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

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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

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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.

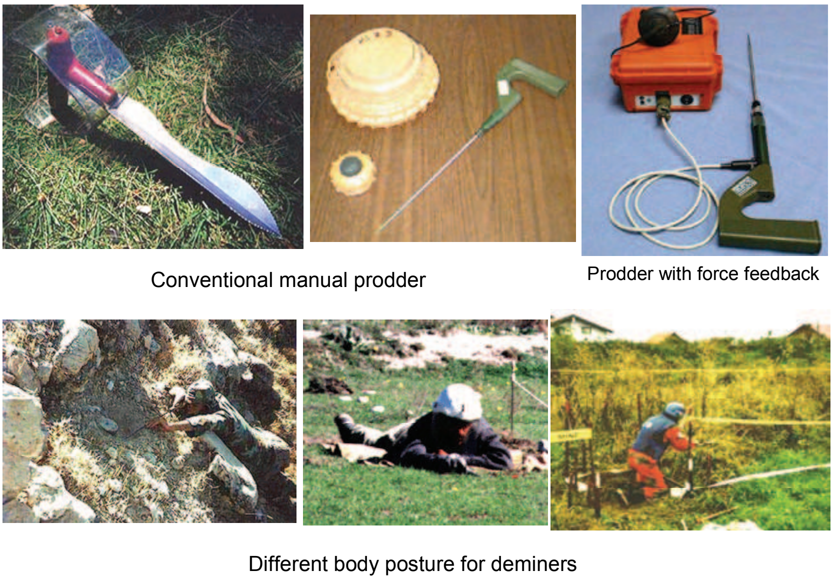

Fig. 1. Examples of different manual prodders and different body postures for deminers

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.

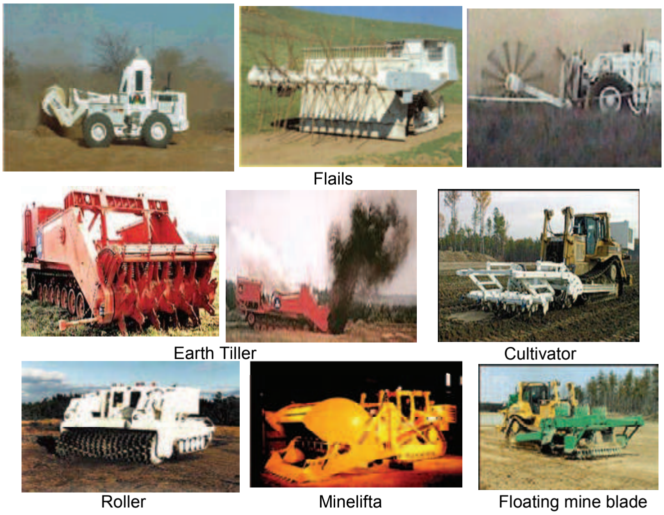

Fig. 2. Examples of demining mechanical machines

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