Mobile Robot Motion by Integration of Low-Level Behavior Control and High-Level Global Planning

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ABSTRACT

This paper presents an efficient strategy for integrating low-level reactive behavior control and high-level global planning for robot motion. In low-level behavior control, robot navigation in unknown environments is performed by behavior fusion using fuzzy logic; while a high-level planning method is used to determine robot motion direction since some information on environments is prior knowledge in many applications. Using behavior fusion by fuzzy logic, a mobile robot is able to directly execute its motion toward a goal position according to range information about environments, acquired by ultrasonic sensors, without the need for trajectory planning. A global planner, therefore, only needs to generate some subgoal positions rather than exact geometric paths. Because such subgoals can be easily removed from or added into the planner, this strategy reduces computational time for global planning and is flexible for replanning in dynamic environments. Simulation results demonstrate that the proposed strategy can be applied to robot motion in complex and dynamic environments.

1. INTRODUCTION

This paper presents an efficient strategy for connecting low-level behavior control with high-level global planning. Since low-level behavior control has real-time response and reliability, it is suitable for dealing with unknown obstacles in dynamic environments. Fig.1 shows robot motion in an unknown environment using behavior fusion approach proposed in [1][2]. This simulation shows that, without using global information, the robot can not generate a good path to reach a specified target. If some information on environments is prior knowledge, a high-level global planning approach can be combined with low-level behavior control to improve the performance of robot navigation.

Behavior based control mainly suffers from two significant problems: 1. The quantitative formulation of reactive behavior. 2. The efficient coordination of conflicts and competition among multiple types of behavior. The coordination of multiple sorts of behavior by inhibiting those with lower levels [3], however, is highly contentious when a mobile robot executes complex tasks in complex environments. Fig.2 shows that the robot is unable to get through a narrow channel to reach a given target. The reason is that the robot always activates a single behavior, obstacle avoidance, when it approaches this channel, so that it turns to right to move into a large free space.

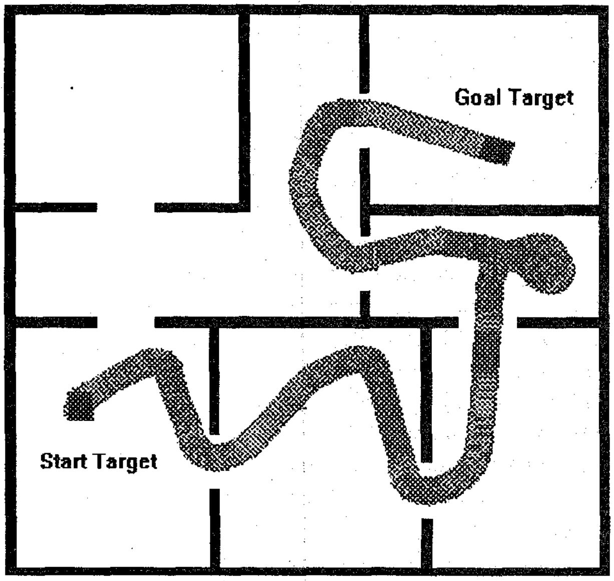

Fig. 1. Robot navigation in unknown environments by low-level reactive behavior control

In [1][2], we have proposed a fuzzy logic based behavior control scheme for robot navigation in uncertain environments. Fig.3 shows that, by behavior fusion using fuzzy logic, the performance of robot navigation can be greatly improved. In addition, since this method is orthogonal to strict geometrical computation on environments, it is more robust than the artificial potential field approach [4][5]. This method also differs from fuzzy control approaches for obstacle avoidance in [6]-[8] since perception and decision units in this method are integrated in one module by use of the idea of reactive behavior, and they are directly oriented to a dynamic environment to improve real-time response and

