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Multi Robotic System and the Development of Cooperative Navigation Behaviors for Humanitarian Demining

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Abstract: Multiple robotic systems can accomplish tasks that no single robot achieve, since ultimately a single robot, no matter how capable, is spatially and physically limited. However, achieving cooperative robotics is quite challenging. Many issues must be addressed in order to develop a working cooperative team, such as action selection, coherence, conflict resolution, resources management, coordination, cooperation and communication. In this paper Pemex-BE robot is used to represent the individual robot that makes up a team for multi robotic system dedicated for humanitarian demining. The multi Pemex-BE robots for mine clearance represents an attempt to reduce the gap between the research level and the actual needs on the ground. The technical features and navigation system with obstacle avoidance along with the scenario of multi robotic system is presented.

Keywords: Robotics, Multi robotic systems, Navigation, Sensors, Antipersonnel mines**,** Humanitarian demining

I. INTRODUCTION

Research on using population of robots for achieving a given task efficiently has mostly been inspired by animal behaviors. There has been increased research interest in systems composed of multiple autonomous mobile robots exhibiting cooperative behavior. The study of multiple-robot systems naturally extends research on single-robot systems. Multiple-robot systems can accomplish tasks that no single robot can accomplish, since ultimately a single robot, no matter how capable, is spatially limited. Achieving cooperative robotics is desirable for a number of reasons [1-4].

1. Many robotic applications are inherently distributed in space, time, or functionality, thus requiring a distributed solution. In addition, tasks may be inherently too complex or impossible for a single robot to accomplish it,
2. It is quite possible that many applications could be solved much more quickly if the mission could be divided across a number of robots operating in parallel by duplicating capabilities across members of the robot team.
3. Building and using several simple robots can be easier, cheaper, flexible, and has the potential of increasing the robustness and reliability of the automated solution through redundancy. It would be much cheaper and more practical in many applications to build a number of less capable robots that can work together at a mission, rather than trying to build one robot which can perform the entire mission with adequate reliability, and
4. The constructive and synthetic approach inherent in cooperative mobile robotics can possibly yield insights into fundamental problems in the social sciences (organization theory, economics, cognitive psychology), and life sciences (theoretical biology, animal ethology).

Achieving cooperative robotics, however, is quite challenging. Many issues must be addressed in order to develop a working cooperative team, such as action selection, coherence, conflict resolution, resources management, coordination, and communication. Furthermore, these cooperative teams often work in dynamic and unpredictable environments, requiring the robot team members to respond robustly, reliably, and adaptively to: unexpected environmental changes, failures in the inter-robot communication, modifications in the robot team that may occur due to mechanical failure, learning of new skills, the addition or removal of robots from the team by human intervention, or full robot failure etc.

Small, lightweight, and inexpensive robots tend to have better mobility but it might be unavoidably slow [5-7, 9, 10]. Smaller in size and light in weight also means reducing certain capabilities. With the use of a large number of such robots, the good mobility can compensate for the low speed while it is necessary to develop efficient group behaviors to compensate for the reduced capabilities. When designing the multi robotic systems for demining, it is important to decide the type of movement strategy the robots adopt when scanning the minefield, the standard set of behaviors that all individual robot should have and the set of specialized behaviors that are assigned to specific individual robots and the way robots are going to communicate information.

Random collective behaviors with improved algorithms have been proposed to look for mines on beaches [8]. This technique cannot fulfill humanitarian demining requirements, as there is a need to assure that every square inch of the terrain is explored reliably and as safely and as fast in a minimum amount of time and cost

II. MULTI ROBOTIC SYSTEM SCENARIO FOR HUMANITARIAN DEMINING

The outline of multi robotic system scenario for humanitarian demining using Pemex-BE robot is stated as follows:

a. The higher level of control is represented by a mobile monitoring station**.** The monitoring station receives the task description either from human-operator through a multimodal graphical interface, or by using a topographical map, or an aerial picture with precise coordinates. The operator divides the area of the assigned minefield into sectors and allocates a robot for each sector. Then, the monitoring station informs the task and the starting global /reference location of each sector to the relevant robots through radio module. Periodical polling tracks task execution, clarifications, and reported difficulties that might be raised by any of the robots or by the searching mission. The monitoring station helps to resolve any problems by individual robots that are in deadlock situations or robots that require additional resources. In this case the monitoring station and human operator can instruct and extend help to the relevant robot directly to fulfill its needs in finding safe path, resolve the deadlock, emergency help and guide, etc. If this is not possible, the monitoring station reports that to human operator. Human operator interacts with the monitoring station to instruct a specialized robot for emergency to help the robot in question and resolve the deadlock, or give charging service, etc.

