Cost-effective robots for mine detection in thick vegetation

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ABSTRACT

The paper deals with design and modelling of four cost-effective crawling robots for landmine localization in uneasy accessible areas covered by thick vegetation. As a universal solution to the landmine problem is unlikely to be achieved in the short time, according to what many other researchers think, time is worth spent on trying to solve a specific aspect of the global problem, rather then treating the problem as a whole. Therefore, the reasons that leaded to recognize mine localization in areas covered by thick vegetation as important and urgent aspect of the global landmine problem are explained. Then, what we mean with cost-effective robots is reported, within the establishment of simple criteria to evaluate the effective impact of proposed robots on the work of demining agencies on field. Finally, four cost-effective robots are presented.

1 INTRODUCTION

Because landmines are very simple and low-cost devices, easy to be hand made, they have been used as weapons for more than 50 years in many different types of conflicts [1].

According to current estimates [2], at the moment up to 90 countries through-out the world are affected by landmines; these stay in place for many years after the conflict has ended and make the affected land inaccessible for long time.

Up to 60% of useful agricultural land in some of the affected countries is unusable. Landmines are also in other places like irrigation canals, ruined houses and bunkers that offer cover and protection, roads, confrontation lines that divided military factions as river banks, abandoned industrial sites and residential areas. Usually many strategically important sites are mined, as the main task of landmines is to deny enemy access to important resources.

Landmines have a drastic socio-economic impact on affected countries. One of the biggest problems related to their presence is that people are obliged to move from their houses leaving all what they have there, including work, medical aid facilities, and so on. So, the consequences of landmines are enormous and difficult to be calculated.

2 AREA-REDUCTION IN MINEFIELDS COVERED BY THICK VEGETATION

Usually, location of landmines is not known. Often only small zones are really mined, although big areas, identified by local demining agencies on the basis of observations such as number of casualties happened there or aerial mapping, are declared inaccessible.

Therefore, an important step towards the reduction of time needed for mine clearance is performing *area-reduction process*. It consists in finding out sub areas where landmines are not, within a suspected contaminated area. Determining where landmines are not is much easier than pinpointing the exact location of a mine, particularly if using detectors with low accuracy. Once, after checking, no mines are found in a sub area of the area considered contaminated, that sub area can be given back to the local population, without the need of further checking, and its resources can be exploited again and immediately.

By now, landmine clearance is still performed mainly by manual deminers. Where it is possible, machines or dogs are used to help manual work. Before demining can start, vegetation must be removed from the field that is going to be checked for mines. This is due to the fact that the sensors used to detect mines, such as metal detectors used by manual deminers or dog noses, have to be swept as near as possible to the ground surface. Vegetation removal can be really hard in places like Vietnam or Cambodia, where plants and bushes grow very fast because of the weather. Machines can be really useful to perform such task, but they work well only where the ground is flat and regular. Where machines cannot access the minefields, vegetation removal has to be done entirely by hand; deminers have to carefully remove the vegetation in front of them before checking for mines. This is a very slow and dangerous work. In areas where vegetation grows very fast, the time needed to remove it is as much as 75% of the total time for mine clearance [3].

Performing area-reduction process in minefields covered by thick vegetation would be very important for reducing the unacceptable post-conflict impact of landmines on civilians [4].

In fact, many times, areas suspected to be minefields reveal to contain just few mines or no mines at all; from data acquired by NPA (Norwegian People Aid), after having performed area-reduction process, typically between 90% and 97% of a total minefield can be considered free of mines, without the requirement of further checking for mines [5]. Therefore, removing vegetation from minefields, to enable access to manual deminers or dogs, can often be avoided, allowing money and time saving.

Although area-reduction process is already performed by some demining agencies, none of the association working for humanitarian demining has applied area-reduction to minefields covered by thick vegetation.

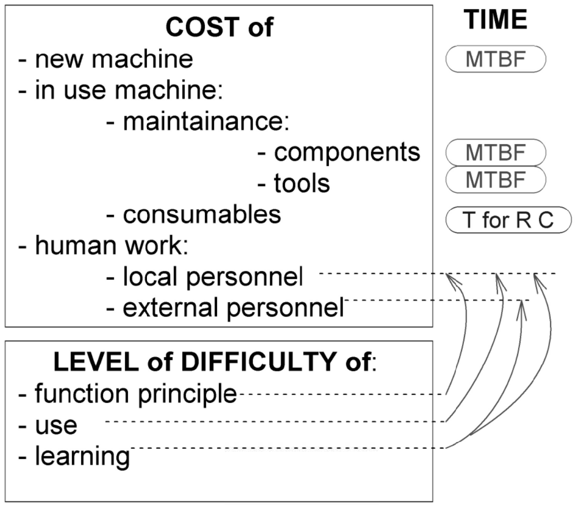

Figure 1: Cost-effectiveness parameters.

