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Odour Sensing Robot Clusters for Humanitarian Demining

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Abstract

The paper describes a research currently being carried on at Brescia University, that aims at using clusters of autonomous mobile robots for locating anti-personnel mines using various sensors, among which odour sensing devices.

Besides an obvious advantage in terms of operating speed, multiple robots offer the possibility of implementing large arrays of connected sensors in a very simple and straightforward way. This is particularly important with some kinds of sensors, that would otherwise be very difficult, if not impossible to use for this application.

Furthermore, different kinds of ground and airborne machines can be used according to the specific needs of the demining tasks. Weight, cost and complexity of each machine can be reduced in comparison with single machines equipped with multiple sensors.

Although the paper deals with an ongoing research, some already available results are presented and discussed.

1. Introduction

The idea of using clusters of simple robots rather than a single complex machine in tasks involving exploration, surveillance, etc. is certainly not new [PAR 92, PAR 94, MAT 94]. The research described in this paper, that is currently being carried on at the University of Brescia, aims at using such techniques for humanitarian demining tasks.

Besides the obvious fact that, all other things being equal, multiple robots require less time than a single one to explore a given area, at least two more advantages can be seen in this technique: the possibility of having robots equipped with different sensors and/or special purpose devices, that exchange information with each other, and the capability of creating large virtual arrays of sensors without having to physically build the supporting frame, a task that would be impossible in most cases, given the nature of the terrain to be searched.

Other advantages, like the increased reliability of the system, will be discussed in the sequel.

This research described in this paper is being carried on at the Laboratory of Advanced Robotics (LRA) of the University of Brescia, in co-operation with people from the Materials Chemistry and Physics Department (MCPD) of the same University.

2. Sensor development

Most of the landmines detection systems that are nowadays being used are based on the principle that mines alter some physical properties of the environment. For instance, their metal parts alter electromagnetic properties of the ground, the body of a plastic mine alters the thermal properties, etc. The corresponding sensors measure such properties and signal anomalies, that can be caused (and often are) by other more or less harmless things. This is especially true for metal detectors, since metal debris is almost everywhere man has been, and leads to a very high number of false alarms. The same applies also to manual probing, because the parameter being measured is a variation in soil mechanical resistance, that can be caused by any solid object. Only at a later stage manual probing determines the shape of the found object, and allows a decision to be taken.

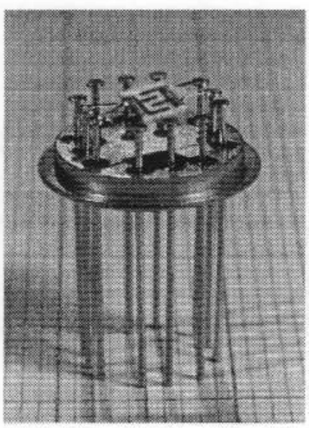

Figure 1 - A sensor built at MCPD facilities

On the other hand, the ideal sensor should only detect the physical parameter (or set of parameters) whose abnormal value (or combination of values) indicates, with no possible error, the presence of a mine. The best way to do this is, of course, to look for something that is absolutely peculiar to the mine and to nothing else, such as the explosive or at least some of its components. This is why odour sensors have always been very appealing, and are nowadays, in their only practically available form (dogs), one of the best means for mine searching.

Since LRA people do not have previous experience in odour sensing, an agreement has been made with people of an MCPD research group, that have already developed specialised sensors to be used in the food industry. This group will take care of experimenting the possibility of using thin film sensors with a tin oxide substrate for this application (Figure 1). An extensive survey on all possible chemical components, uniquely belonging to mines, that could be identified using chemical sensors is also being carried on by this group.

Other sensors, such as the Bofors Schnauzer [BRI 96] will also be considered for application.

3. Experimenting with gas sensors

The first experiments were undertaken to confirm the possibility of building autonomous vehicles that could thoroughly explore a given area, sensing gaseous emissions from the ground. Some previous experiments carried on by Ishida et al. [ISN 94, IKN 96, NIM 96, INM 97] demonstrated that this possibility exists although the operating environment is quite different in this case.

