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Focus on Machine Assisted Demining

Humanitarian Demining and Robotics

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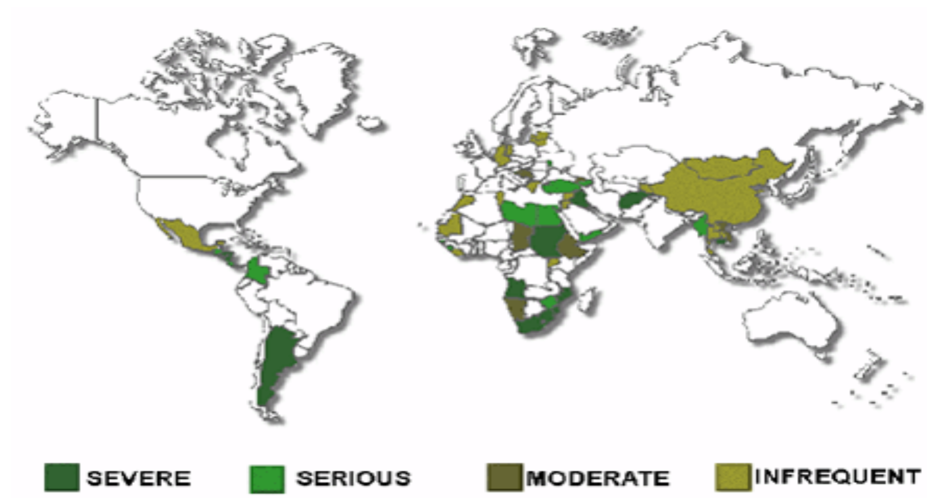
History of Mine Use

Mines were used for the first time during the American Civil War in the United States (1861-1865). Antitank mines were later ameliorated and laid on the battlefields of the First World War. Mine clearing operations did not pose major problems with those visible and easy-to-detect Atk-mines. The reason why Anti-personnel mines have been conceived and systematically used on the Atk minefields during the Second World War was because such mines prevented the enemy from easy demining of the defense system.

Today, anti-personnel mines are more often used as offensive weapons and for sowing the terror among the civilian population of a country affected by guerrilla war. The marking of the minefield does not exist and the anti-personnel mines, often buried in the ground, remain active after the war. About 60 millions AP-mines infest 70 countries all over the world, two-third of them in Africa and Southeast Asia. AP mines from the Second World War still exist in all the countries of Europe.



Anti-personnel Mines

Two definitions coexist: according to the military standards, an AP-mine is a pyrotechnic instrument developed for being activated by an involuntary action of the enemy in order to set him out-of-fighting. An AP-mine is an object placed on or under the ground or any surface. It is conceived for exploding by the presence, the proximity or the contact of a person or a vehicle. In a general way, two models of mines exist: the blasting mines and the fragmenting ones. More then 700 known types of mines have been produced in about 55 countries, varying from each other by the explosive-load, the activation mean, the action-range, and the effects they have on the human body.

Identification	Type	Load	Activation	Range
PMN	Blasting	100/150 g	5-20 kg	local
Home-made Pelota Chimica	Blasting	Variable	Variable	local
POMZ-2	Fragmenting	300 g	Wire	50/200 m
V69	Fragmenting	700 g	Wire	50/200 m

Fig 2 Some examples of AP-mines

Two values also draw our attention on the difficulty of the mine detection and the longevity of a mine: the diameter is often less than 10 cm, the life often exceeds 75 years…all for a price varying from 2.5 to 25 euros.

Estimation of Economical and Human Impacts

Since 1975, mines have killed more than one million people, essentially civilian people and children. This averages out to about 70 victims per day or 26,000 victims per year, and about 300,000 severely disabled children. The people effected by this plague are the most likely to be severely handicapped by the medical, social and economical consequences. The International Committee of the Red Cross (ICRC) estimates that 2/3 of the surviving victims must get into debt for life, their life expectancy is reduced to 40 to 50 years; and they will need about 20 prosthesis's at about 120 euros each. Crutches are often the only tools they can afford. This occurs in countries where the individual mean income varies from 10 to 25 euros per month.

