BEHAVIOR BASED CONTROL FOR ROBOTICS DEMINING

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Abstract: This paper propose a strategy for autonomous navigation of field mobile robots using a behavior based control. The premise of the proposed approach is to embed the human expert's heuristic knowledge into the mobile robot navigation strategy using fuzzy logic tools. The robot navigation strategy developed here is comprised of simple, independent behaviors. The recommendations from these behaviors are combined with appropriate weighting factors to yield an autonomous navigation strategy for the mobile robot that requires no a priori information about the environment.

Keywords: robotics, demining robot, behavior based control, fuzzy logic, landmine search strategy.

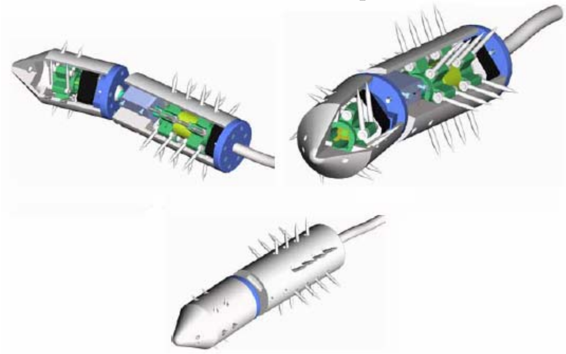
1. INTRODUCTION

Since the mid-19th century, land mines have been an accepted but deadly weapon of war. Long after international and civil battles are over, land mines remain in the ground, ready to kill or maim innocent men, women and children.
The devices primarily responsible for this carnage are antipersonnel landmines, many of which are made of plastic and can be built for as little as $3-5. They are usually about 5-40 cm in diameter (about the diameter of a medium-sized coffee cup) and some can be detonated by a force as light as 10 N (about the weight of two medium cans of soup) .
Currently, there are an estimated 100 to 120 million landmines littering the world in over 70 countries. These mines, left over from past wars, are responsible for killing or maiming 26,000 people a year, many of whom are children and farmers. In some countries, the toll is extremely high. For example, in Afghanistan, (one of the three most-mined countries) about 20 innocent civilians including children and women, daily fall victim to mines, half of whom lose their lives due to lack of medical facilities . In Cambodia, another landmine-infested area, there is one amputee for every 250 people.
Many of these devices are intended to maim, not kill, which usually means a civilian will lose a limb if a mine is detonated.
The devastating effects of these explosives extend beyond physical suffering. Tourism, another source of potential income in many developing countries, is lost because of the danger of the mines. Demining and **U**ne**X**ploded **O**rdnance (UXO) clearance are extremely tedious and dangerous tasks. The use of robots bypasses the hazards and potentially increases the efficiency of both tasks. A first crucial step towards robotic mine/UXO clearance is to locate all the targets. This requires a path planner that generates a path to pass a detector over all points of a mine/UXO field, i.e., a planner that is complete.

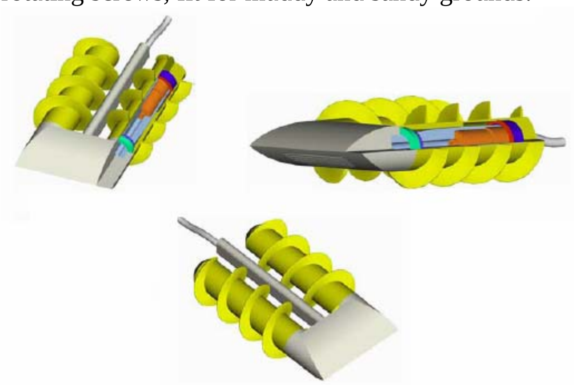
2. NEW ARCHITECTURES IN DEMINING ROBOTICS STRUCTURE

In the last decade the working systems for landmine localization designed for terrains clear and consistent are replaced by the robotic solutions based on biological locomotion suggested by the nature. .The main applications of these bio-inspired robots are the mines localization in difficult terrains and rescue. The robots are thought as mobile devices equipped

