IEEE/RSJ International Workshop on Intelligent Robots and Systems IROS '91, Nov. 3-5, 1991, Osaka, Japan. IEEE Cat. No. 91TH0375-6

Avoidance of Unknown Obstacles Using Proximity Fields

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ABSTRACT

This paper presents a novel real-time obstacle avoidance approach based on proximity sensing. The scheme is designed for the two dimensional navigation of a point object in a totally unknown environment. Navigation is performed by utilizing two proximity sensors of different settings in conjunction with a simple memoriless rule for motion control. Simulation results are given for different types of obstacles. The algorithm has also been implemented on an Adept-1 arm manipulator.

I. INTRODUCTION

Algorithms for path planning and collision avoidance may be divided into two categories; algorithms requiring complete information about the work space "the piano moving problem", and those where no a priori knowledge is present where the information appears on-line from a robot sensor [1]. Processing in the first category is usually carried out off-line with concerns regarding the computational efficiency. However, because little information is being processed by the second scheme, concerns are mainly focused on guaranteeing convergence of motion. Although information obtained from the sensors is local in nature, the algorithm has to demonstrate an acceptable level of global convergence in real situations. Various types of sensors have been used in the past; such as, bumper switches, shaft encoders, sonar transducers [2], proximity sensors [3], laser range finders [4], and vision [5]. Some of these sensors were even fused together for better performance [6]. Although sensing can be arranged such that the conveyed signal is very rich in information, convergence of motion is greatly dependent on the planning algorithm. Several algorithms demonstrated their ability to converge to the target. However, a limited number of these were able to provide a theoretical proof of the global convergence. Many of these global algorithms are relatively involved and they require expensive sensors and a memory [7]. Some heuristics for the navigation of robots were experimentally obtained to help achieve global convergence [8].

This paper describes a method of using two inexpensive proximity sensors of different settings to help navigate a robot in an unknown environment. The proposed algorithm does not require any memory and is very easy to implement. Although no theoretical proof of convergence is provided, experiments and extensive simulation are used to demonstrate the ability of the method to manoeuvre its way to the target in a relatively difficult environment.

The paper is organized as follows; in section II the algorithm is provided and some simulation results are presented; in section III some implementation aspects are discussed, a flow chart to implement the algorithm on an Adept-1 robot is provided, and some experimental results are given. Conclusions are provided in section IV.

II. The Obstacle Avoidance Algorithm

The proposed algorithm utilizes two infrared proximity sensors with two different settings, a short range (SRS) and a long range (LRS). The sensors are used according to the following rules :

1. Move to the target along a straight line orienting the sensors in the direction of motion.

2. If the SRS detect an obstacle, stop and use the LRS to determine the right and left boundary angles.

3. Using these angles with an added safety factor, move in the direction of the closest angle along the straight line connecting the current position with the target.

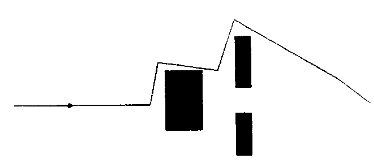
4. Move along the new direction a distance which is equal to the difference between the settings of both sensors. Keep the LRS

oriented towards the obstacle.

5. If the LRS ceases to detect any obstacle, the previous steps are repeated, otherwise the path is reevaluated at the end of motion.

The above scheme is designed to alleviate some of the problems frequently encountered by schemes using beam-type sensors. For example, leaving the LRS pointing toward the object in step 4 reduces the chance of missing an opening that may lie between adjacent obstacles. This improves the chance of the robot selecting a shorter path to the target. Gaps detectability is, also, enhanced by the use of infrared sensors which have a relatively narrow beam width. The settings of the sensors are chosen to correspond to the expected dimensions of the obstacles as well as to the expected spacing between them. This is found to enhance the probability of fast reliable convergence; in fact convergence is almost guaranteed in case of convex obstacles. The scheme can be further enhanced by adding a third intermediate range sensor.