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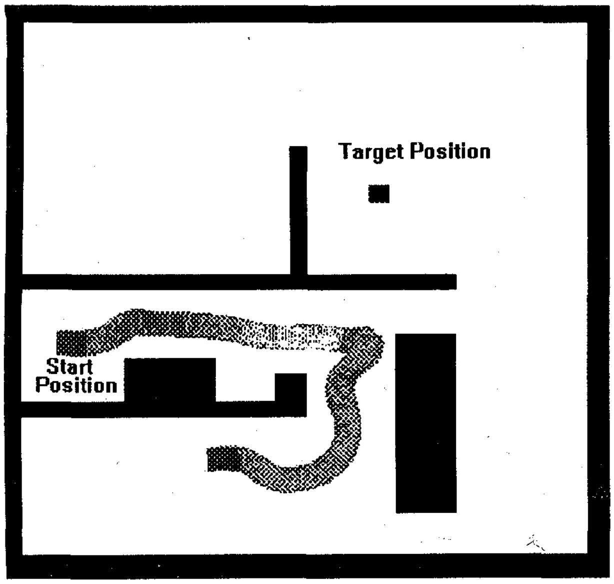

Fig. 2. Robot navigation in uncertain environments according to priority strategy

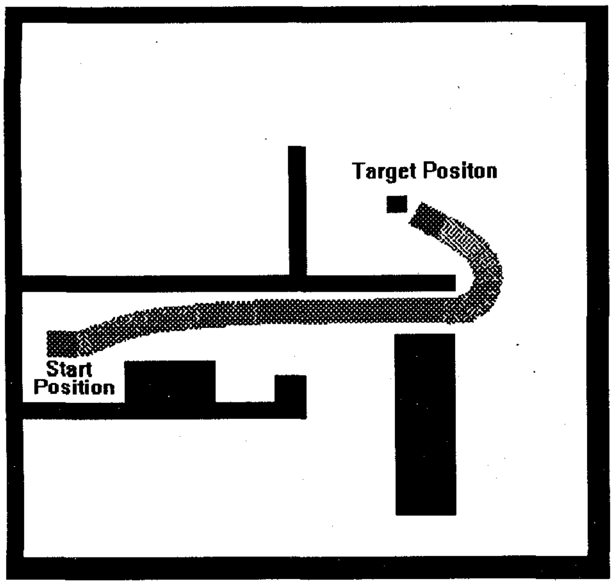

Fig. 3. Robot navigation in uncertain environments by behavior fusion using fuzzy logic

reliability.

Since we are aware of few strategy for integrating fuzzy logic based behavior control and high-level global planning, on the basis of the behavior fusion approach proposed in [1][2], a geometric algorithm "Voronoi Diagram" [9] is used to generate some subgoals according to prior knowledge on environments. Using behavior fusion, a robot is able to directly execute its motion toward a goal position according to range information about environments, acquired by sensors, without the need for trajectory planning. Therefore, global planning only needs to generate some subgoal positions rather than exact geometric paths. Since such subgoals can be easily removed from or added into the planner, this strategy is flexible for replanning in dynamic environments. To demonstrate the effectiveness and the robustness of the proposed strategy, graphical simulations on robot navigation are reported.

This paper is organized as follows: Section 2 gives a brief introduction to behavior based control. Section 3 presents the description of reactive behavior using fuzzy logic. Some fuzzy rules are also given in this section. Section 4 explains the method to fuzzy reasoning, which is used to perform behavior fusion. Section 5 proposes a strategy for combining low-level reactive behavior control with high-level global planning. In section 6, we give some discussions of the proposed approach.

2. BEHAVIOR BASED CONTROL

Behavior control is based on the stimulus-response behaviors in bio-systems. Its idea is used to decompose robot complex tasks into several types of reactive behavior with simple features. The usual approach for implementing behavior based control is the use of artificial potential fields. In combination with artificial potential fields, an inhibiting and suppressing strategy is used to fire a single behavior. In experiments, some deficiencies of this strategy are noted as follows:

1. Much effort must be made to test and to adjust some parameters of potential fields and thresholds for firing reactive behavior during preprogramming.

2. Robot motion with unstable oscillations between different types of behavior may occur in some cases. This is because just only a single behavior could be activated at a given instant and two types of behavior with neighboring priorities, e.g., obstacle avoidance and following edges, as shown in Fig.4, are fired in turn.