It was also decided to use already available equipment: namely, two RWI Pioneer robots were equipped with gas sensors.

Since the main interests of the research group are in the robotic aspects of the problem, rather than in the technology of the sensor to be used, it was also decided to start by using an already assessed technology, that does not involve handling dangerous substances such as explosives.

The choice was to use sensors that would sense traces of ethanol, and the odour sources to be located were small uncapped bottles filled with a 10% solution of ethanol. Two kinds of sensors were used: first, tin-oxide sensors built at MCPD proved to be extremely sensitive, but, since they had to be heated at about 500 °C in order to sense alcohol vapours, they proved to be quite fragile. Therefore, it was decided to continue the experiments using commercial sensors (Figaro TGS 822) that are less sensitive, but exhibit a much sturdier construction.

Although the two prototypes have different structures, all sensors are mounted in the same way: a large section pipe collects air from the area being scanned through a thin opening. A small fan mounted at the opposite end of the pipe creates a depression that forces air to move, and to pass through the sensors that is mounted just before the fan. The device does not "manipulate" the collected air, in order, for instance, to increase the concentration of foreign substances. The chosen structure seems to be the best compromise between the two conflicting needs of having air flowing fast enough, in order to minimise the time delay between the moment it enters the device and the moment it reaches the transducer[1], and slow enough to simplify temperature regulation of the device.

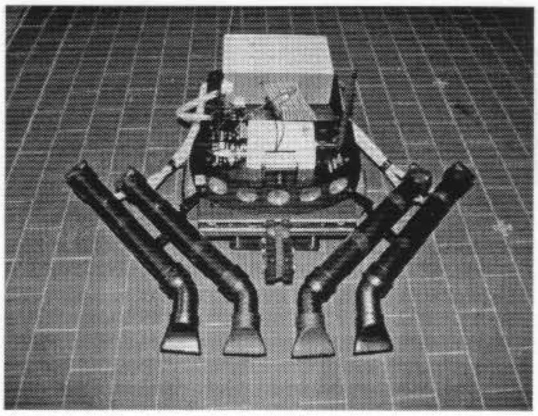

Figure 2 - Tobor equipped with four ethanol sensors

Figure 2 shows the experimental set-up of Tobor robot, with four sensors whose openings are placed on a straight line, without overlapping. Tobor is also equipped with a TV camera and a gripper device. Two radio links (one for video signals, the other for digital data) relay it to a fixed computer, running the control software.

Additional circuits for controlling the gas sensors were placed in the large grey box placed on the robot.

A belt of sonar sensors (five in front, one on each side and one on the back of the robot) is used for measuring distances and for obstacle avoidance.

[1] Placing the transducer closer to the front end of the device seems impractical, because air conditioning systems will eventually have to be added, such as filters, temperature and humidity regulators, etc.

Speedy robot, as can be seen in Figure 3, has only three sensors whose openings are wider and overlap slightly. Besides having no gripper and being completely autonomous (as it can be seen, it carries its own computer on board), it does not have other significant differences from Tobor.

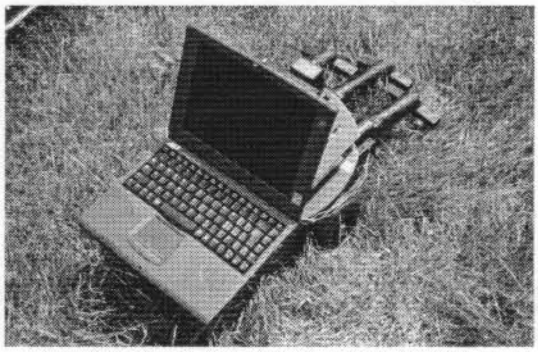

Figure 3 - Speedy carrying three partially overlapping sensors

The number and the shape of odour sensors have been found to be a very important parameter, heavily conditioning the software structure. All the transducers that have been tested exhibit an imprecise behaviour, that is mainly due to the uncontrollable operating conditions (varying temperature and humidity, wind causing turbulence and uneven odour scattering), etc. Moreover, all tested sensors exhibit a strong memory effect, and additional precautions will have to be taken in order to properly use them. For instance, exposure to a high concentration of vapours causes a saturation effect that lasts from some seconds to more than half an hour, and is due to adsorption of alcohol vapours on various parts of the sensor. So, if in calm air and in the best working conditions the concentration of vapours is quite regular around the source, as can be seen in Figure 4, things get much tougher if the air is moving, even slowly (Figure 5).