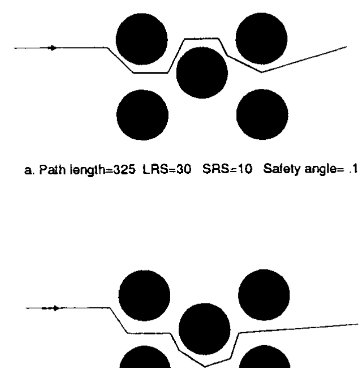
In the following, (figures 1,2, and 3) the method is simulated for different types of barriers. Included is a particularly difficult situation where the robot is required to manoeuvre its way out of a maze (fig. 3).



a. Path length=535 LRS=30 SRS=15 Safety angle= .1 rad

b. Path length=477 LRS=25 SRS=15 Safety angle= .1 rad

Figure - 1



a. Path length=325 LRS=30 SRS=10 Safety angle= .1 rad

b. Path length=345 LRS=35 SRS=10 Safety angle= .1 rad

Figure - 2

Figures 1 and 2 demonstrate the algorithm's ability to navigate efficiently around obstacles with sharp edges (figure 1) and smooth edges (figure 2). Also shown in these figures is the effect of varying the setting of the LRS on the selected path. It is noticed that in a cluttered environment, a reduced setting of the LRS produces a shorter overall path length.

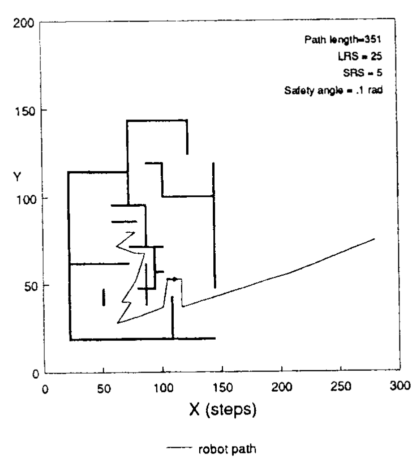
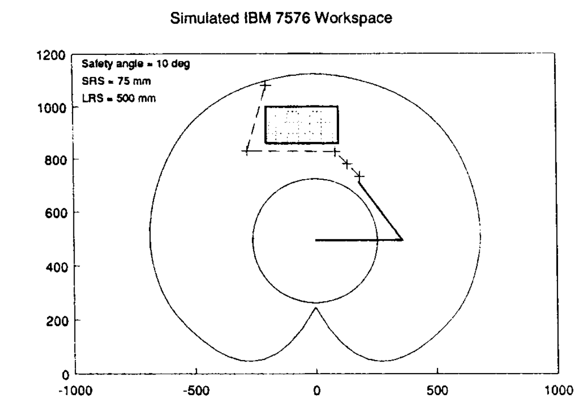


Figure - 3

Figure 3 demonstrates the ability of the technique to perform satisfactorily for maze-type obstacles. For such kinds of obstacles we found that small setting of SRS and a relatively large ratio of LRS/SRS enhances its ability to move in such a complex environment



Scales in millimeters

Figure - 4

In figure 4 the AML/2 robot simulator was used to show the ability of the algorithm to perform under the constraints of an IBM 7576 robot which is similar to the ADEPT-1 robot.

In the next section, the algorithm is implemented on the Adept-1 robot and experimental results are provided.

III. Implementation

This section discusses some general aspects concerning the proposed algorithm. We, also, provide details and a flow chart of the algorithm used to realize the technique using an Adept-1 arm manipulator. Experiments are conducted on the arm, and the results are presented.

An important aspect of operation is to choose the appropriate settings for the proximity sensors. We are operating under the assumption that the minimum spacing between the obstacles is large enough for the robot to pass through. We, also, assume the existence of an upper and a lower bound on the size of the obstacles. Since the primary job of the SRS is to prevent collision, its setting is chosen to guarantee that the arm will safely stop before colliding with the object. The factors governing this choice are primarily related to the mass of an eventual load and the characteristics of the controller. On the other hand the function of the LRS is to detect the boundaries of the obstacles or openings in order for the robot to pass through. An inappropriate setting of this sensor may lead to a loss of the ability of the scheme to converge to the target. We experimentally found that choosing the setting of the LRS close to the upper bound of the obstacles yields very satisfactory results in all the cases that were examined. Such a choice improves the probability of boundary detection. Leaving the sensors pointing toward the obstacles during the motion greatly reduces the chance of missing any gap.