The removal of a mine costs between 250 and 750 euros, depending on the accessibility to the minefield, the professional qualification of the deminer and the type of mines. Assessment of the mean daily productivity of a deminer is 20 to 50m^2, taking into account the false alarms generated by metallic inert objects or by the high iron content of the soil. Starting from a pessimistic estimation of the infested surface, one can evaluate the demining cost at 100 billion (milliard) euros. The actual budget devoted to the mine-clearing operations only allows the removal of 100,000 mines per year while more than one million new AP-mines are unloaded onto the countries affected by civilian wars during the same period. The Médecins sans frontières (MSF), a NGO (non-governmental organization) recently estimated the mine-clearing time of the infested Afghan territory at 4,000 years. Even if the actual statistics seem to be overestimated (40 % according to my observations), it becomes urgent to develop performance, detection, identification and removal techniques, and obviously to condemn and forbid the production and the use of such despicable weapons. In the most infested countries (see appendix I), 20 to 30 % of the economically exploitable surface is unusable. Added to the surface, which doesn't provide any economical interest, one easily understands that their effects on the local economy and the consequences on the worldwide scale are far from negligible.

Demining Problems

Mine clearing operations are very dangerous. For every 5000 cleared mines there is one deminer killed. In order to clear some 60,000,000 mines we could count some 12,000 deminers killed! This fact also explains why only a few experts from developed countries are working on the minefields. Everyone has to be covered by an annual mean insurance premium of 12,500 euros. As a consequence, the manual mine-clearing operations are entrusted to local civilian people whose inexperience and despondency as well as the fear of injuring themselves, slows up the progression of the demining work. Experienced deminers often limit their (important) role to the learning and training of local teams. In some countries however, outstanding demining structures have been developed and entrusted to local managers, as in Cambodia where the Cambodian Mine Action Center (CMAC) coordinates the demining campaigns in a structured way, according to defined priorities.

Another problem lies in the difference existing between the military and the civilian mine clearance. The military demining operations accept low rates of Clearance Efficiency (CE). For these purposes it is often sufficient to punch a path through a minefield. For the humanitarian demining purposes, a high CE is required (**a CE of 99.6% is required by UN**). This can only be achieved through an accurate carding of the terrain, and an accurate scanning of the infested areas. This implies the use of sensitive sensors and their slow systematic displacements according to well-defined procedures or drill rules on the minefields. At present, hand-held detectors seem to be the only and most efficient tools for identifying all unexploded ammunitions and mines. But this first step doesn't solve the problem. The removal task and/or the neutralization and/or destruction task must follow: these last two tasks are time-consuming actions.

Let us conclude this introduction to the problem. The above mentioned difficulty lead to the definition of the global requirements that could accelerate the demining processes. The scientific community can help by pursuing research activities focusing on:

Priority 1	the development of reliable sensors allowing the detection of minefields and , on those minefields, the detection of the mines (or similar explosive items)
Priority 2	the development of data processing algorithms confirming the detection and leading to the identification of the parameters needed for the next actions
Priority 3	the development of fast removal techniques or neutralization

	techniques
Priority 4	**the development of low-cost mobile scanners**

Minefields-Detection and Sensorics

In order to avoid a considerable waste of time, the first essential objective lies in the delimitation of the areas polluted by mines. Local information on observed explosions, craters, injured animals, and/or on hospital casualty reports allows for local technical teams in charge of minefield marking. This marking may never be precise because the suspected area may be much larger or smaller, even if performance ground sensors are used. Therefore, the European Commission encouraging an airborne surveys with color, color infrared and thermal cameras, and other promising sensor funds research efforts. Information on first results may be found at **http://www.itc.nl/ags/projects/demining**. Those first results concern anti-tank mines lying on the ground. The semi-automatic tools developed, combining pre-filtered images with the expertise of human interpreters, have to be achieved by feeding the software with expert-knowledge and accelerating the processing of high-resolution images. Teleoperated helicopters, such as the CAMCOPTERS described in **http://www.schiebel.com/industries/camcopter.htm**, may be considered as promising roboticized solutions.

