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Optimal path planning and navigation for an autonomous mobile robot

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ABSTRACT

This paper presents a methodology of path planning and navigation for an autonomous mobile robot. A fast algorithm using decomposition technique, which computes the optimal paths between all pairs of nodes, is proposed for real-time calculation. The robot is controlled by fuzzy approximation reasoning. Our new methodology has been implemented on a mobile robot. The results show that the robot successfully navigates to its destination following the optimal path.

I. INTRODUCTION

A mobile robot sometimes gets trapped by obstacles or deviates from an optimal path. To avoid being trapped and navigate it efficiently, optimal path planning is necessary. We propose a shortest path planning method that decomposes the world map into several sectors for real-time calculation. The basic idea of robot navigation is to pass through the nodes on the shortest path. In order to pass through the nodes continuously and smoothly, the mobile robot should curve at the nodes without sharp turn. An Intelligent control scheme using fuzzy approximation reasoning is applied for robot control. The linear and angular velocity of the robot are computed by fuzzy logic controllers to minimize deviation from the optimal path. A proposed method for path planning is presented in section II and fuzzy logic control is described in section III. Some experimental results with our two-wheel driven indoor robot are presented in section IV.

II. PATH PLANNING

We propose a new shortest path algorithm for a mobile robot, which computes optimal paths between all pairs of nodes. General shortest path algorithms provide optimal paths between any pair of nodes. But these algorithms impose a heavy computational burden. Therefore the paths can not be computed in real-time when there are many nodes in the world map. We decompose the world map into several sectors in order to compute the paths much faster. The optimal network decomposition algorithm[2] decomposes a network into a number of smaller subnetworks with a minimum number of cut-nodes. In the decomposed network, any path from a node in a subnetwork to a node in another subnetwork must include at least a cut-node. This does not exclude the possibility that the shortest path between two nodes in a subnetwork passes through nodes in any number of other subnetworks. Theorem 1 of [1] describes a sufficient condition that warrants the shortest paths solution of a subnetwork calculated independently of other subnetworks. The algorithm calculating the shortest paths by optimal decomposition consists of the following steps.

Step 1 : Decompose the network using the optimal network decomposition algorithm of [2], and obtain the decomposed cost and initial successor matrices.

Step 2 : Compute the shortest paths between all pairs of nodes in the cut-sets, considering all possible paths in the network.

Step 3 : Compute the shortest paths for each subnetwork.

Step 4 : Compute the shortest paths between all pairs of nodes that are in different subnetworks.

III. NAVIGATION

The basic idea of mobile robot navigation is to pass through the nodes which are determined by the shortest path algorithm. One of the methods to move through three nodes is as follows. First it goes straight to an intermediate node and stops at the node. Second it turns left or right until its heading is adjusted toward a next node. Finally it starts to move straight to the next node(see Fig. 1). By repeating this procedure, it can move to a destination. But this navigation method is undesirable because the mobile robot can not move fast and continuously. Therefore the mobile robot must be controlled to pass through the nodes smoothly with curve and the deviation from a direct path must be minimized not to collide with obstacles. A desired trajectory is presented in Fig. 2. The following objectives should be considered to control the mobile robot to navigate smoothly and safely.

- The heading of the mobile robot must direct toward an intermediate node.
- The mobile robot must pass through the node with a tangent line.
- Entering angle θ_1 must be similar to leaving angle θ_2. θ_1 and θ_2 are defined in Fig. 2.
- A deviation from the direct path must be minimized.
- The robot must be able to navigate fast and smoothly.
- Control inputs for the mobile robot must be calculated on-line.
- The navigation scheme must be robust for the robot to be able to move in various environment.