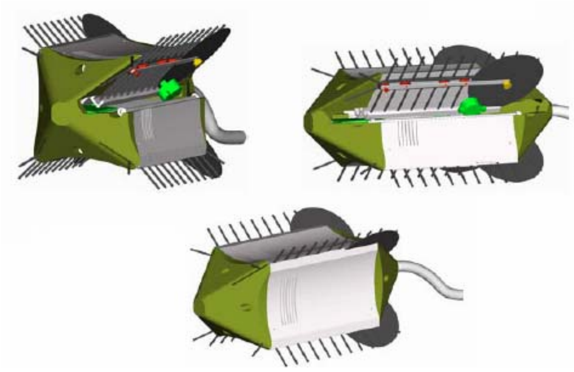
with suitable sensors in order to fulfill specific inspection tasks.
In the following figures are showns some tele-operated robotic modules based on different locomotion principles.
The locomotion of the next module is performed by means of peristaltic movements that provide trust, while grip is provided by needles that are put inside/outside the external envelope.



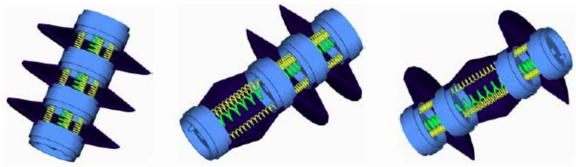
The next figure presents a module trusted by counter rotating screws, fit for muddy and sandy grounds.



The module in next figure is trusted by four needle crawlers; it is equipped with suitable detaching wheels for foliage entangled in the needles of the crawlers.



All these modules are powered by means of an umbilical that also includes wires for signals data. It is noteworthy that these modules have been designed in close collaboration with students involved in robotic courses.



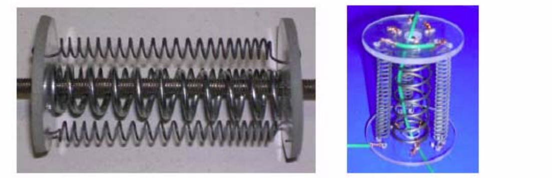


Fig. I. Three 3dof modules actuated by SMA springs.

This type of module was experimented in our laboratory (Mobile Robot Laboratory, Faculty of Control, Computer and electronics, Division Mechatronics). Each module can contract and relax or can bend in any direction to steer the snake. The central steel spring gives shear and torque rigidity to the module.

3. ACTUAL DEMINING METHODS

Manual Demining

While demining teams vary in size, each usually consists of highly trained deminers, a team leader, explosive-ordnance-disposal experts, mechanics and paramedics. Once deminers have viewed the area, they sometimes use wands to test for trip wires. They then cut away foliage with shears and pass metal detectors over the soil. If a signal is found, they use a probe to determine the cause. If the signal is caused by a mine or UXO, a team leader normally disposes of it with a small, explosive charge or, in rare cases, disarms it.
Manual deminers also work with dog detection teams to initially reduce the size of suspected minefields and to examine those where a dog indicates the presence of a mine.
Advantages: Manual demining, which can be used in almost any terrain, is the most reliable method to locate mines. Deminers have the advantage of human intelligence, can typically work for longer periods each day than dogs and can get into areas that machines cannot.
Disadvantages: Manual demining is slow, hazardous and expensive. Metal detectors may not be able to detect nonmetallic or plastic-encased mines and cannot be used on steel bridges or near railroad tracks. Metal detectors cannot distinguish between mines and other metallic objects.

Mine-Detection Dogs

Mine-detection dogs are trained to find the explosive vapors emitted from land mines and can be taught to find plastics, metals and tripwires. They can be used to make an initial survey to quickly determine if an area is contaminated. They can also be used to assess whether any mines were missed with other technologies. Each mine-detection dog works with a human handler with whom there is a close bond of trust.
Advantages: A dog's olfactory capacity for finding explosives has been proved to be highly effective in many terrains where humans operate. Dogs are environmentally friendly to agricultural land or urban areas. They can detect mines in nonmetallic or plastic

casings as well as mines near metal bridges or railroad tracks, where metal detectors are useless. They are easy to transport.

Disadvantages: Some cultures are not accustomed to treating dogs as partners and have difficulty seeing their value. Mine-detection dogs cannot work in certain terrains like swamps, jungles or underwater. They get tired after a four- to six-hour day and can get confused if more than one mine is in proximity.

Mechanically Assisted Demining

Mechanical equipment is used before, after or in combination with other demining technologies.

