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DEMINING ROBOTS : A TOOL FOR INTERNATIONAL STABILITY

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Abstract: One of the main tasks of SWIIS is the application of systems- and control engineering methods for international conflict resolution. In the past the classical approaches from control theory, simulation, decision making…. were used. Here a new idea – application of a very well known tool from production automation "advanced robots" - will be presented. A selected field for international stability or conflict resolution is "humanitarian demining", which has grown dramatically in the last decade. These robots of the new generation offer possibilities to solve this task in a very efficient way. Finally new developments in humanitarian demining at present and in the future will be discussed and the concept of autonomous, intelligent robot swarms for cleaning minefields is presented. *Copyright © IFAC 2002*

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1. INTRODUCTION

Landmines are usually very simple devices which are readily manufactured anywhere. There are two basic types of mines:

- anti-vehicle or anti-tank (AT) mines and
- anti-personnel (AP) mines.

AT mines are comparatively large (0.8 – 4 kg explosive), usually laid in unsealed roads or potholes, and detonate when a vehicle drives over. They are typically activated by force (>100 kg), magnetic influence or remote control.

AP mines are much smaller (80-250g explosive, 7-15cm diameter) and are usually activated by force (3-20kg) or tripwires. More than 700 types with different designs and actuation mechanisms are known today. There are two main categories of AP mines. A blast mine is usually small and detonates when a person steps on it: the shoe and foot is destroyed and fragments of bone blast upwards destroying the leg. When a fragmentation mine explodes, metal fragments are propelled out at high velocity causing death or serious injuries to a radius of 30 or even 100 metres, and penetrating up to several millimetres of steel if close enough. Simple fragmentation mines are installed on knee high wooden posts and activated by tripwires (stake mines). Another common type of fragmentation mine (a bounding mine) is buried in the ground. When activated, it jumps up before exploding. Mines of one type have often been laid in combination with another type to make clearance more difficult: stake mines with tripwires may have buried blast mines placed around them.

According to current estimates, more than 100.000.000 (Trevelyan, 1997) anti-personnel and other landmines have been laid in different parts of the world. A similar number exists in stockpiles and it is estimated that about two million new ones are being laid each year. According to recent estimates, mines and other unexploded ordnance are killing between 500 and 800 people, and maiming 2.000 others per month (Red Cross, 1995), mainly innocent civilians who had little or no part in the conflicts for which the mines were laid. Anti-personnel mines are usually designed not to kill, but to inflict horrible injuries instead (McGrath, 1994). However, many victims eventually die of their injuries, and suffer a long and agonizing death, often with little medical attention.

Some countries have banned the use of landmines and others are supportive of a complete ban. However, their low cost ($3 - $30) and the large numbers in existing stockpiles make them an attractive weapon for insurgency groups which operate in may countries with internal conflicts – the most common cause of wars today. They are used for self-defence by villages and groups of people travelling in many districts where civil law and order provide little effective protection. Many countries retain massive landmine barriers on their borders or near military installations. Some of the most severe landmine problems exist in Egypt, Angola, Afghanistan, Rwanda, Bosnia, Cambodia, Laos, Kuwait, Iraq, Chechnya, Kashmir, Somalia, Sudan, Ethiopia, Mozambique and the Falkland Islands.

2. DEMINING; STATE OF THE ART.

First you have to find (detection) and then you must destroy or remove the mines. Today used methods for detection are:

- High-tech methods for mine detection:
  Radar, infrared, magnetic tools, touch sensors (piezo resistive sensor). Also GPS is used for finding the place again where a mine lies, and for the navigation of the robots.
- Dogs:
  using dogs that sniff the explosive contents of the mines, has significant limitations and cannot be regarded to as general-purpose solution.

Today used methods for destroying or removal are:

- Brutal force methods (include ploughs, rakes, heavy rolls, flails mounted on tanks)
  The problems with these methods are that:
  - ploughs only can by used to clear roads for military use. Mines are only pushed to the side of the road. Some ploughs also attempt to sieve the mines from the displaced soil.
  - Flails are mechanical devices, which repeatedly beat the ground, typically with lengths of chain. These chains are attached to a rotating drum and their impact on the ground causes the mines to explode, but this can cause severe damage to cultivable land.
  - Rollers generally consist of a number of heavy circular disc, which are rolled along the ground in order to cause the explosion of any mines.