b. Individual robots. Each robot (see Figure 1) initializes itself and performs a self-check to emulate his readiness to achieve a set of possible tasks and informs the monitoring station about its availability and readiness to execute these tasks. Each robot in the multi robot team receives the assigned task from that monitoring station and reports back on its activity and performance update: scanning for mines, marking mines, and communicating with other robots. In addition, each robot tries to get out of a detected deadlock situation by means of its own available knowledge and resources before reporting it to the monitoring station. Mines are marked and possibly exploded using a small charge placed by the robot and triggered after the robot has backed at a safe distance. Each robot has its behavior navigation system with set of standard behaviors available for all robots, and set of specialized behaviors that are dedicated for special tasks and needs (See Figure 2). The principle requirement is that each of the demining robot in the team should operate in a remote control mode or, at least, semi-autonomously. All robots are assumed to have the following capabilities: position encoders, GPS, obstacle detection sensors, mine sensor, and radio communication. Some of the robots might have extra sensing and physical capabilities depending on the assigned task requirements.

Fig.1. Pemex-BE in different environments

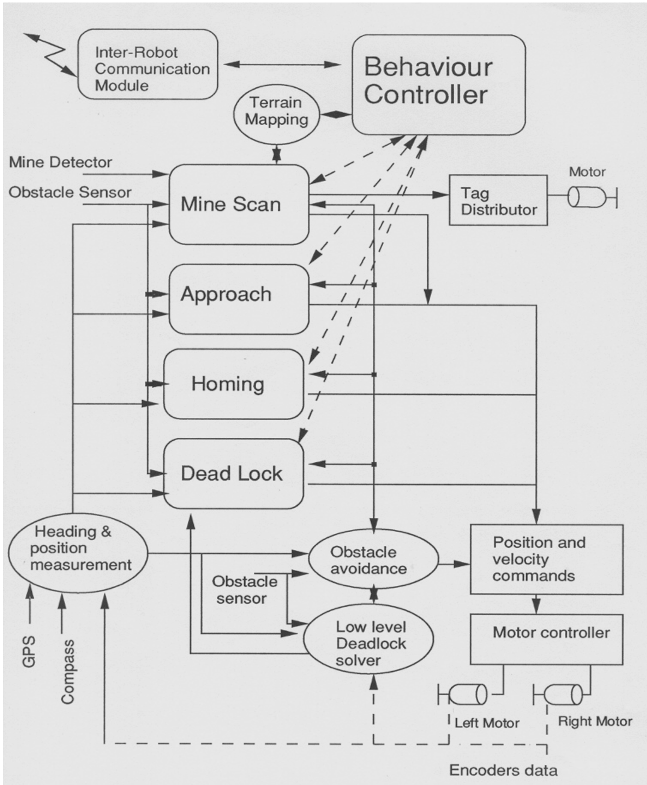

Fig.2. Pemex-BE in different environments

III. IMPLEMENTATION OF THE ADOPTED MULTI ROBOTICS SYSTEM SCANRIO

Pemex-BE robot was used to represent the individual robot that makes up the team for multi robotics system. The mobile monitoring station is considered as a car of suitable size, which can adjust its location as needed to support the demining process and its requirements. In this case, the mobile monitoring station represents the higher level of control. Within this architecture, human-operator stations inside the car interacting with the monitoring station with the possibility to communicate with other land-based sub-operators through radio. The operator describes the task to the monitoring station. The monitoring station interacts with the assigned operator and takes care of task distribution and allocation for individual robots according to the size of the minefield and the available number of robots. The station supervises the execution and control of tasks, and communicates with robots as individuals, groups or as a whole to follow-up task execution, mapping, and problem solving updates. The skill required by human-operator should be kept to minimum. Figure 3 shows an example for dividing a minefield into three sectors, the mobile monitoring station and some high level behaviors. Efficient distributed robotics architecture must allow robots to be efficiently added to the system or removed from it. Once, a Pemex-BE robot starts to operate; it is in a standby mode while reporting to the monitoring station its readiness in performing a set of tasks according to the associated physical functional capabilities.