3. Some targets can not be achieved only by firing a single behavior at a given instance, as shown in Fig.2.

3. DESCRIPTION OF REACTIVE BEHAVIOR USING FUZZY LOGIC

In order to deal with the problems of behavior control, behavior fusion is performed by using fuzzy sets and fuzzy reasoning. Fig.5 shows fuzzy logic scheme for behavior control. The input signals to fuzzy navigation algorithm are the distances between the robot and obstacles to the left, front, and right locations as well as the heading angle between the robot and a specified target, denoted by *left_obs*, *front_obs*, *right_obs* and *head_ang*, respectively. When the target is located to the left side of the mobile robot, a heading angle

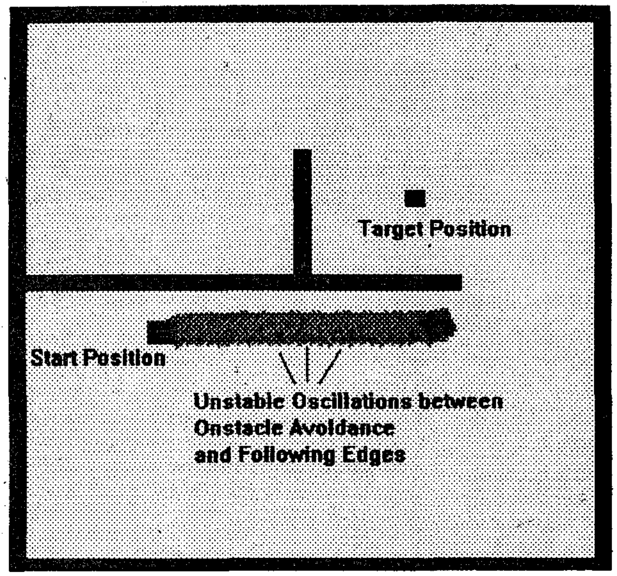

Fig. 4. Unstable oscillations caused by behavior control according to priority strategy

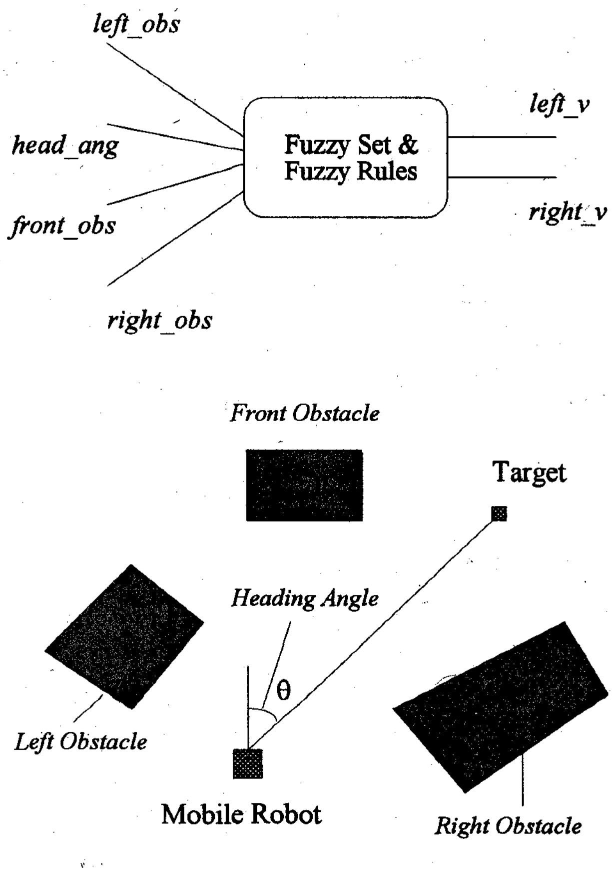

Fig. 5 (a)-(b). Fuzzy logic scheme for behavior control

head_ang is defined as negative; when the target is located to the right side of the mobile robot, a heading angle *head_ang* is defined as positive. According to acquired range information by ultrasonic sensors [10], different types of reactive behavior are weighted by the fuzzy logic algorithm to control the velocities of the two robot driving wheels, denoted by *left_v* and *right_v*, respectively. The linguistic variables far, med (medium) and near are chosen to fuzzify *left_obs*, *front_obs* and *right_obs*. The linguistic variables P (positive), Z (zero) and N (negative) are used to fuzzify *head_ang*; the linguistic variables fast, med, and slow are used to fuzzify the velocities of the driving wheels *left_v* and *right_v*.