3 COST-EFFECTIVENESS

Although many researchers have put big effort on finding new technologies to help landmine clearance, demining methods are still based on manual demining. When it is possible machines and trained animals are used in combination with manual deminers: machines are used to remove vegetation to guarantee access for the metal detector to the ground, while trained animals are used as sensors; they are able to detect the TNT escaping from mine casing into the soil.

There is an urgent need of introducing new technologies in mine clearance operations, to achieve proper effectiveness, safety and reliability. While sensor improvements have been research topics in the past years and several different sensor technologies have been proposed and are still under study and tests, less effort has been concentrated in researching new effective ways to carry sensors around the minefield and sweep them over the ground. Several sensor platforms have been proposed but none of them has been adopted by any demining agency, meaning that they did not meet the real needs of end users. Usually, the machines proposed to be used in humanitarian demining have an high level of complexity, are expensive, usually with a high number of components specially designed for the machine, and are difficult to be driven and maintained. This represents an obstacle for them to be adopted by local demining agencies; in fact, machines will be bought and maintained in contaminated countries, usually poor, and driven by local personnel, usually untrained.

Important requirements, beside the functionality requirements, need to be considered in order to make proposed machinery really useful and accessible for the end-users. What do we mean with cost-effective robots is: robots whose cost is justified by their applicability on fields. Figure 1 sums up some important criteria to evaluate cost-effectiveness of a machine designed to help humanitarian demining operations. The level of difficulty influences time and time influences cost, has shown by arrows and boxes in the Figure (*T for R C* stands for *Time for Replacing Consumable*).

4 ROBOTS

The human collaborative robots (cobots) proposed here are four: Lizard 1, Lizard 2, Lizard 3 and Worm. They are crawling robots specially thought for operating area-reduction on uneven terrain covered by thick vegetation, designed to be cost-effective and to be used on field in a short time.

In such vegetation, wheeled and tracked vehicles are likely to be stuck: bushes and grass, mud, slopes are obstacles difficult to be overcome. However, legs are likely to entangle as well if they are not specially designed.

Although up to 53% of minefields are unstructured terrain in uneasy accessible areas [6], often covered by thick vegetation, most of the machines proposed to be used in humanitarian demining are designed to operate on flat, regular terrain, already cleared from vegetation. Therefore, new means of crawling inside the thick vegetation have been considered and applied to the robots presented.

The solutions proposed encompass two methods of locating landmines, both using sensors detecting traces of explosives escaping from mine casing into the soil and into the air over the landmine. One method consists in bringing the sensors to the minefield by carrying them on a suitable platform, while the other method consists in bringing air samples from the minefield to the sensors, located in a remote safe place. This second method is called REST (Remote Explosive Scent Tracing); it is currently used by two demining agencies.

Both of the methods are used to estabilish where landmines are not; actually they cannot be used to pinpoint the exact loaction of a landmine because of the migration of explosive traces troughout the soil and the air space over the minefield; wherever traces of explosives are not detected, the area is considered free of mines.

All the robots proposed are designed to be light enough in order not to trigger Anti Personnel (AP) mines.

4.1 LIZARDS

Lizard 1, Lizard 2 and Lizard 3 use the first method. They have been designed taking inspirations from the Australian blue tongue lizard, characterized by big dimensions, comparable with the ones of a machine. Lizards seemed a good reference for projecting a mobile sensor platform able to move inside thick vegetation because they are agile in this kind of environments and they walk keeping their stomach very near to the ground, and the sensors work better if they are swept very near to the ground. They are small and light-weight robots designed to move only in forward direction. They are powered by umbilical in order to avoid battery weight on board. Once they have reached the maximum distance they can cover they are retracted by pulling their umbilical.

4.1.1 Lizard 1

Lizard 1 (Fig. 2) is a small caterpillar robot suitably adapted to move on foliage and in presence of quite soft ground with stems and undergrowth. Forward movement is achieved by means of rotating belts carrying needles for penetrating foliage and soil; belts are made

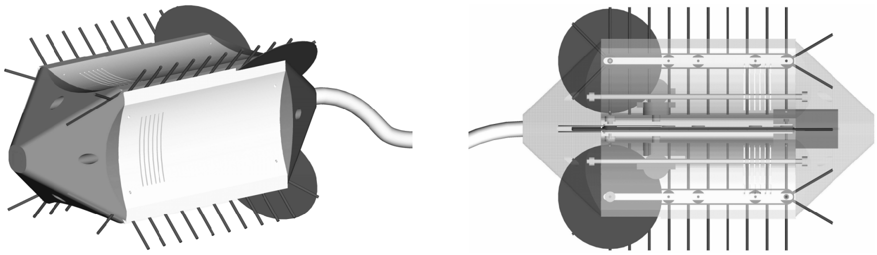

Figure 2: Lizard 1 robot, on the left, and an overview of its locomotion system, on the right.

