the most significant factor affecting mine clearance priorities was the American response to the September 2001 attacks in New York.

Technological development in landmine clearance from within the demining community has mainly been driven by the search for improved safety for deminers and productivity.

In the mid-1990s there was the expectation that, with sufficient research, advanced technology detectors could replace eddy current metal detector technology that had been in use since the 1940s. Metal detectors also react to metal fragments in the ground. A detector that could confirm the presence of explosive, it was thought, would save having to investigate all these false alarms. The most promising line of research seemed to be data fusion: combining signals from a metal detector, ground penetrating radar, infrared detectors, thermal neutron detectors, even acoustic detectors. Astute observers at research conferences have pointed out that these signals were often well correlated, even in the presence of false alarms. Producing a reliable detector was going to be hard work. Their forecasts turned out to be very accurate. Only one such detector is currently in operation: the HSTAMIDS detector used by US military forces in Afghanistan employs a combination of ground penetrating radar and eddy current metal detection. Little information on its effectiveness has been released and no independent trials have been reported. Experienced research groups report that ground penetrating radar requires accurate alignment of the detector with the ground surface (to eliminate ground surface returns) and also with the target centre point to enable the target to be characterized reliably. If the principal metal component of the landmine coincides with its geometric centre, a common feature of minimum metal mines, the metal detector can be used for alignment. However this is not always the case and one cannot guarantee the absence of other metal fragments near the mine. Ground penetrating radar provides confusing returns in very dry or very wet conditions and is also susceptible to false alarm indications from underground discontinuities such as stones, sticks, animal burrows etc. Research reports mostly downplay these difficulties and prefer only to report positive results. These issues only emerge from discussions with developers who have seriously evaluated technology in field conditions. (Many of the comments in this section are based on numerous discussions with experienced demining personnel who have tried new technologies in the field. References have been cited only where further detailed written information is available.)

The major performance improvements in sensing have been obtained by compensating eddy current metal detectors for soil magnetization, enabling them to work in a much wider range of soil conditions. Improvements in sensitivity can help with minimum metal mines but can also result in a large number of false alarms from smaller metal fragments. Metal detector arrays have been fitted to vehicles to speed up clearance of paved areas and roads (Bruschini et al. 1998).

By the late 1990s slow progress with sensors had become more apparent and research priorities after 2000 gradually turned to mine detection dogs and large demining machines.

The Afghanistan Mine Action Centre started using mine detection dogs around 1993 but it was not until 1998 that this program was running effectively. There were several difficulties. The first challenge was that close association between humans and dogs was socially unacceptable in Afghanistan. The second challenge was to devise ways to use dogs and manual mine clearance in an effective combination providing reliable clearance with high productivity. This was much the greater challenge but by 1998 the cost of clearance using dogs was around one third the cost of manual clearance. It was then that the problems started to appear: the occasional missed mine that could not be explained by lack of organization or failure to follow procedures. At the same time, carefully controlled trials

of mine detection dogs in Bosnia had returned highly variable results. On several occasions dogs had walked past blocks of TNT lying almost visible in the ground. Yet, at the same time, a number of commercial demining agencies were routinely declaring land free of mines using similar dogs. In late 1999 the Bosnian Mine Action Centre ran a carefully controlled test in which around 80% of the dogs failed to achieve the required performance standard. The results were hotly contested at the time and the international community organized a systematic trial of mine detection dogs through the Geneva International Centre for Humanitarian Demining (GICHD).

By 2001 it was apparent that there had been little scientific research on the fundamental physiological mechanisms that enable dogs to locate sources of explosive vapour. Dogs had been able to find mines using explosives (such as HMX) with vapour pressure far below measurable detection thresholds. The mechanism by which TNT vapour and its breakdown products reach the ground surface was the subject of considerable scientific debate. By 2003 a systematic trial in Afghanistan, scientific studies at SANDIA Laboratories in the USA and in Scandinavia, explosive trace detection studies with dogs at Auburn University, several other investigations provided some insight into this problem for the first time (Göth et al. 2003). However, the precise physiological mechanisms for canine explosive detection remain unclear, especially for lower vapour pressure explosives. We do not know for sure whether dogs are reacting to vapour, minute particles of explosive suspended in the air, biochemical breakdown products, or a combination.