The mobile robot navigates in a circumstance where there are many obstacles and there is lots of uncertainty in sensor readings. Therefore it is difficult for one to achieve a good performance in mobile robot control using conventional control schemes. We used fuzzy logic control. A mobile robot can be controlled easily by using fuzzy logic scheme because a fuzzy logic controller(FLC) is based on the heuristic decision. Our FLC is divided into 5 sub controllers so as the fuzzy rules to be simple. Angular velocities of the robot are computed by 3 FLCs and linear velocities are controlled by 2 FLCs(see Fig. 3). Each FLC consists of two inputs and one output. Type A, type B and type C represent three cases for the angular velocity control. The inputs of each of them are θ and d, and the output of them is angular velocity. Type D and type E represent two cases for the linear velocity. The inputs of each of them are d and w, and the output of them is linear velocity. Type A is for passing through an intermediate node smoothly without sharp turn. In this situation, the angular velocity must be controlled as follows. The mobile robot turns left as it approaches to an intermediate node closely and it turns right for its heading to direct the node as it arrives at the node. Type B is for controlling its heading toward the node. We use the change of the line-of-sight angle as well as the line-of-sight angle in order to prevent the oscillation. The results will be shown in IV. Type C is for reducing deviation from a direct path. When the mobile robot is far from the path, it turns left or right toward the path. Type D is the case when the mobile robot approaches to a node. When the mobile robot is far from the node and the angular velocity is low, it moves fast. On the other hand, when it is near the node and the angular velocity is big, it moves slow. Type E is for reducing a deviation from a direct path. When it is far from the path and its angular velocity is big, it moves slowly. When it is near the path and its angular velocity is small, it moves fast. The fuzzy logic control system is based on a linguistic description of control strategy. An example for type A is described as follows.

If the distance d from the robot to a goal node is big and the angle θ is positive big, the mobile robot turns right in average angular velocity.

If d is small and θ is negative small, then it turn left slowly.

⋮

In order to navigate the robot, these FLCs are executed in sequence(see Fig. 4). For example, as the mobile robot approaches to node N2, it uses the angular velocity of type B FLC until it is within a certain range. As it is in the range, it turns with the angular velocity which is determined by type A and B FLC(1). When the robot is near the node N2, to pass through the node is more important than to pass by it with curve. Because if the robot deviates from the node N2, then it may collide with an obstacle. A weighting factor is applied to adjust two angular velocities from type A and type B as follows.

$$w = (1-r) \times w_1 + r \times w_2$$
$$r = \frac{1}{(1+d^2)}$$

where w is an angular velocity for an actuator of the robot. w_1, w_2 are the outputs of the FLCs for type A and type B respectively. d is the distance from the robot to node N2. After it passes through the node continuously and smoothly, finally it turns to land on the path with the angular velocity from type C FLC(2).

IV. EXPERIMENTS

These methods, path planning and navigation, are implemented on our mobile robot. A Labmate developed by Transitions Research Corporation has been used as a test bed in our experiments. It is a two wheeled, four castered indoor robot. The robot has a maximum linear speed of 1 m/sec and a maximum angular velocity of $128°/sec$.

An example of our experiments for FLCs is shown in Fig. 5. Fig 5 (a) shows the results when only the line of sight angle is considered and Fig 5 (b) shows the results when the change of the line of sight angle is also considered. The oscillation is attenuated by using the change of the angle as a fuzzy input. An experiment for the shortest path planning is shown in Fig. 6. The working area is a section of a pilot FMS(Flexible Manufacturing System) plant at the Automation and Systems Research Institute of Seoul National University[4]. The size of the area is $16m \times 6m$. The trajectory shows the results when the robot moves along the shortest path by the proposed shortest path planning.

V. CONCLUSION

This paper presents a new method of optimal path planning and navigation for an autonomous mobile robot, which performs task-oriented navigation in FMS. Optimal paths are calculated by our shortest path algorithm. The algorithm divides a working area into small size sectors so as to calculate optimal paths much faster. The mobile robot actuator is controlled by the fuzzy logic controllers. The mobile robot can move through cluttered obstacles and navigate in fast, smooth and continuous motion. Our experiments show that without human control the mobile robot can navigate to a destination following an optimal path.

ACKNOWLEDGMENT

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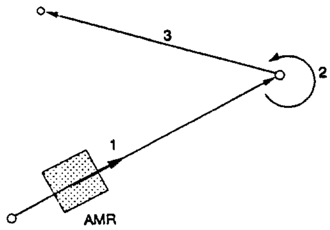

Fig. 1. Direct movement of a mobile robot.