In order to reach a specified target in a complex environment, the mobile robot at least needs the following types of reactive behavior: 1. Obstacle avoidance and deceleration on curved and narrow roads; 2. Following edges; 3. Target steer. Using fuzzy logic, such a behavior with simple feature can be easily formulated [1][2]. For example, the behavior, obstacle avoidance and deceleration on curved and narrow roads, is realized by the following fuzzy rules:

(1) If (*left_obs* is near and *front_obs* is near and
right_obs is near and *head_ang* is any)
Then (*left_v* is fast and *right_v* is slow).

(2) If (*left_obs* is med and *front_obs* is near and
right_obs is near and *head_ang* is any)
Then (*left_v* is slow and *right_v* is fast).

(3) If (*left_obs* is near and *front_obs* is near and
right_obs is med and *head_ang* is any)
Then (*left_v* is fast and *right_v* is slow).

(4) If (*left_obs* is near and *front_obs* is med and
right_obs is near and *head_ang* is any)
Then (*left_v* is slow and *right_v* is slow).

4. BEHAVIOR FUSION BY FUZZY REASONING

One of key issues of behavior based control is how to efficiently coordinate conflicts and competition among different types of reactive behavior to achieve a good performance. In section 2, we have discussed the deficiencies of the priority strategy. Since, using the control strategy proposed in [1][2], reactive behavior is formulated by fuzzy sets and fuzzy rules, and these fuzzy rules are integrated in one rule base, the coordination of different types of reactive behavior can thus be easily performed by fuzzy reasoning. The following is an illustration of how this problem is dealt with by the Min-Max inference algorithm and the centroid defuzzification method. For instance, the inputs, *left_obs*=d1, *front_obs*=d2, *right_obs*=d3, *head_ang*=1, are fuzzified by their membership functions to fire fuzzy rules associated with them simultaneously. Assume that Rule *i* (see below), formulating the obstacle avoidance behavior, and Rule *j* (see below), formulating the following edges behavior, are fired according to the fuzzified inputs (in fact, much more fuzzy rules may be activated):

Rule *i* : If (*left_obs* is near and *front_obs* is near
and *right_obs* is near and *head_ang* is N)
Then (*left_v* is fast and *right_v* is slow).

Rule *j* : If (*left_obs* is near and *front_obs* is med
and *right_obs* is med and *head_ang* is N)
Then (*left_v* is med and *right_v* is med).

By fuzzy reasoning and the centroid defuzzification method, both Rule *i* and Rule *j*, related to the obstacle avoidance and following edges behaviors respectively, are weighted to determine an appropriate control action, i.e., the velocities, *left_v* and *right_v*, of the robot's rear wheels, as shown in Fig.6.