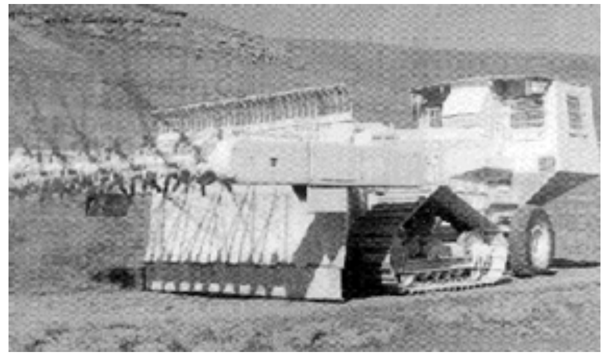
Natural biosensors and artificial biosensors, able to smell, constitute a second hope to accelerate both the detection of minefields and the individual detection of AP-mines. Trained dogs or rats possess a high TNT-sensitive nose. Two methods are actually used. The use of escorting dogs on the field (Swedish program proposed to the CMAC), and the collection of air samples taken by automatic collectors placed on board of armored vehicles. These samples are later submitted to the dog's sense of smell (a program applied with non-negligible successes in South Africa.) Let us nevertheless mention that the explosion of a mine pollutes the air and prohibits the use of biosensors for a week.

Assuming the borders of a minefield have been defined, a systematical scanning of the field must follow. In order to assure the highest probability of detection (with a 99.6 % clearance rate), the use of combined sensors seems still necessary. The most known or proposed multisensor platform under investigation combines the metal detector, the ground penetrating radar (GPR) or Ultra-Wide-Band radar (UWB) and an infrared camera. Added to the possible use of other combinations, the optimization of existing sensors and/or the development of new sensors (NQR or Nuclear Quadrupole Resonance detection of nitrogen bonding in explosives), the simultaneous use of several sensors induces a certain number of problems that have to be solved. The fusion of the different data provided by the sensors, the mutual interaction or compatibility of the sensors, the control of the positioning of the sensors above the inspected ground are all variables to be dealt with.

Mechanization and/or Robotization of Humanitarian Demining Operations

One has to make a clear difference between the mechanization of the mine-clearing operations, the robotization of the mine scanning and the automation of the demining procedures, three steps of increasing difficulty.

Mechanical Mine Clearance



The Chain Flail

The mechanization consists of the use of motorized mine-clearers, adapted military vehicles or armored vehicles of the same or similar type, with same or reduced size. They may be used on large areas (agricultural areas, for instance). The well-known 'Chain Flail ' (350.000 euros) illustrates this kind of system. About 15000 m² (300 times more than a human operator) may be cleared per day. 100 % ATK-mines are removed and destroyed, 90 % AP-mines only. Although other clearance techniques (e.g. heavy road rollers) already lead to higher efficiency (98 %), some AP-mines may be pushed on size or buried deeper or partly damaged making them more dangerous.

This solution has been applied for a long time in Afghanistan and has considerably reduced the number of victims there. We are convinced that the mechanical mine-clearance techniques are, at this stage of the research activities, the 'fastest and safest' technology for facing the prejudicial social and economical consequences of the problem.

The Robotization of the Mine Detection

The robotization consists of the use of tele-operated or autonomous mobile scanning platforms. Such robots could improve the safety of the mine-detection operations. Let us examine the specifications such vehicles could fulfill:

Requirements	**Possible solutions**
a high mechanical reliability	robust materials and electronics
a good resistance to explosions (ATK, AP)	a robust construction, a protection shield
easy to deploy	an apparent limited command system
easy to use	a simple Man Machine Interface
easy to service and repair	a modular construction
important autonomy (at least one half day)	an on board gas engine (stand alone or to produce electricity)
easily transportable by a light	a light weight

vehicle	
adapted to several kinds of terrain	legs, articulated tracks, wheels
low cost	off-the-shelf technologies, large series
water, sand, temperature and humidity resistant	corrosion resistant material, high tech electronics

Requirements of robots used for the detection:

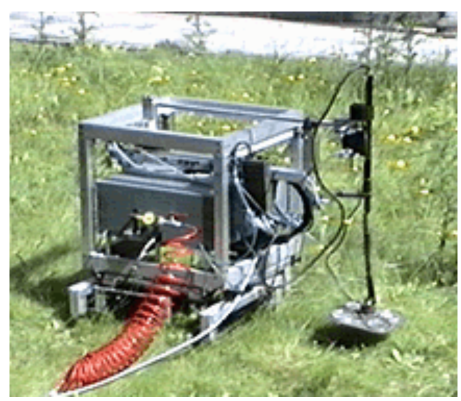
- One sees immediately some contradictions:
- the protection (armor) and the weight
- the autonomy and the weight
- the use of off-the-shelf components and their resistance to extreme conditions
- etc.

