We are IntechOpen,
the world's leading publisher of
Open Access books
Built by scientists, for scientists

6,900
Open access books available

186,000
International authors and editors

200M
Downloads

Our authors are among the

154
Countries delivered to

TOP 1%
most cited scientists

12.2%
Contributors from top 500 universities

CLARIVATE ANALYTICS
BOOK CITATION INDEX
INDEXED

WEB OF SCIENCE™

Selection of our books indexed in the Book Citation Index
in Web of Science™ Core Collection (BKCI)

Interested in publishing with us?
Contact book.department@intechopen.com

Humanitarian Demining:
The Problem, Difficulties, Priorities, Demining
Technology and the Challenge for Robotics

Maki K. Habib

Graduate School of Science and Engineering, Saga University
Japan

1. Introduction

Landmines and explosive remnants of war (ERW), which include unexploded ordnance (UXO) and abandoned explosive ordnance, represent a major threat to civilian. This demands that all the mines and ERW affecting the places where ordinary people live must be cleared, and safety of people in areas that have been cleared must be guaranteed. UXO is explosive ordnance that has been primed, fuzzed, armed or otherwise prepared for action; that has been fired, dropped, launched, projected, buried, or placed in such a manner as to constitute a hazard to operations installations, personnel or material; and that remains unexploded either by design malfunction, preplanned, abandoned or for any other cause. Landmines are prominent weapons, and they are harmful and effective, yet cheap, easy to make and lay. A typical landmine consists of a firing mechanism, detonator that sets off the booster charge, booster charge (may be attached to fuse, originator, or be part of the main charge), and an explosive charge that constitutes the body of the mine and plastic or metal casing that contains all of the mentioned elements. A landmine is a type of self-contained explosive device, which is placed onto or into the ground to constitute a minefield, and it is designed to destroy or damage, equipment or personnel. A mine detonates by the action of its target (a vehicle, a person, an animal, etc.), the passage of time, or controlled means. A number of fuse activation mechanisms may activate a landmine, such as pressure (step on or drive over), pressure release, movement, sound, magnetic influence (change of magnetic field around the mine), vibration, electronic, and command detonation (remote control).

Landmines can be categorized into two groups, Antipersonnel (AP) and Antitank (AT) mines.

a)   AP mines are quite small, weighing a few hundred grams at most. These mines are typically laid on the surface or buried within a few centimeters of the ground surface (Normally but not always, on average 4-50mm), or buried under leaves or rocks. AP mines are widely considered to be ethically problematic weapons with ability to kill or incapacitate their victims and can damage unarmored vehicles. AP mines commonly use the pressure of a person's foot as a triggering means (low triggering pressure), but tripwires are also frequently employed. There exists about 2000 types of landmines

around the world; among these, there are more than 650 types of AP mines. Most AP mines can be classified into one of the following four categories: blast, fragmentation, directional, and bounding devices. These mines range from very simple devices to high technology (O'Malley, 1993; US Department of State, 1994). AP minefields are scattered with AT mines to prevent the use of armored vehicles to clear them quickly. The production costs of AP mines are roughly between 1 and 30 US$ while some are more expensive based on the sophistication of the used technology. However, the current cost rate of clearing one mine is ranging between 300-1000 US$ per mine (depending on the mine infected area and the number of the generated false alarms).

b) AT mines are significantly larger with a weight of several kilograms and require more pressure to detonate. AT mines are buried at depths of up to 30 cm below the surface and designed to immobilize or destroy vehicles and their occupants. The high trigger pressure (normally 100 kg (220 lb.) and some are triggered with slightly more pressure) prevents them from being set off by infantry. More modern AT mines use shaped charges to cut through armor. Most modern AT or anti-vehicle mines use a magnetic influence trigger to enable it to detonate even if the tires or tracks did not touch it. AT minefields can be scattered with AP mines to make clearing them manually more time-consuming. Some anti-tank mine types are also able to be triggered by infantry, giving them a dual purpose even though their main intention is to work as AT weapons.

Some minefields are specifically booby-trapped to make clearing them more dangerous. Mixed AP and AT minefields, double-stacked AT mines, AP mines under AT mines, mines with tripwires and breakwires, and fuses separated from mines have all been used for this purpose. Some types of modern mines are designed to self-destruct, or chemically render themselves inert after a period of weeks or months. Conventional landmines around the world do not have self-destructive mechanism and they stay active for long time. Modern landmines are fabricated from sophisticated non-metallic materials. Even more efforts that is radical to develop mines capable of sensing the direction and type of threat. These mines will also be able to be turned on and off, employing their own electronic countermeasures to ensure survivability against enemy countermine operations. In addition, new trends have been recognized in having minefields with self-healing behavior. Such minefields will includes dynamic and scatterable surface mines used to complicate clearance and preserve obstacles by embedding them with capability to detect breaching and simple mobility to change its location accordingly. New, smaller, lightweight, more lethal mines are now providing the capability for rapid emplacement of self-destructing AT and AP minefields by a variety of delivery modes. Minefields may be laid by several means. The most labor-intensive way to lay mines is to have assigned personnel bury the mines. Mines can be laid by specialized mine-laying launchers on vehicles. In addition, mine-scattering shells may be fired by artillery from a distance of several tens of kilometers. Furthermore, mines may be dropped from through both rotary and fixed-wing aircraft, or ejected from cruise missiles.

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 that need to be cleared (O'Malley, 1993; Blagden, 1993; Physicians for Human Rights, 1993; US Department of State, 1994; King, 1997; Habib, 2002b). Additional stockpiles exceeding 100 million mines are held in over 100 nations, and 50 of these nations still producing a further 5 million new mines every year. Currently, there are 2 to 5 millions of new mines continuing to be laid every year. The annual rate of clearance is far slower.

The international Committee of the Red Cross (ICRC) estimates that the casualty rate from mines 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 (ICRC, 1996a; ICRC, 1996b; ICRC, 1998). The primary victims are unarmed civilians and among them children are particularly affected. Worldwide, there are some 300,000-400,000 landmine survivors. Survivors face terrible physical, psychological and socio-economic consequences as it undermines peace and stability in whole regions by displacing people and inhibiting the use of land for production while requiring extensive healthcare and rehabilitation. For example, in Angola one of every 334 individuals is a landmine amputee and Cambodia has more than 25,000 amputees due to mine blasts (Rosengard et al., 2001). The direct cost of medical treatment and rehabilitation exceeds US$750 million. This figure is very small compared to the projected cost of clearing the existing mines. The major effect of mines is to deny access to land and its resources and subject people life to a continuous danger. Besides this, the medical, social, economic, and environmental consequences are immense (O'Malley, 1993; Blagden, 1993; Physicians for Human Rights, 1993; US Department of State, 1994; King, 1997; ICRC, 1998, Habib, 2002b). The canonical approach to humanitarian demining aims to have efficient tools that can accurately detect, locate and deactivate/remove every landmine, and other UXO as fast and as safe as possible while keeping cost to a minimum. The efficient fulfillment of such a task with high reliability represents vital prerequisites for any region to recover from landmines and associated battlefield debris by making land safer and allows people to use it without fear. Such a process involves a high risk and a great deal of effort and time, which results in high clearance cost per surface unit. However, while placing and arming landmines is relatively inexpensive and simple, the reverse of detecting and removing/destroying them is typically labor-intensive, expensive, slow, dangerous and low technology operation due to their unknown positions. Landmines are usually simple devices, readily manufactured anywhere, easy to lay and yet so difficult to detect.

Applying technology to humanitarian demining is a stimulating objective. Many methods and techniques have been developed to detect explosives and landmines (Habib, 2001a). However, the performance of the available mine detection technologies are limited by sensitivity and/or operational complexities due to type of terrain and soil composition, vegetation, mine size and composition, climatic variables, burial depth, grazing angle, and ground clutter, such as, shrapnel and stray metal fragments that produce great number of false positive signals and slow down detection rates to unacceptable levels. It is almost impossible with the current technology to assure the detection of every single mine that has been laid within an area. It is estimated that the current rate of mine clearance is about 10-20 times lower than the rate of ongoing continuous laying of mines, i.e., for every mine cleared, 10-20 mines are laid. Hence, it becomes urgent to develop detection (individual mine, and area mine detection), identification and removal technologies and techniques to increase demining efficiency by several orders of magnitude to achieve a substantial reduction to the threat of AP mines within a reasonable timeframe and at an affordable cost (Habib, 2007a). Demining is costly and searching an area that is free of mines is adding extra high cost. Hence, the first essential objective should be to identify what areas are mined by having sensing technology that can facilitate surveying and reducing suspected mined-area.

A good deal of research and development has gone into mechanical mine clearance (military and nonmilitary equipment), in order to quickly unearth mines or force them to explode under the pressure. The aim of using machines is typically not to clear land from mines, but to prepare ground for post-machine full clearance. Hence, no equipment has been developed specifically to fulfill humanitarian mine clearance objectives and for this, there is no form of any standalone mechanical mine clearance technologies that can give the high clearance ratio to help achieving humanitarian mine clearance standards effectively while minimizing the environmental and ecological impacts. However, there are positive indications that mechanical mine clearance can highly contribute to the demining process when employing the right technologies and techniques best suited to regional conditions (climate, terrain, type of ordnance, etc.).

Robotized solutions can be helpful to increase mine clearance rate by automating the detection process and contribute to the removal of AP mines. However, this need to have a good understanding of the problem and a careful analysis must filter the goals in order to avoid deception and increase the possibility of achieving results (Nicoud, 1996). Mechanized and robotized solutions properly sized with suitable modularized mechanized structure and well adapted to local conditions of minefields can greatly improve the safety of personnel as well as work efficiency and flexibility. Such intelligent and flexible machines can speed the clearance process when used in combination with handheld mine detection tools. They may also be useful in quickly verifying that an area is clear of landmines so that manual cleaners can concentrate on those areas that are most likely to be infested. In addition, solving this problem presents challenges in robotic mechanics and mobility, sensors, sensor integration and sensor fusion, autonomous or semi autonomous navigation, and machine intelligence. Furthermore, the use of many robots working and coordinating their movement will improve the productivity of the overall mine detection process with team cooperation and coordination.

UXO and abandoned explosive ordnance represent a global challenge as its detection and clearance are difficult and present complex technical problems. The solution to this problem is very difficult and challenging one from a scientific and technical point of view. Greater resources need to be devoted to demining both to immediate clearance and to the development of innovated detection and clearance equipment and technologies. This chapter introduces the problem of mines and its impact. It also, focuses on the aspects of demining, the requirements and the difficulties facing it. Then, the chapter evaluates the available mine clearance technologies along with their limitations and discusses the development efforts to automate tasks related to demining process wherever possible through mechanization and robotization. It aims to evaluate current humanitarian demining situations and technologies for the purpose to improve existing technologies and develop an innovative one. In addition, it introduces solutions and priorities beside the requirements in terms of technical features and design capabilities of a mobile platform that can accelerate the demining process, preserve the life of the mine clearing personnel and enhance safety, and achieve cost effective measures.

2. Military and Humanitarian Clearance Missions

The areas of clearing UXO and the abandoned explosive ordnance missions include Countermine (CM), Explosive Ordnance Disposal, (EOD), Humanitarian Demining (HD),

Active Range Clearance (ARC), and UXO Environmental Remediation UER). All areas except HD are classified under military clearance. In relation to demining, the military use the term 'breaching' (the process of undertaken by soldiers to clear a safe path through a minefield that block strategic pathways required in the advance or retreat of soldiers at war) to describe their main mine-clearing concern. It is dictated by the strategies of warfare aiming to speedily clear areas to sustain specific operations, allow an attacking force to penetrate rapidly through mines area as it attacks a target, the pace of this process is very quick as time is a critical factor in military breaching. In military demining, individual mines need not be found, and any clearance rate over 80% is generally considered satisfactory. Military accepts relatively high risk that some of their vehicles and soldiers will still be destroyed and killed during and after breaching has been completed. Military mine clearance equipment tends to be expensive and may be high-tech, large in size, requiring highly trained logistical personnel. The mechanical landmine clearance has been conducted using different type of mechanical machines, such as, ploughs, flails, rollers, tracks, etc.

Humanitarian demining scenarios differ from military ones in many respects. The objectives and philosophy are different in comparison with military demining. Solutions developed for the military are generally not suitable for humanitarian demining. Humanitarian demining is a critical first step for reconstruction of post-conflict countries and it requires that the entire land area to be free of mines and hence the need to detect, locates, uncover and removes reliably and safely every single mine, and other ERW from a targeted ground. The aim of humanitarian demining is to restore peace and security at the community level. It is carried out in a post-conflict context, and the important outcome of humanitarian demining is to make land safer for daily living and restoration to what it was prior to the hostilities. In addition, it is allowing people to use their land without fear; allowing refugees to return home, schools to be reopened, land to be reused for farming and critical infrastructure to be rebuilt (Espirit HPCN, 1997; Bruschini et al., 1999; Habib, 2002b; Goose, 2004).

The standard to which clearance must be achieved is extremely high as there is a need to have at least 99.6% (the standard required by UNDHA) successful detection and removal rate (Blagden, 1993) to a depth of 200 mm from the ground surface, and a 100% to a few centimeter depth according to International Mine Action Standards (IMAS). The amount of time it takes to clear an area is less important than the safety of the clearance personnel and the reliability and accuracy of the demining process. Safety is of utmost importance, and casualties are unacceptable. Any system to be developed should compliment this effort, not to hamper it or simply move the problem elsewhere. The risks to those carrying out the task must also be maintained at a lower level than might be acceptable in a military situation. Another consideration by humanitarian demining is the use of land for development, i.e., there is a need to reduce the environmental and ecological impacts that may results from the demining operation. The currently available technologies are not suited to achieve these objectives of humanitarian demining. Until now, detection and clearance in humanitarian demining very often relies on manual methods as primary procedure. The problem resides primarily in the detection phase first, and then how to increase productivity by speeding up demining process reliably and safely.

3. Landmine Detection and Clearance: The Difficulties

Landmines are harmful because of their unknown positions and often difficult to detect. The development of new demining technologies is difficult because of the tremendous diversity

of terrains and environmental conditions in which mines are laid and because of the wide variety of landmines. There is wide range of terrains (rocky, rolling, flat, desert, beaches, hillside, muddy, river, canal bank, forest, trench, etc.) whereas mines are often laid. The environmental conditions may cover different climate (hot, humid, rainy, cold, windy), different density of vegetation (heavy, medium, small, none), and type of soil (soft, sand, cultivated, hard clay, covered by snow, covered with water). In addition, residential, industrial and agriculture areas, each has its own features and needs to be considered.

Landmines are many in terms of type and size. AP mines come in all shapes and colors are made from a variety of materials, metallic and nonmetallic. Metal detector works well with metal cased mines, but metal in modern mines has been increasingly replaced by plastic and wood that making them undetectable by their metallic content. There are many methods to detect explosives and landmines. However, most of them are limited by sensitivity and/or operational complexities due to type of terrain, climatic variables, and ground clutter, such as, shrapnel and stray metal fragments that produce great number of false positive signals and slow down detection rates to unacceptable levels. Soils are contributing to the difficulties as they represent complex natural bodies made up of a heterogeneous mixture of mineral particles, organic matter, liquid and gaseous, materials, etc. In addition soils vary from location to location as a result of soil-forming processes that depend on geological parent material, topography, climate, plant and animal life, and time (Baumgardner, 2000; Hendrickx et al., 2003). IN addition, the spatial variability of soil texture, organic matter, and bulk density has a large impact on soil water variability. However, the performance of a sensor under specific soil conditions can be predicted using a thorough understanding of the physics of the soil-mine-sensor system. Identifying and removing a landmine is a time-consuming and costly process.

AP mines can be laid anywhere and can be set off in a number of ways because the activation mechanisms available for these mines are not the same. Mines may have been in place for many years, they might be corroded, waterlogged, impregnated with mud or dirt, and can behave quite unpredictable. Some mines were buried too deep to stop more organized forces finding them with metal detectors. Deeper mines may not detonate when the ground is hard, but later rain may soften the ground to the point where even a child's footstep will set them off. Trip-wires may be caught up in overgrown bushes, grass or roots. In addition, there is no accurate estimate on the size of the contaminated land and the number of mines laid in it.

4. Humanitarian Demining and the Challenge of Technology

The diversity of the mine threat points out to the need for different types of sensors and equipment to detect and neutralize landmines. The requirements to develop equipment for use by deminers with different training levels, cultures, and education levels greatly add to the challenge. The solution to this problem is very difficult because, given the nature of landmines and the requirements of humanitarian demining, as any instrument must be 100% reliable for the safety of the operators and the people whom will use the land (Blagden, 1993; Habib 2002b). Hence, it becomes urgent to develop detection (individual mine, and area mine detection), identification and removal technologies and techniques to increase the efficiency of demining operations by several orders of magnitude to achieve a substantial reduction to the threat of AP mines within a reasonable timeframe and at an affordable cost.

Technology has become the solution to many long-standing problems, and while current mine detection and clearance technologies may be effective, it is far too limited to fully address the huge complex and difficult landmine problem facing the world. The challenge is in finding creative, reliable and applicable technical solutions in such highly constrained environment. Applying technology to humanitarian demining is a stimulating objective. Detecting and removing AP mines seems to be a perfect application for robots. However, this need to have a good understanding of the problem and a careful analysis must filter the goals in order to avoid deception and increase the possibility of achieving results (Nicoud, 1996). In order to approach proper and practical solutions for the problem, there is a need for the scientists in each discipline and deminers to share their knowledge and the results of their experience and experiments in order to design and test viable solutions for humanitarian demining. Technologies to be developed should take into account the facts that many of the demining operators will have had minimal formal education and that the countries where the equipment is to be used have poor technological infrastructure for equipment maintenance, operation, and deployment.

Greater resources need to be devoted to demining both to immediate clearance and to the development of innovated detection and clearance equipment and technologies. There is an urgent need to speed up the development to have compact and portable, low cost, technically feasible, fast response, safe, accurate, reliable, and easy to operate mine detector systems with flexible mobile platforms that can be reliably used to detect all types of available landmines and support fast and wide area coverage. Appropriate mine clearance technologies are those inexpensive, rugged, and reliable technical products, processes and techniques that are developed within, or should be transferred for use in mine-affected areas. These technologies should be cheap enough to be purchased within the regional economy and simple enough to be made and maintained in a small workshop. We should favor technologies that can be manufactured in mined countries; technologies that are transferable, and which provide employment and economic infrastructure where it is most urgently required.

5. The Core Components of Humanitarian Mine Action Plan

The objective of humanitarian mine action plan is to reduce the risk from landmines to a level where people can live safely where economic, social and health development can occur free from the constraints imposed by landmine contamination, and in which the victims' needs can be properly addressed.

The process of landmine clearance comprises five components (Habib, 2002b),

1. Locate, identify and mark any of the recognized minefields. This includes: Survey, assessment and planning, mapping, prioritization of marked minefields and resources, etc. This should be associated with mine risk education, human skill development and management, public awareness process, information management, safety and benchmark consideration, etc.
2. Prepare the marked minefields for the clearance operation by cutting vegetation and clearance, collecting metal fragments, etc. Area reduction is considered at this component too.

3.   Apply suitable mine clearance techniques that suit the relevant minefield to locate and mark individual landmines within the identified area,
4.   Remove the threat of the detected mines by neutralization: removal, or detonation,
5.   Apply quality control measures (Post clearance inspection). There is a need to verify and assure with a high level of confidence that the cleared area is free from mine.

In parallel to the above, healthcare, rehabilitation, and medical support should be provided to affected persons. In addition, implementing continuous educational and awareness program, infrastructure building, job creation and initiating economical support should be established.

6. Demining Techniques and the Prospect of the Available Technologies

Mine clearance itself can be accomplished through different methods with varying levels of technology and accuracy, but the most laborious way is still the most reliable.