Brush cutters and flails clear thick vegetation to help deminers and/or dogs do their work. Rollers identify the perimeters of mined areas or exert enough pressure to explode some land mines; manual deminers or dogs double-check their work. Loaders scoop contaminated soil and take it to an area where deminers can go through it with metal detectors; this is especially helpful on roads or paths that must be traveled.

Advantages: Mechanical technologies can more speedily verify that an area is clear of land mines, allowing manual deminers to concentrate on contaminated areas.

Disadvantages: Mechanical technologies are expensive and difficult to maintain and transport. They can work only in certain terrains and environments and can disturb and destroy areas where they are used. Humans and/or dogs must follow machinery to ensure that the area is mine-free.

The current state of path planning for mine/UXO clearance is to guide a robot randomly or use heuristics .

4. ROBOTICS LANDMINE SEARCH STRATEGY

It has been believed that random strategies are suitable for inexpensive robots because of their low sensor and computational power requirements.

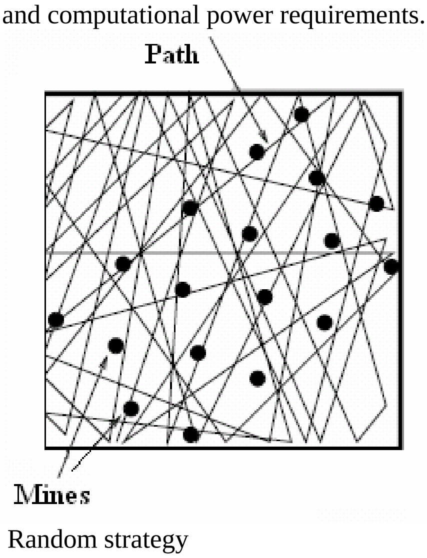


Fig. II. Random strategy

However, these strategies do not guarantee full coverage. Healey et al. (1995) analyze such a random coverage strategy for “pick up and carry away” type unexploded ordnance clearance scenarios. They characterize performance improvements with random methods by demonstrating that the number and locations of mine disposal areas can expedite the demining process. Gage (1995) also characterizes random strategies by comparing them to complete ones. He shows that random strategies start to become as effective as complete coverage when lots of robots are used or the accuracy of the detector degrades.

Other approach is the complet coverage strategy. To ensure complete coverage, is used coordinated approach.

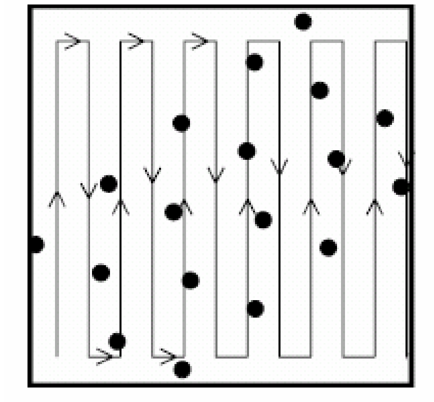


Fig. III. Complete coverage strategy

The coordinated method achieves complete coverage in a considerably shorter time than the random methods, particularly in the presence of obstacles. There exists a variety of coordinated coverage using different approaches and making certain assumptions about the obstacle configurations and the sensors. An interesting solution is based on a geometric structure called cellular decomposition, which is the union of non-overlapping subregions of the free space, called *cells*. The cells are defined in such way that simple back-and-forth motions cover each cell, and thus complete coverage is reduced to finding an exhaustive walk through the adjacency graph that encodes the topology of the cells. The framework allows us to design a path planner that uses feasible sensor systems and works in more general obstacle configurations. Is no need to place a grid on the space or to assume that only polygonal obstacles exist. These attributes of the framework become especially important for demining because minefields are inherently unstructured.

Thus far, we have outlined complete coverage which does not require a priori information at all.

The probability algorithm utilizes the prior information. If we know certain information about the minefield, e.g., the mine laying pattern, we can expedite the demining process.

For example, when ground vehicles or humans place mines, they tend to follow a regular pattern. This information, which can reflect the structure of a minefield, can be exploited to guide a robot opportunistically when the resources are limited.