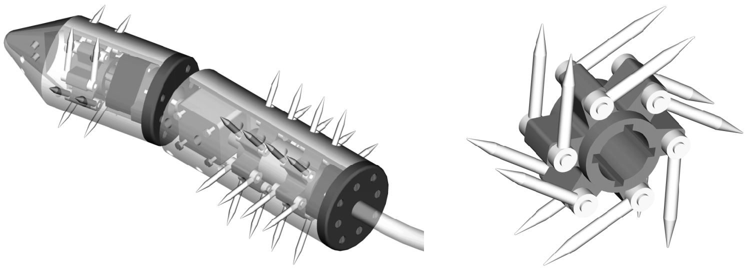

Figure 3: Lizard 2 robot. Head, on the left, and trunk, on the right. In transparency the wheels which actuate the needles, and the push-pull equipment between head and trunk.

rotating on pulleys placed inside the robot body. Both needles and belts are compliant enough in order to bend and follow the ground texture. Each caterpillar is independently actuated in order to provide some steering capability; while two of the four caterpillars directly lean on ground, the other two contribute to locomotion by gripping the stems and undergrowth overhanging the robot. Thin disks on one side of each caterpillar allow entangled foliage to detach from needles. The robot has a fully modular architecture since it is obtained by assembling four identical caterpillar modules; so it is possible to assemble robots with six or more caterpillars as well.

4.1.2 Lizard 2

Lizard 2 (Fig. 3) is a grab-inspired robot composed of two modules, a head and a trunk, connected by a spherical joint and a push-pull rod. Both head and trunk contain wheels with needles hinged to them; when a wheel rotates, the needles are driven out of the robot body by a suitable set of holes in order to grip the ground. Locomotion is achieved by peristaltic crawling in three phases (Fig. 4): first, while the needles of the head are out grasping the ground, the needles of the trunk retract; then, the robot contracts, the needles of the trunk go out and the needles of the head retract; finally, the robot extends pushing forward its head.

4.1.3 Lizard 3

Lizard 3 (Fig. 5) is a robotic platform trusted by helices, which provide both locomotion and floating. It is designed for localising landmines on sandy terrains covered by bush, where stems grow up on a quite bare soil without remarkable deposit of leaves and twigs.

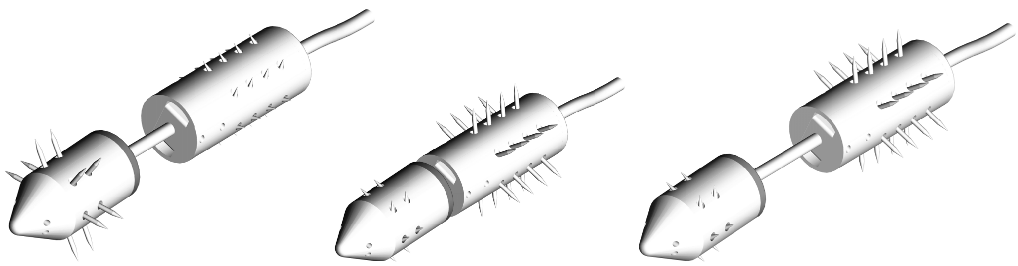

Figure 4: Lizard 2: the three locomotion phases.

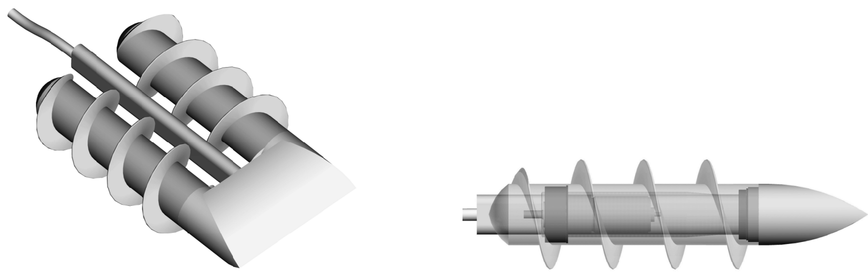

Figure 5: Lizard 3 robot.

The motors which actuate the helices are placed inside the helix bodies, while the flat head can contain sensors, provides stabilization and drives the robot over the soil.

4.2 WORM

Worm is a crawling robot able to move on uneven terrain covered by thick vegetation, designed to perform area-reduction process using REST technique. It is conceived to automate the sampling phase of REST area-reduction method, i.e. to carry special filters over the minefield. Filters are then analysed by trained dogs: when they sniff TNT in one of the filters, the sub-area sampled with that filter needs to be further checked for landmines [7].