In 2003 a US company, NOMADICS, demonstrated the FIDO detector, the first that could reliably measure the presence of TNT vapour with more sensitivity than a highly trained dog. However field trials showed that TNT vapour could be detected everywhere in a mine contaminated area! An explosive vapour sensor was just the beginning of the story and warns of a complex task ahead.

By 2004 the international community realised that the early confidence in a breakthrough resulting from advanced sensor technology, demining machinery and mine detection dogs had been misplaced. GICHD commissioned the first serious study of manual demining to see whether productivity improvements could be made. A systematic series of trials were conducted in Africa to determine the effectiveness of several innovations such as magnets and rakes. The final report issued in 2005 revealed that greatly improved productivity was possible but it would depend more on improving contracting arrangements, management and training than technology.

The American response to the New York attacks in September 2001 fundamentally changed research priorities. After the invasion of Afghanistan, removing UXO resulting from ammunition dump explosions and cluster bomb strikes became the top priority for the next 12 months. Resistance to the US and international occupation of Iraq and the easy availability of explosive both from former Iraqi armed forces and UXO from US military operations led to the proliferation of Improvized Explosive Devices (IEDs) to attack organized military forces and police. Similar tactics have appeared in Afghanistan, albeit at a lower intensity. IEDs, therefore, are now considered to be the main threat and the focus for much of the funding and operational and research expertise formerly available to support mine clearance operations. This development has also placed ordnance disposal teams at the front line for the first time, rather than working in well protected and secure areas. Iraqi insurgent groups attack ordnance disposal teams both because they are

attempting to disarm some of the insurgents' most effective weapons and also because they remove the main sources of explosives available to insurgent groups.

Improvised explosive devices, when detected, are often investigated and neutralized using remotely operated robots. While there are non-destructive methods to neutralize IEDs, the fastest method usually involves placing a small demolition charge on the device. Operational details remain confidential to reduce the risk that IEDs will be modified to defeat current neutralization methods.

Fig. 4. Bozena teleoperated demining vehicle (Way Industry, Slovakia)

Paradoxically it is this development that has enabled robotics to make a greater contribution to the problem by contributing improvements in remote manipulation technology. These improvements come more in the form of low-cost commercial off-the-shelf components (mobile platform, motors, TV cameras etc) than from fundamental research advances. Improvements are still being made: improved remote manipulation, blast survivability, operator interface improvements and mobility improvements have all contributed significantly to performance and reduced operating costs.

Military counter-mine priorities have shifted in the mean-time. Slow progress in development of multi-sensor fusion devices and significant improvements in mine-resistant vehicle design have moved the priority from mine detection to protection. Much of the vehicle design technology originated in Rhodesia and South Africa in the 1970s and has since been refined in Australia and elsewhere, mostly in the defence sector.

4. Response to Change

The relocation of the Afghanistan Mine Action Centre from Islamabad to Kabul in 2002 significantly reduced our ability to maintain working level contacts with Afghan demining agencies. I initially refocused our research resources in Pakistan on water supplies for settlements near Islamabad: a problem with just as much significance in terms of human disease and suffering as landmines in Afghanistan. An investigation into the relative cost-effectiveness of several alternative solutions led to a startling discovery. The real cost of water, even in areas of Pakistan where water supply schemes had been installed, was much higher than expected and up to 30 times the cost per litre in Australia (Trevelyan 2005). This led to a realization that difficulties in obtaining cost-effective engineering solutions in Pakistan were occurring on a large scale. Here there seemed to be a close link with the

surprising observation that demining costs in Afghanistan and Cambodia were at least as expensive as in Croatia and Bosnia where labour costs are at Western European levels, and could be even more expensive.