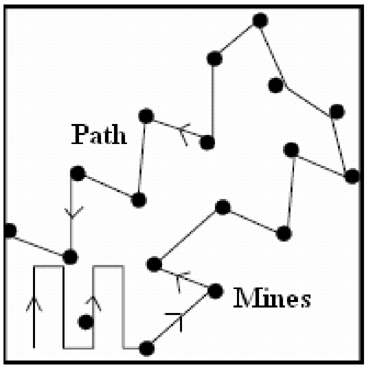


Fig. IV. Probabilistic strategy

For example, the mines can be laid out using a regular pattern that has rows and columns. By simply identifying the intended inter-row and inter-column spacing, the robot can bypass exhaustively covering the entire region by driving to the probable mine locations.

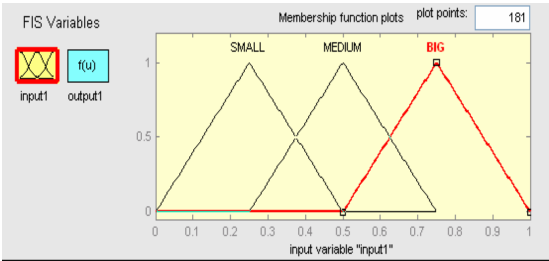
5. BEHAVIOR BASED CONTROL APPROACH

Behaviors are the fundamental building blocks of Behavior Based Control (BBC) and the basis for a behavior arises from different view points for Example it may a copy of an animal's behavior or it may a behavior designed experimentally. Behaviors are simply taking sensory inputs from sensors and producing some outputs to the actuators. The mapping of input to output is done in two ways called discrete encoding and continuous encoding. Discrete encoding may be a rule base based on Fuzzy Logic or it may be some finite set of (situation, response) pair. Fuzzy Logic based encoding provides robust behavior while facilitating online adaptation.
The assembling of behaviors is necessary when we have more than one behaviors producing output to the same actuator at the same time. Assembling is done in two ways in behavior based control system, one is called competitive where the behaviors are assembled in priority order and when the behaviors with high priority is active it suppress or inhibits the output of the low priority behavior output. The other one is cooperative where the outputs or active behaviors are considered in some way (may be just an addition) to produce an out put to the actuators.
In this paper is proposed a five layer competitive BBC for demining robot, in order to assure a complete combinative search strategy and an increased control of fault sensor indication.

5.1 Strategy Selector Behavior

First level of the behavior based controller is dedicated to strategy selector. As was presented every strategy have advantages and disadvantages. In order to assure a complete demining robot, the strategy selector level will have to implement all the search strategy. The inputs for this level is the operator selection and the coordinates for the mine deploy point, start demining point and the end point of landmine search area. The operator selection is the highest level priority input.
The differences between the start point and the end point offer information concerning demining area for first step $A=(x_{Start}-x_{end})(y_{Start}-y_{end})$, and after first step the Start coordinates are replaced by the Last Mine (detected) coordinate $A=(x_{Last\ Mine}-x_{end})(y_{Last\ Mine}-y_{end})$
The selection for search strategy based on the landmine area conduct to following fuzzy rules:

- IF A is SMALL, THEN RANDOM.
- IF A is MEDIUM THEN COMPLETE.
- IF A is NOT BIG THEN PROBABILISTIC.



The membership SMALL, BIG, MEDIUM are triangular membership and RANDOM, PROBABILISTIC, COMPLETE are crisp specific strategy coordinates.

5.2 Target Behavior

The problem addressed in this section is to navigate a mobile robot on a natural terrain from a known initial position to a user-specified goal position. The control variables of the robot are the rotational speed for left and right wheel. These variables are represented by three triangular linguistic fuzzy sets {FAST,LOW, ZERO}. The fuzzy navigation rules for the TARGET BEHAVIOR are divided in rules for robot orientation and for robot target approach.
The fuzzy rules for the robot rotational motion are as follows:

- IF φ is FAR-LEFT, THEN ω_{Left} is FAST.
- IF φ is NEAR-LEFT, THEN ω_{Left} is SLOW.
- IF φ is NEAR-RIGHT, THEN ω_{Right} is SLOW.
- IF φ is FAR-RIGHT, THEN ω_{Right} is FAST.

where φ the heading error is represented by the five linguistic fuzzy sets{F AR-LEFT, NEAR-LEFT, HEAD-ON, NEAR-RIGHT, FAR-RIGHT}.
The following rules are used for the robot trans-lational motion:

- IF d is VERY-NEAR OR φ is NOT HEAD-ON, THEN ω_{Left} is ZERO and ω_{Right} is ZERO.
- IF d is NEAR AND φ is HEAD-ON, THEN ω_{Left} is SLOW and ω_{Right} is SLOW.

