Multiple single-sensor robots rather than multi-sensor platforms: a reasonable alternative?

Riccardo Cassinis

ARL - Advanced Robotics Laboratory

Department of Electronics for Automation, University of Brescia, Italy.

E-mail: riccardo.cassinis@unibs.it

Abstract. This paper describes an ongoing research work being carried on at Brescia University Advanced Robotics Laboratory (ARL). The aim of the research is to introduce robots in humanitarian demining operations, with the aim of reducing risks to human operators, and of speeding up operations allowing using multiple robots where, for safety reasons, only one human operator can be employed at any given time.

The original aspect of the research is that, instead of using a single, multi-sensor equipped vehicle, multiple simple machines are used, each one carrying a very limited amount of mine detection sensors, that cooperate in the identification process. This approach obviously poses heavy coordination and management problems, but seems promising because it would allow using light, simple small and inexpensive vehicles rather than heavy and cumbersome ones.

I. Introduction

It is well known that landmines are one of the biggest problems that nowadays affect many countries throughout the world. Their wicked nature makes it extremely difficult, and in some cases impossible, to locate them using traditional sensors. In addition, landmines are usually placed in hard-to-navigate environments, such as the terrain shown in Figure 1.

Figure 1 - Vegetation in a minefield

Lastly, the overall logistic problem can strongly condition the process, given the difficulty of properly transporting, maintaining and using high-tech equipment in countries that often have heavily underdeveloped infrastructures. This, connected with the stringent time limit posed by the so-called Ottawa convention, signed at the end of 1997, that requires that all landmines be eliminated before year 2010 [1], makes Humanitarian Demining (HuD) an extremely difficult, yet extremely important to solve and scientifically challenging task.

II. Currently used techniques

Humanitarian demining is a highly complex process, that involves several phases [7]. This paper only deals with the intermediate phases of pinpoint locating mines, after the so-called *area reduction* and *ground preparation* phases have been carried on.

Despite a large amount of ongoing research [2], the detection methods that are nowadays practically used only rely on one, or more frequently a combination of, these three techniques:

a. Mechanical means for exploding mines without actually locating them, by activating their own triggering mechanisms (mechanical flails, ploughs, etc.);

b. Methods for physical detection of mines based on non-contact sensors (metal detectors) or on actual contact (hand prodding);

c. Methods based on the detection of vapors leaking from mines (currently only performed using dogs).

Class *a* methods do not usually guarantee the confidence factor that is required for HuD (99.6% of existing landmines must be detected: this practically means that no mine can be left in a cleared minefield), and are often used as a means for removing vegetation and for preparing the ground for subsequent exploration. Furthermore, devices normally used for flailing are large and heavy, and pose severe logistic problems. Reducing their dimensions on the other hand is not easy, because in many environments one must take into account the possible presence of anti-tank mines and of unexploded ordnance in the minefield.

Class *b* methods are the most widely used, and guarantee an extremely high degree of confidence, despite their low speed, that translates into the high costs that HuD involves. Low speed is due to the presence of human operators, that requires great attention and strict procedures, and to the extremely high number of false alarms. Such alarms are caused by the fact that what these methods actually look for is not specific to landmines, but is common to many other objects: for example, metal debris in a former battlefield can yield a false alarms ratio of more than 1000:1. The same applies to manual prodding, since mines and stones often have similar shapes.

Class *c* methods are widely used and, despite their cost and complexity (they require specially trained dogs, who in turn need specially trained personnel) they are quite successful, because their false alarm rates is low compared to class b methods.

III. Chances for using robots in HuD

An extensive observation of HuD projects shows that the combination of factors that must be taken into account for deciding the correct intervention methodology depends on so many parameters, that it gives rise to a virtually unlimited set of possible solutions. It is then clear that no universal machine can be designed. Furthermore, it is absolutely clear that in many cases the environment to be dealt with is so hostile that no autonomous robot has any chance of being used. Even tele-operated vehicles are often out of question, because their remote human controllers would have a too limited feedback and would be unable to drive them effectively. Strangely enough, this is particularly true for urban areas normally full of rubble, while agricultural areas seem to be more robot-friendly, as will be shown in the sequel.