One of the main issues encountered with our demining research in Pakistan (in support of Afghanistan mine clearance) was an unexpected difficulty with dissemination of technology improvements. Part of the reason for researching low cost incremental improvements to existing demining methods was to eliminate potential difficulties with implementing costly high-tech solutions. One example of this was a suggestion to improve the quality of saws issued to Cambodian deminers. Commercial saws available in hardware stores in industrialized countries could provide around 10% productivity improvement because Cambodian deminers spend much of their time cutting thick vegetation and use low quality tools that quickly became blunt. However, with a deminer pay rate of US$120 per month, the benefit from using the saws was insufficient. The anticipated 10% performance improvement would be outweighed by the cost of the saw at $35 and expected saw life of 1 month.

However, by focusing on the deminers' pay rate one falls victim to a common and widespread myth that countries with low pay rates provide a low cost operating environment. The simplistic argument against using improved saws in Cambodia misses the cost of supporting, feeding, housing, training, equipping and supervising deminers in the field, typically between US$1500 and US$3000 per month. A 10% performance improvement then provides a monthly benefit of at least $150, far exceeding the cost of a saw.

A further issue with even greater financial effects is the almost complete absence of engineering management skills available from people supervising demining operations in countries like Cambodia and Afghanistan. Two examples will illustrate this problem. In Afghanistan, demining organizations using mechanized equipment (before the US invasion) achieved very low utilization and hence relatively high costs in real terms. (In practice the consequences were mainly frustration among sponsoring organizations because the equipment had actually been donated.) In Cambodia, close examination of demining productivity revealed wasted efforts clearing large areas where the evidence strongly suggested localized patterns of landmine contamination (GICHD 2005a). While the demining organizations report impressive clearance statistics, a significant proportion of the effort achieves no useful results other than distributing donated funds among demining agency staff. Yet demining operations are supervised by engineering staff who have qualified in institutions with curricula and standards roughly equivalent to engineering schools in any industrialized country. If one examines engineering practice elsewhere in Cambodia and Afghanistan, even in Pakistan, in India and many other developing countries one finds similar patterns. This helps to explain the high costs for water observed in Pakistan, for example. GICHD(2005a) identified these skill gaps as the main reason inhibiting productivity improvements in demining.

5. Engineering Practice: An Enigma

These observations raised an intriguing issue: how does one define engineering management skill? How and why to these skills develop in industrialized countries but not in developing countries, noting that many highly competent engineers in industrialized countries obtained their education in developing countries?

These questions led me to interview and make observations of engineers in Pakistan with the expectation that comparison with reference data on engineering practice in countries like USA, Europe, Japan, Canada and Australia would soon indicate the essential differences. Solving this problem could lead to large productivity improvements, not only in mine clearance, but also with critical engineering services like transport, energy distribution, food processing and water supply in most developing countries. Unfortunately we found that the anticipated reference data on engineering practice does not yet exist. This was a remarkable discovery: it is astonishing that at the start of the 21st century there is no systematically researched account that explains what engineers and technologists actually do in their daily work, except for a handful of narrow case studies and some work on glamorous aspects of high-tech design processes (Trevelyan and Tilli 2007).

Thus, the author has reached a critical turning point in this journey that started with research on landmine clearance. Such an obvious question "what do engineers do?" with such universal significance presented an irresistible change in approach. With the help of around 20 colleagues, this author is now working on answers that offer significant long term improvements in engineering practice (e.g. Trevelyan 2007). That offers, in turn, the prospect of making significant improvements in living standards in both industrialized and developing countries and also substantial improvements in demining practice.

6. Future Prospects for Robotic Demining

Figure 4, a teleoperated flail machine, represents the current state of the art in robotic demining. Teleoperated devices, often known as 'bomb disposal robots' and similar in principle, are used for neutralizing IEDs. What, then, are the research challenges for robotics researchers working on landmine and unexploded ordnance clearance in the future that could lead to significant advances?