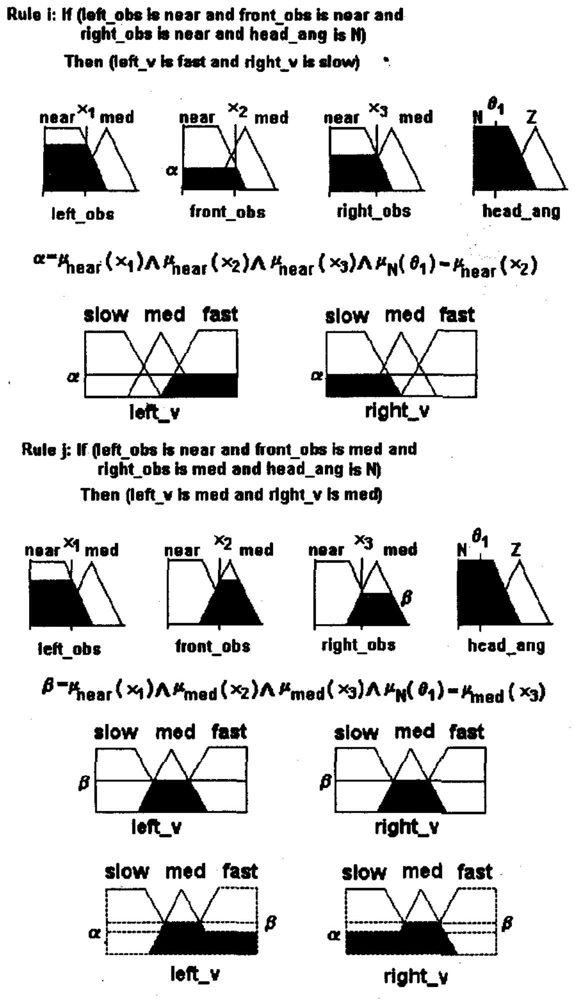

Fig. 6. Behavior fusion by fuzzy reasoning

In general, the weights of the behaviors, obstacle avoidance and target steer, depend largely on the distances between the robot and the obstacles to the left, front, and right locations; while the weight of the behavior, following edges, depends on a heading angle between the robot and a specified target. Since robot navigation is controlled by integrating all types of behavior rather than by firing a single behavior, unstable oscillations between different behaviors are avoided, and the local minimum problem in artificial potential field that causes robots to be trapped is lessened.

Fig.7 shows robot motion in a cluttered environment. Several targets that are randomly chosen are located among different obstacle distribution. It can be observed that, only using ultrasonic sensors to acquire dynamic information, the robot can successfully reach all targets by efficiently weighting multiple types of reactive behavior using the proposed fuzzy logic algorithm. Fig.1 shows that a start position and a target position are located in different regions. Using the fuzzy navigation algorithm, the robot can automatically act "following edge" behavior (in our algorithm the right-oriented principle is implemented) so as to reach the target when it "hits" the wall.

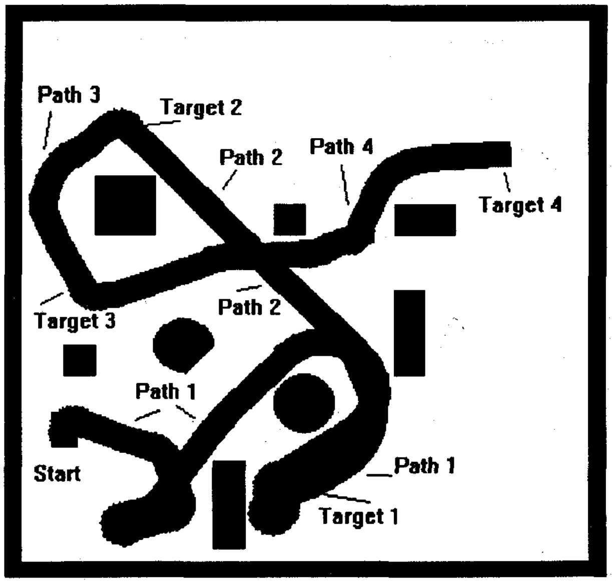

Fig. 7. Robot motion to reach multiple targets in a cluttered environment

5. COMBINATION WITH HIGH-LEVEL GLOBAL PLANNING

Fig.1 and Fig.7 show robot navigation only by behavior control. In this case, the robot does not generate a good path to reach a target without using global information on environments. In fact, some prior knowledge of an environment can be obtained in many applications, such as a geometrical picture of a manufacturing shop.