6.1 Manual Mine Clearance

Manual mine clearance represents one of the fundamental components of mine action plan and it has been undertaken in various forms over many decades. Manual mine clearance equipment and techniques have evolved over the years by adapting what were basically military skills to the needs of a specialist, largely civilian activity (GICHD, 2005). Detection and clearance in Humanitarian Demining very often rely on manual methods as the primary procedure that uses 'prodding' or 'probing' excavation tool within its loop to assure high reliability. 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. When operating in this way the detection phase still relies heavily on metal detectors and/or sniffer dogs, whereby each alarm needs to be carefully checked until it has been fully understood and/or its source removed. This is normally done visually by trained deminer, and by prodding and excavating the ground using long and thin prodders to locate the mine. 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.

Manual demining is still the process that employs the most staff, uses the most resources, and clears the most mines. Manual deminers check the ground inch by inch with a metal detector, a prod and a trowel. Prodder consists of 30 cm long prod that deminer inserts into the soil at a shallow angle (approximately 30 degrees). When the prod touches something hard the operative will begin "feeling" the contour to find out whether it is a rock, debris or a mine. Unfortunately, metal detectors cannot differentiate a mine or UXO from metallic debris. Hence, the contamination of the soil within a minefield by large quantities of shrapnel, metal scraps, etc., leads to have false alarms in the range between 100 and 1,000 for each real mine. Each alarm should be treated as a possible mine and this causes waste of time, induces a loss of concentration, and increases cost.

Manual demining methods are still perceived slow, repetitive, extremely dangerous, expensive, labor intensive and stressful process. At the management level, there are wide variations in the recording of clearance rates (in various soil or vegetation types) and no standardized methodology to calculate the costs and rates of manual mine clearance. Nevertheless, it provides a higher degree of reliability than any other methods and

techniques at present. It has reported an average clearance rate per deminer of about 15-25 square meters a day. Greater emphasis should be placed on hydrating deminers, and thermal and physical comfort to aid their performance. In addition, it is important to consider the use of personal protective equipment as it plays an important role in protecting an individual deminer while certain factors should be considered when using a particular type, as it can impair performance affecting the wearer in several ways (GICHD, 2005).

The lying posture is mandated as the safest posture since it minimizes deminer exposure to danger. Even though lying is safer, deminers in Afghanistan, Bosnian and Cambodian mostly squat or kneel. It is important to consider the proper protection for individual deminer while providing deminers with suitable tool-set to facilitate their work reliably. The tool-set may contain an excavator, an MIT profile probe, a pick-prod, a demining trowel or mini-spade, a brush, shears, mine-markers, root cutters, a tripwire feeler, maintenance tools and a saw. A pulling device is an optional extra. Vegetation clearance in humanitarian demining occurs in two categories, vegetation clearance above and to ground level, and vegetation clearance below ground level (Busuladzic and Trevelyan, 1999). In general practice, the vegetation clearance can be done either manually and/or by mechanical means. Figure 1 shows examples of different manual prodders and different body postures for deminers.
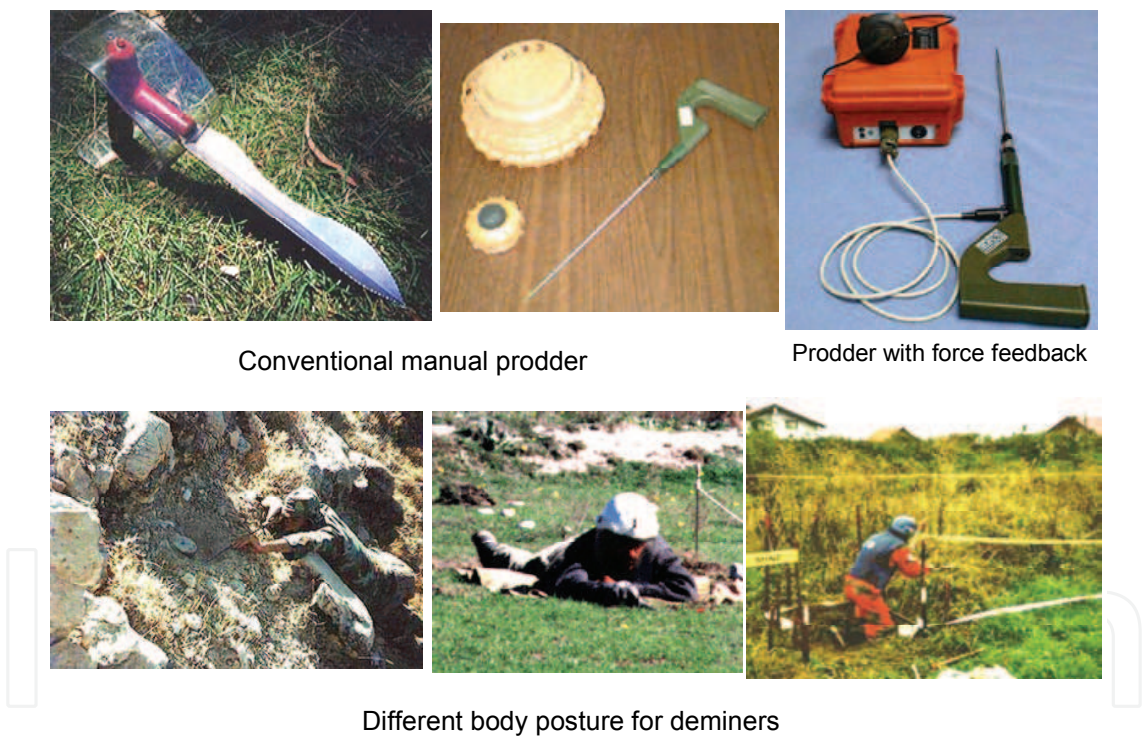

Conventional manual prodder   Prodder with force feedback

Different body posture for deminers

Fig. 1. Examples of different manual prodders and different body postures for deminers

6.2 Mechanical Equipment and Tools for Mine Clearance

A good deal of research and development has gone into motorized mechanical mine clearance in which their early design was influenced by the military demining requirements. The use of such machines aims to unearth mines or force them to explode under the pressure of heavy machinery and associated tools and to avoid the necessity of deminers

making physical contact with the mines. A number of mechanical mine clearing machines have been constructed or adapted from military vehicles, armored vehicles, or modified commercially available agriculture vehicles of the same or similar type, with same or reduced size (Habib, 2001b). A single mechanical mine clearance machine can work faster than a thousand deminers over flat fields. They are mostly appropriate and cost effective in large and wide areas without dense vegetation or steep grades. In small paths, thick bush, or soft or extreme hard soil such machines simply cannot maneuver. Mechanical clearance equipment is expensive and it cannot be used on roadsides, steep hills, around large trees, inside a residential area, soft terrain, heavy vegetation or rocky terrain. Mobility and maneuverability where wheeled vehicles cannot travel efficiently on anything other than flat surfaces, tracked vehicles cannot travel in areas with steep vertical walls, machines in general cannot climb undefined obstacles, and machines cannot in general deform to get through narrow entrances. In addition, mechanical clearance has its own environmental impact such as erosion and soil pollution. The logistical problems associated with transporting heavy machinery to remote areas is critical in countries with little infrastructure and resources.

The aim of using machines is typically not to clear land from mines, but to prepare ground for post-machine full clearance by manual and mine detection dog teams (GICHD, 2004) along with other possible technologies. Hence, none of the equipment within this category has been developed specifically to fulfill humanitarian mine clearance objectives and for this, there is no form of any available mechanical mine clearance technologies that can give the high clearance ratio to help achieving humanitarian mine clearance standards effectively while minimizing the environmental impact. It has been suggested that few AP blast mines are left behind in a functional condition after treatment by certain machines in suitable terrain, and in order to achieve better clearance rate, manual deminers and mine detection dog teams should follow up to compensate for the likely residual mine threat left by that machines.

A number of mechanical mine clearing machines have been tested during the past. The general trend goes from "mechanical demining" towards "mechanically assisted demining", adaptable to local circumstances. Some examples of mechanical clearance equipment include but not limited, Vegetation cutters, Flails and Light-Flails, Panther mine clearing vehicle, Armored bulldozer, Ploughs and the rake plough, the M2 Surface "V" mine plow, Earth tillers, Mine sifter, Mechanical excavation, Armored wheel shovel, Mine clearing cultivator, Floating mine blade, Mine rolling, Mine-proof vehicles, Swedish Mine Fighter (SMF), Armored road grader, etc. (US Department of Defense, 1999; Humanitarian Mine Action Equipment Catalogue, 1999; Department of Defense, 2002; Habib, 2002a; GICHD, 2006a). Demining operations conducted by some mechanical machines are showing promising results that need to be enhanced further given suitable conditions against an appropriate target (GICHD, 2004). Figure 2 illustrates examples of some of the available mechanical machines used for demining.
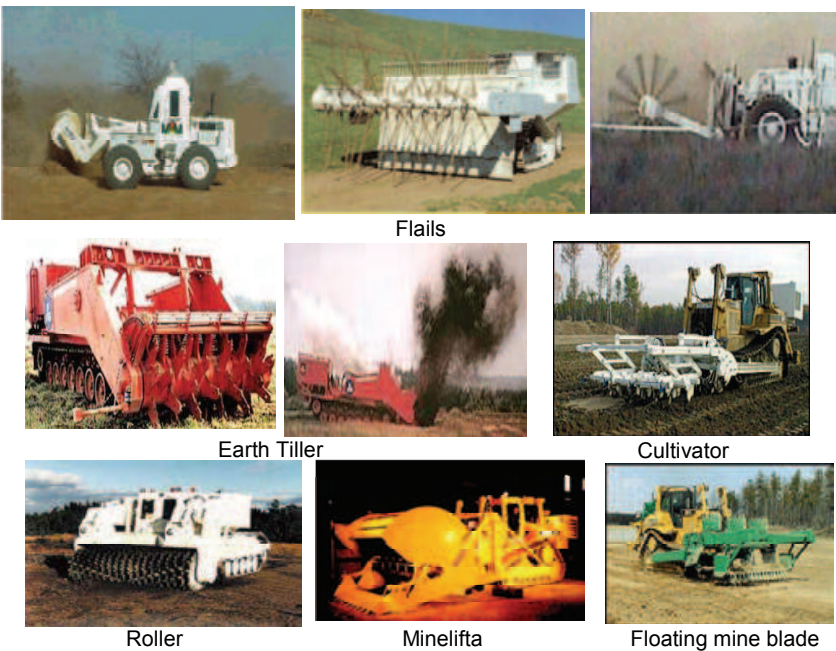
Fig. 2. Examples of demining mechanical machines

In addition, vegetation is a large problem facing demining (mainly in tropical countries) and often poses major difficulties to the demining efforts. The vegetation removal can take up a substantial fraction of the time and for this there is a need to properly mechanized vegetation cutting and removal (See Fig.3 for some examples). These machines should be designed to cut down on the time required for demining. In their simplest form, vegetation cutters consist of adequately modified commercial devices (e.g. agricultural tractors with hedge cutters or excavators). There is an urgent need for effective vegetation clearance technology and techniques that avoid detonating mines.

Examples of Vegetation cutters

Fig. 3. Examples of available vegetation cutters

Cost effective and efficient clearance techniques and mechanisms (flexible and modularized) for clearing both landmines and vegetation have been identified as a significant need by the

demining community. Hence, it is important to highlight the importance to extract the clearance potential of current and future mechanical machines in order to use their speed and potential cost-efficiency. In order to enhance the possibility of a successful usage of demining machines, it is important to understand the physical limits imposed upon a demining machine by its operational environment and ecological needs. This would include factors of topography, soil, ordnance type and machine. Furthermore, there is urgent need to standardized method of recording mechanical clearance data (GICHD, 2004) and set up proper benchmarks for evaluations, testings and risk assessment.

6.3 Mine Detection and Sensing Technologies

Mine detection represents the most important step of the demining process, and the quality of mine detector affects the efficiency and safety of this process. The main objective of mine detection is to achieve a high probability of detection rate while maintaining low probability of false alarm. The probability of false alarm rate is directly proportional to the time and cost of demining by a large factor. Hence, it is important to develop more effective detection technology that speed up the detection process, maximize detection reliability and accuracy, reduce false alarm rate, improve the ability to positively discriminate landmines from other buried dummy objects and metallic debris, and enhance safety and protection for deminers. In addition, there is a need to have simple, flexible and friendly user interaction that allows safe operation without the need for extensive training. Such approach needs to incorporate the strength of sensing technologies with efficient mathematical, theoretic approaches and techniques for analyzing complex incoming signals from mine detectors to improve mine detectability. This leads to maximize the performance of the equipment through the optimization of signal processing and operational procedures. Furthermore, careful study of the limitations of any detection device and technology with regard to the location, climate, and soil composition is critically important besides preparing the required operational and maintenance skills. It is important to keep in mind that not all high-tech solutions may be workable in different soil and environmental conditions. The detection technologies are presently in varying stages of development. Each has its own strength and weaknesses. The development phase of new technologies requires a well-established set of testing facilities at the laboratory level that carried out in conditions closely follow those of the mine affected area. In addition, the verification test should be carried out at the real minefield site. This should be followed by extensive field trails in real scenarios to validate the new technologies under actual field conditions for the purpose to specify benefits and limitations of different methods while fulfilling certain benchmark requirements. The work must be performed in close cooperation with end-users of the equipment while real deminers should carry out the test at a real site, in order to ensure that the developments are consistent with the practical operational procedures in the context of humanitarian demining, and that it is fulfilling user requirements. In addition, there is a need to have reliable process of global standard for assessing the availability, suitability, and affordability of technology with enabling technology represented by common information tools that enable these assessments and evaluations. The benchmarking is going to enhance the performance levels that enable the development of reliable and accurate equipment, systems and algorithms.

Most of the available methods to detect explosives and landmines are limited by their sensitivity and/or operational complexities. Methods of detecting mines vary from, simple in technology but exhaustive searching by humans using some combination of metal

detectors and manual probing, to a variety of high biological and electronic technologies. Metal detectors find objects containing metal by utilizing a time-varying electromagnetic field to induce eddy-currents in the object, which in turn generate a detectable magnetic field. Old landmines contain metal parts (e.g. the firing pin), but modern landmines contain very small amounts or no metal at all.

Increasing the sensitivity of metal detector to detect smaller amounts of metal results to make it very sensitive to soils with high ferrous content or metal debris often found in war zones and areas where mines may be located. Metal detectors can only succeed in finding anomalies in the ground without providing information about whether an explosive agent is present or not. Another technique that is widely used is the direct detection of explosive material by smell using a dog (Sieber, 1995). Trained dogs are the best known explosive detectors but they need excessive training and inherently unreliable because they are greatly impeded by windy conditions, and have only 50-60% accuracy.

An interesting departure from the use of electromagnetic radiation involves approaches focusing on developing and using detection tools that can identify explosives residue in mined areas as a robust primary indicator with no regards to the mine container. Understanding the behaviors and capabilities of animals, insects and other living creatures, along with close collaboration between biologist and engineers, present unique opportunities for enhancing, genetically manipulating, and creating new capabilities through mimicry and inspiration, developing biosensors through the integration of living and non-living components, such as, genetically engineered bacteria, plants, etc.; and the direct use of complex biological systems, such as dogs, bees, rats, pigs, etc.; with focus to support wide range of applications throughout the process of humanitarian demining (Habib, 2007b).

Detection techniques, for buried low-metal landmines that are in development can be grouped into three main categories: sensors that detect the landmine explosives or chemicals that are associated with the explosives; sensors that recognize an image of the landmine through scattering, and sensors that detect anomalies at the surface or in the soil. Most if not all of these sensors are affected to some degree by soil conditions

New technologies are being investigated to improve the reliability and speedup the detection operation, some of these technologies are: Electromagnetic Induction Metal detectors (EMI), Infrared Imaging, Ground-Penetrating Radar (GPR), Acoustics-to-seismic waves coupling, Acoustic Imaging, Thermal Neutron Activation (TNA), Photoacoustic Spectroscopy, Nuclear Quadrupole Resonance (NQR), X-ray Tomography, Nneutron Back-scattering, Biosensors, Commercial sniffers, etc. (Healy & Webber, 1993; Van Westen, 1993; Hewish & Ness, 1995; Sieber, 1995; McFee, 1996; Cain & Meidinger, 1996; Habib, 2001a, Habib, 2007b).

Mine detection represents the slowest component within the demining process. Currently, there is no single sensor technology that has the capability to attain good levels of detection for the available AP mines while having a low false alarm rate under various types of soil, different weather, all types of mines, natural and ground clutters, etc. If one sensor can detect a mine with a certain success rate coupled with a certain probability of generating a false alarm, could two sensors working together do a better job? The idea of developing multi sensor solutions involving two or more sensors coupled to computer based decision support systems with advanced signal processing techniques is attractive and is advocated by many as a fruitful line of development. Hence, there is a need to use complementary

sensor technologies and to do an appropriate sensor data fusion. The ultimate purpose is to have a system that improves detection, validation and recognition of buried items for the purpose to reduce false alarm rates and to overcome current landmine detection limitations. A promising solution will be to apply fusion of sensory information on various sensor outputs through the use of advanced signal processing techniques, by integrating different sensor technologies reacting to different physical characteristics of buried objects. Critical to demining is the ability to distinguish fragments or stones from the target material in real time.

Sensor fusion using soft computing methods such as fuzzy logic, neural networks and rough set theory must be further explored and computationally inexpensive methods of combining sensory data must be designed. These methods should also have the capability to assess the quality of the mined area once the mines have been cleared.

6.4 Robotized solution for Mine detection and Clearance

Many efforts have been recognized to develop effective multi operational mode robots for the purpose to offer flexible, modular, reliable, cheap and fast solutions for the demining operations. The development and implementation of robotics in mine and UXO clearance is attractive and it is building up momentum to spare human lives and enhance safety by avoiding physical contact with the source of danger in mined area, improve accuracy, help in mined area reduction, increase productivity and enhance effectiveness of repetitive tasks such as, probing/prodding, searching patter with sensors, digging, sifting, vegetation removal, etc. Solving this problem presents challenges in robotic mechanics and mobility, sensors and sensor fusion, autonomous or semi autonomous navigation and machine intelligence. In spite of some reported level of success research into individual, mine-seeking robots is still at the early stages. In their current status, they lack flexibility and yet they represent a costly solution for mine clearance operation. But, if designed and applied at the right place for the right task, they can be effective solutions. Four main directions can be recognized in development: teleoperated machines, multifunctional teleoperated robot, demining service robots, and unmanned aerial vehicles.

7. Solutions and Priorities

The priorities for research and development in the field of humanitarian demining require strategies that require to start with the following needs:

a) Develop reliable and accurate techniques/technologies that can enhance the performance of the demining process and allow efficient area detection and reduction of minefields. There is an urgent need to recognize and reliably locate minefields and isolate them by defining proper signs and limits to make the public aware, and to avoid further accidents,

b) Have quality-training programs that fit the needs of local environment. Such training programs need to integrate cultural, environmental and operational considerations when developed,

c) Enhance the safety of deminers by providing them with suitable protective clothing, tools and equipment and isolate them as possible from direct physical contact with the mines and UXOs,

d) Enhance the performance of the sensors and the deminers. To achieve this, there is a need to develop efficient techniques for sensor integration (array of homogeneous and/or heterogeneous sensors) with advance level of data fusion and signal processing algorithms that can confirm the detection in real-time and lead to the identification of mine parameters needed for the next actions.

e) Develop a portable, reliable and easy to use handheld approach to sensor movement that is still required in difficult and physically constraint environments (woods, uneven terrain, residential, etc.) although such approach is slow and hazardous for the individuals. Hence, the sensors can be integrated with vehicle-based platforms to support automatic mine clearance in open areas.

f) Use information and communication technologies with aim to enhance contact, experience exchange, research, planning and to share results and data among all parties and personnel within the demining community.

g) Mechanized vegetation cutting. However, it would be better to find a technology that can detect and mark mines without having to cut vegetation.

h) Develop simple, modular, efficient, compact and low cost mechanical machines for mine clearance that suit the target task and environment aiming to unearth mines reliably and efficiently,

i) Increase mine clearance daily performance by improving productivity, accuracy, and increase safety of demining personnel. There is a need to have a means of moving the portable mine detection device as it searches for landmines. Hence, it is important to automate/mechanize detection and removal of mines, and to improve the safety of the deminers through the use of efficient, reliable and cost effective humanitarian mine action equipment (such as robots, flexible and intelligent mechanisms, etc.), that have minimum environmental impact. It is necessary to have a robot with efficient and modularized surface locomotion and mobility that is well adapted to unstructured environment and different type of terrain. The design should integrate proper balance between maneuverability, stability, speed, and the ability to overcome obstacles. Such robots should have decision-making capability to locate, mark or neutralize individual mine precisely, and

j) To have efficient quality control assurance methods that is reliable and accurate in ensuring that there is no residual mines within an area declared clear of mines.