We need further advances in mechatronics design, sensing and accurate understanding of the problems to be solved using robots.

The best starting point for research is to witness people undertaking mine clearance operations which are often readily accessible in many countries. It is unfortunate that many researchers think a visit would be far too hazardous and, as a direct result, have failed to appreciate the practical difficulties involved. Photographs taken at mine clearance operations are available to provide researchers with a web site for reference purposes, partly in answer to this need to understand the practical realities (Trevelyan 2000a).

One of the main motivations for robotics researchers has been the perception that mine clearance is a hazardous occupation and that it would be more preferable for robots to be exposed to minefield risks than human beings. While mine clearance is certainly a hazardous occupation it is not necessarily dangerous. Accident records show that mine clearance in Afghanistan in 1998 resulted in about half the rate of injury of the United States forestry industry and about one third the rate of injury for the United States building

construction industry per hundred thousand working hours. Mine clearance agencies use advanced techniques to improve safety when possible (Trevelyan 2000b). In terms of deaths, demining is considerably less hazardous than mining, construction of building foundations, and especially offshore drilling rigs (GICHD 2005b, p11-14).

Another motivation for research is to reduce deaths and injuries among local people who have to live with the daily threat of landmines and unexploded ordnance. Again, there are misperceptions of risk. The incidence of death and injury from mine explosions is often very small compared with disease, for example. The main priorities for local people tend to be improvements for water and food supplies, education, sanitation and physical security: landmine clearance is usually a much lower priority and it is often hard to justify significant local resources.

Fig. 5. Evolution in deminerprotection – visor and upper body protection by ROFI. (Photo: Andy Smith)

It is also important that robotics researchers intending to contribute to the solution of this problem, understand the relatively small size of humanitarian demining operations which have been funded from a combined international humanitarian aid budget of approximately US$400 million. These programs spend an estimated $20 million annually on all equipment needs. The market for specialized humanitarian demining detectors is therefore very small and manufacturers cannot afford research and development specifically to support humanitarian demining solutions (Newnham and Daniels 2001). Adapting technology developed for other purposes, such as military equipment or civil engineering construction machinery, is more likely to be feasible.

The last 10 years has seen significant improvement in mine clearance techniques but progress is still slow and robotics may well provide the final solution in the long term. There is plenty of time to develop robotic techniques that ultimately could provide the only cost-effective method for removing this menace.

7. References

Bruschini, C., Gros, B., Guerne, F., Piece, P.-Y., and Carmona, O. (1998). "Ground penetrating radar and imaging metal detector for antipersonnel mine detection." *Journal of Applied Geophysics*, 40(1-3), 59-71.

Bruscini, C., and Gros, B. (1998). "A Survey of Research on Sensor Technology for Landmine Detection." Journal of Mine Action.

GICHD. (2004). *A Study of Mechanical Application in Demining*, Generva International Centre for Humanitarian Demining, Geneva.

GICHD. (2005a). *A Study of Manual Mine Clearance*, Geneva International Centre for Humanitarian Demining, Geneva.

GICHD. (2005b). *A Study of Manual Mine Clearance: Part 4 - Risk Assessment and Risk Management*, Geneva International Centre for Humanitarian Demining, Geneva.

Göth, A., McLean, I. G., and Trevelyan, J. P. (2003). "How do dogs detect landmines? A summary of research results." *Mine Detection Dogs: Training, Operations and Odour Detection*, I. G. McLean, ed., Geneva International Centre for Humanitarian Demining, Geneva, 195-207.

Newnham, P., and Daniels, D. (2001). "The market for advanced humanitarian mine detectors." *Detection and Remediation Technologies for Mines and Minelike Targets VI, Apr 16-20 2001*, Orlando, FL, United States, 1213-1224.

Trevelyan, J., and Tilli, S. (2007). "Published Research on Engineering Work." *Journal of Professional Issues in Engineering Education and Practice*, (accepted for publication in 2007).