The only idea that seems to have possible applications is to design a series of simple 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 automatic.

A. Categories of operations

The main categories of operations that have been taken into consideration for a possible introduction of robots are surface preparation and marking, actual detection, and mine removal or neutralization.

The preliminary phases of HuD, namely the identification of minefields, are also likely to be automated, but they call for other methods, such as GIS systems and remote sensing techniques.

Surface preparation is either accomplished by hand or using mechanical devices such as flails. The goal is to eliminate all vegetation and other obstacles that prevent sensors from coming in touch with the ground and deminers from moving freely on the minefield. Another important operation performed during this phase is the detection and elimination of tripwires, for which no effective detectors exist yet. If surface preparation is performed by hand, each small step taken in this direction must be immediately followed by actual demining, in order to avoid exposing people to the danger of a still unexploded mine. This would then require a strict man-machine cooperation, that is currently being investigated by several researchers.

B. Carrying sensors around

Among all the available sensors, some could be selected for being mounted on autonomous vehicles, rather than moved by hand. In some cases, this would be even desirable, because they either require an accurate positioning according to some pattern (e.g., ground penetrating radars equipped with contact antennas), or because their response is too slow for handheld use (e.g. sniffers).

Given the fact the no single sensor exists that allows locating any kind of landmine, and that the combination of sensors to be used depends on several factors, using a set composed of multiple sensors and appropriate data fusion techniques seems to be mandatory. There are two possible solutions: one is to mount all necessary sensors on a single vehicle, while a less traditional one would be to use several vehicles, each one equipped with a single sensor [8], [3]. Advantages and drawbacks of the latter solution are quite obvious, since carrying a single sensor calls for a smaller, lighter and simpler robot, while completing the task requires cooperation among several units, and this in turn poses problems related to information exchange, precise localization systems, etc.

C. Practical examples

Figure 2 shows a minefield that is being cleared using a mechanical flail to remove vegetation and to explode a number of existing mines, and metal detectors and hand prodders to perform the final clearance. This particular minefield is placed along the Zimbabwe - Mozambique border, where a large quantity of mines was laid about 20 years ago.

The state of the terrain prior to demining was similar to what can be seen in the background. Such terrain is extremely difficult to navigate even with a tele-operated device. However, after flailing, the whole minefield becomes quite even, and vehicles moving on tracks or on multiple wheels could be quite easily used.

This example shows how, in a terrain where a “robot only” approach would surely fail, the combination of man-driven and autonomous devices could yield interesting results.

IV. THE ONGOING RESEARCH

The research described in this paper is being carried on at ARL, and has been divided into two main sectors. The first one is the study of the possibility of using autonomous robots to carry odor sensors, designed to detect the presence of landmines by “sniffing” small quantities of vapors, released by their explosive content. The second one deals with simulated robot swarms that cooperate in the detection process.

Figure 2 - A minefield being cleared using a large flail

A. Odor-sensing robots

We are not directly involved in the research on odor sensors. The goal of this part of the research is to study the appropriate strategies that should be used when such sensors will be available. To achieve this, a preliminary study has been done to investigate how odors propagate in the environment, and how wind affects such propagation. An easy-to-detect vapor (ethanol) has been used, and data have been collected using an appropriate sensor mounted on a robot, both in calm air (Figure 3) and in presence of wind (Figure 4). Both figures represent readings taken on a grid whose dimensions were 600 by 350 mm.

As it can be seen, odor concentration has a very sharp peak around the source, but in presence of wind, it is necessary to use appropriate movement strategies, in order to avoid false readings. Such strategies clearly require knowledge of the wind direction and speed, and of the amount of air turbulence in the area being surveyed.