In order to approach a proper and practical solutions for the problem, there is a need for the scientists in each discipline and deminers to share their knowledge, and the result of their experience and experiments in order to design and test viable solutions for humanitarian demining without ruling out any possible technology or technique.

The challenges associated with configuring humanitarian demining equipments are many. Technologies to be developed should take into account local resources and the facts that many of the demining operators will have had minimal formal education and that the countries where the equipment is to be used have poor technological infrastructure for equipment maintenance, operation, and deployment. The resultant system must be inexpensive and easy to use with minimal training by locals. In addition, the equipment must be flexible and modular to address a variety of clearance tasks and for case-by-case scenarios. Furthermore, the logistical support of the equipment must be consistent with third world countries.

8. Robotics and Humanitarian Demining: The Challenge and Requirements

The portable handheld mine detection approach to sensor movement is slow and hazardous for the individual deminers. Armored vehicles may not thoroughly protect the occupants and may be of only limited usefulness in off-road operations. Most people in the mine clearance community would be delighted if the work could be done remotely through teleoperated systems or, even better, autonomously through the use of service robots. Remote control of most equipment is quite feasible. However, the benefit of mounting a mine detector on a remotely controlled vehicle should have careful considerations that lead to decide whether the anticipated reduction in risk to the operator justifies the added cost and possible reduction in efficiency. A cost analysis should be made to determine to what extent remote control approach is a valid solution.

To increase mine clearance daily performance by improving productivity and accuracy, and to increase safety of demining operations and personnel, there is a need for an efficient, reliable and cost effective humanitarian mine action equipment with flexible and adaptable mobility, and some level of decision making capabilities. Such equipment should have selectable sets of mine detectors and work to locate and mark individual mines precisely, and at a later stage to neutralize the detected mines. Robotics solutions properly sized with suitable modularized mechanized structure and well adapted to local conditions of minefields can greatly improve the safety of personnel as well as work efficiency, productivity and flexibility. Robotics solution can range from modular components that can convert any mine clearing vehicle to a remote-controlled device, to prodding tools connected to a robotic arm, and to mobile vehicles with arrays of detection sensors and area mine-clearance devices. The targeted robot should have the capability to operate in multi modes. It should be possible for someone with only basic training to operate the system. Robots can speedup the clearance process when used in combination with handheld mine detection tools, and they are going to be useful for quick verification and quality control. To facilitate a good robot performance in the demining process, there is a need to employ mechanized systems that are able to remove obstructions that deter manual and canine search methods without severely disturbing soil. Solving this problem presents challenges in the robotics research field and all relevant research areas.

Robotics research requires the successful integration of a number of disparate technologies that need to have a focus to develop:

a) Flexible mechanics and modular structures,
b) Mobility and behavior based control architecture,
c) Human support functionalities and interaction,
d) Homogeneous and heterogeneous sensors integration and data fusion,
e) Different aspect of fast autonomous or semi-autonomous navigation in a dynamic and unstructured environment,
f) Planning, coordination, and cooperation among multi robots,
g) Wireless connectivity and natural communication with humans,
h) Virtual reality and real time interaction to support the planning and logistics of robot service, and
i) Machine intelligence, computation intelligence and advanced signal processing algorithms and techniques.

Furthermore, the use of many robots working and coordinating their movement will improve the productivity of overall mine detection and demining process through the use of team of robots cooperating and coordinating their work in parallel to enable parallel tasks (Gage, 1995; Habib, 1998).

The possible introduction of robots into demining process can be done through surface preparation and marking, speeding-up detection, and mine removal or neutralization. In addition, service robots can be used for minefield mapping too. However, the cost of applying service robot's technologies and techniques must be justified by the benefits it provides. There is no doubt that one of the major benefits would be the safety, by removing the operator from the hazardous area.

It is clear that the development of a unique and universal robot that can operate under wide and different terrain and environmental conditions to meet demining requirements is not a simple task. In the short term, it appears that the best use of robotics will be as mobile platforms with arrays of mine detection sensors and area mine clearance devices. Teleoperations are promising but are limited too, because their remote human controllers have limited feedback and are unable to drive them effectively in real time. There are still some doubts whether such equipment will operate as effectively when the operator is at a long distance or has been removed altogether. Strangely enough, this is particularly true for urban areas normally full of rubble, while agricultural areas seem to be better, but that is not always true. A possible idea in using robots for demining is to design a series of simple and modularized robots, each one capable of performing one of the elementary operations that are required to effectively clear a minefield. An appropriate mix of such machines should be chosen for each demining task, keeping in mind that it is very unlikely that the whole process can be made fully autonomous. It is absolutely clear that in many cases, the environment to be dealt with is so hostile that no autonomous robot has any chance to be used in mid and short terms. The effort devoted to robotic solutions would be more helpful if it is directed at simple equipment improvements and low-cost robotic devices to provide some useful improvements in safety and cost-effectiveness in the short to medium term.

Several practical difficulties in using robots for mine clearance have been highlighted (Treveylan, 1997). There is little value in a system that makes life safer for the operator but which will be less effective at clearing the ground. Accordingly, a serious evaluation and analysis should be done along with having efficient design and techniques. The high cost and sophisticated technology used in robots which required highly trained personal to operate and maintain them are additional factors limiting the possibilities of using robots for humanitarian demining. In spite of this, many efforts have been recognized to develop effective robots for the purpose to offer cheap and fast solution (Nicoud & Machler, 1996; Habib, 2001b).

Before applying robotics technology for the mine clearance process, it is necessary to specify the basic requirements for a robot to have in order to achieve a better performance. These requirements include mechanisms, algorithms, functions and use.

a) It is essential to design a robot that will not easily detonate any mines it might cross on its way, i.e., to apply ground pressure that will not exceeds the threshold that sets off the mines in question. Ground pressure is recognized as an important constraint on a demining vehicle, because ground pressure is what disturbs the ground and triggers many landmines. If a demining vehicle is to safely traverse a minefield, it must exert as

low a ground pressure as possible (less than 10 kg). Preferably this would be lower than the minimum pressure value, which would detonate a mine.

b) The robot should be able to cross safely over the various ground conditions. This can be achieved by having adaptable and modular locomotion mechanism both for the mobility and structure. The mechanical structure of the robot should be simple, flexible and highly reliable.

c) The robot must be practical, low purchased cost and cheap to run, small, lightweight, and portable.

d) The robot should have efficient surface locomotion concept that is well adapted to unstructured environment. The design should assure proper balance between maneuverability, stability, speed, and the ability to overcome obstacles.

e) It should employ multi sensors system for detecting and recognizing different mines.

f) It should have suitable mechanism for self-recovery for some levels of the problems that it might face during navigation and searching for mines.

g) Design considerations should be given to have a robot that can resist water, sand, temperature and humidity.

h) The mechanical design of the robot should consider practical technology and should be as simple and low in technology so that anyone can find and replace and possibly make it using locally available materials, such as, bicycle components, bamboo, etc.

i) The robot should work in more than one operational mode, such as teleoperated, semi-autonomous, and autonomous modes while keeping the deminer out of physical contacts with mine areas. Operator safety should be guaranteed.

j) In case of accidentally triggering a mine, the robot should be capable of withstanding the explosive blast without suffering major damage. At the minimum the high tech parts of the robot that cannot be replaced locally should be well protected.

k) The robot should be easy to maintain in terms of service and repair by indigenous users. Ease of maintenance is built in at the design stage so that if repair is ever necessary it may be carried out locally without the use of special test equipment or specialized staff. The robots need to be tested and deployed with minimum cost.

l) Sustaining a reasonable power supply to enable the robot to operate for long period.

m) Efficient navigation techniques with sensor based localization in the minefield, and man-machine-interfaces including the ergonomy of lightweight portable control stations with friendly user interface.

Research into individual, mine-seeking robots is in the early stages. In their current status, they are not an appropriate solution for mine clearance. This is because, their use is bounded by sensing devices and techniques improvements, the difficulties facing automated solutions raised by the variety of mines and minefields, and the variety of terrains in which mine can be found. Examples of such terrains may include dessert, sides of mountains, rocky, forest, rice paddy, riverbanks, plantations, residential areas, etc. Also, robotized solutions are yet too expensive to be used for humanitarian demining operations in countries like Angola, Afghanistan, Cambodia, etc.

9. Robotization of Humanitarian Demining

Many efforts have been recognized to develop effective robots for the purpose to offer cheap and fast solutions. Three main directions can be recognized:

1.   Teleoperated machines,
2.   Multifunctional teleopeated robot,
3.   Demining service robots, and
4.   Unmanned Aerial Vehicles and Airships.

9.1. Teleoperated Machines

9.1.1 Light-Flail

Smaller and cheaper versions of the flail systems are developed with chains attached to a spinning rotor to beat the ground and integrated with remotely controlled, line-of-sight, skid loader chases. The use of light-flails aim to safely clear light to medium vegetation, neutralize AP-mines and UXOs from footpaths and off-road areas, and assist in area reduction of minefield (See Fig. 4). These machines are developed to provide a capability to remotely clear AP mines and proof areas that have been cleared (Humanitarian Demining Developmental Technologies, 1998; GICHD, 2006a). The design of such machines was in particular for dealing with vegetation clearance and tripwires as a precursor to accelerate manual clearance. These flail systems are not designed for heavily vegetated or extremely rough terrain. Some systems can clear AP mines from off-road locations and areas that are not accessible by larger mechanical mine clearing equipment. The light-Flail can defeat bounding, tripwire, fuzzed, and simple pressure AP mines. In addition, these machines have flail clearance depth between 150mm and 200mm and range of working width between 1.4m and 2.22m. These machines are designed to withstand blasts up to 9 kg of TNT. They are remotely controlled up to a range of 5,000m through feedback sensors and up to 500m away (line-of-sight distance) if it is working in an open space. An armored hood is available to protect these machines against AP mine blasts. Furthermore, there are set of tracks for installation over the tires when working in soft soil conditions to improve traction. Different machines made by different manufacturers with almost similar concept are available and have been used in real minefields. Some of these are (Humanitarian Demining Developmental Technologies, 1998; GICHD, 2006a; Croatia Mine Action Centre, 2002; Danielsson et al., 2003; Danielsson et al., 2004; Leach, 2004):

a) Two machines of Armtrac 25 are in service with the UK Ministry of Defense with no information for actual usage in a real minefield,

b) More than 110 Bozena machines have been produced. These machines have been, or are currently, in service in Afghanistan, Albania, Angola, Azerbaijan, Bosnia and Herzegovina, Cambodia, Czech Republic, Eritrea, Ethiopia, Iraq, Kenya, Kosovo, Lebanon, The Netherlands, Poland, Slovakia, Sri Lanka, and Thailand,

c) The Compact Minecat 140 was developed in 2001 as a direct follow-up improvement of the MineCat 230 and has not yet been used in real minefields,

d) There are 62 MV-4 light flails have been purchased by various organizations/demining companies. Some of the organizations are, US Army (21 units), Swedish Army (5 units), Croatian Army (2 units), Irish Army (2 units), International Mine Action Training Centre (IMATC) Kenya (1 unit), Croatian Mine Action Centre (CROMAC) (4 units), Iraqi National Mine Action Authority (4 units), Norwegian People's Aid (NPA) (3 units), Swiss Foundation for Mine Action (FSD) (5 units), etc,

e) Mini-Flails have been tested extensively in Kuwait, Bosnia, Kosovo, and Jordan. Currently, Six Mini-Flails are deployed today in the Balkans, and four systems are

deployed in Afghanistan. The new version `Mini-Deminer` incorporates improvements to the problems associated with the U.S. Army's original Mini-Flail identified during field evaluations. Development testing of the Mini-Deminer took place during the spring and summer of 1999, and

f) There is no information available by the manufacturer on the actual usage of Diana 44T machine in real minefields.

All light flail machines are featured by, small and compact in size, ease to transport on a light trailer, remotely controlled, ease of maintenance and repair, powerful engine with efficient cooling system, etc.

Light flail machines have difficulties to operate with precision from a long distance (this applies to all remotely controlled machines), as they require line of sight operation with suitable feedback. The ground flailing systems creates large dust clouds and the high vegetation will restrict operator's view on the machine. They also exhibit difficulty in flailing in soft soil, and can inadvertently scatter mines into previously cleared areas. All machines are not intended to be used in areas where AT mines are present, and they may not be usable in steep or rocky terrain.
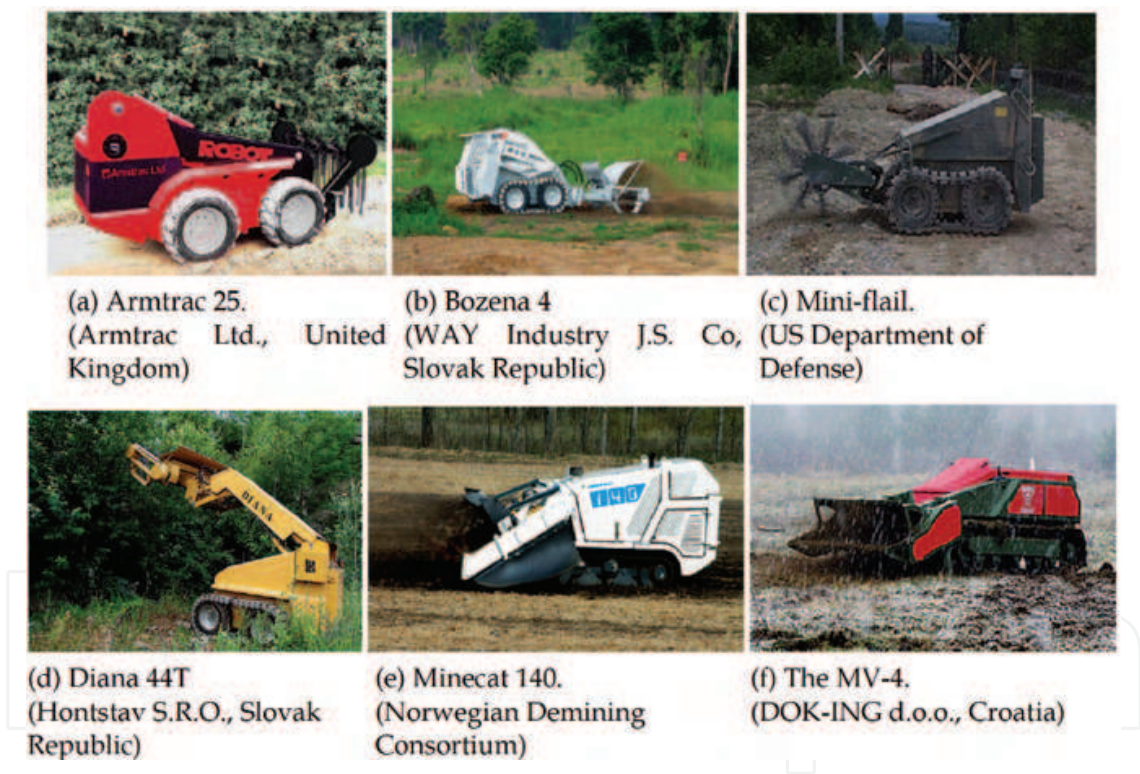

(a) Armtrac 25. (Armtrac Ltd., United Kingdom)

(b) Bozena 4 (WAY Industry J.S. Co, Slovak Republic)

(c) Mini-flail. (US Department of Defense)

(d) Diana 44T (Hontstav S.R.O., Slovak Republic)

(e) Minecat 140. (Norwegian Demining Consortium)

(f) The MV-4. (DOK-ING d.o.o., Croatia)

Fig. 4. Different types of light flails in action

9.1.2 Remotely Operated Vehicles (Kentree Limited)

Kentree Limited has been designing and manufacturing variety of remotely operated vehicles. Hobo was the early developed vehicle and it has a reasonable maneuverability, 6 robust heels to allow carriage goes over obstacles and through water. Many updates have been introduced to meet the continued requirements in Explosive Ordnance Disposal (EOD)/Improvised Explosive Device Disposal (IEDD) applications and those required in

battle zones, nuclear, chemical or fire fighting situations. The most apparent are the articulating rear axle and the Radio Control. The tracked chassis has a front ramp section which lowers to provide a variable footprint. With this additional traction, the vehicle negotiates slopes, stairs and steps with ease. Hobot is the track version of Hobo for use in areas where tracks are the required option as in certain nuclear or chemical environments. The dimension of Hobo L3A15 is L= 148.3cm, W= 70.76cm and H= 88.81cm, the vehicle weight when empty is 228 kg, the payload of the arm is 30 kg, and the maximum speed is 4km/h. Other teleoperated vehicle developed by Kentree includes, Vegabond, Rambler, Max, Brat, Tramp and Imp.

One of the latest additions to the Kentree family of vehicles is the "Thrasher" mobile vehicle designed for the purpose of demining. Kentree and the Irish armed forces are developing Thrasher as cost-effective solution for demining operations. Thrasher is small and it is capable of dealing with narrow laneways. The remotely controlled route clearance flail system is aimed at clearing a 4 feet wide path of booby traps and AP mines to allow safe personnel passage. The vehicle can also be fitted with an offset rear flail attachment, to increase the beat area to 8 feet. This will allow the access of small transport vehicles. The ROV can be controlled via secure radio link from the front passenger seat of a jeep by means of a laptop control console with video feed to virtual reality goggles. Alternatively, it may be operated by backpack style system with hand control for foot-mounted demining operations. No information for demining testing and evaluation is available. Figure 5 shows Hobo, Hobot and Thrasher robots.
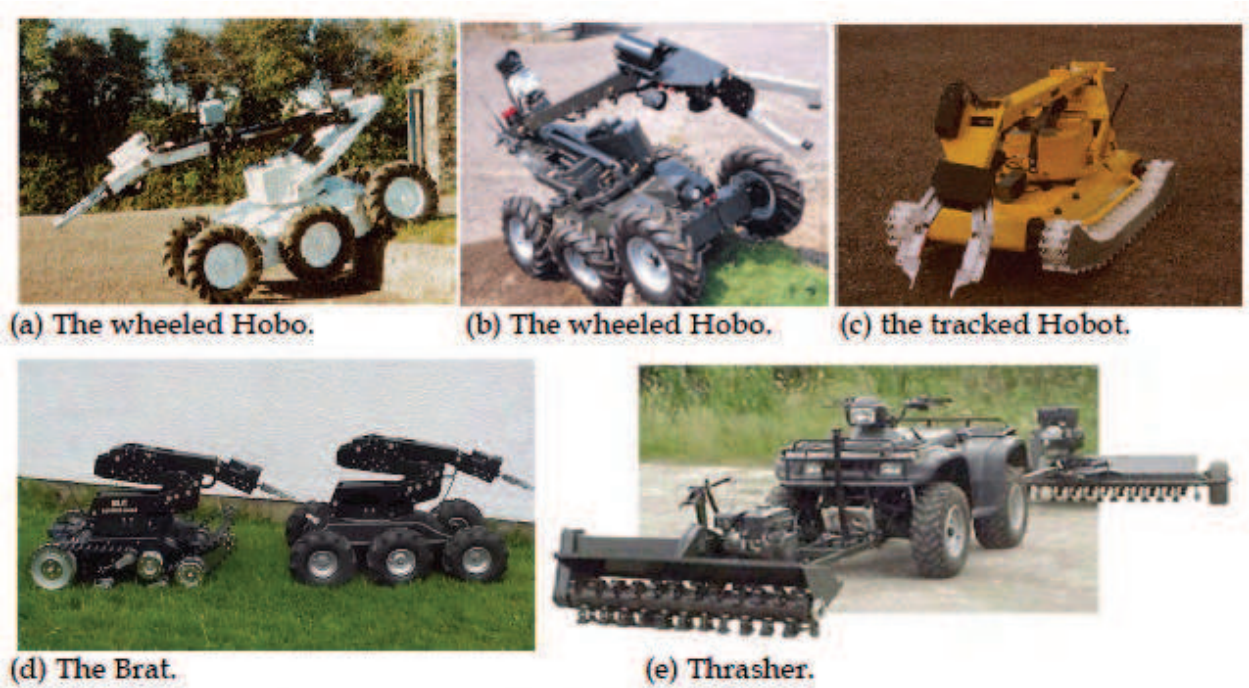

(a) The wheeled Hobo.   (b) The wheeled Hobo.   (c) the tracked Hobot.