Hand-prodding is today the most reliable method of mine removal, but it is a very slow, and extremely dangerous method of mine clearing. A person performing this type of clearing can normally only perform this task for twenty minutes before requiring a rest. This method clears one square meter of land in approximately 4 minutes (Baudoin,2000)

The tools of a deminer are:

1. A whisker wire which is gently swung or lifted gently to check for tripwires.
2. A metal detector which is swung from side to side to check for metal objects.
3. A prodder (typically a bayonet, screw driver or knife) which is used to probe the ground at an angle of about 30 degrees to the horizontal and to excavate earth from around a suspect object. Usually a prodder is used to investigate a suspect metal object. However, which dealing with minimum metal mines or large numbers of metal fragments, the entire area has to be prodded by hand.

One must not forget the essential human skills that deminers need. With experience and training, their eyes reveal vital cues such as slight depressions in the ground caused by settling after mines were buried, their ears can distinguish different sound from the metal detector, and their hands develop a feel for different buried objects.

The UN estimates the cost of removing a single mine at 300 to 1000 $. The primary factor is the local cost of labour. So in low labour-cost countries such as (Cambodia, Afghanistan, or Africa) US$ 100 per month (Nicoud, 1997) is a high rate pay for manual work, even with the obvious risks. In contrast, the labour cost for de-mining in the former Yugoslavia may be twenty times higher.

Thinking about the number of mines is rather pointless which estimates range from a few million word-wide (including national borders) to 150 million. It is much more sensible to think in terms of the areas of land which are:

a) known to be affected by mines, and are important to local or displaced population: homes, food producing land, roads, infrastructure (roads, canals, power lines, water supplies etc.)
b) believed to be affected by mines
c) known or believed to be affected by mines, but land is of no immediate importance.

The standard required for humanitarian demining is a guaranteed 99.6% clearance at minimum. So you see there is still a maximum risk of 0.4% to be injured or killed by a mine. In the future it will be necessary to reach nearly 100%.

Mechanical mine clearance means either actuating the mine, or removing it for later destruction. Mine actuators imitate the target by hitting the mine, hoping to exert force on the top of the mine at a level above the operating force. The main problem is to find a method of applying the pressure which is relatively immune to the explosive effect of the mine.

3. ROBOTS FOR DEMINING.

Several projects have proposed the use of autonomous robots to search for antipersonnel mines. The sensor problem is nearly solved now and it will take only few time until a combination of sensors will be available and sufficiently tested in order to give full confidence that all the mines have been discovered. There may be false alarms, but no mine must be left. Once the location of a mine is known, several manual techniques are easily applied to neutralize it. A robot can also be developed to do this easy job, which is simply to go to a precise spot, avoiding obstacles and other mine locations. Then it should deposit a shaped charge or some chemical to destroy the mine.

The necessary features of a demining robot are:

- Ability to distinguish mines from false alarms like soil clumps, rocks, bottles and tree roots. This we name high false rate. A high false rate is wasting time.
- Operation in a variety of soil types, moisture contents and compaction states
- Ability to detect both types or in fact variety of different mine types and sizes
- Operation in vegetated ground cover
- Operation on bumpy and/or sloping ground surfaces
- Costs should lower then 10.000 US$ including the sensors.

Today there are some appropriate, reasonable cheap sensors available or in development based on optical technologies, acoustic and seismic detection, radio frequency resonance absorption spectroscopy, trace explosion detection (Baudoin, 2000). Worldwide approximately 100 companies or research institutes offers intelligent, mobile platforms but the price is too high according to the small lot sizes in production. It’s only a question of time until this problem is solved.

Random navigation for covering the field and searching for mines has been proposed. Even with improved algorithms applied to a group of robots, it is difficult to accept ignoring a small proportion of uncovered areas. Systematic navigation is theoretically easy with a global positioning system (GPS), but the resolution must be better than the size of the detector, in order to be sure to cover all the area.

A robot has been designed as a light-weight autonomous robot to search for antipersonnel mines. The pressure force on the ground, 5kg, is not intended to trigger the mines. The sensor head oscillates under the alternating movement of the wheels, in order to scan a width of about 1.2 m. the project is suspended until an adequate sensor, weighing less than 4kg, can be installed inside the head.