Trevelyan, J. P. (1992). *Robots for Shearing Sheep: Shear Magic*, Oxford University Press.

Trevelyan, J. P. (1996). "A Suspended Device for Humanitarian Demining." *MD96: IEE Conference on Detecting Abandoned Landmines*, Edinburgh.

Trevelyan, J. P. (1997a). "Better Tools for Deminers." *International Workshop on Sustainable Humanitarian Demining*, Zagreb, s6.1-s6.12.

Trevelyan, J. P. (1997b). "Robots and landmines." *Industrial Robot*, 24(2), 114-125.

Trevelyan, J. P. (1999). "Protecting Deminers." *Austcare Conference on Humanitarian Demining*, Sydney.

Trevelyan, J. P. (2000a). "Demining Research at the University of Western Australia." <http://www.mech.uwa.edu.au/jpt/demining/>

Trevelyan, J. P. (2000b). "Reducing Accidents in Demining." <http://www.mech.uwa.edu.au/jpt/demining/reports.html> (June 2005)

Trevelyan, J. P. (2002). "Technology and the landmine problem: practical aspects of landmine clearance operations." *Detection of Explosives and Landmines: Methods and Field Experience*, H. Schubert and A. Kuznetsov, eds., 155-164.

Trevelyan, J. P. (2004). "Landmine Research: Technology Solutions Looking for Problems." *Symposium on Defense & Security: 5415-Detection and Remediation Technologies for Mines and Minelike Targets IX*, Orlando.

Trevelyan, J. P. (2005). "Drinking Water Costs in Pakistan." <http://www.mech.uwa.edu.au/jpt/pes.html>

Trevelyan, J. P. (2007). "Technical Coordination in Engineering Practice." *Journal of Engineering Education*, 96(3), 191-204.

Trevelyan, J. P., Tilli, S., Parks, B., and Teng, H. C. (2002). "Farming Minefields: Economics of Remediating Land with Moderate Landmine and UXO Concentrations." *Demining Technology Information Forum Journal*, 1(3).
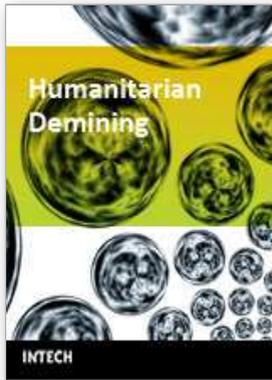
Humanitarian Demining

Edited by Maki K. Habib

United Nation Department of Human Affairs (UNDHA) assesses that there are more than 100 million mines that are scattered across the world and pose significant hazards in more than 68 countries. The international Committee of the Red Cross (ICRC) estimates that the casualty rate from landmines currently exceeds 26,000 persons every year. It is estimated that more than 800 persons are killed and 1,200 maimed each month by landmines around the world. Humanitarian demining demands that all the landmines (especially AP mines) and ERW affecting the places where ordinary people live must be cleared, and their safety in areas that have been cleared must be guaranteed. Innovative solutions and technologies are required and hence this book is coming out to address and deal with the problems, difficulties, priorities, development of sensing and demining technologies and the technological and research challenges. This book reports on the state of the art research and development findings and results. The content of the book has been structured into three technical research sections with total of 16 chapters written by well recognized researchers in the field worldwide. The main topics of these three technical research sections are: Humanitarian Demining: the Technology and the Research Challenges (Chapters 1 and 2), Sensors and Detection Techniques for Humanitarian Demining (Chapters 3 to 8), and Robotics and Flexible Mechanisms for Humanitarian Demining respectively (Chapters 9 to 16).

How to reference

In order to correctly reference this scholarly work, feel free to copy and paste the following:

James Trevelyan (2008). Humanitarian Demining: Research Challenges, Humanitarian Demining, Maki K. Habib (Ed.), ISBN: 978-3-902613-11-0, InTech, Available from:
http://www.intechopen.com/books/humanitarian_demining/humanitarian_demining__research_challenges

INTECH
open science | open minds