(d) The Brat.   (e) Thrasher.

Fig. 5. Remotely operated vehicles from Kentree

9.1.3 Pookie

The Pookie has been co-developed and manufactured by Trevor Davies Engineering. The robot named Pookie because of its resemblance to the small wide-eyed African bush baby.

Pookie is a manned vehicle with a possibility to be teleoperated by simply extending its functionalities. Pookie was constructed on a lightweight chassis and carried a one-person armor-plated cab. The cab had a V-shaped undercarriage designed to deflect any blast away from the driver and to combat centre blast mines. The wheels were positioned some distance from the cab, again to protect the driver in the event of detonation by offsetting the seat of explosion. The crucial difficulty was how to avoid detonating the mine and thereby avoid destroying or damaging the detecting vehicle. The solution was to house the wheels of Pookie with the widest and softest tires available, such as Formula One racing tires, to give the Pookie a low pressure they exert a minimum ground force. The width of the tires, in any case, spanned most landmine holes, lessening the chance of a detonation. In addition, the Pookie was propelled by an engine from a Volkswagen Beetle that was capable of taking Pookie to mine detection speeds of up to 60 kilometers per hour. Two drop-arm detectors were mounted left and right and equipped with a detection system that bounced magnetic waves into the ground as well as an acoustic signal to indicate metal.

On first trials, even though Pookie did detonate AP mines and several booby-trapped AT mines in action with the Rhodesian army, this was only at the cost of new wheels and rim replacements. In stage two of Pookie project, trials were conducted combining Pookie with 5 GPRs. These were held in Somaliland. While the results show some promise, it indicate that Pookie would need additional enhancement to do a better job.

As of the second phase of Pookie (Lawrence, 2002), the VW engine was replaced by a hydraulic pump system, a Hatz 40 Horsepower hydraulic motor manufactured in Germany and used on numerous small vehicles in the mineral mining world. The motor is capable of traveling at 10 kilometers per hour, slow for the movement of a Pookie between targets, but a good average speed for quality GPR data gathering. Pookie was set to run on slightly inflated tiers, delivering a weight distribution that exerts a pressure of only four pounds per square inch per wheel on the road surface. The 5 GPRs sensors were fixed to Pookie with aluminum spars designed to overhang the front of Pookie by approximately 1.5 meters. Each sensor is covering a width of 40 centimeters giving a total width of coverage of two meters. The data was integrated to a GPS to give a position that was then translated to a distance measurement along the road. The system recorded both distance from the start point to target and distance in from the edge or verge. A small tachometer mounted on the rear drive axle was used to pinpoint the position of potential mines with an accuracy of up to one meter at 1000 meters. In addition, a hydraulic steering system and steering ram have been used with the new version of Pookie. Figure 6 shows the development phases of Pookie.

In 2001, Pookie was used to scan location on roads in Senafe, Eritrea with two objectives. The first objective was specifically to test the operational issues of the whole system and its performance as a means of gathering data along suspect roads, and the second aimed to assess the steps required to link a Pookie/GPR demining solution to international demining standards. The trail tests of Pookie shows that Pookie had difficulty performing in very stony conditions. The "Formula One" tires are good for most roads experienced in Eritrea. However, if seriously rocky terrain is to be surveyed, a durable tire is needed. Finally, MineTech is also investigating the role of Pookie as a platform for a broad loop metal detector, and a prototype system is currently under construction.
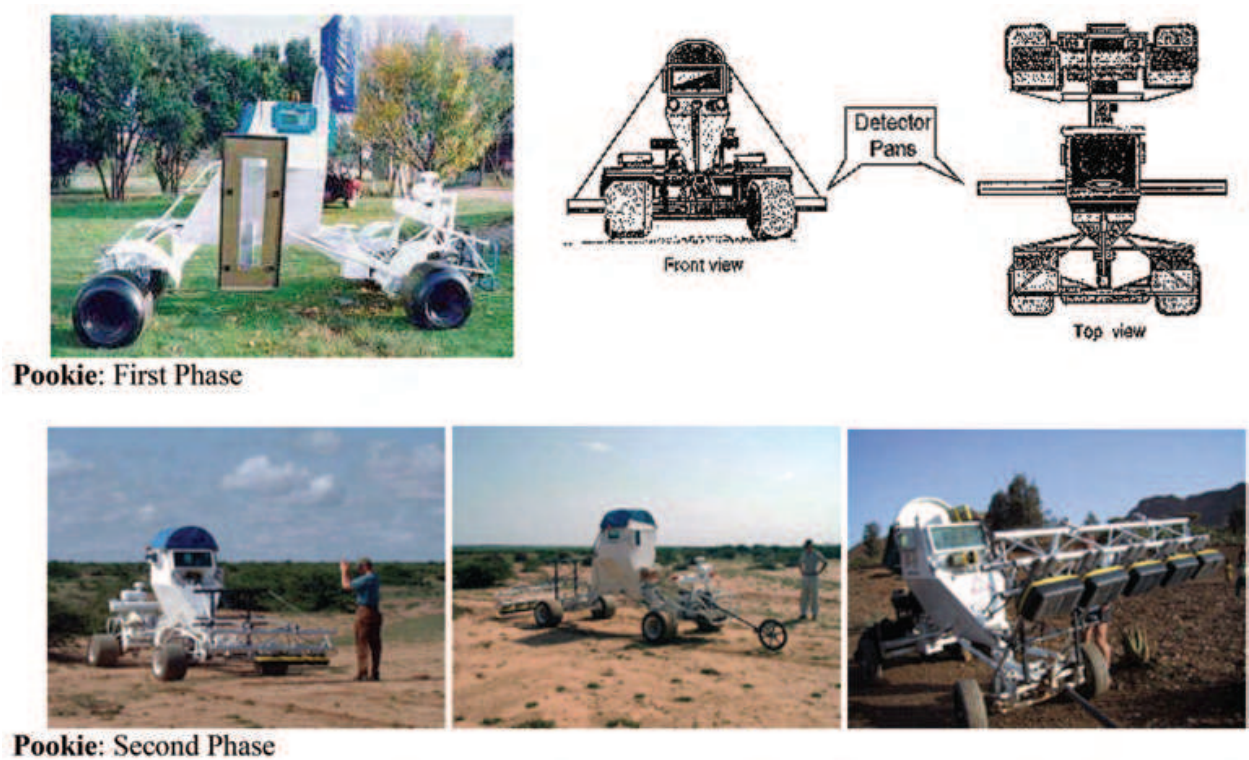
Pookie: First Phase

Pookie: Second Phase

Fig. 6. Development phases of Pookie

### 9.1.4 Vehicle Mounted Detection System (VMDS)

This system detects on/off-road landmines using a multi-sensor mine detection suite mounted on a commercial skid steer chassis platform modified to incorporate a remote control capability. This system provides deminers with the ability to detect antipersonnel and antitank mines with minimal metal content using a flexible metal detection array for close-in detection and infrared (IR) and ultraviolet (UV) sensors for standoff detection. The VMDS sensor package consists of a 2m wide Schiebel metal detection array, a Thermal-Neutron Analysis (TNA) sensor and infrared (IR) sensor. The 2m arrays detect metal objects in the vehicle's path, while the TNA indicates those targets that contain explosives. In testing, the 2m-detection array performed well. The TNA found most Anti Tank mines, but had difficulty identifying Antipersonnel mines and proved very complicated to operate. The prototype was built to conduct testing in 1995.

Fig. 7. Vehicle Mounted Detection System

9.1.5 Improved Landmine Remote Detection Vehicle (IL-RDV)

This was a project financed by Defense R&D Canada, Canadian Department of National Defense started in 1994 and a prototype was completed during 1997. The purpose was to design and build an advanced development prototype of a teleoperated, vehicle-mounted, multi-sensor mine detector for low metal content and non-metallic mines to meet the Canadian requirements for peacekeeping on roads and tracks. This project aimed to develop a reliable route mine detection systems with the ability to rapidly detect mines for logistic or even refuge location areas while minimizing the risks to engineering troops who will clear these areas. The development process of this system employed multiple detectors based on technologies which had limited success for the high intensity conflict problem or in a single sensor role, mainly because of high false alarm rates. The system consists of a teleoperated vehicle carrying a 3m wide down-looking sensitive electromagnetic induction sensor array, forward-looking infrared thermal imaging, a 3m wide down-looking ground penetrating radar. The, Suspicious targets are then confirmed by a thermal neutron activation (TNA) detector. Data fusion methodology is used to combine detector outputs for the purpose to reduce individual detector false alarm rates and provide redundancy. A teleoperated platform was chosen to improve safety to the operators and the platform was custom-designed to have a low signature, in particular ground pressure, with respect to anti-tank mine fuzzes to increase system survivability. The IL-RDV is a part of a larger system called Improved Landmine Detection System (ILDS) that consists of two teleoperated vehicles (the RDV and the protection vehicle (PV)), and a command control vehicle. This completion schedule of this system was during 2002. ILDS was deployed in Afghanistan during 2003. In the Bosnian test calibration area, it was reported that the system was able to maintain a detection probability of 94 per cent. (Faust et al., 2005; GICHD, 2006b).
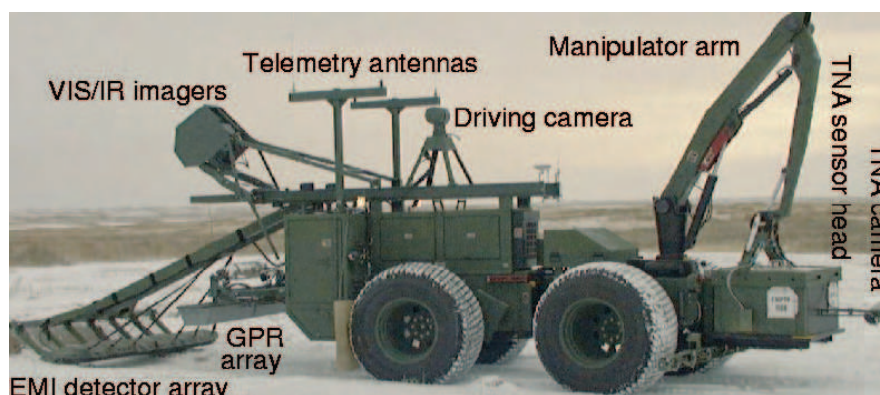
Improved Landmine Remote Detection Vehicle (IL-RDV)

Protection vehicle (PV)

Fig. 8. The two teleoperated vehicles within the Improved Landmine Detection System (ILDS)

9.2 Multi Functional Teleoperated Robots

Multi functional teleoperated machines would have added values to perform besides
demining tasks, other activities, such as: disaster rescue and anti-terrorist operations, or,
several civil engineering works. This is the concept of the remotely operated vehicle with on
board manipulation robotic mechanisms and sets of task oriented tools for performing
particular tasks (Havlík, 2005). This is the concept of modularized teleoperated vehicle with
sets of range of task oriented tools for performing that suit to the need of each individual
task and environment.

9.2.1 Articulated Modular Robotic Mine Scanner
(Engineering Service Incorporation (ESI))

The available conventional vehicle-mounted systems employ an array of sensor heads to
provide a large cross-track detection profile. An example of such systems is the Canadian
improved landmine detection system that uses 24 metal detector coils to cover a 3 m swath.
In addition, it uses 3 Ground Probing Radar (GPR) modules, each consisting of a number of
antenna pairs, to achieve the same coverage. Instead of that, another concept has been
developed to replace an array of multiple sensors by a single sensor head that moves side-
to-side and provides uniform coverage. Such concept incorporates the advantages of
manual and vehicle-mounted operations and capable of autonomously moving a mine
detection sensor over natural ground surfaces including roads and tracks in a manner
similar to a human operator.

The articulated robotic mine scanner is an off-road, modular, teleoperated, multi-sensor
mobile platform designed to detect landmines, including those with minimal metal content,
and UXO. The robot is a modular system comprising a remotely operated vehicle (ROV),
control station communicates with and displays data from the subsystems through a
hardwired or radio telemetry link, scanning mechanism consists of two modular arms like
devices that can be mounted on any vehicle. The first arm carries the laser range camera
and the second arm is the detector arm that carries the metal detector (ESI, 2003). The robot
uses a swept metal detector (of-the-shelf unit that can be easily detached and used
manually), and a small sensor head that combines laser/ultrasonic based terrain imaging
technology that allows the metal detector to adaptively follows the terrain surface while
avoiding obstacles. The robot has a small sensor head, which allows the metal detector to
adaptively follow the profile of a road or a natural surface at a close range without actually
touching it. The robot can perform neutralization of landmines using a modular arm (MR-1)
under the supervision of remotely located operator. MR-1 is a ragged modular dexterous
robotic arm (See Fig. 9). The currently used ROV is capable of turning 360 degrees in 1.5 m
wide hallway, traversing virtually any terrain up to 45 degrees in slope, over 70 cm ditches,
curbs, etc. It operates either with wheel or track and quick mount/dismount tracks over
wheels. The ROV works at high-speed scanning (up to 5 km/hour) with wide detection path
(about 3 m). The MR-2 is a multimode (autonomous, semiautonomous and manual) mine
detection system that operates at high speed with minimum logistic burden. The ROV is a
high cost and heavy robot that is designed to search for mines in terrain with rich vegetation
stones, sand, puddles and various obstacles. The open architecture of the articulated
modular robot allows expansion with generic and custom-made modules (semi-
autonomous navigation, pre-programmed motion, landmine detection, etc.). Sensor
payloads can be extended to include a range of multisensors, such as metal detection array,

an infrared imager, GPR and a thermal neutron activation detector. Data fusion methodologies are used to combine the discrete detector outputs for presentation to the operator. No evaluation and testing results in relation to demining are available.
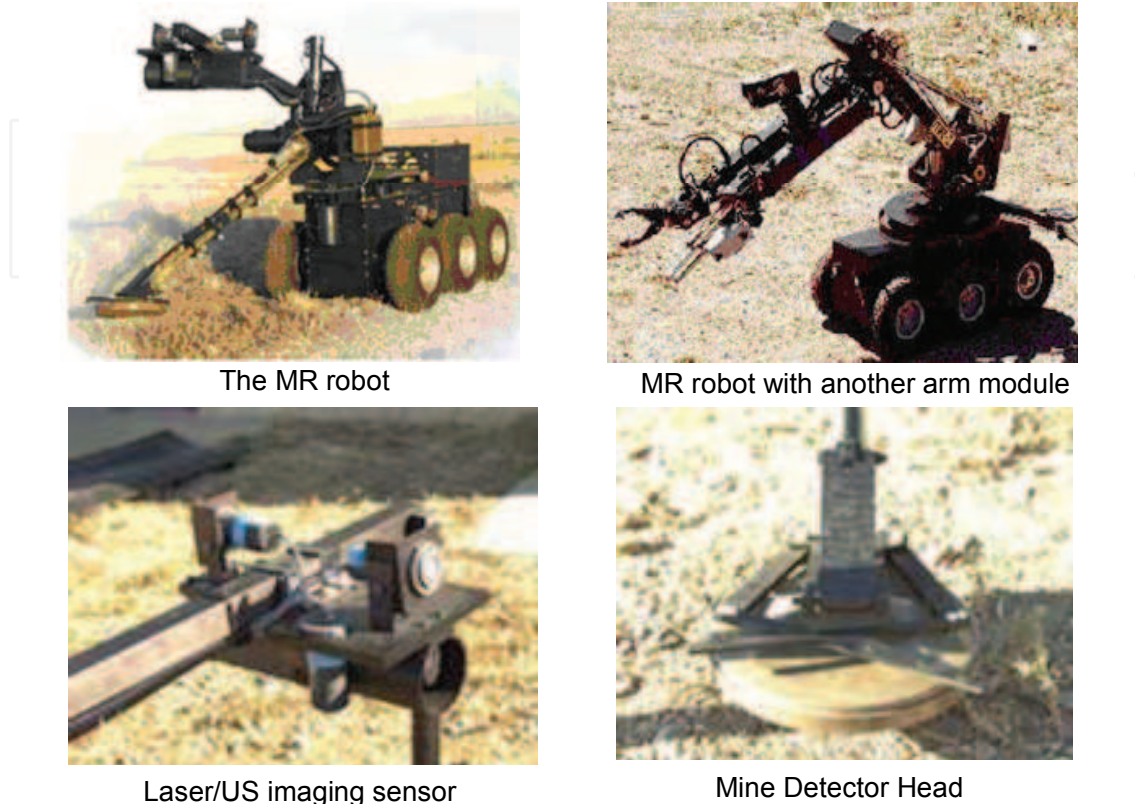

The MR robot

MR robot with another arm module

Laser/US imaging sensor

Mine Detector Head

Fig. 9. Articulated Modular Robotic Mine Scanner

9.2.2 Enhanced Tele-Operated Ordnance Disposal System (ETODS), (OAO Corporation, Robotics Division)

The Enhanced Teleoperated Ordnance Disposal System (ETODS) is a remotely controlled teleoperated system that is based on a modified commercial skid loader with a modular tooling interface which can be field configured to provide the abilities to remotely clear light vegetation, detect buried unexploded ordnance (UXO) & landmines, excavate, manipulate, and neutralize UXO & landmines mines, to address the need of various mechanical clearance activities associated with humanitarian demining (Eisenhauer et al., 1999). ETODS has an integrated blast shield and solid tires.

ETODS includes a heavy vegetation cutter and a rapidly interchangeable arm with specialized attachments for landmine excavation. Attachments include an air knife for excavation of landmines, a bucket for soil removal, and a gripper arm to manipulate certain targets. Remote control capability combined with a differential GPS subsystem and onboard cameras enable the system to navigate within a minefield to locations of previously marked mines. Mines or suspicious objects already marked or identified with GPS coordinates can be checked and confirmed with an on-board commercial detector, and then excavated with a modified commercial backhoe, an air knife, excavation bucket, or gripper attachment. ETODS was developed and configured for the US DoD humanitarian demining research and development Program starting in 1995. It has been through many field test activities,

and they found it suitable for use in humanitarian demining (HD) operations. The HD issues that have been evaluated include accuracy, repeatability, and feasibility of usage in remote environments. In relation to vegetation cutting, three attachments have been tested. One front mounted bush hog and two side mounted boom mowers. In this case, the HD issues that have been evaluated include the ability to cut dense undergrowth, the proper preparation of the ground for ensuing detection activities, and the ability of the operator to effectively and efficiently clear an area under remote control. As for commercial backhoe that can be field mounted to the ETODS, the HD issues that have been evaluated include the effectiveness and efficiency of locating and excavating mines, operator training requirements, inadvertent detonation rates, techniques for deeper excavations, techniques to identify mines and their status (e.g. booby trapped), and blast survivability/repair. A chain flail attachment converts the ETODS into a system capable of clearing AP mines through detonation, and for this case the HD issues that have been evaluated include the minimum sized mine cleared, depth of clearance, effectiveness of clearance, speed of clearance, and blast survivability/repair. During testing, ETODS was subjected to a 12 lb. TNT blast replicating an AT mine detonation. ETODS drove away with field repairable damage. ETODS has proven effective in detonating M14 AP mines and is survivable through repeated 1.0 lb. TNT detonations (OAO-Robotics, website). TODS provides safe, effective delivery of tools necessary for the clearance of landmines and UXO. ETODS is simple, rugged, and can provide a high technology indigenous demining capability in remote environments.