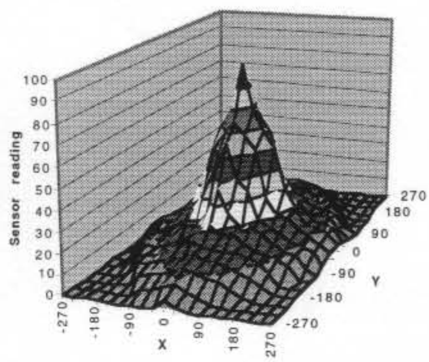

Figure 4 - Vapour concentration in controlled situation

This suggests that quantitative methods cannot be used in such situations, and that all conclusions based on such sensor readings will have to be drawn using qualitative reasoning, such as fuzzy logic techniques.

It must also be noted that, even with relatively "strong" sources of odour, like those used in the experiments, concentration levels of the vapours are significant only when the sensor is placed very close to the source (in our experiments, less than three meters in calm air, and less than one meter in moving air, due to the dilution of the vapour in turbulent air.

Two programs have been written for the robots, whose task is to patrol a given area and, if ethanol vapours are detected, to move around in order to pinpoint the precise source. Since the robots do not have any absolute positioning system yet, and experiments were undertaken in a closed laboratory, sonars were used to drive the robots along lines parallel to one of the walls of the room. A laser beam driving system, currently in the testing phase, will soon replace sonars in this task, and will be integrated with a differential GPS system.

