BEHAVIOR FUSION FOR ROBOT NAVIGATION IN UNCERTAIN ENVIRONMENTS USING FUZZY LOGIC

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ABSTRACT

A key problem in behavior based control is to coordinate conflicts and competitions among multiple reactive behaviors. This paper presents a new method for behavior fusion for robot navigation in uncertain environments using fuzzy logic.

The inputs to the proposed fuzzy control scheme consist of a heading angle between a robot and a specified target and the distances between the robot and the obstacles to the left, front, and right locations, acquired by an array of ultrasonic sensors. The outputs from the control scheme are commands for the speed control unit of two rear wheels of the mobile robot.

The simulation results show that the proposed method, only using range information acquired by ultrasonic sensors, can be efficiently applied to robot navigation in complex and uncertain environments.

1 INTRODUCTION

On the basis of the stimulus-response behavior in bio-system, behavior based control [1][2][3] has been proposed for robot navigation in unknown environments since this method does not need building an entire world model and complex reasoning process. A key issue in behavior-based control, however, is how to coordinate conflicts and competitions among multiple reactive behaviors efficiently. In [1], the coordination of multiple behaviors is done by inhibiting those reactive behaviors with lower levels. However, this strategy is not very efficient for robot navigation when a mobile robot executes tasks in complex environments. The example in Fig.1 shows that the robot must efficiently weight multiple reactive behaviors, such as avoiding obstacle, following edge, and moving to the target and so on, according to range information, when it reaches a specified target.

This paper presents a new method for behavior fusion for robot navigation using fuzzy logic [4][5][6]. The main idea of this method is to weight multiple reactive behaviors in dynamic environments by a fuzzy logic algorithm rather than simply to inhibit some reactive behaviors according their priority. This method also differs from the fuzzy control approaches for obstacle avoidance in [7][8][9] since perception and decision units in this method are integrated in one module and are directly oriented to dynamic environments to improve real-time response and reliability. To demonstrate the effectiveness and the robustness of the proposed method, we report simulation results on robot navigation in uncertain environments, such as moving obstacle avoidance in real-time, decelerating at curved and narrow road, escaping from a U-shaped object and moving to target and so on.

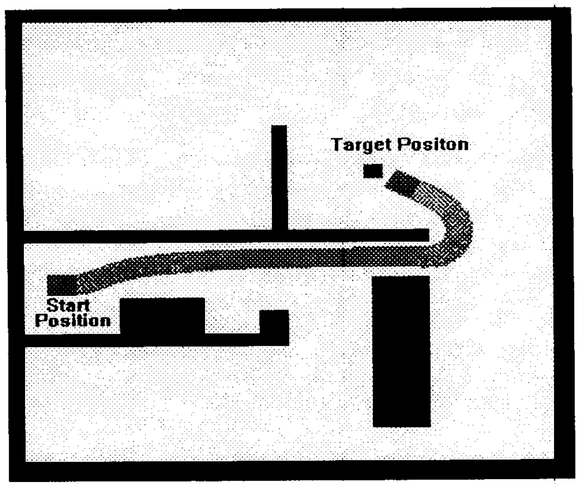

Fig.1: Robot motion to a target by behavior fusion using fuzzy logic

2 BEHAVIOR-BASED CONTROL USING ARTIFICIAL POTENTIAL FIELDS

The usual approach for implementing behavior-based control is artificial potential fields [10][11][12]. In combination with artificial potential fields, an inhibiting and suppressing strategy in [1] is used to fire a behavior. In our experiment, 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 behaviors during preprogramming.
2. Robot motion with unstable oscillations between different behaviors may occur in some cases. This is

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because just only one behavior could be activated at a given instant and two behaviors with neighboring priority, e.g., *obstacle avoidance* and *following edges* shown in Fig.2, are fired in turn.

3. Some targets can not be achieved only by firing one behavior at a given instance. Fig.3 shows that the robot is unable to get through the narrow channel to reach the given target. The reason is that the robot always activates *obstacle avoidance* behavior when it approaches this channel, so that it turns to right to move into a large free space.