The ETODS has completed operational field evaluations in Jordan and Egypt, where it was found to have several significant limitations that make it less than suitable for humanitarian demining operations (Figure 10 shows the ETODS is action). These include the tendency to become mired in mud or desert sand conditions, as well as the requirement for significant training to develop teleoperation skills (Department of Defense, Development Technologies, 2001and 2002).

Fig. 10. The ETODS in action

9.2.3 TEMPEST.
(Development Technology Workshop (DTW)

TEMPEST is designed to safely clear light to medium vegetation, clear tripwire fuzzed mines, and assist in area reduction as a precursor to accelerated manual clearance. DTW began production of the TEMPEST Mk I in 1998-99 in which it was designed purely as a vegetation-cutting device, and currently, the TEMPEST Mk V is in production. The TEMPEST Mk V is a remotely controlled, lightweight multi-tool system with vegetation

cutting and trip wire clearing abilities (See Fig.11).

TEMPEST is a low cost, small size and light weight radio controlled AP mine blast-protected multi purpose ground based system. These features aim to ease of transport and agility over difficult terrain. It can support a variety of interchangeable clearance heads to clear vegetation, removal of metal fragmentations by using large and small magnets for the removal of metal fragmentations, engage the ground with flail head, and neutralize tripwires, etc. It is designed to clear AP mines from off-road areas inaccessible to large-area mine clearers. The TEMPEST system consists of a diesel powered hydraulically driven chassis, a radio control subsystem, and each of its four hydrostatic wheels is driven by an independent motor to improve maneuverability. The wheels are easy to remove, repair and replace. The TEMPEST also has a 1.2-meter wide horizontal chain flail with vegetation cutting tips, and an adaptable flail head with hydraulic feedback system that can sense the load on the flail, i.e., the operator can set the speed control to maximum and the TEMPEST will automatically control its cutting rate and drive speed, and progress accordingly. The TEMPEST's ground engagement flail is designed to dig into the soil in order to destroy or expose mines by cutting 10 cm deep into the ground to initiate surface and sub surface mines at that level. Its V-shaped chassis and sacrificial wheels minimize damage from anti-personnel mine or UXO detonation and provide some protection against anti-tank mines. TEMPEST's vertical axis "slasher" is capable of cutting through difficult vegetation such as bamboo and vines and its large magnetic array is capable of extracting ferrous material from the ground. It is able to clear up to 200m2/h of light vegetation (500mm tall thick grass) and to cut 100 mm tree in 3-4 minutes. TEMPEST is featured by ease of operation, maintenance, and repair.

TEMPEST is inexpensive to purchase and operate relative to other vegetation clearance systems. Currently, the TEMPEST is produced in Cambodia as well as the United Kingdom, thus representing a regional capability in Southeast Asia (Department of Defense, Development Technologies, 2001 and 2002).

The TEMPEST is an excellent example of how an operational evaluation can lead to improvements that realize the potential of a prototype design. The early prototype of TEMPEST underwent extensive tests in Cambodia for AP and AT mines. The TEMPEST began an operational evaluation in Thailand in January 2001. Although it was effective at clearing vegetation in mined areas, Thai operators identified overheating problems. The unit's promising performance warranted the investment of funds to improve the system. TEMPEST Mk IV has been tested in Mozambique during 2003. The actual use of TEMEST systems and the continuous evaluation results in having TEMPEST Mk V as a reliable system with more speed and engine power capacity compare to the previous versions.

As evaluated by the manufacturer, the hydraulic hoses are vulnerable to fragmentation attacks, and the machine is not intended to be used in areas where AT mines are present. As evaluated by deminers, the TEMPEST requires the operator to maintain direct line of sight with the system from a minimum of 50 meters and the operator can only be this close if behind the system's portable shield. This poses a problem in dense vegetation or rolling terrain. The TEMPEST has limited traction on wet muddy terrain due to the steel wheels clogging with mud. The machine has the ability to clear both mines and vegetation, even though with limitations. The ground flailing system creates large dust clouds. The view of the operator on the machine can be restricted and the air filters can be clogged (Leach et al., 2005).

Currently, there are now 25 machines operating in Angola, Bosnia, Cambodia, DR Congo, Mozambique, Sri Lanka and Thailand. The TEMPEST is currently used by seven demining organizations around the world (GICHD, 2006a). The new TEMPEST Mk VI will mitigate the highlighted problems by use of a new remote control system and the integration of tracks in place of the steel wheels to enable the vehicle to operate on most soil conditions and terrains.

Fig. 11. Tempest during operational field evaluation

10.2.4 The Armored Combat Engineer Robot (ACER)
      Msea Robotics

Mesa Robotics has developed a series of teleoperated mobile platforms targeting range of applications. Among these are MARV, MATILDA and ACER Robotic Platform,

The mobile base platform of ACER is armored with ballistic steel has a size of 83"Wx62"Hx56"L and it weights 4500 LB. It is powered by (12 VDC) NiMH battery with possible operating time between 1 to 2 hours. It has a hydraulic driven system with maximum speed of 6.3 mph and its payload capacity is 2500 Lb. Driving color camera with IR is integrated with ACER. The vehicle can negotiate obstacle up to 10 inch and moves on slopes of 60 degree up/down. ACER accepts a range of custom and standard attachments such as, flail, blades, buckets, etc. and it has towing capacity of 25000 Lb. and arm lift capacity of 1000 Lb. The vehicle's fording depth is 2 inch with zero turning radiuses (see Fig. 12).

ACER can be remotely controlled by one person through a belly-box operator control unit (OCU) with control range of about 500 meters (see Fig. 13). The OCU is featured by 900 MHz digital control, 1.8 or 2.2 GHz analog video system, 6.4" display and two control joy sticks: one for the vehicle and the other for arm control. ACER weights 6 Lb. and powered by (12 VDC) NiMH with (120 VAC) adapter.

Fig. 12. The mobile base unit of ACER with some of possible attachments

Fig. 13. Belly-Box Operator Control Unit (OCU)

ACER provides a variety of capabilities for remote operations: UXO Handling and Removal, Clearing and Breaching, Combat Engineer Support, Hazardous Material Handling, Logistics Support, Decontamination, and Fire Fighting.
ACER is still new and no testing for demining has been reported yet.

9.2.5 Modular Robotic Control System (MRCS) for Mine Detection
A Modular Robotic Control System (MRCS) has been developed and integrated on a light utility tracked vehicle for landmine detection technology applications. The MRCS architecture incorporates a modular design providing remote control of vehicle functions and control of payload tools while annual operation capability of the platform is maintained. The MRCS system consists of three main elements: a man-portable Operator Control Station (OCS), Platform Control Components (PCC), and a wireless data and video link (See Fig. 14 (top)). Nemesis HD Robotic Platform was used as light-weight, and utility-tracked vehicle. The OCS is a man-portable unit that supports all command, control, and communications to the target platform. Operation of the robotic platform is performed through control of the joysticks and functions on the touch-screen. Architecture of the PCC, located on the robotic platform, is fully modular and highly scalable. Adding a new payload can be accomplished by plugging the payload node into the network on the platform and selecting the payload configuration library at the OCS for control and display. Control for the vehicle platform is accomplished through a single control node on the PCC. MRCS is designed to facilitate change-out of radios as needed. The radios are external to the OCS and other platform components so they can be easily exchanged. Closed-loop speed control was designed to provide the capability to drive very slowly (< 0.5 km/hr) over varying terrain at different engine revolutions per minute levels. Based on field-testing and results evaluation, a stepped frequency ground penetrating synthetic aperture radar (GPSAR) array with 2m wide antenna, and a time domain electromagnetic inductance (EMI) 2m wide array were used as the primary detection sensors to detect both AP and AT landmines for the Nemesis project (See Fig. 14 (bottom)).. Navigation and positioning is provided from the robotic platform to aid in correlation of data from the two sensors. The sensor arrays are capable of 3cm spatial resolution. Finally, the system has been developed but no data is available on

testing it for mine detection.

Platform Control Components (PCC)

Nemesis HD Robotic Platform with
integrated components of MRCS

Operator Control Station (OCS)

Detection Sensor Arrays Attached to Robotic Platform

Fig. 14. Modular Robotic Control System (MRCS) at the sensor arrays attachment for mine
    detection

9.3 Demining Service Robots

9.3.1 Three Wheels Dervish Robot
(University of Edinburgh/ UK)

Dervish was originally designed to bypass the problem of mine detection by deliberately
rolling over the mines with mine-resistant wheels. The Dervish is a remotely-controlled
wheeled vehicle designed to detect and detonate AP mines with charge weights up to 250
grams that is equivalent to the largest size of AP mines. It is a three-wheeled vehicle with
wheel axles pointing to the center of a triangle. The weight of Dervish closely emulates (a
little more than) the ground loading of a human leg (Salter& Gibson, 1999). But, because of
its low weight, Dervish will not explode AT mines. The wheels are placed at 120 degrees
from each other. The Dervish drive uses three variable-displacement computer controlled
hydraulic pumps driven by a 340 cc Honda engine, and controlled by a microprocessor to
drive a Danfoss hydraulic motor at each wheel. The steel wheels weight about 80 kg and are
4-6 cm thick. Due to the position of the wheels, if all Dervish wheels were driven at the same

speed then it would merely rotate about its center and make no forward progress. However, carefully timed, small, cyclical variations of wheel speed make the Dervish wheels describe spirals and progressively translate in a chosen direction so that every point in its path is covered, twice, by a loading of about 90 kg in a pattern of overlapping circles. Repeatedly locking one wheel and driving the other two wheels spins the machine through 120 degrees about the locked one and allows traversing. Dervish has a very open steel frame with all members' oblique to the path of blast fragments. It effectively has a zero-radius turning circle. A wide path can hence be stamped by radio control. Figure 15 shows Dervish and illustrates the spiral movements of the robot. It is claimed by the designer that in case of mine explosion, the wheel and the compact hydraulic motor should resist. The tetrahedral structure linking the three wheels and the central power source will be easily repaired.

In normal mine-detonating mode, the Dervish advances at about one meter a minute, a rate set by the requirement that there should be no mine-sized gaps between its wheel tracks, i.e., covering the ground at intervals of only 3cm to avoid any mine-sized gaps between its wheel tracks. A possible change to the wheel design may increase this by a factor of three. With its design structure, it can sweep a 5 meter wide track with a possible coverage of 300-900 square meters per hour. The machine is designed for the clearance of agricultural land. It can operate on open, uneven, or moderately sloping ground. All the electronic equipment is fitted into steel tubes made from old nitrogen bottles with carefully-machined O-ring seals and uses military specification connectors. The Dervish can carry a metal detector placed in a thorn-resistant protective shroud with the sensor head just inboard of the wheel radius at 60 degrees from a wheel. Other sensors for non-metallic targets especially ones that respond to explosives in gram quantities have not been introduced. In a test with a 10kg charge, damage was confined to one corner and the axle and bearings from that test are still in use. The repair cost would be a few hundred dollars. The main limitations of this robot are: not suitable for difficult terrain, hard to navigate, blast-resistant wheels are unsuited to very soft ground, and the inability of the robot with its particular wheel configuration and available power to have enough torque to get out of a hole after a mine blast. This has prompted the team to work on a future complementary design aimed purely at sensor movement with no mine detonation.

Fig. 15. DERVISH robot

9.3.2 Spiral Terrain Autonomous Robot (STAR)
(Lawrence Livermore National Laboratory (LLNL)

An autonomous vehicle has been developed for versatile use in hostile environments to help reduce the risk to personnel and equipment during high-risk missions. In 1996 LLNL was in the process of developing the Spiral Track Autonomous Robot (STAR), as an electro-mechanical vehicle that can be fitted with multiple sensor packages to complete a variety of desired missions. STAR is a versatile and maneuverable multi-terrain mobile robot that can to be used as an intelligent search and rescue vehicle to negotiate fragile and hostile environments (Perez, 1996). STAR can help with search and rescue missions after disasters, or explore the surfaces of other planets (See Fig. 16).

Although four-wheel and track vehicles work well, they are limited in negotiating saturated terrain, steep hills and soft soils. The two key mechanical components in the structure of STAR are the frame assembly and the two Archimedes screws. The mechanical frame is made of hollow aluminum cylinders welded together with an aluminum faceplate on each end. The second key mechanical component of the STAR is the screw drive The STAR rolls on a pair of giant Archimedes screws (one left-hand and one right-hand) that serve as the drive mechanism in contact with the local environment to propel itself along the ground. The screws take advantage of ground forces. Rotating the screws in different rotational combinations causes the system to instantly translate and/or rotate as desired in four possible directions, and to turn with a zero turning radius. When they rotate in opposite directions, the robot rumbles forward. When they rotate in the same direction, it scuttles sideways, and when one screw turns while the other holds still, the screw-bot deftly pirouettes. Versatility in directional travel gives the system flexibility to operate in extremely restricted quarters not accessible to much larger pieces of equipment. Furthermore, the Archimedes screws give the vehicle enough buoyancy to negotiate saturated terrain. In water, the hollow screws float and push like propellers. The STAR is compact, measuring 38 inches square and 30 inches high; it has a low centre-of-gravity allowing the system to climb steep terrains not accessible to other hostile environment hardware.

The STAR is also equipped with a complete on-board electronic control system, data/video communication links, and software to provide the STAR with enough intelligence and capabilities to operate remotely or autonomously. During remote operation, the operator controls the robot from a remote station using wireless data link and control system software resident in a laptop computer. The operator is able to view the surrounding environment using the wireless video link and camera system. Remote operation mode is desirous when personnel must enter an unsecured hostile environment that may contain nerve gases, radiation, etc. Ultrasonic sensors are mounted around the external perimeter of the robot to provide collision-avoidance capabilities during remote and autonomous operations. All power is placed on-board the system to allow for tether less missions involving distant travel. The system is responsible for high-level decision-making, motion control, autonomous path planning, and execution. The cost of the STAR is dependent on the sensor package attached. The STAR is equipped with a differential GPS system for autonomous operation and it can accommodate the Micro-power Impulse Radar (MIR) for landmine detection technology developed by LLNL. A disadvantage of STAR is the high friction between the screw wheels and the ground, which keeps the machine to a one-and-a-half-mile-per-hour speed limit while moving forward or backward. STAR has been studied

in specific mine projects. The robot is not suitable for environments that are full of rocks. Experiments have shown the ability of STAR to negotiate successfully, hard and soft soils, sand, pavement, mud, and water. No demining testing and evaluation was reported.

Fig. 16. STAR robot in different situations

9.3.3 The MILmine

MILmine Sweeper was originally known as "Little Ranger". The MILmine project was established to investigate the feasibility of utilizing an autonomous robot to detect and mark landmines in a possible safe and accurate manner (See Fig. 17). MILmine was built and tested at the University of Florida at the Machine Intelligence Lab (MIL). Mine detection was considered through the use of a Schiebel AN-19/2 as a NATO-approved mine detector head, and the marking of mines is accomplished through the use of spray paint when the robot declares the detection of a landmine. The MILmine's original incarnation included rudimentary collision avoidance via infrared detection in addition to the primary metal-detecting sensor rig. Its processing power was similarly rudimentary, as it used a Motorola 68HC11 EVBU with an expanded 32k of volatile SRAM. The project is being expanded to provide greater mobility and utility for outdoor use, including the addition of a rear-wheel drive system with four-wheel independent suspension. This is an ongoing project where currently the upgrading of the processor is being undertaken to improve the overall functionality as well as to provide the processing power necessary to implement research into machine learning and intelligence. The MIL Mine robot has limited mobility and is not suitable for navigation in difficult and rough terrain. Further development is required but no extension is taken place for this project.
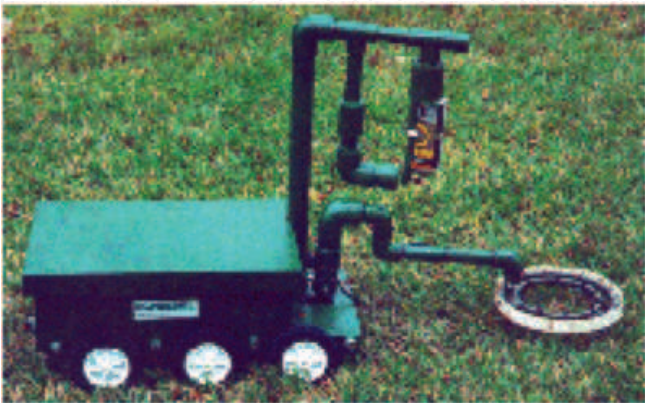

Fig. 17. MILmine robot

9.3.5 FETCH II

The Fetch program is sponsored by the Naval Explosive Ordnance Disposal Technology Division and aims to develop a team of low cost robotic mine hunters that will provide rapid and complete coverage of a mine field. It is being developed by IS robotics. The first phase aims to develop a principal swarm robot structure. The robot features advanced computational and mechanical components, yet are designed for low-cost duplication. The second phase aims to enable these robots to cooperatively clear a field of landmines under the supervision of a single operator.

Fetch I aims to detect, retrieve, and safely deposit munitions in the real world. The main component associated with Fetch I was the autonomous navigational system augmented by a supervisory control station. At a later stage, behavior based intelligence in each Fetch II enables it to navigate through real world terrain using a relative coordinate positioning system and task-specific sensors mounted on its mobility platform. No real minefield test has been reported. Teams of Fetch II robots (See Fig. 18) can be considered to verify an area of interest is free of mines.

Fig. 18. FETCH II demining robot

9.3.6 Finder

The Robotics Institute at Carnegie Mellon University is interested in building a fleet of inexpensive robots so that the cost of losing one robot is minimal. To demonstrate this ability they developed a demining robot called Finder (See Fig.19). Finder carries 16 ultrasonic sensors for obstacle detection and avoidance and a positioning device for coverage. Ultrasound was chosen over infrared for collision detection, as Finder must operate outside, where the sun saturates all infrared sensors. The obstacle sensors, motors, and localization are driven by a set of embedded computers on board Finder. A Pentium single-board computer (SBC) running a custom Linux provides high-level control of the robot, communicating via standard RS-232 serial lines with two Motorola 68HC16 slave micro controllers. One micro controller drives the sonar and buffers the distance-to-object values returned by the sonar board; the other handles low-level motor control and servoing (using feedback from the positioning system to follow a specific trajectory). A second Pentium SBC is used by the visual localization system. For mine detection, Finder will be equipped with a standard metal detector, but this seems to be a naive choice for the most safety-critical sensor on the robot. It is clear that the mechanism of Finder is limited to work in an almost flat terrain with no impact of vegetation and other environmental constraints.

Fig. 19. Finder demining robot

9.3.7 PEMEX-BE (PErsonal Mine EXplorer)
(EPFL/Switzerland)

Pemex is a low cost solution for carrying a mine sensor and exploring automatically an area. Pemex is a two-wheeled robot built uses mountain bicycle wheels and aims to investigate cross-country navigation and to evaluate sensors for the detection of AP mines (See Fig. 20). It is a lightweight vehicle (less than 16 kg) and exerts a maximum force of 6 kg on the ground that is not supposed to trigger any of AP mines it detects. The wheels are driven by 90W DC motors from Maxon with 1:72 reductors aiming to give to the robot a maximum speed of 6 km/h power it. When searching for mines the Pemex head oscillates right and left in a zigzag movement covering a 1-meter wide path (Nicoud & Habib, 1995; Nicoud, 1996). The on-board 68331 microprocessor permits autonomous or teleoperated navigation. Polaroid and Sharp PSD ultrasonic sonar sensors detect obstacles. The mine sensor head currently contains as a metal detector. It is intended to be integrated a combination of a metal detector (MD) and a ground-penetrating radar (GPR) that have been evaluated in real minefield. The ERA radar was selected in early 1996, and different metal detectors brands

from (Schiebel-Austria, Foerster-Germany and Ebinger-Germany) were used and tested (Nicoud at el., 1998). Pemex has rechargeable batteries that can provide 60 minutes of autonomy.

