Behavior Based Autonomous Navigation System for Mobile Robots

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Abstract- **Mechanized and roobotized solutions properly sized with suitably modularized structure and well adapted to local conditions of minefields can greatly improve the safety of personnel as well as efficiency and flexibility. Such flexible machines with some level of decision-making capabilities can speed the clearance process when used in combination with other mine detection. A population of lightweight, robust, adaptable, low-cost, and multi operational mode robots that can integrate high speed mine detection and deactivation system is a clear answer to the problem of demining vast condemned areas. They will work together under close supervision of a monitoring station. The robot has three levels of control: Local scan, navigation (GPS and odometry) and collective behavior through radio coordination. Ground pressure of the developed robot is low enough not to make the mine explode. Pemex-B has to scan a large area, and assure the coverage of every part of it.**

I. Introduction

The major effect of landmines is to deny access to land and its resources, affect rebuilding process, causing deprivation and social problems among the affected populations. In addition the medical, social, economic, and environmental consequences are immense [1-4, 6-8]. The international Committee of the Red Cross estimates that the casualty rate from mines currently exceeds 26,000 people every year [5]. Unlike a bomb or artillery shell that explodes when it approaches or hits its target, a landmine is a blind weapon that lies dormant until a person, vehicle, or animal triggers its firing mechanism. Mines are prominent weapons because they are simple devices, so effective, yet so inexpensive, readily manufactured anywhere, easy to lay and yet so difficult and dangerous to find and destroy [1-4, 6-8]. Landmine technology ranges from very simple to high technology devices. There are many different varieties of mines produced by many countries worldwide that can be categorized in the following groups: landmines (anti-tanks (AT) and vehicles, antipersonnel (AP)) and sea-mines. In addition to mines, areas of ongoing or former conflict are contaminated with unexploded ordnance (UXO): grenades, mortar and artillery shells, bombs, rockets, and cluster bombs [5]. Modern AP mines are fabricated from sophisticated non-metallic materials and incorporate advance electronics. According to the United Nation there is a need to have at least 99.6% clearance success rate [7]. The amount of time it takes to clear an area is less important than the safety of the clearance personnel.

Humanitarian demining aims at locating and neutralizing of all landmines, UXO and booby traps in order to make infected areas available for human activities and development, and to allow people to use their land without fear. It should be performed efficiently, reliably and as safely and as rapidly as possible while keeping cost to the minimum. Engineers and other scientists can and should help in accelerating the speed of demining, lowering its cost and reducing the deminers' risks, by providing adequate, i.e. really usable in the field and cost-effective tools, sensors and platforms. Most people in the mine clearance community would be delighted if their work could be performed remotely or, even better, robotically. The task for a robot is to detect mines, mark them and eventually destroy them. Generally robots should improve quality of tasks performed by humans, and release human beings from working in hazardous environment, i.e., reduce the role of the human on the actual mine field.

Realistic environment is covered with vegetation of various sizes, containing rocks, holes, roots and other different sized obstacles, steep slopes and trenches. All those obstacles will have different properties and negotiability according to the size of the robot. Accordingly, the open question is: Is it effective to build one huge robot that will be powerful enough to destroy or go across the obstacles, or bunch of small-sized robots? Robots could increase productivity, saving in cost and could improve the safety of the mine detection operations and its targets by keeping the deminer of AP mines out of physical contacts with mines. The detection capability of landmines under all conditions with near 100% probability is dictated by the sensor(s) while the complete coverage of a defined area is the responsibility of the robot.

Demining robots solution can be as, modular components that can convert any mine clearing vehicle to a remote-controlled device, prodding tools connected to a robotic arm, multi modes mobile robot platforms (Teleoperated, Semi-autonomous and Autonomous), etc. with arrays of sensors and area mine clearance devices.