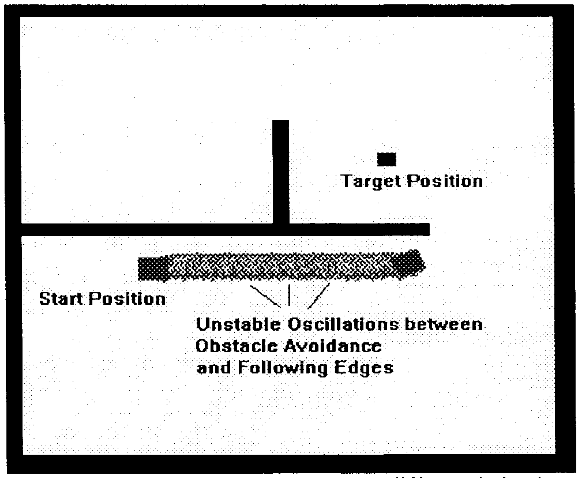


Fig.2: Unstable oscillations between different behaviors by potential fields

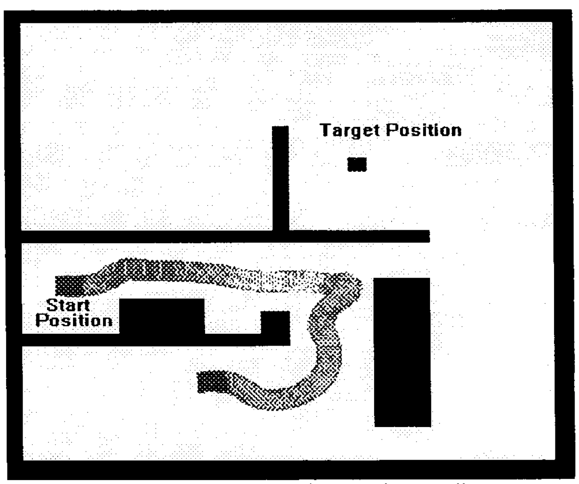
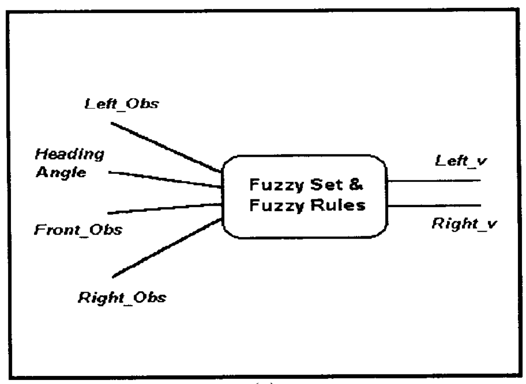


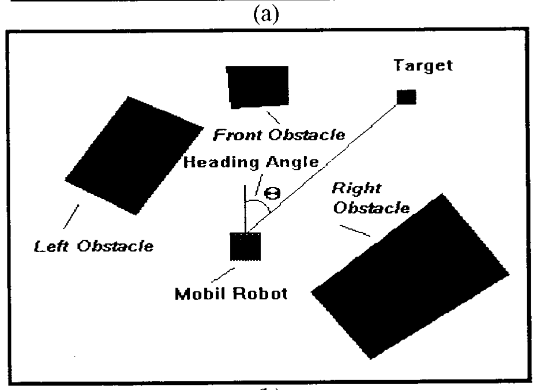
Fig.3: Behavior based control according to priority strategy

3 DESCRIPTION OF REACTIVE BEHAVIORS USING FUZZY LOGIC

In order to improve navigation performance, in the paper behavior fusion is done by using fuzzy sets and fuzzy reasoning. 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, as shown in Fig.4a. When the target is located to the left side of the mobile robot, a heading angle *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, as shown in Fig.4b. According to acquired range information by ultrasonic sensors [13], reactive behaviors 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 fuzzifiy *head_ang*; the linguistic variables *fast*, *med*, and *slow* are used to fuzzify the velocities of the driving wheels *left_v* and *right_v*.



(a)



(b)