Mined terrain is often overgrown with dense vegetation. Pemex-BE's mountain bike wheels allow it to move in high grass. With climbing cleats mounted on its wheels, Pemex-BE can climb irregular slopes of 20° to 30°. It can also climb stairs. The wheels go first when climbing to prevent the sensor package leaving the ground. Pemex is equipped with optional water wings that enable it to float and swim. This allows it to operate in environments such as rice paddies and, on land, reduces the pressure on the ground when searching for very sensitive pressure-triggered mines. For transport, the wheels can be removed and attached to the sides of the main chassis. All components can be packed and easily carried by one person.
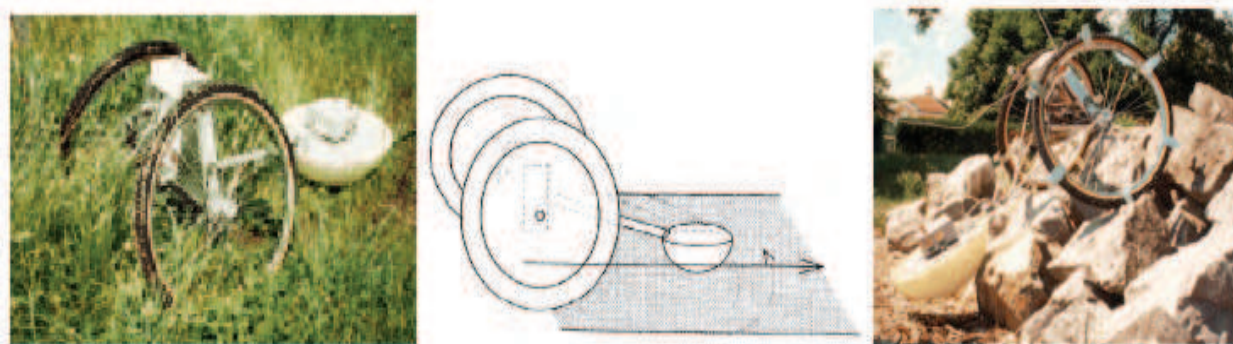
Fig. 20. PEMEX-BE (PErsonal Mine EXplorer)

9.3.8 Shrimp Robot (EPFL/Switzerland)

As part of the field and space robotics activities at the Autonomous Systems Lab (ASL) of EPFL-Switzerland, an innovative robot structure has been developed. The first prototype is called the "Shrimp Robot". Shrimp is a high mobility 6-wheels mobile platform. One wheel is front-mounted on an articulated fork, one wheel in rear directly connected to the body and two wheels are mounted on each of two lateral bogies. The total weight of this first prototype is 3.1 kg including 600 g of batteries and a 1.75 W DC motor powers each wheel. The dimensions are L 60 cm x W 35 cm x H 23 cm; the ground clearance is 15 cm. Shrimp as a new mobile platform shows excellent off-road abilities overcoming rocks even with a single bogie. Shrimp adapts its structure purely passively during motion to insure its stability. This allows very simple control strategy as well as low power consumption. The secret of its high mobility lies in the parallel architecture of the front fork and of the bogies ((Estier et al., 2000a; Estier et al., 2000b). With its passive structure, Shrimp does not need to actively sense obstacles for climbing them. Instead, it simply moves forward and lets its mechanical structure adapt to the terrain profile. With a frontal inclination of 40 degrees, Shrimp is able to passively overcome steps of twice its wheel diameter, to climb stairs or to move in very rough terrain. Shrimp has not been used yet in demining operation, but it can be considered an attractive candidate because of its well-adapted locomotion concept and the excellent climbing and steering capabilities that allow high ground clearance while it has very good stability on different types of rough terrain. In May 2001, the developer announced version 3 of the robot, Shrimp III (See Fig.21). This version is powered by 6 motors integrated inside the wheels and steered by two servos. This robot is able to turn on

the spot. It is built in anodized Aluminum and it is equipped with modular electronics.
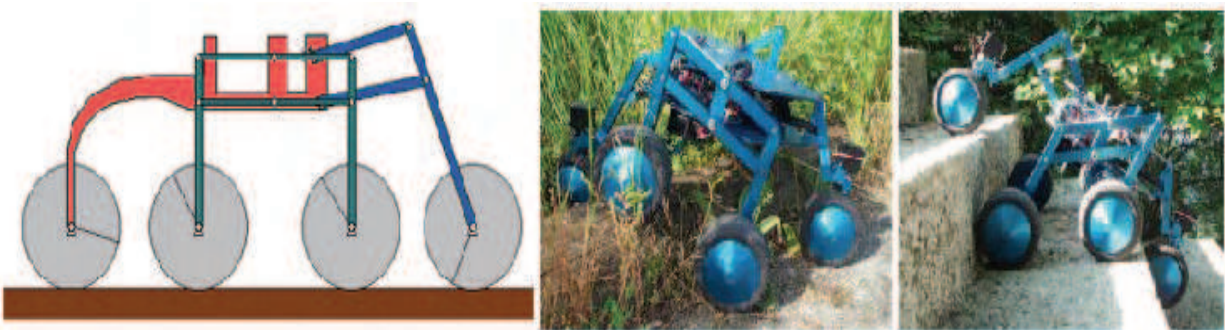

Fig. 21. Shrimp III Robot

9.3.9 Automatic Mechanical Means of Manual Land Mine Detection

The aim is to design an automated, single or multiple-prodding device that can be mounted installed in front of a remotely controlled all terrain vehicles. In this regards, at the suggestion of the Defense Research Establishment Suffield (DRES), the 1996 senior design project the University of Alberta was to design innovative mechanical method to detect non-metallic landmines (Fyfe, 1996). The developed design tries to emulate and multiply the performance of manual prodding done by human operator. The design consists of an automated and hydraulically actuated multiple-prodding device designed to be mounted either in front of a BISON armored personnel or in front of a remotely controlled all terrain vehicle called ARGO. The detection unit consists of a frame, traversing rack and multiple probes. Each of the 41 or 8 probes (depending on the design) used to penetrate the ground, is individually mounted on a hydraulic cylinder (See Fig. 22). The hydraulic fluid pressure in each cylinder is continuously monitored by a computer data acquisition system. When the probe strikes the soil or a solid object, the pressure in the cylinder rises in proportion to the force on the probe. Once this pressure rises above a threshold value, a solid object is determined to be present. A solenoid valve controlled by the computer releases the pressure in the cylinder, thus stopping the probe from further motion. This valve is quick enough to stop the cylinder in order to prevent the accidental detonation of the suspected mine. Based on the probe separation distance, this system ensures that no landmine is going to be missed by passing between the probes.
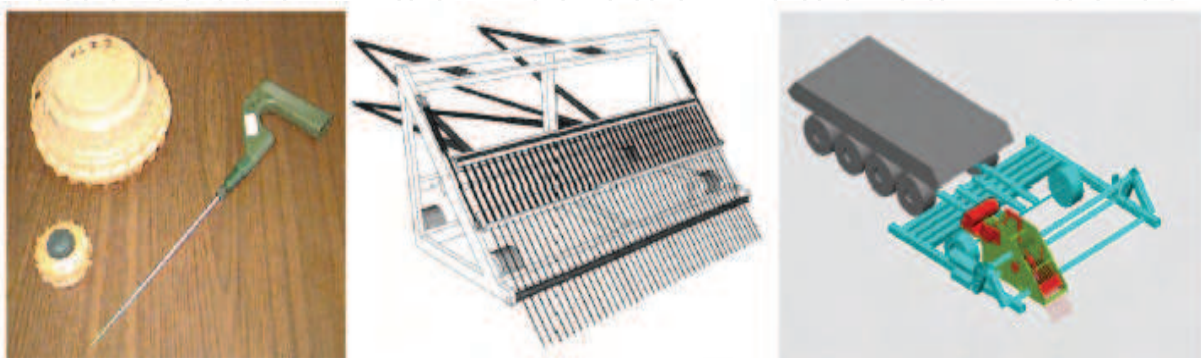

Fig. 22. Design of multiple mechanical means of manual prodding

A similar approach has been developed (Dawson-Howe & Williams, 1997). They have assembled a lab prototype, as shown in Fig. 23, intended to demonstrate the feasibility of automatic probing using on an XY table for the motion (to be fixed on a mobile platform at a later stage), together with a linear actuator, a force sensor and a sharpened steel rod. Probing test was done on an area of 50cm x 50cm and the probing was done at an angle of 30 degrees.
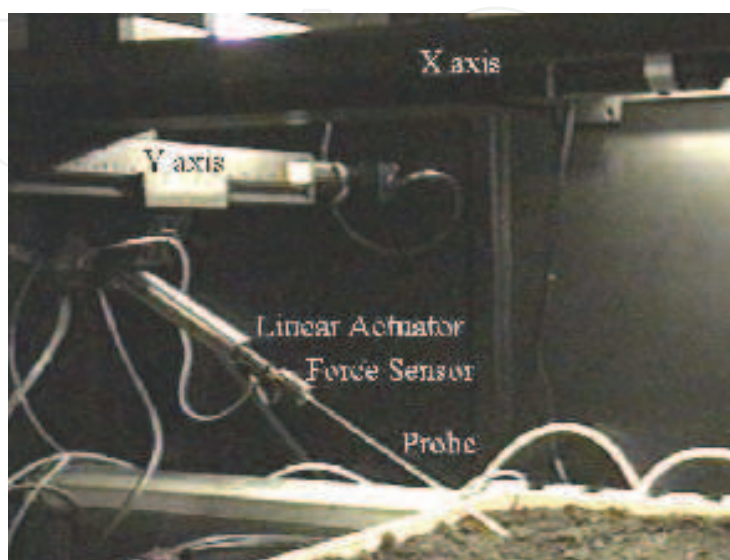

Fig. 23. Laboratory prototype of a single mechanical means of manual prodding

9.3.10 AMRU and Tridem (I and II) (Belgium HUDEM)

The Belgian joint research program for HUmanitarian DEMining (HUDEM) aims to enhance mine detection by a multi-sensor approach, speed up the minefield perimeter determination and map the minefields by robotic platform. Several mobile scanning systems have been developed, such as the AMRU (Autonomy of Mobile Robots in Unstructured environments) series 1-4, have been modified from previously developed walking mobile robots by Belgium Royal Military.

One of the main purposes of developing such robots was to achieve low-cost machines. In order to meet this constraint, simple mechanical systems for the legs were used and high cost servomotors were replaced by pneumatic and other actuation systems. A simple but robust digital control was implemented using industrial PLCs for the early versions. AMRU-1 is a sliding robot actuated by rodless pneumatically cylinders with the capacity to have 4*90 degree indexed rotation. When the metal detector detects something, the robot stops and an alarm is reported to the operator. The robot is equipped with a detection scanner. This robot has poor adaptability to irregular terrain with limited flexibility. AMRU 2 is a six-legged electro-pneumatic robot. Each leg has 3 degrees of freedom rotating around a horizontal axis allowing the transport/transfer phase, a rotation around a horizontal axis used for the radial elongation of the legs and a linear translation allowing the choice of the height of the foot. The first two dofs are obtained by use of rotating double acting pneumatic motors plus double acting cylinders. Other versions have been developed (AMRU 3 and 4) but they are still waiting for testing. The next generation AMRU 5 has 6 legs.

In order to obtain a better mobility, the Tridem robot series have been developed. This series of robots has been equipped with three independent modular drive/steer wheels. Each wheel has 2 electrical motors. A triangular frame connects the wheels. This frame supports holding the control electronics and the batteries. The robot has been design to have a 20-kg payload and a speed of 0.1 m/sec. Two versions of this robot have been developed (Tridem I and II). Figure 24 illustrates different versions of AMRU and Tridem robots.

(a) AMRU1   b) AMRU2   (c) AMRU 5

d) Tridem robot series
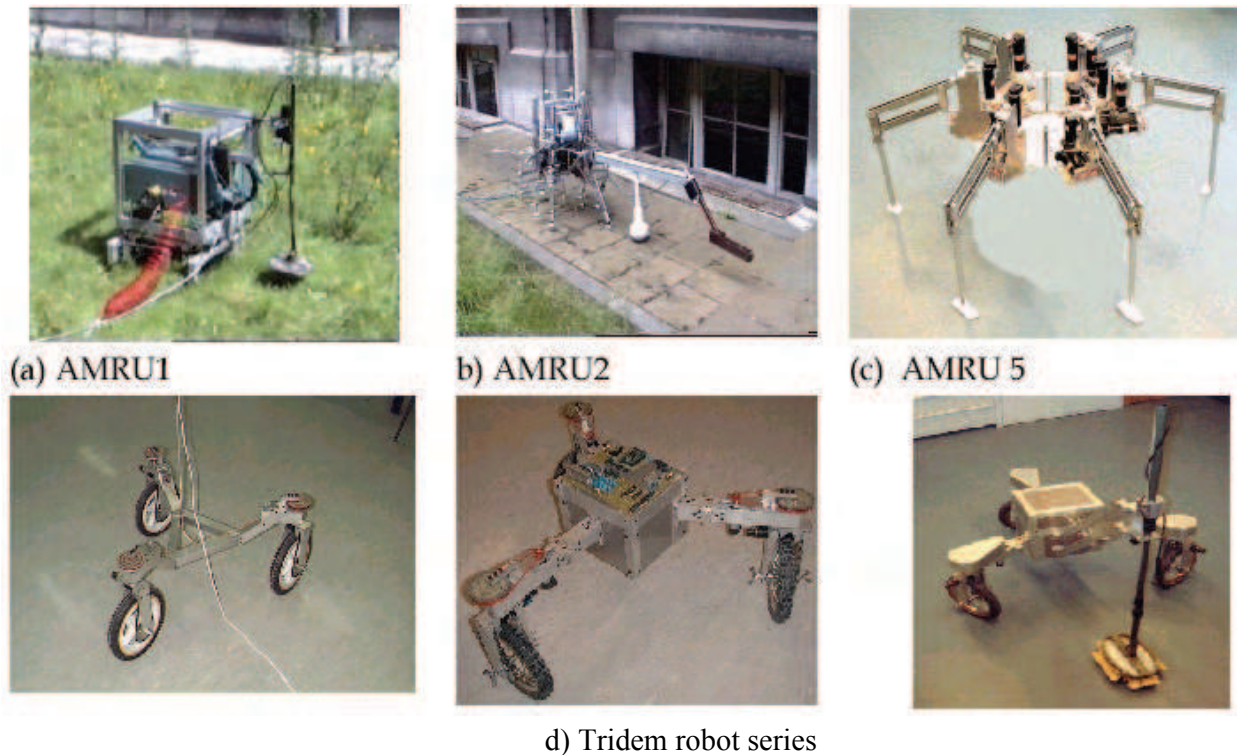
Fig. 24. Different versions of AMRU and Tridem robots

9.3.11 WHEELEG
(University of CATANIA, Italy)

Since 1998, the WHEELEG robot has been designed and built for the purpose to investigate the capabilities of a hybrid wheeled and legged locomotion structure in rough terrain (Muscato & Nunnari, 1999; Guccione & Muscato, 2003). The main idea underlying the wheeled-legged robot is the use of rear wheels to carry most of the weight and front legs to improve surface grip on climbing surface and overcome obstacles (See Fig. 25). This robot has two pneumatically actuated front legs, each one with three degrees of freedom, and two rear wheels independently actuated by using two distinct DC motors. The robot dimensions are Width=66cm, Length=111cm, and Height=40cm. The WHEELEG has six ST52E301 Fuzzy microcontrollers for the control of the pistons, two DSP HCTL1100 for the control of the wheels and a PENTIUM 200MHz microprocessor for the global trajectory control and the communications with the user. Preliminary navigation tests have been performed showing that WHEELEG cannot only walk but also run. During walking, the robot can overcome obstacles up to 20 cm high, and it can climb over irregular terrain. Possible applications that have been envisaged are humanitarian demining, exploration of unstructured environments like volcanoes etc. The robot mobility and maneuverability is

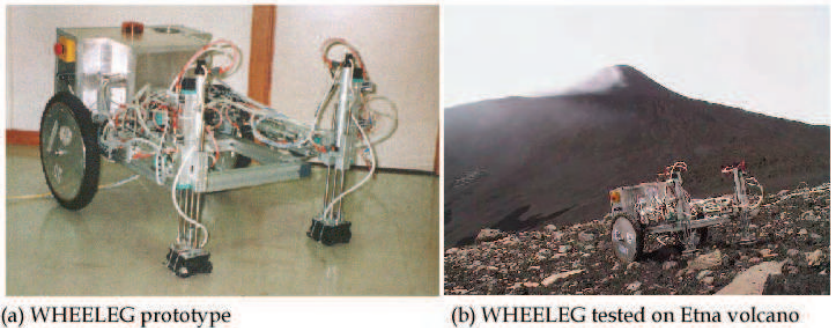limited, no demining sensors have been used, and no demining testing and evaluation has been reported.

(a) WHEELEG prototype   (b) WHEELEG tested on Etna volcano

Fig. 25. The WEELEG Robot

9.3.12 COMET I, II and III: Six legged Robot
(Chiba University in Japan)

COMET I and II have six legs and is equipped with several sensors for mine detection (Nonami, 1998). COMET III has 2 crawler and 6 legs walking/running robot with two arms in the front. It is driven by hydraulic power. The robot weight 990 kg, its length 4m, width 2.5m, and height 0.8 m. The COMET is made of composite material for legs and manipulators like CFRP to reduce the total weight. Currently, COMET-I can walk slowly at speed 20m per hour with detection mode using six metal detectors. On the other hand, COMET-II can walk at speed 300m per hour with detection mode using mixed sensors of metal detector and GPR at the tip of its right manipulator. In both cases there was no indication to the scanned area during movement. COMET robots are equipped with CCD camera, IR camera and the laser sensor. Different experiments haven been conducted to detect artificially located mines based on the use of infrared sensors that can deal with different terrain (Nonami et al., 2000). Figure 26 presents different versions of COMET. The presented technical solutions are heavy in weight, require logistical and maintenance care, high in cost, and have limited maneuverability.
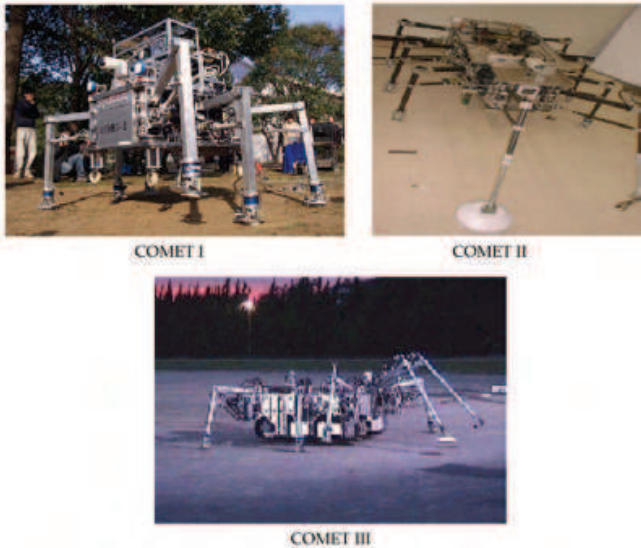