Since the path produced by the method consists of straight-line segments, the direction that the robot chooses for avoiding an obstacle has a great effect on reducing the length of the path and making it as close as possible to the optimal one. In our case, when the SRS detects an obstacle a line is constructed connecting the current coordinates of the robot with those of the target. This line is used as a reference for the LRS to sweep the object in order to detect its boundaries. The smallest angle in the c.w. or c.c.w. direction is chosen as the new direction. To ensure safety, a safety angle (Θ_s) is added. This angle is computed as :

$$\Theta_s = \arctan(dm/2R_{ls})$$

where, dm is the minimum gap distance, which is required to be greater than the dimensions of the robot's end effector, and R_{ls} is the setting of the LRS. The sensors used are EX-D200E and EX2-D300 proximity sensors supplied by Sandtron Automation Ltd. Specifications regarding the sensors and the Adept-1 arm can be found in [9,10] respectively.

Experiments are carried out for two cases (figures 5 and 6), one with several objects in the work space, and the other with barriers surrounding the arm. In both cases, the robot successfully manoeuvred its way to the target. A point worth mentioning, is that the path in both cases, does not contain any redundancies, and it is close to the optimum. This observation was also seen for the cases that were simulated.

Figure 5 represents the results of an implementation on an ADEPT-1 robot, the solid line shows the path in the presence of obstacles. The dashed line represents the path without any obstacles. Small deviations are present close to the goal position due to round-off errors in calculating the straight line path. Figure 6,7 and 8 show the results of the implementation in a more complex environment.

Figure - 5

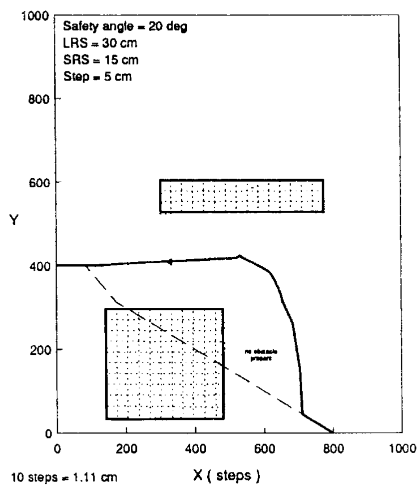


Figure - 6

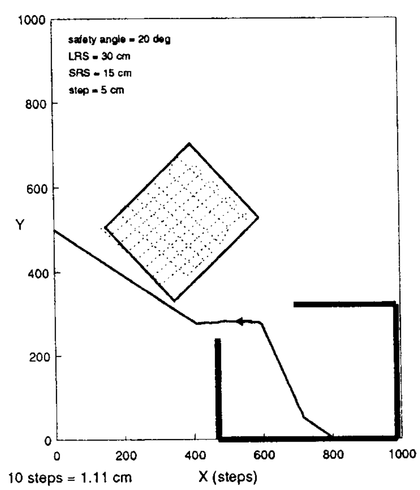


Figure - 7

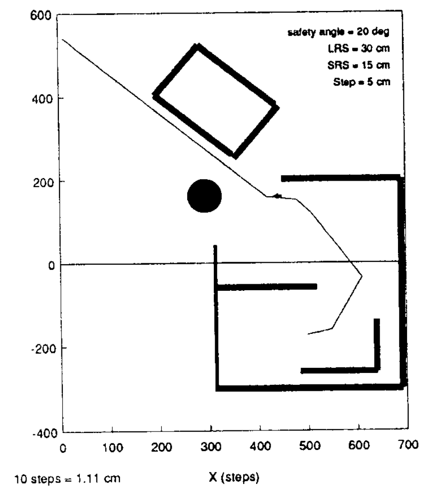
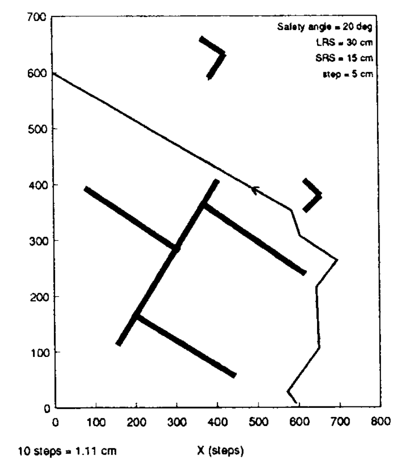