- IF d is FAR AND φ is HEAD-ON, THEN ω_{Left} is MODERATE and ω_{Right} is MODERATE.
- IF d is VERY-FAR AND φ is HEAD-ON, THEN ω_{Left} is FAST and ω_{Right} is FAST.

where the position error (goal distance) d is represented by the four linguistic fuzzy sets {VERY-NEAR, NEAR, FAR, VERY-FAR}.

5.3 *Avoid-Obstacle Behavior*

The mobile robot has three groups of proximity sensors mounted on front, right, and left of the robot facing. Each sensor transmits the distances between the robot and the closest obstacle from his direction. Using three linguistic fuzzy sets {VERY-NEAR, NEAR, FAR} for each sensor the fuzzy rules are:

- IF di is VERY-NEAR, THEN ω_{Left} is ZERO and ω_{Right} is SLOW.
- IF di is NEAR, THEN ω_{Left} is ZERO and ω_{Right} is SLOW.

where i is front, left, right sensor and distances.

5.4 *Safe Sensor Behavior*

The most dangerous situation is the situation when the sensing ability of demining sensor is affected.
If positive error (false indication of mine) conduct to increasing the exploration time, which is not a dangerous situation, the negative error (mine is not detected) conduct to a hazardous situation. To solve this situation are used two demining sensor $S_{demining\ 1}$ and $S_{demining\ 2}$. From 5 to 5 minuts, the robot is stoped and are send to sensors test signal. If the sensor respons are FALSE, MEDIUM, TRUE then the following fuzzy rules are taken:

- IF ($S_{demining\ 2}$+ $S_{demining\ 1}$) is FALSE THEN HOME.
- IF ($S_{demining\ 2}$+ $S_{demining\ 1}$) is MEDIUM THEN THEN ω_{Left} is SLOW and ω_{Right} is SLOW.

HOME is movements which follow the anterior coordinates from the current point to start position.