On the basis of fuzzy logic based behavior control, therefore, we propose a strategy for combining low-level reactive behavior control with high-level global planning. Global planning is used to determine motion direction according to prior knowledge; while reactive behavior control is to deal with unknown obstacles. For this purpose, a geometric algorithm "Voronoi Diagram" [9] is proposed for generating some subgoals. The Voronoi Diagram generated by a set of points in a Euclidean space partitions the space into convex regions that have a single nearest point under some metric, as shown in Fig.8. Considering the Voronoi Diagram, two types of points are chosen to generate subgoals as follows: 1. Intersection points, e.g., SP_i in Fig. 8, are candidates for subgoals; 2. Such points that represent the nearest distances between different obstacles, e.g., SP_k in Fig. 8, are considered as subgoals. Using behavior control, the robot can automatically execute its motion to reach each subgoal with collision avoidance to unknown obstacles, e.g., as shown in Fig. 9.

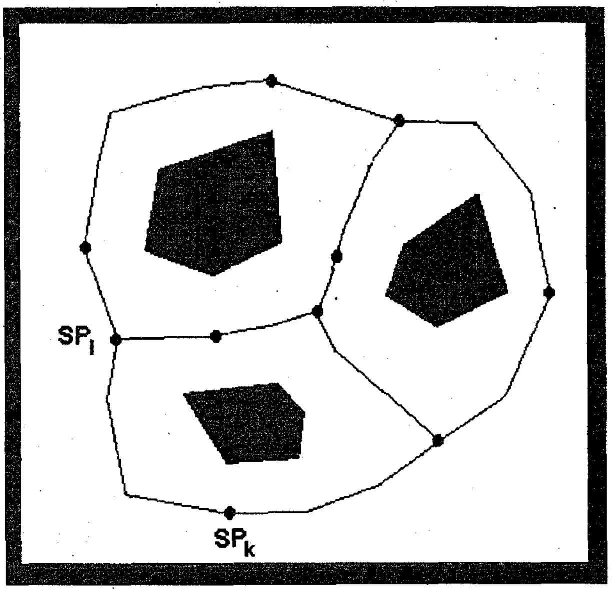

Fig. 8. Generating subgoals by Voronoi Diagram

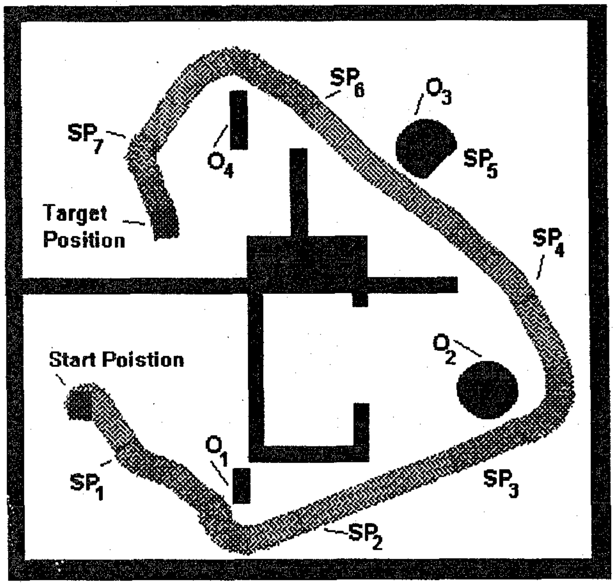

Fig. 9. Robot motion by combining behavior control and global planning with unknown obstacles

Since the proposed strategy does not need to plan exact geometric paths or to generate trajectory, this reduces computational time for global planning and thus is flexible for replanning in dynamic environments since only some subgoals need to be removed from or added into the planner.

6. CONCLUSIONS

This paper presents an efficient strategy for connecting low-level behavior control to high-level global planning for robot motion. Since this method is to perform behavior fusion by fuzzy logic rather than simply to inhibit those reactive behaviors with lower levels, it is more efficient than traditional reactive behavior control using artificial potential fields. Using behavior fusion by fuzzy logic, a robot is able to directly execute its motion toward a goal position according to information about environments, acquired by ultrasonic sensors, without the need for trajectory planning. A global planner, therefore, only needs to generate some subgoal positions rather than exact geometric paths. This reduces computational time for global planning and is flexible for replanning in dynamic environments since only some subgoals need to be removed from or added into the planner. Simulation results demonstrate that the proposed strategy can be applied to robot motion in complex and dynamic environments. Besides, this method is suitable for robot navigation by multisensor integration [11].

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