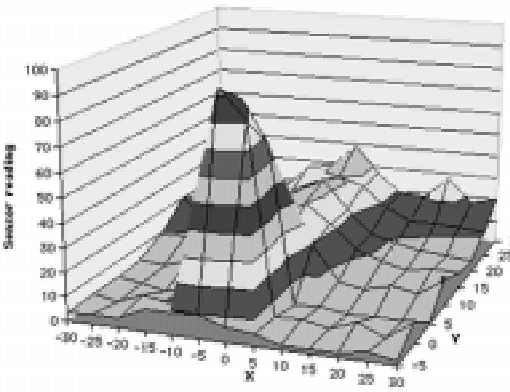

Figure 3 - Odor distribution in almost still air

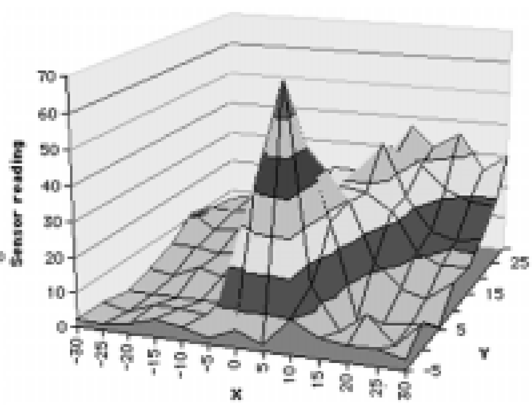

Figure 4 - Odor distribution in presence of moderate wind

In order to study appropriate movement strategies, two experimental robots (Figure 5) were equipped with sensors, and programmed in order to locate odor sources [3]. Some of the obtained results are described in detail in the paper.

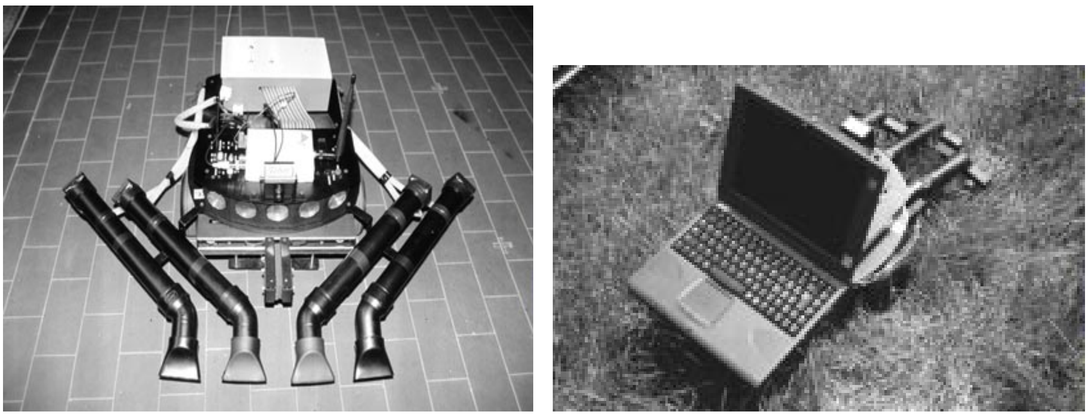

Figure 5 - The two developed prototypes

B. The simulated environment

As it has been said, the main part of the research is devoted to the study of swarms of simple, co-operating robots. In order to conduct experiments and to develop and compare strategies for mine detection, a software package has been developed that allows simulating the detection process, performed by a number of different robots. The huge number of possible situations would have made it unfeasible to start experiments using real machines, not to mention the cost of such research. The simulator (Figure 6), whose current release has been put into the public domain [4], offers the following features:

a. It allows describing a two-dimensional environment, that may contain obstacles (represented by bricks and trees), mines (of up to four different kinds), and robots;

b. Once the environment has been defined, up to four squads of robots can be put to work. Each squad is composed of up to four robots of the same kind, i.e. of robots ideally equipped with the same sensors.

c. Robot squads move according to a pre-defined strategy, selected among a library of different strategies. A detailed description of such strategies, together with the methods used to compute robots movements, can be found in [5].