As a consequence, no unique solution can be proposed. It is not advisable to use robots if such systems don't offer a cheaper and faster solution. Furthermore, the displacement velocity of the robot on the field strongly depends on the sensor data collection rate and the risks generated by the vibrations induced in the ground.

Nevertheless, original solutions already appear on the 'market of the trials'. The Personal Mine Explorer Robot (PEMEX-BE) developed in Lausanne (Switzerland) weighs 16 kg and exerts a force of 6 kg on the ground (critical load, see fig.2), It climbs 30° slopes and stairs (destroyed urban areas), and floats on the water, propelled by paddles. This autonomous robot (one hour) controlled from Motorola 68331 processors offers other practical advantages. The structure may be mounted with pieces from bicycles; the electric actuator and the electronic control are protected by an epoxy casing and could be reused in case of explosion. The robot costs about 5000 euros.

A similar solution is developed in the CMR-lab of the ULB (http://ulb.ac.be/scmero), under the Belgian HUDEM (Humanitarian Demining) project described on the Web Site of the RMA: see par. 4

Both robots are characterized by a continuous motion, which may be interrupted if a sensor delivers a signal of a probable suspected object. The major problem lies in the control of those interrupted motions, which strongly depend on the reliability of the detectors and their interfacing with the vehicle.



AMRU-1 Sliding Robot, equipped with a 3D scanner (RMA)

The step-by-step motion of multi-legged vehicles equipped with a 3D-scanning device may suggest another strategy. The robot AMRU-4, developed at RMA – see par 4) is a sliding robot that will be tested this year on dummy minefields laid in Belgium: http://mecatron.rma.ac.be

The department of Mechano-Aerospace Engineering of Tokyo also developed a quadruped robot. The advantages of legged robots can be summarized in a few words: high adaptability on uneven and rough ground, modularity lightweight replaceable legs, omni-directional motion or orientation, and attitude and altitude control Tracked robots are commercially available and may be adapted for a frontal or lateral scanning of the minefield: see also par 4.

Fig. Tracked Hunter-Robot equipped with a metal detector

The Automation of the Demining Operations

Automation implies the **automatic** scanning of the minefield. This is the autonomous or tele-operated robot following a predefined path or procedure. It then sends the recorded data to its expert system in charge of the fusion of the data and their processing. Finally, it marks the ground if a mine is detected with a probability of predefined level.

It is excluded to simultaneously remove and/or destroy the mines. Neutralization techniques could however be envisaged during the work of the robot on the field and so achieve the whole demining action. Several techniques are experienced which could lead topracticalsolutions. The use (spray) of special foams containing the explosive nitromethane (hand-held sprayers are already proposed for 10000 euros); the injection of a chemical product (the diethyletriamine) neutralizing the TNT; the use of HighPower Microwaves could also be used.

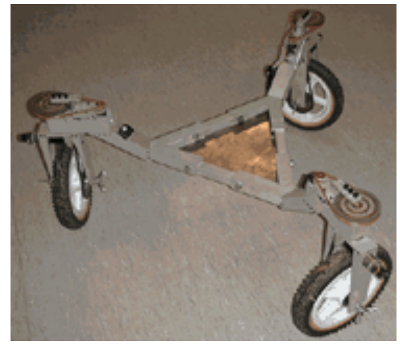
The Belgian HUDEM Robotics Activities

Experts of the United States Robotics community, focusing on possible use of their techniques in the domain of the Humanitarian Demining, recently identified and ordered technical areas requesting investment in research activities:

- The planning and the control for coordinating multiple robots.
- The design of small, cheap, reliable, modular platforms for UXO sensors
- The navigation techniques, including the localization of the sensors on the minefield
- The man-machine-interfaces including the ergonomy of lightweight portable control stations, convivial screen users interface optimal real-time sensor-motions synchronization, etc.
- The development of non-line-of-sight wireless communications.