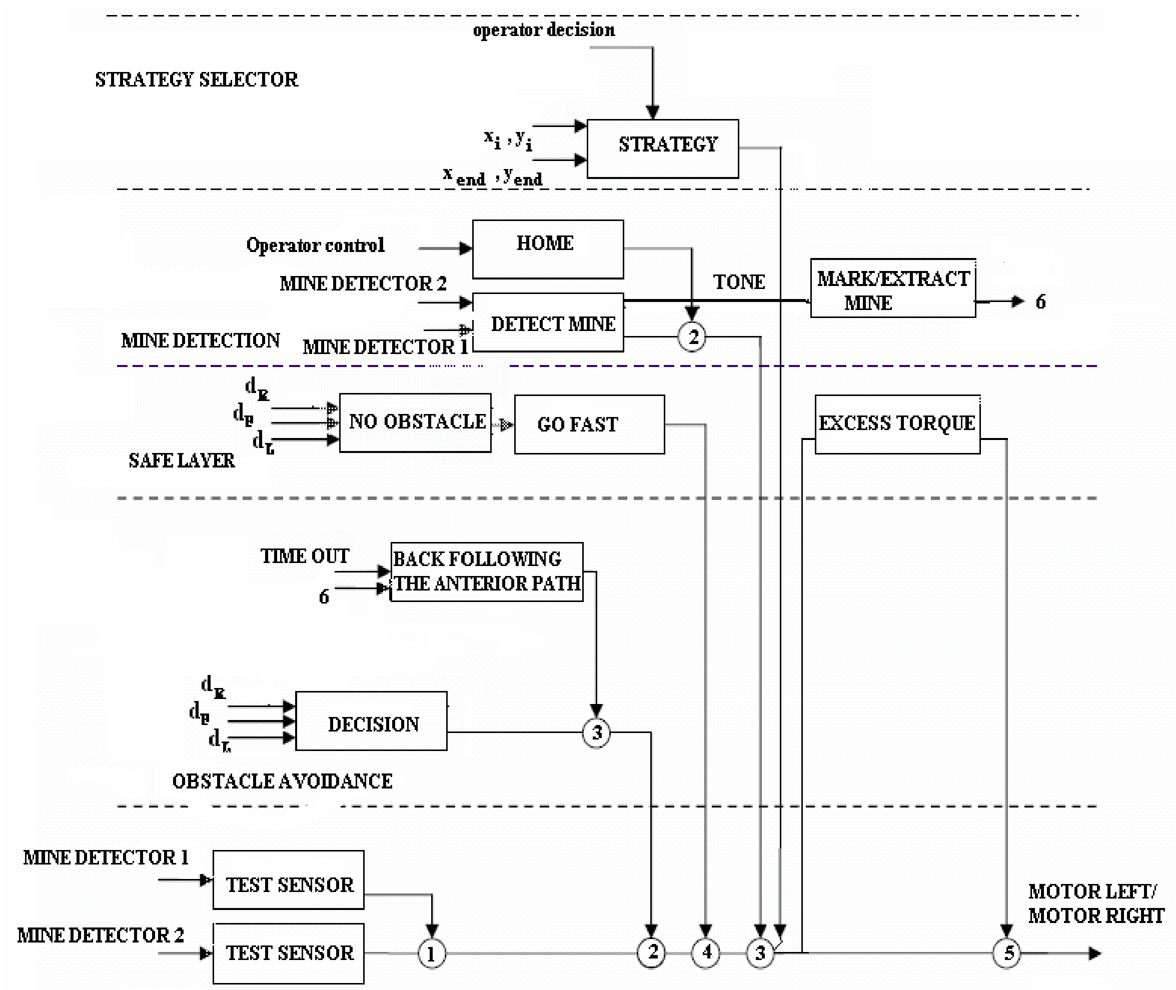


Fig. V. Behavior Based Control (BBC)

5.5 Combination of Multiple Behaviors

Combining behaviors in case of dangerous action seems to be a very risky strategy. In reality, human operator, act in a similar mode: evaluate the situation, extract the main characteristic/characteristics for the actual situation, decide which action is suitable for the robotic structure, related to current situation. The selection is made from a mental list of possible activities. If this decision chain is compare with fuzzy logic, one can find that the correspondence is perfect. The main task is to find all the possible behavior and especially the main elements which conduct to proper behavior selection. For this case the distance between current robot position and the final point of landmine search (target point) is the main selector. In developing fuzzy logic controller based on behavior arbitration are two approaches:

- from the possible behavior only one is selected and all other are ignored
- all five behavior have independent recommendation. Combining all the recommendations using different gain or weighing factor a decision is made combining the possible selected behavior.

Using first strategy, in the Figure V, we indicate the priority of each behavior. Every behavior has his neutral rule, and in case that the behavior is not activated, the arbitration strategy goes the next inferior priority level.

For the second strategy, we impose to every moving behavior his weighting factor, and decision rules:

For safe layer, the weight factor is s^w with two variable HIGH and NOMINAL (neutral, non firing value) and the rules are:

• IF d is VERY-NEAR OR d_i is VERY-NEAR, THEN, THEN s^w is NOMINAL.

• IF d is NOT VERY-NEAR AND d_i is NOT VERY-NEAR, THEN s^w is HIGH.

For obstacle avoidance layer, the weight factor is o^w with two variable HIGH and NOMINAL (neutral, non firing value) and the rules are:

• IF d is VERY-NEAR, THEN o^w is NOMINAL.

• IF d is NOT VERY-NEAR, THEN o^w is HIGH.

For target behavior layer, the weight factor is t^w and the rules are:

• IF d is VERY-NEAR, THEN t^w is HIGH.

• IF d is NOT VERY-NEAR, THEN t^w is NOMINAL.

The resulting crisp weights are then used to compute the final control actions for left and right turn rate wheel using the Centroid method.

6. CONCLUSION

The proposed Behavior Based Controller is a promising structure.

The apparent complexity of layered controller is compensated by the rule simplicity.

Still for this type of controller the selection of possible behavior, decision elements and weight factor are important.

The human experience used as decision model is as in reality a subjective decision. For the case of landmine detection, after a robotic inspection and mine removal, still a manual demining and inspection is required for the confirmation of safe area.

The main problem for robotic demining team is the sensor precision.

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