Research groups experienced with walking robots try to suggest the use of their devices for this application. Snake robots are more attractive, since they should be able to crawl close to the ground inside dense vegetation. Their design is, however, quite challenging.

The advantages of robots for demining are

- Minefields are dangerous to humans; a robotic solution allows human operators to be physically removed from the hazardous area.
- Robots can be designed not to detonate mines. The advantage is that mines includes a lot of chemicals which when they detonate are put into the ground which is later used for food producing.
- The use of multiple, inexpensive robotized search elements minimises damage due to unexpected exploding mines, and allows the rest of the mission to be carried on by the remaining elements.
- Teams of robots can be connected so that one team is for searching and one for destroying or displacement.

This means that many robots are searching and a few or only one robot is destroying or displacing the mines.

But there are also disadvantages of using robots:

- it is very difficult for robots to operate in different frequently rough terrain
- they are still expensive
- you need special qualified operators

4. HUMANITARIAN DEMINING FOR INTERNATIONAL CONFLICT RESOLUTION

From the systems theoretical and engineering viewpoint SWIIS dealt until now mainly with time continuing systems well known from the field of process automation. Meanwhile in the field of production automation or in terms of systems engineering - time discrete, digital processes - new methods comes up in the last years, probably applicable to the tasks of SWIIS. One of the main ideas of SWIIS in the early eighties was to apply modern methods, developed in systems as well as control engineering for resolution and avoidance of conflicts. More or less conflicts could be seen as a classical stability problem. There are stabilising de-stabilising parameters. Humanitarian demining is definitely a parameter of the first category. After a conflict – or possibly a war – a minefield occupy land, homes, infrastructure (Kopacek, 2000). A lot of organisations worldwide use clearing of minefields and reactivate the land for the displaced local population as an integrating factor in peace discussions to offer native people (e.g. in Kosovo) the possibility to came back to their homes and their lands.

During and especially after the war there are always a lot of refugees. These refugees are usually concentrated in the neighbor country in so-called refugee camps with all advantages and disadvantages. This costs a lot of money for worldwide acting refugees relief agencies. Meanwhile the houses at the country of these refugees are open for plundering.

As pointed out demining is today a very time consuming, dangerous and expensive task. Automatised demining e.g. as presented in this paper by robots, is today and will be in the future a powerful tool to solve these problems.

5. FURTHER DEVELOPMENTS

In the future worldwide scientific research is done to use so-called "robot swarms" for demining actions. In principle there are two possibilities

a. using mobile intelligent robots equipped with devices for mine detection as well as for mine removing
b. using two swarms of robots equipped either with detection devices or removing devices.

The features of the robot for these both tasks have to be quite different. For detection a light-weight robot only able to carry little load has to be developed. For removal the robot has to be more stiff and heavy constructed because removal requires force.
Another point of view which has to be taken into account is the time necessary for both operations. Detection is usually relatively fast and is not so time consuming than removal. According to some experiences the removing time is 3 to 5 times more than the detection time.

Therefore it could be advantageous to use two different robots. Robots for detection and robots for removal for the mines. Disadvantage of this philosophy is if a robot of the swarm D (detection) has found or detected a mine it has to send a command to the host computer or to the other robots. The host computer or the other robots have to decide which of the robots of the swarm R (removal) is in the neighbourhood of this mine and not busy at that time with removal operations on another mine. If a robot of the swarm R is selected this robot gets usually wireless the position data and some other information about the place of the mine. The R robot is now moving to displace and start with the removal work. After the removal of the mine it has to pick up this and has to carry it to a collecting place.

Another approach could be a third robot swarm which we could call mine transportation swarm. We have now to decide about two possibilities. The robot has to carry only one mine to the collecting place or the robot is able to pick up more than one mine which is much more timesaving than the first approach. A disadvantage of this is the danger of the explosion of a mine during the transportation process.