There exist different approaches to develop and use robots for demining. Proposals have been initiated to adapt available robot mechanisms and functionalities, to design and develop new robots, and then some of these robots were used in a team to enable parallel tasks. The navigation problem of a demining robot has some similarities with that of service robots [9, 10]. Obstacles avoidance while following a predefined trajectory is a general problem for planetary rovers [11, 12]. Much work has been performed on path planning which is not relevant to this application, because the robot is semi-autonomous and has to follow precise trajectories it defines only partly by itself. Coordination of the work of several robots is also simplified by a central monitor station allocating the task to every robot, and reassigning the work according to the observed situation. The control architecture is also simplified by a limited number of obstacle sensors, and by the possibility to better sense the obstacles with motion control, in order to obtain more precise information on their shape. Vision is powerful but is not yet, considered for economical reasons. Reliability and robustness of the control system is very important for that application [13]. This paper presents the general architecture of the Pemex-B robot, and some preliminary navigational software. Tests are conducted on a reduced size model using Khepera processor, sensors, and positioning system.

II. Development of the Demining Robot

The conceptual principles of Pemex-B structure include a robot with two large wheels robot built to investigate cross-country navigation and to evaluate sensors for the detection of AP mines. The sensors (for obstacle and mine detection) are located inside a hemisphere at the front side of the robot that acts as the third contact point on the ground surface (Fig. 1). In addition, the hemisphere can act as a shield to protect the sensor from dust and other environmental effect. The size of the robot will depend on the type of the terrain. Wheels of one or two meters in diameter may be adequate for most situations; scaling up will not significantly increase weight and cost. Local material resources, such as bamboos, gunny bags, etc. can be used for building up the wheels. The motors, accumulators and control electronics are packaged in a solid box to protect them from any possible explosion. This type of technology can be employed for marking the position of located mines and eventually destroy or neutralize them. Wheels are slanted in order to increase the stability with the same size and weight for the central part like a wheelchair for sports; it may also improve mobility below trees.

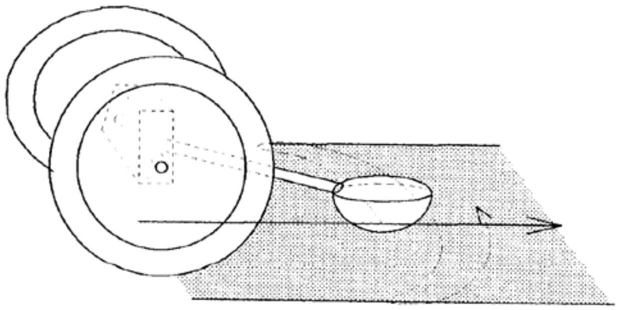
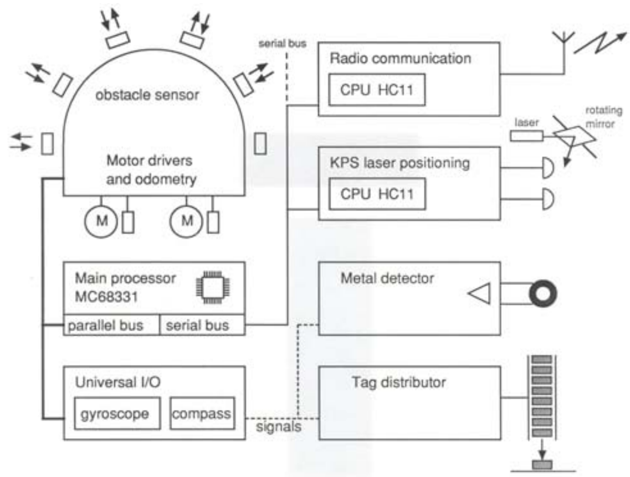


Figure 1: The structure principle of Pemex-B.

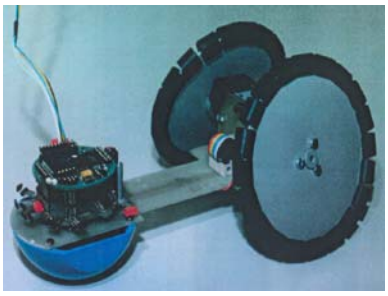
There is no problem due to the hemisphere rubbing on the ground: when the effort increases, the couple on the wheels reduces the apparent weight of the hemisphere, hence the friction. Of course odometry is less reliable due to the torque increase on the wheels, which creates skid. Experience shows that this effect is negligible on dry terrains. If the sensor is inside the head of the Pemex-B robot, its position may be given by the odometry of the wheels. Due to the slippering of the wheels, a repositioning mechanism must be used (laser, ultrasounds, precise GPS). In case of an expected explosion of a mine, the sphere will be blown up by the explosion and may get less damage by describing half a circle in the air around the wheels rather than by resisting the explosion.