Worm (Fig. 6) is a modular, under-actuated, hyper-redundant, re-configurable, serial mechanism. It is adapted from directional drilling machines: the body is composed by rods, or modules, connected by rotational joints with horizontal axis, leaving only one degree of freedom, which allow the machine to follow the ground surface profile (terrain adaptation is passive).

Rods are pushed one after the other over ground through vegetation, by a pushing machine at the minefield border. Each rod presents at one end a built in joint, already assembled together with a bayonet coupling, and at the other end the place to insert the coupling, as shown in Fig. 6.

Every time a rod is inserted into the pushing machine it is connected through the rotational joint to the previous one; every time it is pushed behind the others the head rod crawls along a straight line over the ground and the Worm extends. Worm is under-actuated having just the joint connecting the head rod to the following one, actuated: the pushing machine provides trust while the head provides steering.

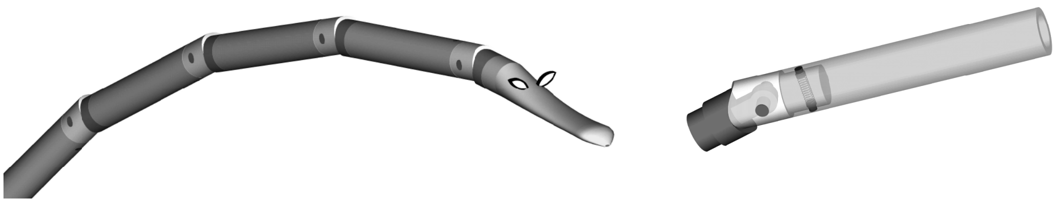

Figure 6: Worm robot, on the left, and a detail of the worm module, with joint and fastening, on the right.

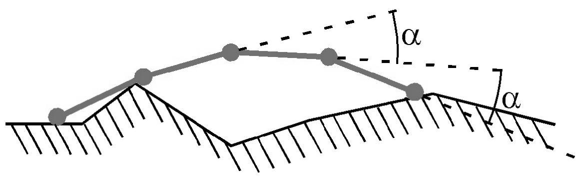

Figure 7: Worm robot body forming hump.

Filters are inserted inside rods; they are activated by a simple mechanism, which allows air to enter them or not. Sampling process can be done while the rods are pulled back, once the number of rods introduced over the minefield has reached the maximum. The filters are activated as soon as the rods start to be pulled and deactivated when the last rod introduced is totally retracted. In this way, each filter samples the same path length and the entire path is sampled when the first filter is pulled back.

Joint mobility is limited in order to make Worm going forward on uneven terrain simply by pushing it. This method of locomotion is very simple and practical to be used inside thick vegetation but Worm behaviour is quite difficult to be predicted and controlled.

A model was developed in order to test Worm behaviour in different situations, on different types of ground and vegetation. The main problem found from analysis performed on the model arose on quite irregular surfaces, where, sometimes, Worm body formed an arc, as shown in Fig. 7.

Assuming the hypothesis of static equilibrium and the hypothesis of having the first joint of the arc and the last joint of the arc at the same height, a simplified model was studied and the general equation governing this phenomenon (hump) was obtained. Worm can be assumed to be in static equilibrium, because its speed is very low and its motion can be considered as a sequence of static states. If Worm is always in static equilibrium, the sum of the forces acting on it is zero at every time.

As it can be seen, the problem of finding the general equation governing this phenomenon is made easier by the fact that the Worm modules involved in the arc are sides of a regular polygon, having the same length and the same angle with respect to the previous side. The angle between one module and the previous is equal to the maximum joint mobility angle, a. The general form of the inequality that has to be satisfied in order not to have arc, obtained from the simplified model, is here reported:

$$F_s{}'L\sum_{k=1}^{n} sin\Big(\frac{\alpha}{2}+(n-k)\alpha\Big) < pL\left(\sum_{k=1}^{n}\left(\frac{1}{2}\cos\Big(\frac{\alpha}{2}+(n-k)\alpha\Big)+\sum_{j=1}^{k-1}\cos\Big(\frac{\alpha}{2}+(n-j)\alpha\Big)\right)\right) \quad (1)$$

The equation states a relation between several design variables of the model: • number of rods involved in the arc, $2n$; • weight of each rod, p, as all the modules are made by steel, p is function of rod length, L; • joint maximum mobility angle, α; • pushing force, F_s, through $F_s{}'$, which can be calculated from F_s.

5 CONCLUSIONS

The paper argues the importance of cost effectiveness as main requirement for a robotic device thought to help humanitarian demining operations. Four robots especially designed for operating area-reduction on terrains covered by thick vegetation are presented. Area-reduction process sensibly lowers the application of destroying, time-expensive techniques like vegetation removal on large areas where mines are suspected to be. The cost-effectiveness of these robots enhance the opportunity that the growing countries have to access to this technology.

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