Today we are in the position to develop robots of all three types mainly using commercially available mobile platforms. As pointed out earlier it is not economically feasible to develop so-called single purpose robots for each of these three types. A good approach could be a kind of a tool kit (Shivarov, 2001) of mobile robots consisting of a mobile platform and different equipments and tools compatible in the sense of hard- and software. A good approach could be to have two platforms, one with wheels or chains and one walking platform. According to the types of mines as well as the surface of the minefield these platforms could be equipped with necessary tools in a very short time.

Usually the mobile robots of both types available today are moving relatively slow. Usual speeds for wheeled and chained robots are between 0.5 and 0.7m/s, walking robots are usually much more slower. This could be a disadvantage concerning the demining time but from the viewpoint of control and path planning it is much more easier to work with such slow robots. We have in that case the usual problem of path planning of robots in a changing environment. Usually in a minefield we have fixed obstacles like trees, rocks, buildings as well as moving obstacles usually the robots of the own or other swarms. To solve the path planning problem in this dynamic environment we have in principle two possibilities.

a. The robots are only partially intelligent (brainless) and are controlled by a host computer by means of wireless communication. In that case we have for each swarm an own host computer and probably we need a supervising computer for these two or three hosts.

b. Research work is going on to replace the host computer – concentrated intelligence – by software packages implemented in the onboard computer of each robot – really intelligent robots.

Today we are in the position to use the possibility “a” but in the future we will work with robot swarms with intelligent robots.

This approach is similar to “Multi Agent Systems – MAS” (Kopacek, 2000). These systems are very well known in software engineering since more than 20 years. In the last years there are some works related to the application in production automation. A MAS consists of a number of intelligent, co-operative and communicative hardware agents e.g. robots getting a common task. Because of the intelligence they are able to divide the whole task in subtasks as long as at least one of the agent is able to fulfill one subtask.
Repeating this procedure yields to the solution of the common task. Newest research goes in the direction of MMAS – Multiple Multi Agent Systems – different MAS are involved for the solution of a complex task.

In SWIIS we have some similarities to MAS. Our actors are humans with a distinct degree of intelligence and ability to communicate and cooperate with others. A conflict could be defined as a competition between two or more MAS – in terms of system engineering a MMAS – with not co-operative single MAS. That’s definitely a difference to production automation – here we create always co-operative MAS working together and not contraproductive.

This new approach could be an additional step to improve the original idea of SWIIS.

5. SUMMARY AND OUTLOOK.

As pointed out earlier all the existing and planed robots for humanitarian demining are only able to detect the mines. Brutal force methods destroy mines without detection – but with a not reasonable probability. In a next step our robots have to be able to remove the mines from the ground.

These concepts could be also applicable for “Humanitarian Demining” with minor adoptions. Our tool kit for intelligent, mobile robots offers the possibility to develop, in a very easy and cheap way, demining robot swarms with a broad variety of features (e.g. different mine detecting sensors, different moving mechanisms, various gripping devices..........).

In a mid or long term perspective it might be possible to develop “ Humantarian Demining Multi Agent Systems – HDMAS ” consisting of a number of such robots or agents (Kopacek, 2000).

6. LITERATURE

Baudoin, Y. et.al. (2000): Humanitarian Demining: Sensory and Robotics. Proceedings of the IMEKO World Congress 2000, Vienna, **Vol. XI**, p. 241 – 251.

Kopacek, P. (1999): Preprints of the IARP Workshop on “Humanitarian Demining”, Harare, November 1999.

Kopacek, P. (2000): SWIIS – An Important Expression of IFAC’s Commitment to Social responsibility, *Preprints of the IFAC Workshop on Supplemental Ways for Improving International Stability – SWIIS 2*000, 22. – 24. May 2000, Ohrid, Macedonia

McGrath, R. (1994): *Landmines, Legacy of Conflict: A Manual for Development Workers*, Oxfam, Oxford.

Nicoud, J.D. (1997): Vehicles and Robots for humanitarian demining. Industrial Robot, 24 (1997), Nr.2, p.164 – 168.

Red Cross (1995): Landmines must be stopped. International Committee of Red Cross, Geneva, Switzerland.

Shivarov, N. (2001): A tool kit for modular, intelligent, mobile robots. PhD. Thesis, Vienna University of Technology, 2001.

Trevelyan, J. (1997): Robots and landmines. *Industrial Robot*, **24**, **Nr.2**, p.114-125.