Figure - 8



In the following (figure 9), a flow-chart for implementing the technique on the Adept-1 arm is provided. The following are definitions of the variables used in the flow-chart:

- Straight : A Boolean variable, a value of TRUE indicates that the robot is heading toward the target, else it is avoiding an obstacle.
- Object : A Boolean variable, which indicates whether the robot is avoiding an object or not.
- Around : Temporary place holder used when going around the object in steps. It holds the incremented steps to ensure that avoidance does not continue past a given distance of LRS-SRS.
- Long : Boolean output from the LRS. It indicates the value TRUE if an object is within the long range.
- Short : Boolean output from the SRS. It shows the value TRUE if an object is within the short range.

When the LRS has detected an obstacle but the SRS has not yet done so, the robot approaches the obstacle by a pre-set step. This step is not included in the general algorithm and was included for practical purposes.

IV. Conclusions

In this paper, we present and implement a simple scheme for avoiding unknown obstacles. Despite the simplicity of the technique and its ease of implementation it is found to perform efficiently in real situations. However, some difficulties in setting the sensors were experienced when the target is surrounded by a number of obstacles or when the robot attempts to find an opening in the relatively long wall to proceed to its target. We expect that such a difficulty can be overcome by introducing a third intermediate sensor, which could enhance the performance with minor modifications to the algorithm logic. Overall, when compared to other more sophisticated techniques utilizing richer sensing and more involved logic, the performance of the proposed technique is considered to be quite satisfactory.

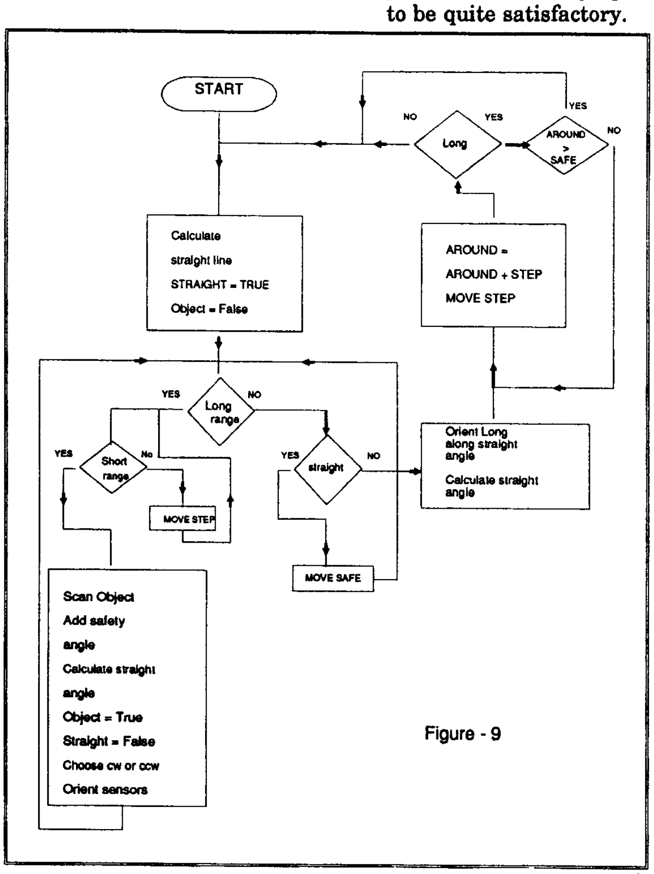


Figure - 9

Acknowledgment

We would like to thank Sandtron Automation Ltd. for the use of the photoelectric sensors used for the experiments shown in this paper. The authors acknowledge the financial support of the Manufacturing Research Corporation of Ontario, the Institute for Robotics and Intelligent Systems, the Electrical Engineering Department and the School of Graduate Studies and Research, Queen's University.

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