The small-scale prototype robot Pemex-BS is one of the main objectives of first development stage. Khepera [14] consists of several printed circuit boards having 6cm in diameter and it has been installed on the top of scaled down hemisphere after removing its wheels while keeping its motor drives (Fig.2.a). The motors, the power supply, the metal detector and the tag distributor are installed on the main board. Larger sized motors and batteries have been installed in the central block between the wheels. The infrared distance sensors are used for obstacle detection and they are able to detect objects/obstacles within short-range (2-6cm) and are far to provide reliable range information on the obstacles. In addition, the robot has radio communication, compass and gyroscope modules. Figure 2.a shows the block-diagram of the hardware modules associated with Pemex-B. Nevertheless, this has the advantage of stimulating the development of robust algorithms. For demonstration purposes, a metal sensor is installed inside the sphere, and a motor driven distributor of color tags is used to mark the ground when hidden metallic objects are found. The laser positioning consists of a laser and a rotating mirror, both fixed on the ceiling above Khepera. The precision of the positioning system is 8mm (5% of the wheel base) and 5 degree for the angle, which corresponds to what can be obtained from a military GPS on the final Pemex.

The Pemex-BS model robot is shown in Fig.2.b. The length of the robot is 10 inches and wheel diameter is 5 inches for each. With 4 AA-sized batteries, the robot runs for 1 hour. During algorithm, programming and testing development, the robot is powered through a cable that also carries a serial line for downloading programs and providing in return sensor data to the workstation. Programs are written in C and Labview is frequently used for testing interactive modules [14]. Pemex-BS was successfully tested using experimental laboratory setup.



(a) The block-diagram of the hardware modules of Pemex-BS.



(b) Pemex-BS with its Khepera control boards.

Figure 2: Pemex-BS model robot

During the second stage a larger robot model called Pemex-BE has been built [8]**.** The total weight of this robot is less than 16 kg (exerts a maximum force of 6 kg on the ground). This robot can climb 30 degree slopes and stairs that the robot might face in destroyed urban areas, and it floats on the water, propelled by paddles, and can be carried as hand luggage. It is powered by rechargeable batteries which provide 60 minutes of autonomy. The locomotion of Pemex-BE is based on two mountain-bike wheels driven by 90W DC motors from Maxon with 1:72 reductors (Fig. 3) aiming to give to the robot a maximum speed of about 6 km/h with excellent cross-country capabilities. The on-board 68331 microprocessor permits autonomous or teleoperated navigation. Infrared and ultrasonic sensors are used to detect obstacles. In relation to the mine detection capabilities that are intended to be integrated with the robot, an AP mine sensor has been evaluated that is based on a combination of a metal detector (MD) and ground-penetrating radar (GPR). The ERA radar was selected and different metal detectors brands. The sensor was tested in the laboratory under controlled conditions with the ultimate objective of conducting tests on a real minefield

Figure 3: Pemex-BE in different environments

III. BEHAVIOR BASED NAVIGATION SYSTEM

For the developed demining robot, simple fixed priority layered behavior based navigational architecture will be adequate.. A sector of land is assigned to the robot with width, depth, starting position and orientation as a reference location. This location is specified at the utmost left of the sector and toward the cleared road or pathway. Each sector is divided into lanes. The width of each lane is equal to the arc of the zigzag fine movement to the left and right sides of the robot. The search for mines is conducted lane by lane and from left to right within the assigned sector.