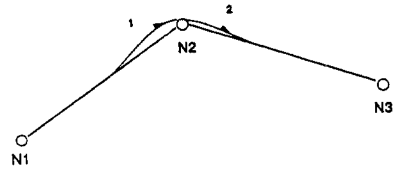

Fig. 4. Desired trajectory bending at a node.

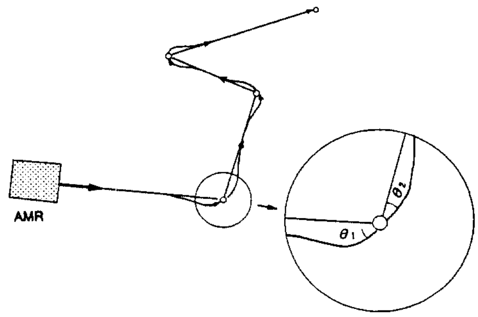

Fig. 2. Desired trajectory for a mobile robot.

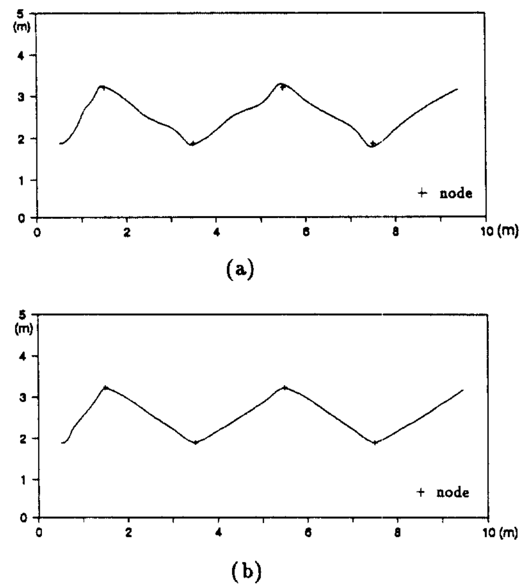

Fig. 5. An example of navigation.

a) Only the line of sight angle is considered.

b) The change of the angle is also considered.

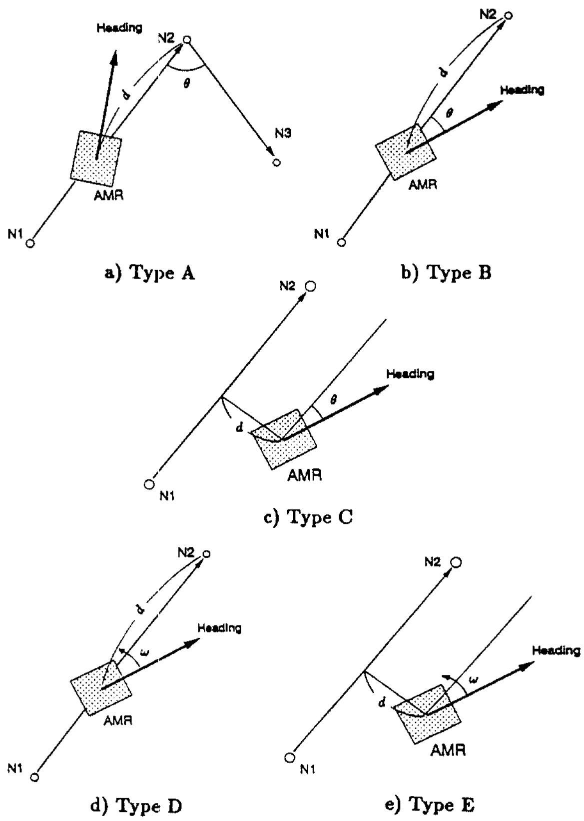

Fig. 3. Fuzzy logic controllers for a mobile robot.

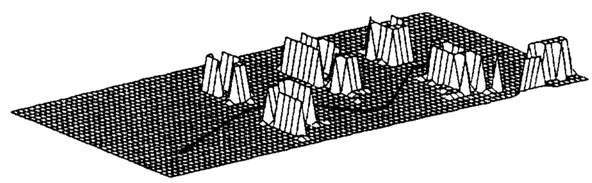

Fig. 6. A shortest trajectory in our factory.