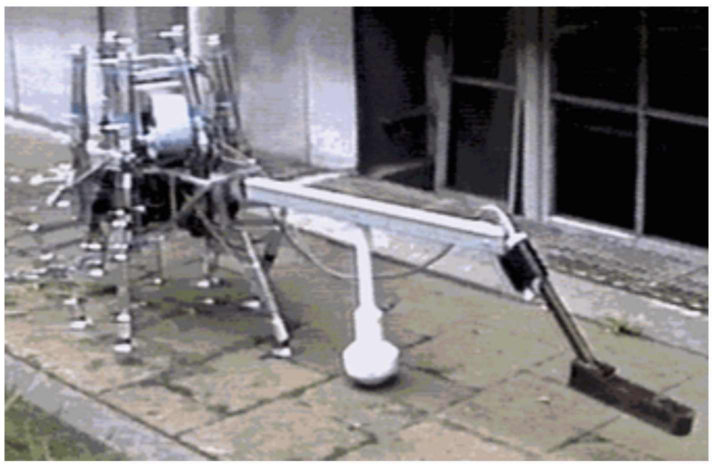
Starting from the analysis described in the previous paragraphs we developed the same conclusions in 1997. After a detailed study of the state-of-the-art technology and a visit of real minefields located in Cambodia (December 1997) we took into account the fact that only 25% of the HUDEM budget could be allocated to the Robotics aspects (see priorities defined in table 1.3). The partners of HUDEM decided to focus on ***the robotization***

of the detection tasks, and in particular, to the next objectives:



TRIDEM: prototype developed at ULB

DESIGN: the realization of prototypes, which could meet the major requirements, defined under par 3.2: laboratory-prototypes had to be realized by end 1998. A three-wheeled electrical robot (TRIDEM) and an electro-pneumatical sliding robot (AMRU-4); two existing robots had to be adapted for testing several scanning devices: a tracked robot (HUNTER) which is now equipped with a remote-controlled frontal or a lateral 3D-scanner, an electro-pneumatical hexapod equipped with a boom rolling on the ground (AMRU-2)



AMRU-2: feasibility-study on multi-legged robots at RMA and ULB

NAVIGATION: the definition and programmatic of a localization system based on the use of a color-camera fixed on the border of the minefield and tracking the motion of the robot and/or the sensor carried by the robot. First indoor-trials had to be achieved by end 1998 with a positioning precision of 5 cm at a distance of 25 m: a standard-laboratory-robot (NOMAD) and the HUNTER have successfully been used for this purpose.

Nomad Robot for tracking and navigation studies

MAN-MACHINE-INTERFACE: The design of a coherent man-machine-interface integrating the data collection from a detector equipping the HUNTER and the optimal visualization of the processed signals on the screen of a PC. This task has started with the second phase of the project 1999/2000)

PLANNING: The programming of High-Level (HL)-low-level (LL) path-generators: The ‘a-priori probabilistic’ knowledge of the minefield may generate an efficient search pattern based on several known methods (A*, potential field method, Gain-over-distance heuristics, etc.) from which a probabilistic path will be followed by the robot (HL). Along this path, the fine scanning of the ground could lead to the detection of mines considered as new unsuspected obstacles implying a correction of the followed path. Such a methodology may however not be considered as mature as long as aerial detection's of AP-mines and/or UXO will not be improved, but indoor trials with commercial laboratory-robots may prepare this promising hierarchical search-procedure. The commercial

US-NOMAD robot is used for this purpose. In the meantime, the manual standard demining procedures will be adopted for controlling the movement of the robot on the field. Starting from a free-of-mines line, lateral-scanning motions will be executed, completed by the intervention of human beings in case of detection.

Conclusions

A considerable amount of fundamental research and experiences on dummy and real minefields have to be performed before any automation can solve the problem. We consider, at this stage of the research, that robots are useful for the safety and for preliminary tests on semi-autonomous search-procedures. A considerable amount of effort must also be done at the politic level for promoting the peace. Aerial minefield detection allows for an efficient mapping of large areas of Angola, in 1998: end 1998, the civilian war flared up again, April 99 AP-mines are laid in Kosovo.

References:

http://jupiter.ulb.ac.be/mines/home.html

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