COMET I   COMET II

COMET III

Fig. 26. Different versions of the six legged mobile robot COMET

9.3.13 Buggy and Legged Robots
(TIT in Japan)

The research at TIT has been mainly focus to develop biologically inspired robots. Part research group targets are to adapt different robotics technology and mechanisms to support humanitarian demining needs. They have considered quadruped-walking robot "TITAN-IX" among the TITAN series of robots for demining mission (Arikawa & Hirose, 1996; Hirose et al, 2005]. The developers considered having adaptable robot with respect to the terrain and able to handle several tasks by utilizing the legs as a manipulator with different module attachments (see the concept in Fig.27). The dimension of TITAN-IX is L=1000 mm, W=1600 mm, and H= 550 mm. Its weight is 170 kg and powered by 36 volt lead-acid battery. The mechanism of the robot has four legs and it is possible to use the leg as the manipulator of the mobile working platform and also fold the leg to facilitate the portability of the robot. In addition, leg's joints have wide motion range. The control system of TITAN-IX consists of computer, motor drivers, and DC motors. DC motors are mounted inside base part. TITAN-IX has totally six motors for each leg, four 150 W and two 20 W. Two of 150 W motors drive a knee joint, one drives hip and the other drive turn. The two 20 W motors drive ankle and clamp mechanism cooperatively. In operation, TITAN-IX can be in one of four phases with the ability to transit between them: a) working; b) tool changing; c) walking and d) transportation configuration. In working phase, one leg works as a manipulator and the other three legs try to keep the robot stable. The tool change phase deals with tool changing (digging, sensing, grasping) and the transition between working and walking. In the walking phase, each leg demonstrates its ability to adaptively move and perform various walking styles as needed. No operation, performance evaluations, and testing were presented yet in direct relation to demining.
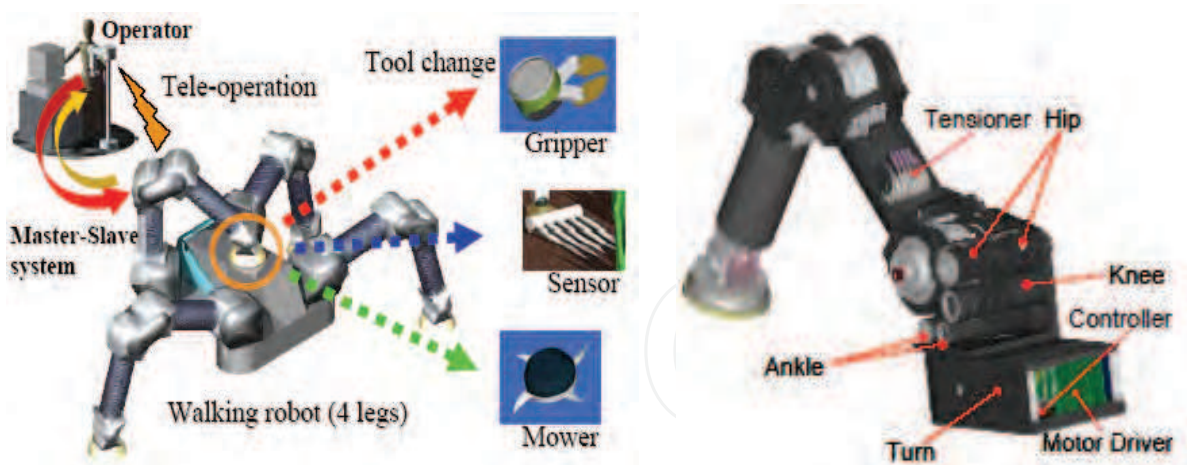

Fig. 27. The concept of TITAN-IX with implementation of the leg unit for the demining
        mission

In addition to the legged robot, the group has developed a robot system consists of a manipulator mounted on top of an automated buggy system called "Gryphon" with remote control mode (Debenest et al., 2003), and it was enhanced by the development of an energy-weight-compensated manipulator, which is composed of a 5-nodes parallel linkages. Mine detector can be attached to the manipulator arm to scan an allocated area for verification purposes. The buggy system and its arm was integrated with advanced landmine imaging

system (ALIS) (see Fig. 28), developed by Tohoku University in Japan and consists of a
metal detector and GPR for evaluation test flat terrain in Afghanistan (Dec. 2004) and then
in Cambodia (Nov. 2006).

To perform its job, the buggy system requires having a safe lane to the side of the minefield
and the manipulator should scan the terrain from the side of the buggy toward the
minefield with controlled displacements. No result on the testing evaluation in relation to
the control of the robot system has been reported yet. Currently, the group is conducting the
dynamic analysis of the robot system.

Fig. 28. Buggy system mounted ALIS and a picture of ALIS

Fig. 29. The Minehand unit

A shielded Minehand unit was developed for demining equipment for the possibility to
reduce the physical contact between the deminer and the mines (see Fig. 29). The Minehand
unit supports the so-called prodding work stage, or manual excavation of mines. It is a
lightweight unit that equipped with a clear shield to protect against blasts. With a range of
about 1.6 meters, the Minehand lets operators to interact with the ground and the buried
objects. With this system, the operator has a limited visibility and flexibility in feeling and
interacting with respect to the buried object and this affects the performance level of the
operator and raise safety concern.

9.3.14 Mine Hunter Vehicle (MHV)
Fuji Heavy Industries (FHI)

FHI has developed a crawler type MHV as a portable sensor platform under the sponsorship of Japan Science and Technology Agency's (JST) with aim to support humanitarian demining activities. The vehicle was originally designed to carry two working arms. The first arm is a SCARA type arm to be equipped with interchangeable sensors for detecting buried landmines. The other arm is a six degree of freedom articulated robot that can be equipped with tools to support prodding and uncovering landmines (see Fig. 30).

The development of MHV aims to negotiate tight turns and rough terrain, and safely access to minefields to provide fine underground images through the mine detectors integrated with it. The water and dust-proof sensor system are considered to enable the vehicle to withstand the difficult conditions associated with minefields. The vehicle can be remotely-controlled as a step for possible safety enhancement. Metal-collection electromagnets and air blowers can also be attached to the vehicle's robot arm.

There are two interchangeable varieties of the GPR systems that can be attached to the SCARA robot arm and the selection depends on the operational conditions. The first module is the soil-type adaptation sensor (see Fig. 31(right)). This sensor has a wide bandwidth from 10MHz to 4GHz and SAR technology that can clear up radar clutter in mixed soil. The second module is the high-speed sensor module that is small and lightweight radar (see Fig. 31(left)). The two sensors modules can show underground images in two and three dimensions. The 3D imaging mode allows for mine depth and attitude to be easily determined, while the 2D mode provides more detailed images.

The MHV requires having safe path to the side of the minefield and its scanning area is limited by the reach of the SCARA robot. The vehicle was tested but not in a real minefield and no evaluation results for the robot performance and justification is available. In addition, critical points are directly associated with the required logistics, system and maintenance cost, and operational speed.
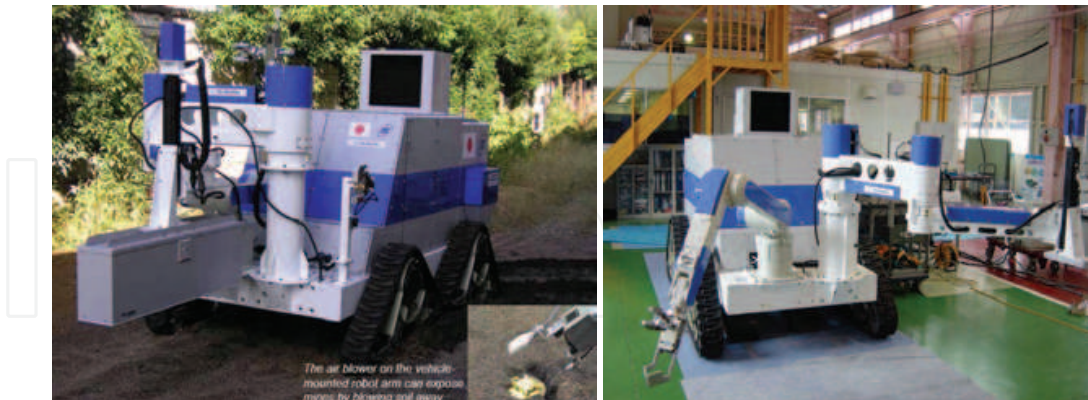

Fig. 30. Mine Hunter Vehicle (MHV)

Fig. 31. Two interchangeable Radar sensor modules

9.3.15 Ares – A Wheeled Robot
IntRoSys

Ares robot has been developed with consideration to have a portable remote monitoring toolkit with possible fleet of robots featured by good mobility, ground adaptability, and reduced in size (Cruz et al., 2005). The design of the robot was developed with aim to have low cost, light, four-wheel steering mobile robot with a biologically inspired locomotion control. The robot is integrated with sensor package that enables navigation within cluttered minefields while achieving helping to achieve its assigned task. To maximize the traction and adaptability in difficult environments, this robot is equipped with four mountain bike wheels, rotating independent axles, and a short wheelbase (see Fig. 32(left)). A compass and upper sonar set sensors have been supported by pendulum system located in the middle of the robot. The sonars are intended for obstacle detection. The Ares robot has a differential steering system to assure better mobility. The robot is capable of executing different locomotion modes, such as a car-like locomotion (Ackerman mode), rotate around its geometrical centre (Turning at a point mode), aligning the wheel to produce linear trajectories (Omnidirection mode), and wheels aligned perpendicular to the main axis of the robot allowing sideway movement (lateral mode).

The first prototype of this robot was aiming to prove the design concept and it has been built using steel frame and weight about 20 kg. The robot was integrated with low cost metal detector and odor sensor. No specific sensors preferences have been assigned to support scanning minefield for mine detection. With the second prototype the developers tackle the slippage problem associated with the first version by having new mechanism (see Fig. 32(right)) that enables the robot to emulate differential, Ackerman and omnidirectional steering. Hence, it would be possible to steer the robot in different direction. Both front and rear axes can freely and independently rotate around a longitudinal spinal axis (Santana et al, 206). By being passive, the robot is capable of being compliant with respect to an uneven terrain. The robot can estimate its posture, tilt, pitch, and yaw using Honeywell HMR 3000 sensor. Speed/position motor control is performed by four RoboteQ AX3500 boards (one per wheel), which among other advantages, accommodates a possible change to more powerful motors. The computational unit is a Diamond Systems Hercules EBX running Linux, and the robot is connected to a wireless network through a conventional wireless access point. The developers are currently investigating the selection of lighter materials in building new version of the robot. The work is still in the progress and neither navigation test nor mine detection test have been reported yet.

Fig. 32. Ares Robot

9.3.16 PEACE: An Excavation-Type Demining Robot

Mori's research group has developed a conceptual design for an excavation-type demining robot *PEACE* dedicated for farmland mine clearance (Mori et al., 2003, Mori et al., 2005). They have considered the clearance of farmland due to its direct effect on people normal life. The conceptual design of the robot is shown in Fig. 33, and it uses crawlers for the locomotion mechanism because of their high ground-adaptability. The robot has a large bucket on its front. A mine crusher is inside the bucket, and a metal separator is in its body.
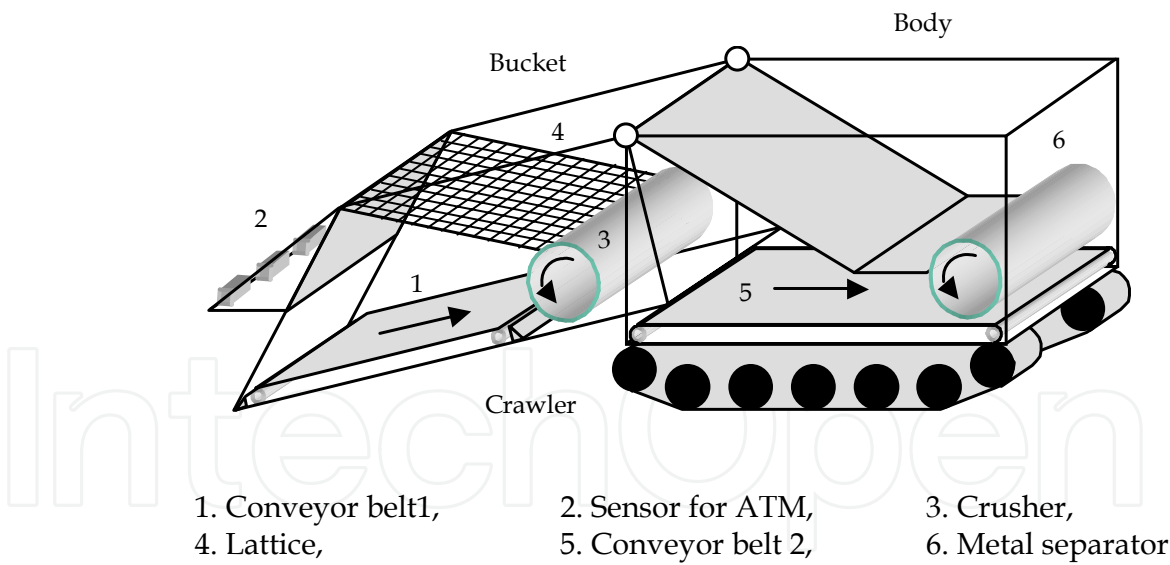

1. Conveyor belt1,   2. Sensor for ATM,   3. Crusher,
4. Lattice,   5. Conveyor belt 2,   6. Metal separator

Fig. 33. Conceptual design of the robot

10.3.17 The cable suspended searching platform

For searching dangerous terrain and relatively large operation space the conceptual study and analysis of the cable suspended robotic platform was designed (Havlik & Licko 1998). The suggested system consists of three cable winches fixed on mobile columns (See Fig. 34). The ends of cables from particular winches are connected on the platform moving above the

working place. Each winch mechanism is equipped by the cable length measuring sensor and the position/velocity control system. The ends of the cables are fixed to the moving platform. Thus, for such a parallel mechanical structure any actual position of the moving platform determine three distances, i.e. measured lengths of cables between the platform and end pulleys of winch mechanisms. The central control system performs transformations and coordinated motion control of the platform with respect to a world reference frame defined on place. The system to be equipped with ultrasonic sensors that enable operators to control its motion within a given distance over dangerous terrain as well as to avoid any obstacles when performing searching motions. The platform carries sensors and tools for detecting and neutralizing mines. When performing scanning motions, it is possible to create a map of detected and marked mines.
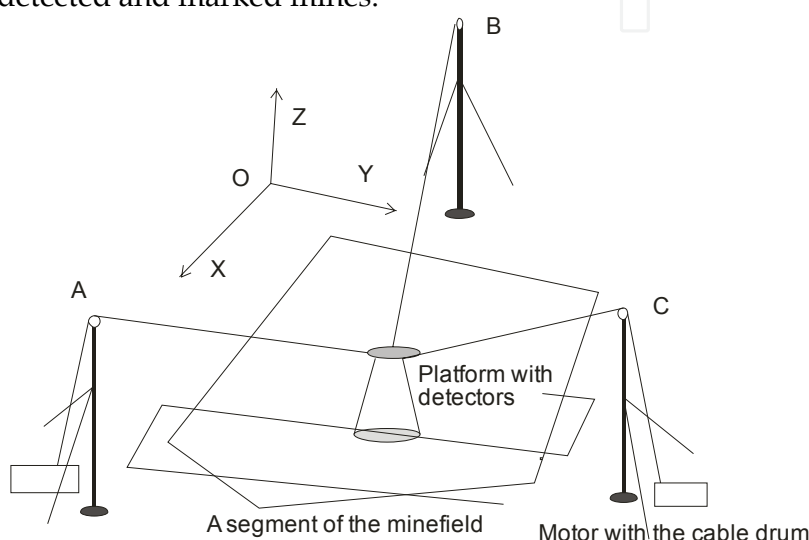

Fig. 34. Cable suspended platform concept of searching dangerous terrain

The presented concept of scanning dangerous terrain has the advantage to cover large operational workspace of that is reconfigurable according to actual terrain conditions, low weight and easy to install and transport, and operation and control can be achieved with Cartesian coordinates. It is obvious that the operation space is given by the triangle created by the fixation positions of the end pulleys. It is approximately above the ground projection of this fixation triangle.

10. Unmanned Aerial vehicles (UAV)

Technology is improving remarkably, and today's air-borne and space-borne technologies that can fly autonomously or be piloted remotely are indispensable with strategic importance for various applications and can be used in different environments where human intervention considered difficult or constrained. UAVs are generally divided into three categories: micro UAVs (very small size and very light payload), tactical UAVS and, strategic "high endurance" UAVs. The latter are further sub-divided into medium altitude long endurance (MALE) and high altitude long endurance (HALE) UAVs. There are also hybrid categories of UAVs with both defensive and offensive capabilities designed for

electronic warfare and/or air-to-surface or air-to-air attacks. The UAVs can provide intelligence, disaster response, minefield and surface ordnance survey, surveillance, target acquisition, communication-rely, environmental monitoring, border patrol and reconnaissance for wide range of applications. In case of humanitarian demining, these technologies aim to improve locating and detecting minefield and also greatly enhance wide-area survey and assessment. These technologies can provide a rapid and precise, low risk and cost effective means for surveying a region and producing the large-scale and up-to-date maps which are needed for detailed planning. Advances in sensor technology promise to substantially speed up the process of minefield mapping and survey. The following sensors have been considered for detection of scatterable or pattern minefields from airborne platforms: active and passive thermal infrared imaging and passive hyper-spectral imaging in the visible waveband using a compact airborne spectrographic imager (CASI). Computer based signal processing of airborne gathered data with advance techniques of sensors fusion can lead to the production of important maps as an aid to area reduction as well as clearance planning. These maps also facilitate the process of marking suspected mined areas, and are useful for such requirements as planning access routes and detecting important features hidden from the view of an observer outside the suspect area (Shim et al, 1998; Acheroy, 2005; Santana & Barata, 2005). Currently, commercial solutions are expensive and hence more affordable solutions should be developed for a sustainable humanitarian demining approach. Gaining the capability of designing an Unmanned Rotor Aerial Vehicle (URAV) will be even easier and cheaper due to the availability of know-how in designing manned rotorcraft field. An autonomous and unmanned helicopter is a very attractive solution as a helicopter can operate in different flight modes, such as, vertical take-ff/landing, longitudinal/lateral flight, pirouette, and bank to turn. Due to their versatility in maneuverability, helicopters are capable to fly long period of time. These characteristics make helicopters invaluable for terrain surveying, surveillance, and clean-up of hazardous waste sites. Figure 35 show some of the commercially available URAV (top of the figure) developed by Schieble, and also it shows (bottom) the Airships for mined area detection and reduction under EU-HUDEM project.

The demining community is looking forward to methods and technologies that can reduce the suspected areas as this will save efforts, time, and cost. Due to the fact that the available high aerial photography can not detect AP mines, Space and airborne Mined Area Reduction Tools (SMART) project has been adopted with aims to provide deminers with methodology, user-friendly, cost-effective, safe, and efficient tools that help task interpretation for the monitoring of environment, terrain, and minefields in countries afflicted by landmines (SMART Consortium, 2004; Acheroy, 2005). Information collected using airborne multispectral scanners and airborne full polarimetric SAR, together with context information are integrated through a GIS, and then combined and classified in order to find out any indicators about the presence of mines. In addition, it provides image analysis to help interpreting mine suspected sconces for the purpose of area reduction. Multisensor data fusion technique facilitated by intelligent computational techniques has been developed and applied to enhance tasks interpretation.

Camcopter 5.1   Camcopter S-100   Remote control unit

Airships

Fig. 35. Unmanned aerial vehicles for mined area detection

11. Conclusions

The major technical challenge facing the detection of individual mine lies on having the ability to discriminate landmines from metal debris, natural clutters, and other objects without the need for vegetation cutting. Future efforts to improve detection should focus on providing discrimination capabilities that includes the fusion of information coming from multi heterogeneous and/or homogenous sensors, and the incorporation of advanced signal processing techniques to support real-time processing and decision making. For the purpose of mine clearance, there is an urgent need to have cost-effective and efficient clearance techniques and technologies to clear landmines in different types of terrain and under different climate variations. This should be associated with neutralization of mines, in which there is a need to develop safe, reliable, and effective methods to eliminate the threat of individual mines without moving them while minimizing environmental and ecological effects.

Working in a minefield is not an easy task for a robot. Hostile environmental conditions and strict requirements dictated by demining procedures make development of demining robot a challenge. Demining robots and intelligent mechanisms offer a challenging opportunity for applying original concepts of robotic design and control schemes, and in parallel to this there is urgent need to develop new mine detection techniques and approaches for sensor integration, data fusion, and information processing.