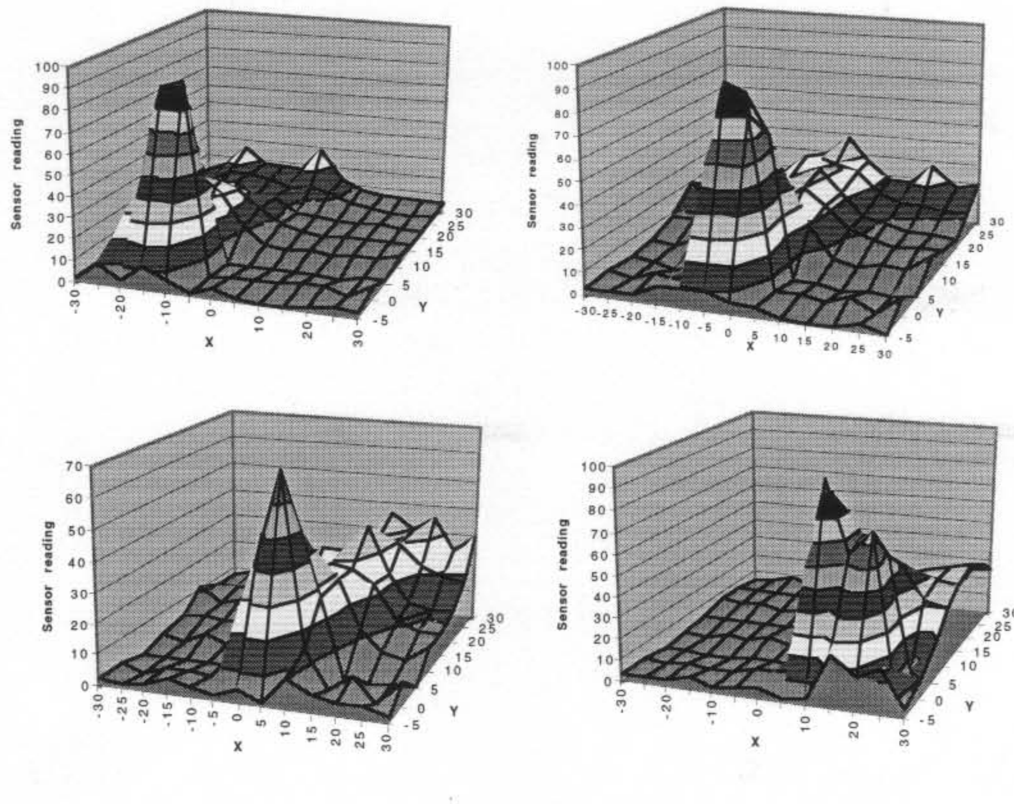

Figure 5 - Sensor readings in mildly turbulent conditions

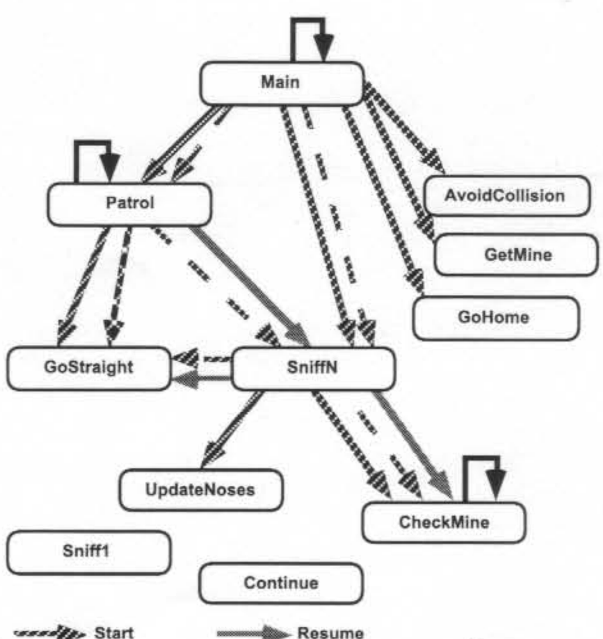

Figure 6 - Tobor software structure and hierarchy

The two programs are quite similar to each other, and have shown a very good behaviour also in conditions that were quite far from ideal, i.e. with many people walking around and open windows causing turbulence build-up and quick temperature changes. The programs were written using the Saphira software package that comes with the Pioneer robots, and that allows defining and manipulating "behaviours" and "activities". It was decided to write the program using activities, and the general structure and hierarchy of the developed software are shown in Figure 6.

Although apparently simple, the task of looking for an absolute maximum in a non-monotonous two-dimensional surface with a single set of sensors is not trivial at all, especially if the shape of the surface changes continuously. A lot of "tricks" had to be included in each activity in order to get it to work properly. Obviously, things would have been easier if a variable geometry array of sensors were available, or, even better, multiple robots that would exchange information with each other.

4. Experimenting with robot clusters

A great amount of research has been devoted, during the last years, to robot swarms, i.e. systems composed of large amount of very simple robots whose collective behaviour exhibits some "intelligence", although the single components of the swarm are not intelligent at all. Some applications of this theory to humanitarian demining have already been proposed: the scope of this research, however, is to investigate the behaviour of organised groups of quite sophisticated robots. In other words, the idea is to use multiple machines not to achieve an intelligent behaviour, but to enhance the capabilities of the single machines without increasing their complexity. It is obvious, for instance, that locating a mine and removing it are two different tasks, and that a single robot capable of both operations would be very complex, expensive and, last but not least, heavy. Further breakdown can be done with different sensors: since different kinds of mines must be sensed in different ways, and given the different kinds of terrain on which the search has to be done, the squad can be configured as required for a specific operation without the need of reconfiguring the single machines. It should always be kept in mind that there is no unique sensor that will solve the demining problem, and that all the developed devices will have to be integrated, in order to allow each one of them to contribute according to its peculiar characteristics.

This idea implies that the multirobot system has to be a well-organised platoon of smart machines that exchange great amounts of information with each other and that operate in a hierarchical network. Design and implementation of such system will be a long and complex task, and will require several years to be completed.