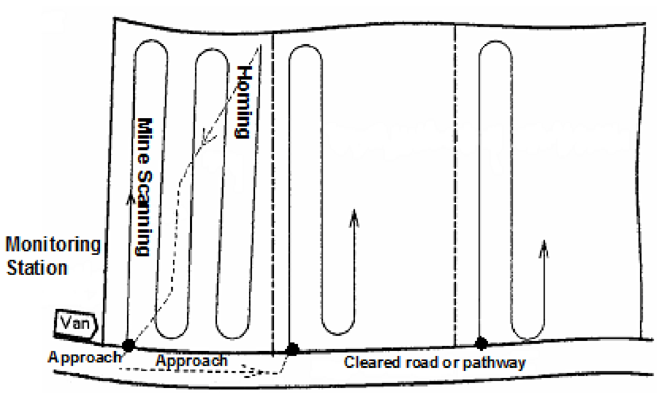

Fig.3. Terrain to be cleared with three robots

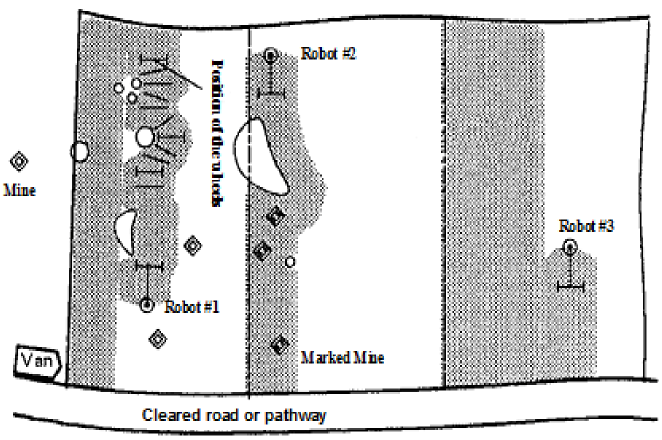

Fig.4. Terrain scanned after certain time by the work of three robots

Each of the dedicated robots for mine search receives the global reference location of an assigned sector along with its width and depth. A digital map of the minefield and the searched area within each of the assigned sectors have to be maintained and continuously updated with the support of a seamless interactive interface between the human operator and the monitoring station from one side and between each robot and the monitoring station from the other side. Each robot maintains its own version of the map based on its searching activity and shares it with the monitoring station. For the purpose of this work, the operator at the monitoring station is responsible decide whether the minefield is completely cleared or there is still remaining issues or regions within the assigned sectors that need to further follow-up (see Figure 4). Hence, the operator must have a comprehensive view of the demining process performed by the participating robots that constitute the demining team. Marking a detected mine within an assigned land on a digital map enables immediate and easy interactive interpretation by human operator or the monitoring station. In addition, it helps to decide whether further exploration for that land is needed or not.

During the actual operation of mine searching, an assigned working area for each individual robot can be redefined depending on the circumstances facing the robot and the searching progress, e.g., help can be requested when one robot is discovering more mines or more obstacles within its own assigned area and needs some help from other robots that already finished searching their sectors. Coordination of movements is required if one robot is stuck into a hole or at a corner or lost its detection or mechanism capabilities; in such situation, another robot (either specialized emergency robot for such mission or any of the other individual robots) should pull it back and such a decision is made in consultation through the monitoring station and possibly through human operator too.

The main functional capabilities of the monitoring station can be summarized as:

1. It receives a demining task description through human-friendly graphical user interface using, for example aerial pictures, topological maps, etc.
2. It divides the located mined area into sectors and allocates a robot to each sector. Human has the capability to interfere and do or adjust this job directly.
3. It communicates with the available robots by radio transmission through periodical polling or per demand as needed. This aims to announce a task, track task execution, solve deadlock, manage collaborative action, mapping searched area, re-planning, etc.
4. Tracks all marked mines.
5. It maintains a global and updated digital map of the minefield.
6. It confirms and announces the completion of a demining task.
7. Adding new robots to the team or removing damaged members.

IV. COMMUNICATION MANAGEMENT

In order to enable parallel behaviors and efficient task achievement, follow up progress and update, and to extend support to any robot in need, a communication management module at each robot and at the mobile monitoring station is considered necessary under the work of this paper for message and information exchanges. Group communication among all robots (inter robots communication) including the monitoring station requires protocols that can operate without central control and handle dynamic topology changes due to the mobility of the robots and the station itself. Multicast is the most important group communication primitive and it is critical in applications where close collaboration of teams is needed. A radio based communication module has been developed and its communication framework consists of communication protocol to establish physical communication link and message protocol to exchange messages corresponding to necessary information. The main functions of the message protocol are negotiation (task assignment, cooperation, etc.), inquiry (look for information, etc.), offer (information, help, etc.), announce and synchronize, deadlock solve, etc.

It is important to remember that even the most sophisticated radio systems are subject to interference, both loss of bandwidth due to RF noise and competition for bandwidth. In addition, when dealing with tasks in real-time, much information has a severely limited useful lifetime which influences how reliability of communication must be addressed. The communication management will be helpful to add new robots to the system and removing damaged ones. When a robot is unreachable through communication by others for varying periods of time, it is considered temporarily to be damaged and the system requires dynamically to do change in the makeup of a robot team.

V. CONCLUSIONS

The multi Pemex-BE robots for mine clearance structure presented in this paper as an attempt to reduce the gap between the research level and the actual needs on the ground. This requires proper understanding of the exact problems at the minefields sites and concludes a design of a low cost, flexible, and light weight mobile robot while considering local resources and constraints.

There is still a need for further analysis to formulate the efficient navigation system for Pemex and its motion. A better sensory combination and fusion techniques are still needed. Better mobility is of high demand. Further analysis is required to develop dynamic behaviors supporting coordination, communication and cooperation capabilities.

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