Pemex-BE robot behavior depends on a list of typical situations stored in memory and analyzed by a simple fuzzy algorithm. Figure 4 shows the architecture of the developed navigation system for Pemex-BE robot. The highest layer of the navigation system is a task oriented navigational layer. This layer represents a collection of high-level behaviors, which guide the robot through roughly predefined trajectory pattern to guarantee scanning coverage of the assigned sector by the robot. Environmental constraints, such as obstacles or narrow paths, etc. should through appropriate sensors, trigger lower level set of behaviors that are responsible for obstacle avoidance and stability maintenance for coverage purposes. Deviations from predefined search path caused by natural environmental influences should be recorded using suitable grid based mapping techniques. At the end of the mission, checked and skipped area should be clearly marked using incrementally built digital mapping of the terrain, together with the detected and marked mine targets. The robot can adaptively selects a suitable search pattern while negotiating the terrain, or the search pattern can be decided by a higher level of control (like a supervisory controller) using digital model of the terrain.

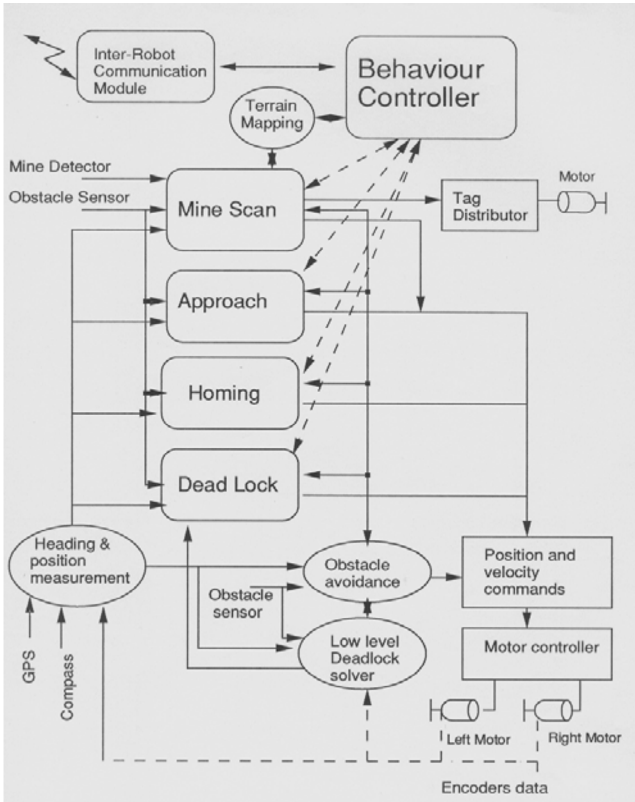


Figure 4: The developed navigation system for Pemex-BE

The Pemex-BE robot has the following core functionalities:

1. Initialize itself, perform self-check, and declare its readiness to execute a set of specified mission to a higher level of control,
2. Receive an allocated task from a higher level of control that describes a sector of land within a minefield in terms of width, depth, and the global reference starting point, i.e., enables the robot to know about the boundaries of the sector to be explored. In addition, the robot plans for its own S-

path to assure proper search coverage with sufficient overlaps while considering all possible navigational errors. Furthermore, the trajectory planner starts its work by dividing the allocated sector into lanes,

3. Search the assigned sector using the set of behaviors available at the task oriented navigational layer. The following set of behaviors are executed as needed during the searching process for mines (see Fig. 4):

a) Approach

This phase is described by the "Approach" behavior that aims to move the robot on a safe terrain in order to reach the stated global reference starting point of the assigned sector while avoiding any possible obstacles along the way.

b) Mine Search

The essential function of this behavioral phase is to generate a fine zigzag movement that is suitable to search a lane by lane completely while utilizing efficiently the effective range of the mine detector. The fine zigzag movement enables the robot to achieve a reliable search for mines and to detect any possible obstacle within any lane the robot is negotiating at the time. Since the robot is scanning a width larger than the wheel-base, obstacles may force the robot to reduce the scanning width, without the necessity to modify the trajectory as long as the available width is still larger than the wheel-base. Otherwise, the obstacle has to be avoided, and in this case the scanning amplitude on the opposite side may be reduced, because it overlaps the adjacent lane. During the mine search, behaviors from a lower layer may be triggered for avoiding and tracing the boundary of any obstacle blocking the searching process (Mine search).

c) Homing

When the robot complete the search/scan of the allocated sector, it returns to the mission lunching area using only the information available about the previously explored land within the sector (already mapped terrain), and moving backward at a faster speed using course zigzag movement.

c) Dead Lock

This behavior is executed when one of the navigational behaviors reports that it cannot exit a deadlock situation using robot's own resources. In this case, the navigational layer triggers a higher level of deadlock solver behavior. If this also fails in solving the deadlock, this behavior reports to a higher level control through the behavioral module to help guiding the robot to go out of the deadlock.