Difficulties can be recognized in achieving a robot or other mechanical solutions with specifications that can fulfill the stated requirements for humanitarian demining. A lot of demining tasks cannot yet be carried out by the available robots because of their poor locomotive mechanism and mobility in different type of terrains. This is because there is still lack of well-adopted locomotion concepts for both outdoor and off-road locomotion. Hence,

there is a need to develop modular, light-weight, and low-cost mobile platforms with flexible mechanisms that can deal with different types of terrain and climate. Modularized robotic and teleoperated machine solutions properly sized and adaptable to local minefield conditions is the best way to enable reconfiguration that suite the local needs, greatly improve safety of personnel as well as improving efficiency. In order to be able to design and build successful robot or mechanized solution, it is necessary to carefully study conditions and constraints of the demining operations relevant to the targeted area and the type of the ordnance. The technologies to be developed should take into account the facts that many of the demining operators will have had minimal formal education and that the countries where the equipment are to be used will have poor technological infrastructure for servicing and maintenance, spare parts storage, operation and deployment/logistics.

Research into individual, mine-seeking robots is still in the early stages. In their current status, they don't represent an effective solution for mine clearance. This is due to the gap between scientists developing the robots and the deminers in the field, and because none of the developed robots (specifically these presented in section 10.3) yet entered a minefield for real and continuous mine detection and removal operations. Several large research efforts have failed so far to develop an effective mine clearance alternative to the existing manual technique. Robots have been tried at great expense, but without success yet. There is still a large amount of skepticisms on the role and use of autonomous robots for demining purposes. In general, experts in robotics know little about the practical challenge of demining: hence the robot is designed like all other autonomous robots attempting to navigate an unknown environment. Although some aspects of navigation may be extended to demining robots, it will be more reliable if robots were designed specifically for the purpose of landmine detection than as an after thought. High cost and high tech features are additional constraints in using robots for using it for demining in poor and low infrastructures countries. Understanding the current and previous failed research efforts may help to avoid similar mistakes. Detecting and removing AP mines seems to be a perfect challenge for robots. But, this requires having a good understanding of the problem and a careful analysis must filter the goals in order to avoid deception and increase the possibility of achieving results. In addition, the development of new flexible and intelligent mechanisms, such as small and modular snake like, and small scale lightweight (flapping and fixed wings) flying robots supported by the progress of new technologies in the filed of smart materials and new actuations technologies are promising directions to facilitate the progress of humanitarian demining. However, this depends on the type, weight and reliability of sensors that will be integrated with such flexible and intelligent mechanisms.

The approach to solve the humanitarian demining problem and fulfill its needs requires a strategy for research and development with both short and long-term components. In the short and mid terms, robots can help to accelerate searching and marking mines. In addition, it can be helpful to be used for quality assurance stage for verification purposes. Teleoperated and modular demining machines is feasible and may be a good intermediate step toward full autonomy. Any single breakthrough in technology should be viewed as yet another tool available for use in the demining process, and it may not be appropriate under all conditions. Furthermore, careful study of the limitations of any tool with regard to the location and environment is critical; not all high-tech solutions may be workable everywhere. The knowledge required to operate a machine may not match the skill level of the deminers, many of whom are drawn from the local public. In addition, cost of

maintenance, spare parts and its availability are critical parameters too. While current technology may be slightly effective, it is far too limited to fully address the huge mine problem facing the world. Finally, today's companies are not ready financially of doing long term research and development for humanitarian demining, simply because it does not turn a fast profit and as such there should be a recognized contributions from the developed countries and international organizations to support humanitarian demining efforts.

References

Acheroy, M. (2005). Spaceborne and Airborne Mined Area Reduction Tools. Workshop on Inventory and analysis of operationally validated results related to mine action space and airborne surveys, Zagreb, Croatia, Scientific Council of CROMAC.

Arikawa, K. & Hirose, S. (1996). Development of Quadruped Walking Robot TITAN-VIII," *Proceedings of the IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS'96)*, 1996, pp.208-214.

Baumgardner, M. F. (2000). Soil databases. In Handbook of Soil Science, M.E. Sumner, Ed., Boca Raton, FL, CRC Press, 2000, pp. 1-40.

Blagden, P. M. (1993). Summary of UN Demining. *Proceedings of the International Symposium on Anti-Personnel Mines*, Montreux, April 1993, CICR/ICRC, pp 117-123.

Bruschini, C.; Bruyn, K. De; Sahli, H. & Cornelis, J. (1999). EUDEM: The EU in Humanitarian DEMining. *EU report*, Brussels, 1999.

Burke, S. (2003). The U.S. Department of Defense Humanitarian Demining Research and Development Program. *Journal of Mine Action*, Vol. 7, No. 1, April 2003.

Busuladzic, D. and Trevelyan, J. (1999). An Ergonomic Aspect of Humanitarian Demining. http://www.mech.uwa.edu.au/~jamest/demining/tech/dino/ergonomics.html

Cain, B. & Meidinger, T. (1996). The Improved Landmine Detection System. *EUREL*, 1996, pp. 188-192.

Cruz, H.; Lisboa, J.; Pedro Santana, P.; ARui Maltez, R.; Barata, J. & Luís Flores, L. (2005). Two Sustainable and Compliant Robots for Humanitarian Demining. In *Proceedings of the IARP International Workshop on Robotics and Mechanical Assistance in Humanitarian Demining (HUDEM2005)*, June 2005, Tokyo, Japan, pp. 64 – 69.

Danielson, G. & P. Blachford, P. (2003). DIANA 44T Test and Evaluation – August 2003. Ref.: 13 345:60629, *Swedish Armed Forces, Swedish EOD and Demining Centre*, 2003.

Danielsson, G. & G. Coley, G. (2004). Minecat 140 Test and Evaluation – Sept. 2003. Ref.: 13 345:60099, *Swedish Armed Forces, Swedish EOD and Demining Centre*, 2004.

Dawson-Howe, K. M. & Williams, T. G. (1997). Automating the probing process. *Proceedings of the International Workshop on Sustainable Humanitarian Demining* (SusDem'97), Zagreb, Croatia, Oct.1997, pp. 4.24-4.29.

Debenest, P.; Fukuhima, E. F. & Hiroso, S. (2003). Proposal for Automation of Humanitarian Demining with Buggy Robots. *Proceedings of the IEEE/RSJ International Conference on*

Intelligent Robots and Systems (IROS'03), 2003, pp. 329-334.

Department of Defense, Humanitarian Demining Research and Development (R&D) Program (2002). Other Completed Mine/Vegetation Clearance Equipment. *Development Technologies Catalog 2001-2002*.

Eisenhauer, D. J., Norman, C. O., Kochanski, F. K., and Foley, J. W. (1999). Enhanced Teleoperated Ordnance Disposal System (ETODS) for Humanitarian Demining. *Proceedings of the 8th International Meeting of the American Nuclear Society (ANS)*, Pittsburgh, PA, April 1999.

E. S. Inc. MR-2 Demining and Hazardous Materials Handling Robot. Available online at (2005-03-23): *http://www.esit.com/mobile-robots/mr2.html*.

Espirit HPCN, (1997). Industrial R&D Requirements for Humanitarian Demining. (Available through <*http://www.cordis.lu/espirit/ src/report43.html/*).

Estier, T.; Piguet, R.; Eichhorn, R. & Siegwart, R. (2000a). Shrimp, a Rover Architecture for Long Range Martian Mission. *Proceedings of the Sixth ESA Workshop on Advanced Space Technologies for Robotics and Automation (ASTRA'2000)*, Netherlands, Dec. 5-7.

Estier, T.; Crausaz, Y.; Merminod, B.; Lauria, M.; Piguet, R. & Siegwart, R. (2000b). An Innovative Space Rover with Extended Climbing Abilities. *Proceedings of Space and Robotics 2000,* Albuquerque, USA, February 27-March 2, 2000, pp. 333-339.

Faust A.A.; R.H. Chesney; Y. Das; J.E. McFee & K.L. Russell (2005). Canadian tele-operated landmine detection systems Part I: The improved landmine detection project. *International Journal of Systems Science*, Vol. 36, No. 9, July 2005, pp. 511-528.

Fyfe, K. R. (1996). A Mechanical Means of Land Mine Detection. *University of Alberta, Department of Mechanical Engineering*, 1996, Canada.

http://www.mece.ualberta.ca/staff/fyfe/landmine.html

Gage, D. W. (1995). Many-robot MCM Search Systems. *Proceedings of the Autonomous Vehicles in Mine Countermeasures Symposium,* Monterey, CA, April 1995, pp.9.56–9.64.

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

Geneva International Centre for Humanitarian Demining (GICHD), (2005). A Study of Manual Mine Clearance (Books 1-5). *Geneva International Centre for Humanitarian Demining*, Geneva, Switzerland.

Geneva International Centre for Humanitarian Demining (GICHD), (2006a). Mechanical Demining Equipment Catalogue. *Geneva International Centre for Humanitarian Demining*, Geneva, Switzerland.

Geneva International Centre for Humanitarian Demining (GICHD), (2006b). Guidebook on Detection Technologies and Systems for Humanitarian Demining. *Geneva International Centre for Humanitarian Demining*, Geneva, Switzerland.

Goose, S. (2004). Overview of Antipersonnel Mine Stockpile Destruction. *ICBL Treaty Working Group*, June 2004.

Guccione, S. & Muscato, G. (2003). Control Strategies Computing Architectures and Experimental Results of the Hybrid Robot Wheeleg. *IEEE Robotics and Automation Magazine*, (IEEE Piscataway, U.S.A.), Vol.10, N.4, December 2003, pp. 33-43.

Habib, M. K. (1998). Multi Robotics System for Land Mine Clearance. *Proceedings of the International Conference on Robotics and Computer Vision (ICRACV'98)*, Singapore, Dec. 1998.

Habib, M. K. (2001a). Mine Detection and Sensing Technologies: New Development Potentials in the Context of Humanitarian Demining. *Proceedings of the IEEE International Conference of Industrial Electronics, Control and Instrumentation (IECON'2001)*, USA, 2001, pp. 1612-1621.

Habib, M. K. (2001b). Machine Assisted Humanitarian Demining Mechanization and Robotization", *Proceedings of the International Field and Service Robots'2001*, Finland, pp. 153-160.

Habib, M. K. (2002a). Mechanical Mine Clearance Technologies and Humanitarian Demining: Applicability and Effectiveness. *Proceedings of the 5th International Symposium on Technology and Mine Problem*, California, USA, April 2002.

Habib, M. K. (2002b). Mine Clearance Techniques and Technologies for Effective Humanitarian Demining. *International Journal of Mine Action*, Vol.6, No.1, 2002.

Habib, M. K. (2007a). Humanitarian Demining: Reality and the Challenge of Technology - The State of the Arts. *International Journal of Advance Robotic Systems*, Vol. 4. No.2, June 2007, pp. 151-172.

Habib, M. K. (2007b). Controlled Biological and Biomimetic Systems for Landmine Detection. *Journal of Biosensors and Bioelectronics*, Elsevier Publisher, 2007. In press doi:10.1016/j.bios.2007.05.005.

Havlik, S. & Licko, P. (1998). Humanitarian demining : The challenge for robotic research, *The Journal of Humanitarian Demining*, Issue 2.2, USA, May 1998

Havlík, Š. (2005). A modular concept of robotic vehicle for demining operations. *Autonomous Robots,* Vol. 18, 2005, pp. 253-262.

Healy, A. & W., Webber, W. (1993). Sensors for the Detection of Land-based Munitions. *Naval Postgraduate School*, Monterey, California, N PS-M E-95-003, September 1993.

Hendrickx, M.H.; Van Dam, R. L.; Borchers, B.; Curtis, J. O.; Lensen H. A. & R.S. Harmon, R. S. (2003). Worldwide Distribution of Soil Dielectric and Thermal Properties. *In Proceedings of SPIE Conference, Detection and Remediation Technologies for Mines and Minelike Targets VIII*, Vol. Orlando, FL, 2003, pp. 1158–1168.

Hewish, M. & Ness, L. (1995). Mine-detection Technologies. *International Defense Review*, October 1995, pp. 40-46.

Hirose, S; Takita, K.; Kato, K.; Torri, A., Ogata, M. & Sugamuna, S. (2005). Quadruped Walking Robot Centered Demining System - Development of TITAN-IX and its Operation. *Proceedings of the 2005 IEEE International Conference on Robotics and Automation (ICRA'2005)*, Barcelona, Spain, April 2005, pp.1284-1290

Humanitarian Mine Action Equipment Catalogue (1999), German Federal Foreign Office.

Institute for Defense Analyses (2005). Proof of Performance Test Report on Mine Clearing/Survivable Vehicle. Alexandria-USA, March 2005.

International Committee of Red Cross (1993). Antipersonnel Mines: An Overview. Geneva, September 1996. (See also: http://www.icrc.org/).

International Committee of Red Cross (1996). Antipersonnel Mines- Friends or Foe? ICRC Publication, Ref. 0654, Geneva, 1996.

International Committee of Red Cross (1998). The Silence Menace: Landmines in Bosnia and Herzegovina. ICRC Publication, Ref. 2160, Geneva, 1998.

International Test and Evaluation Program for Humanitarian Demining (ITEP), (2006). *ITEP Work Plan 2000-2005*. Portfolio of the ITEP Participant's finalized test and evaluation activities, March 2006.

Kentree Ltd, Kilbrittain, Co Cork, Ireland

King, C. (1997). Mine Clearance in the Real World. *Proceedings of the International Workshop on Sustainable Humanitarian Demining,* Zagreb (SusDem'97), pp. S2.1-8.

Lawrence, W. (2002). Pookie Rides Again. *Journal of Mine Action*, Issue 6, No. 2, August 2002.

Leach, C. (2004). Bozena 4 Mini Mine Clearance System Assessment Phase 1: QinetiQ/FST/LDS/CR044502/1.0. Farnborough, 2004.

Leach, C.; Blatchford, P.; Coley, G. & Mah, J. (2005). TEMPEST V system with Ground Engaging Flail Cambodia Trials Report. *Farnborough: NETIQ/FST/LDS/TRD052379*, 2005. p. 3

McFee, J. E. (1996). Multisensor Mine Detector for Peacekeeping: Improved Landmine Detector Concept. SPIE Technical Conference 2765, March 1996.

Mori, Y.; Takayama, K. & Nakamura, T. (2003). Conceptual Design of an Excavation-type Demining Robot. *Proceedings of the 11th Internastional Conference on Advanced Robotics*, pp. 532-537.

Mori, Y.; Takayama, K.; Adachi, T.; Omote, S. & Nakamura, T. (2005). Feasibility Study on an Excavation-Type Demining Robot. *Autonomous Robots, Vol.* 18, pp. 263-274.

Muscato, G. & Nunnari, G. (1999). Leg or Wheels? WHEELEG a Hybrid Solution. *Proceedings of the International conference on climbing and Walking Robots (CLAWAR'99)*, Portsmouth, U.K., 14-15 September 1999.

Nicoud, J.-D. & Habib, M. K. (1995). PEmex-B Autonomous Demining Robots: Perception and Navigation Strategies. *Proceedings of the IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS'95)*, Pittsburgh, August 1995, pp. 419-424.

Nicoud, J.-D. (1996). A Demining Technology Project. *Proceedings of the International Conference on Detection of Abandoned Land Mines (MD'96)*, Edinburgh UK, October, 1996, pp.37-41..

Nicoud, J-D. &. Machler, Ph. (1996). Robots for Anti-Personnel Mine Search. *Control Engineering Practice*, Vol. 4, No. 4, pp. 493-498.

Nicoud, J.-D.; Guerne, F. & Brooks, J. (1998). Report on the DeTec-2 Testing in Cambodia Nov. 18-21, 1997. *The Journal of Humanitarian demining*, Vol.2, No.2, 1998.

Nonami, K. (1998). Robotics for Humanitarian Demining. *Proceedings of the 9th International Conference on Advanced Robotics* (ICAR'98), Tokyo, 1998, pp. 591-594.

Nonami, K.; Huang, Q.J.; Komizo, D.; Shimoi, N. & Uchida, H. (2000). Humanitarian Mine Detection Six-Legged Walking Robot. *Proceedings of the 3rd International Conference on Climbing and Walking Robots*, Madrid, Spain, 2000, pp. 861-868.

OAO-Robotics, OAO Robotics. Remote Operated Mine Detector website *http://www.manitgroup.com/oao.htm*

O'Malley, T. J. (1993). Seek and Destroy - Clearing Mined Land. *Armada International*, Vol. 17, No. 1, February-March 1993, pp. 6-15.

Perez, M. L. (1996). A Low-Cost Multi-Terrain Autonomous Vehicle for Hostile Environments. *UCRLFJC-124S0, Technical Information Department, Lawrence Livermore National Laboratory,* University of California, Livermore, California 94551, December 1996.

Physicians for Human Rights (1993). Landmines, A Deadly Legacy. *Human Rights Watch*, New-York, 510p, ISBN 1-56432-1 134.

Republic of Croatia, Croatian Mine Action Centre (CROMAC) (2202). Testing of MV-4 Mine Clearing Machine, *Sisak*, May 2002.

Rosengard U.; Dolan T.; Miklush D. & Samiei M. (2001). Humanitarian Demining: Nuclear Techniques May Help the Search for Landmines. *IAEA Bulletin*, Vol. 43, No. 2, 2001. pp. 16-19.

Salter, S. H. & Gibson, CNG. (1999). Map-Driven Platforms for Moving Sensors in Mine Fields. *Mine Action Information centre Journal*, Vol.3, No.2, Summer 1999.

Santana, P. F. & Barata, J. (2005). Unmanned Helicopters Applied to Humanitarian Demining. In *Proceedings of the 10th IEEE International Conference on Emerging Technologies and Factory Automation (ETFA 2005)*. pp.729 - 738 (vol. I), Catania, Italy, September 2005.

Santana, P.F.; Cândido, C. & Correia, L.(2006c). A Biologically Inspired motion controller for Four-Wheel Steering-Robots. *Technical Report*, IntRoSys, November, 2006

Shim H.; Koo, T. J.; Hoffmann, F. & Sastry, S. (1998). A Comprehensive Study of Control Design for an Autonomous Helicopter, *In Proceedings of IEEE Conference on Decision and Control*, Florida, December 1998.

Sieber, A. (1995). Localisation and Identification of Anti-personnel Mines. Joint Research Centre, *European Commission*, *EUR 16329N*, 1995.

SMART consortium (2004). SMART - final report.

Tojo, Y.; Debenest, P.; Fukushima, E. F. & Shigeo Hirose, S. (2004). Robotic System for Humanitarian Demining - Development of Weight-Compensated Pantograph Manipulator. *Proceedings of the IEEE International Conference on Robotics and Aumrnatlon (ICRA'2004)*. New Orleans, LA, 2004, pp. 2025-2030.

Treveylan, J. (1997). Robots and Landmines. *Industrial Robots*, Vol. 24, No. 2, pp. 114-125.

US Department of Defense, (1999). Humanitarian Demining Development Technologies.

Catalogue, USA, 1998.

US Department of State (1994). Hidden Killers: The Global Landmine Crisis. *Report to Congress*, Washington D. C., Publication 10225, December 1994 (See also: http://www.state.gov/

Van Westen, C. J. (1993). Remote Sensing and Geographic Information Systems for Geological Hazard Mitigation. *ITC-Journal*, No. 4, 1993, pp. 393-399.

Wetzel, J. P.; Schultz, G. M.; Midura, M. G. & Taylor, J.-M. (2006).Modular Robotic Control System for Landmine Detection. In Proceedings of the 6th Annual Intelligent Vehicle Systems Symposium & Exhibition, Michigan, June 2006.

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:

Maki K. Habib (2008). Humanitarian Demining: the Problem, Difficulties, Priorities, Demining Technology and the Challenge for Robotics, Humanitarian Demining, Maki K. Habib (Ed.), ISBN: 978-3-902613-11-0, InTech, Available from:
http://www.intechopen.com/books/humanitarian_demining/humanitarian_demining__the_problem__difficulties__priorities__demining_technology_and_the_challenge_

INTECH

open science | open minds

www.intechopen.com

Fax: +385 (51) 686 166

Fax: +86-21-62489821

www.intechopen.com