It should be noted that actual working conditions have been taken into serious account during the development of the software package. This means that simulated robots are affected by sensor and actuator errors, and that the method used for driving them and for keeping them in the correct position has been designed in such a way that it can be quite easily implemented in practice. This method uses a number of vectors, representing attraction and repulsion forces, whose combination at any moment represents the direction and the speed each robot should have to keep its correct position in the formation.

This method is quite independent from the localization system being actually used, and works equally well with absolute positioning systems, such as DGPS, and with relative or local systems (triangulation, time-of flight, etc.)

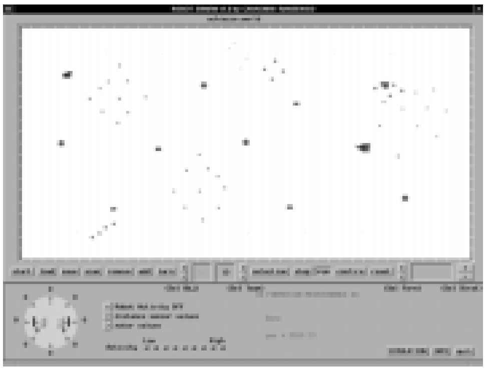

Figure 6 - The simulator screen

Besides using the simulator for demonstration purposes, the whole package has been built in such a way that all features (number of robots and of squads, sensors simulated behavior, movement strategies, etc.) can be easily changed by altering simple software routines or by introducing new ones.

Some interesting results, concerning the way movement strategies can affect the reliability and the efficiency of the clearing process have been obtained, and are described in detail in [5].

One very important aspect that is currently being investigated is the communication problem. It is obvious that robots that cooperate in the mine localization process must exchange a great quantity of information concerning their relative positions, their findings, etc., but it is highly undesirable that unnecessary information be exchanged among the machines, because the bandwidth available for inter-robot communication is limited. A study is being carried on in order to formally define the kind of information that should be exchanged, and the best format of such information.

V. CONCLUSIONS

Despite the encountered difficulties, we are fairly convinced that autonomous robots have good chances of being employed in the HuD process. However, there are still countless problems to be solved, and a global application of robots is still far from being feasible.

Therefore, small steps should be undertaken, addressing each elementary problem separately, and taking advantage of the existing techniques for multi-robot and multi-agent systems.

VI. BIBLIOGRAPHY

[1] Barlow, D.: "Demining 2010 - A Challenge to the Demining Community", The Journal of Humanitarian Demining, http://www.hdic.jmu.edu/hdic/journal/2.2/editors/director.htm

[2] Bruschini, C., Gros, B.: "A Survey of Current Sensor Technology Research for the Detection of Landmines", SunDen '97, 29 Sep-1 Oct. 1997, Zagreb (Croatia), pp 6.18-6.27.

[3] R. Cassinis: "Odour Sensing Robot Clusters for Humanitarian Demining", Proc. IARP- International Advanced Robotics Programme, First Workshop on Robotics for Humanitarian Demining, Toulouse, 1998.

[4] R. Cassinis: Robot swarm simulator package, preliminary version available at ftp://frank.ing.unibs.it/ftp/pub/software/swarmsim.tgz

[5] R. Cassinis, G. Bianco, A. Cavagnini, P. Ransenigo: "Strategies for navigation of robot swarms to be used in landmines detection", Proc. Eurobot '99, Zürich, 1999.

[6] Mataric, M.: "Interaction and Intelligent Behavior", Technical Report AIM-1495, MIT AI Lab, 1994.

[7] A. R. R. McAslan and A.C. Bryden, "Humanitarian demining in South Eastern Europe - An analysis of capability shortfalls and user needs", The Geneva International Centre for Humanitarian Demining, 14 April 2000, http://demining.jrc.it/aris/events/infomtg0400/StabilityPact.pdf

[8] Parker, L.: "Heterogeneous Multi-Robot Cooperation", PhD Thesis, MIT AI Lab, Cambridge, MA., Technical Report AIM-1465, 1994.