4. Lower navigational layer that includes a set of behaviors, such as, Obstacle avoidance, Mine tagging and reporting, Deadlock solver, power supply monitoring, etc.

5. Communicate through the inter-robot communication module to exchange information with other robots, and also to exchange information with a higher level control to report its activities and receiving further instructions about the task. The robot may send information about:

   a) Any detected mine with its coordinate for mapping purpose and following up,
   b) Detected deadlocks that can't be solved by robot's own resources.
   c) Ask for help and request for needed resources.

   The robots use the following communication strategies to support these activities:

   i. Communication with nearby robots (single or group of robot broadcasting);
   ii. Communication with a higher level of control (in a polling or a demand based broadcasting)

IV. CONCLUSIONS

Research into individual, mine-seeking robots is still in the development stages. In addition, robotized solutions are yet too expensive to be used for humanitarian demining operations in economically poor countries. In their current status, they need to have flexible mechanisms integrated with different type of sensors to support their autonomous navigation. In order to make these systems adaptable to various situations and type of goals to be pursued, it is necessary to dynamically select behaviors and to change their respective priority to make the system behave appropriately according to the situations it encounters in the real world.

REFERENCES

[1] T.J. O'Malley, "Seek and Destroy - Clearing Mined Land", Armada International, 1993, pp 6-15.
[2] C. King, "Mine Clearance in the Real World", SusDem97: International Workshop on Sustainable Humanitarian Demining, Zagreb, 1997, pp. S2.1-8.
[3] P.M. Blagden, "Summary of UN demining", Symposium on Anti-Personnel Mines, Montreux, April 1993, CICR/ICRC, pp 117-123.
[4] M. K., Habib, "Mine Detection and Sensing Technologies: New Development Potentials in the Context of Humanitarian Demining", 2001 IEEE IECON'2001, USA, 2001, pp. 1612-1621.
[5] International Committee of Red Cross, "Antipersonnel Mines-Friends or Foe?", Geneva, Ref. 0654, 1996.
[6] M. K., Habib," Mine Clearance Techniques and Technologies for Effective Humanitarian Demining", International Journal of Mine Action, Vol.6, No.1, 2002.
[7] M. K. Habib, "Machine Assisted Humanitarian Demining Mechanization and Robotization", International Field and Service Robots'2001, Finland, pp. 153-160.
[8] J.-D. Nicoud and M.K. Habib, "PEmex-B Autonomous Demining Robots: Perception and Navigation Strategies", IROS'95, Pittsburgh, Aug. 1995, pp. 419-424.
[9] P., Burkhanpurkar, "Design of Commercial Autonomous Service Robots" , 25th ISIR, 1993, pp. 267-272.
[10] H. R. Everett, et. al., "Coordinated Control of Multiple Security Robots", SPIE on Mobile Robots,, Vol. 2058, 1993, pp. 292-305.
[11] C., Gourley, R1. Trivedi, "Sensor Based Obstacle Avoidance and Mapping for Fast Mobile Robots", IEEE Robotics an Automation Conference, 1994,
[12] Y., Koren, and J. Borenstein, "Potential Field Method and their Inherent Limitations for Mobile Robot Navigation", IEEE Robotics an Automation Conference, 1991, pp 1398-1404
[13] C., Ferrell, "Robust and Adaptive Locomotion Control of an Autonomous Hexapod", PerAc'94 from Perception to Action, IEEE CS Press, 1994, pp 66-77
[14] F., Mondada et al, "Mobile robot miniaturization: A tool for investigation in control algorithms", ISER' 93, Kyoto, Oct 1993.