Experiments on robot clusters have just started, and are presently carried on with a modified Kephera [MIC 96] robot simulator, that allows the study of the behaviour of multiple robots, either similar or of different kinds. Some preliminary experiments have already been carried on, their purpose being of simulating a squad of equal robot exploring an unknown environment. In this experiment each robot explores a section of the given area but, if one machine fails to operate, its job is redistributed among the other machines (Figure 7).

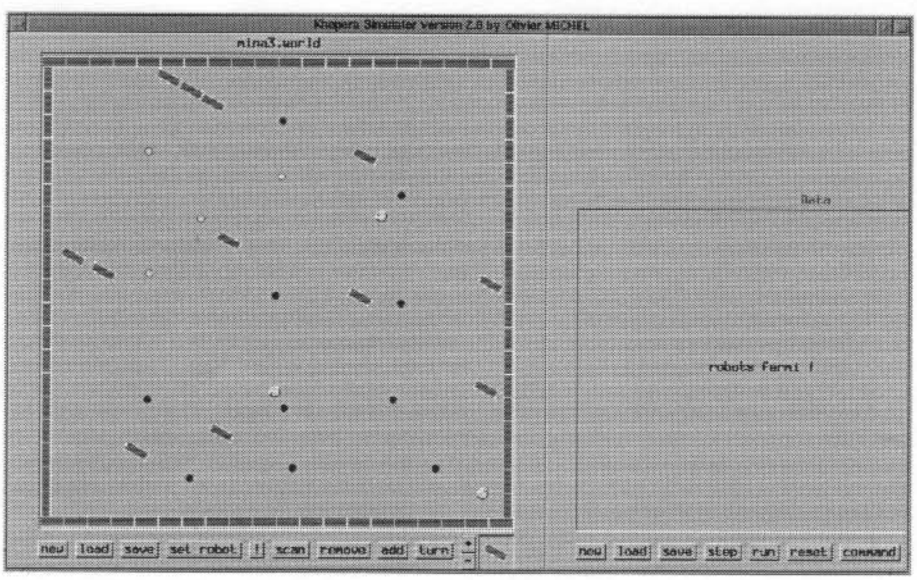

Figure 7 - A Kephera simulation of a squad of robots

5. Conclusions and future perspectives

A currently ongoing research that aims at using groups of robots equipped with various kinds of sensors has been illustrated. Emphasis is placed on two main points: clusters of well-organised robots work better than single machines, and strategies to be used when odour sensors are employed need thorough investigation.

The research is still far from conclusion but, as it has been shown, the first results are all but discouraging.

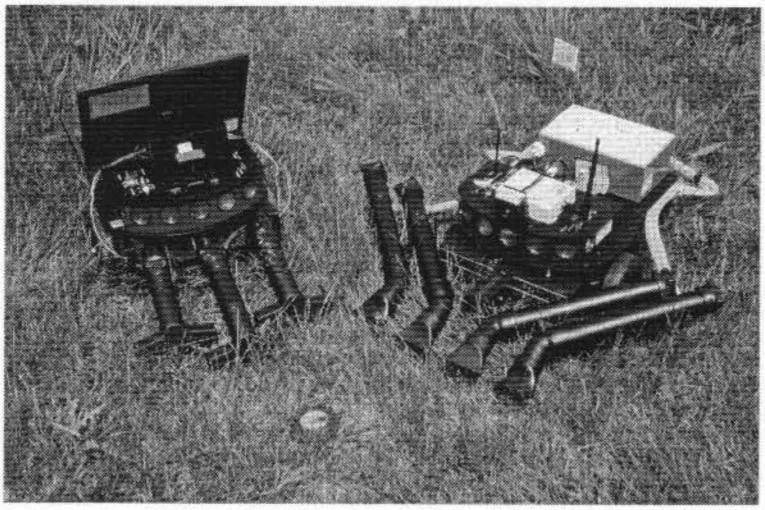

Figure 8 - Speedy (left) and Tobor searching a fake mine in the grass

6. Acknowledgements

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