Fig.4: Fuzzy logic scheme for behavior based control

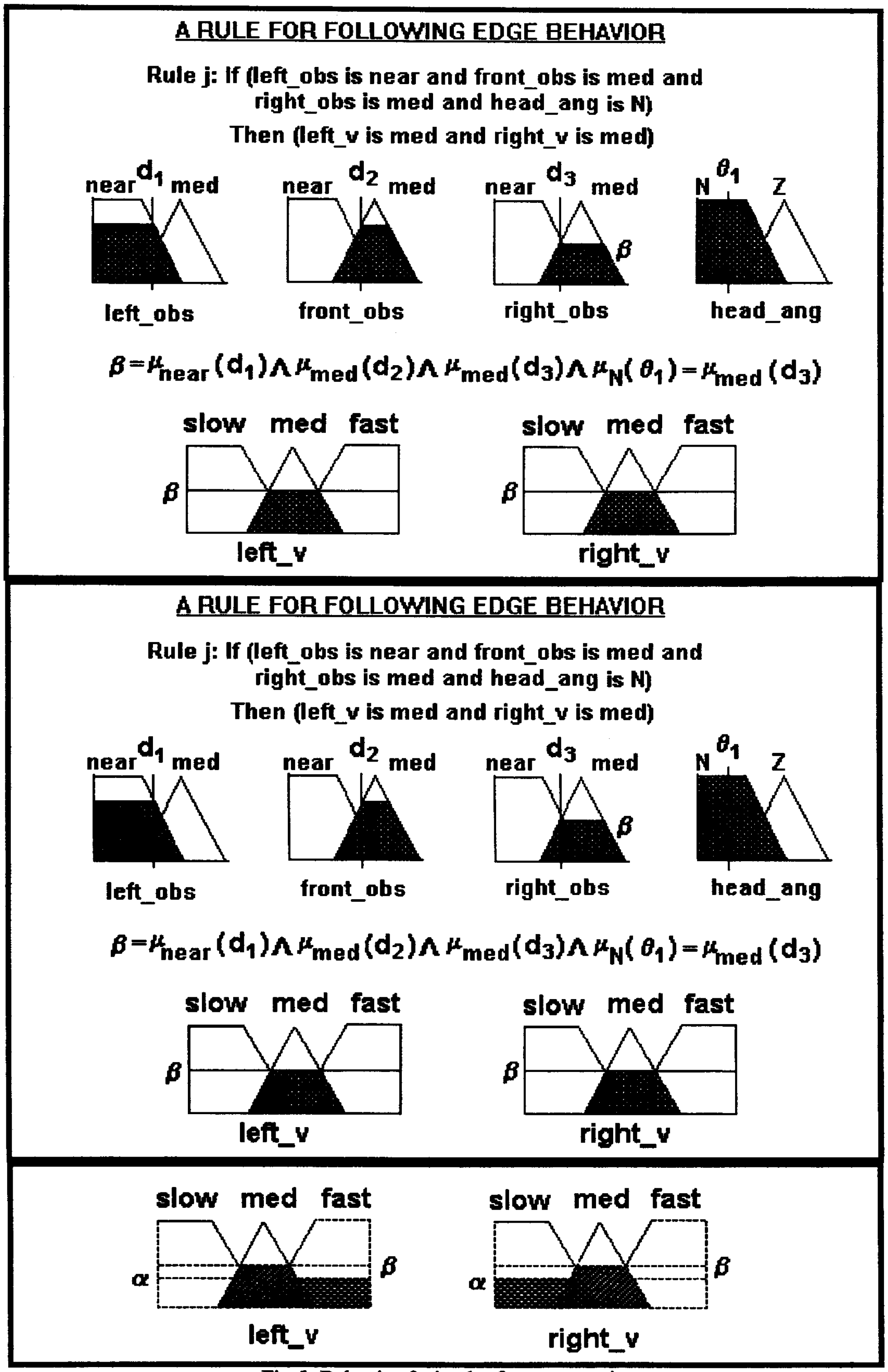


Fig.5: Behavior fusion by fuzzy reasoning

In order to reach a specified target in a complex environment, the mobile robot at least needs the following reactive behaviors: 1. Obstacle avoidance and decelerating at
curved and narrow roads; 2. Following edges; 3. Target steer. In this case, a set of fuzzy logic rules is used to describe the reactive behaviors mentioned above. Now, we list parts of fuzzy rules from the rule base to explain, in principle, how these these reactive behaviors are realized (in fact, much more fuzzy logic rules have been used in our navigation algorithm).

3.1 Obstacle Avoidance and Decelerating at Curved and Narrow Roads

When the acquired information from the ultrasonic sensors shows that there exist obstacles nearby robot, or the robot moves at curved and narrow roads, it must reduce its speed to avoid obstacles. In this case, its main reactive behavior is decelerating for obstacle avoidance. We give the first and second of fuzzy logic rules for realizing this behavior as follows:

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).

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).

Such fuzzy rules represent that the robot only pays attention to obstacle avoidance and moves slowly when it is very close to obstacles or at curved and narrow roads.

3.2 Following Edge

When the robot is moving to a specified target through a narrow channel, as shown in Fig.1, or escaping from a U-shaped obstacle, it must reflect following edge behavior. The first and second rules for describing this behavior are listed as follows:

If (left_obs is far and front_obs is far and right_obs is near and head_ang is P) Then (left_v is med and right_v is med).

If (left_obs is near and front_obs is far and right_obs is far and head_ang is N) Then (left_v is med and right_v is med).

These fuzzy rules show that the robot shall follow an edge of an obstacle when the obstacle is very close to the right (or left) of the robot, and the target also is located to the right (or left).

3.3 Target Steer

When the acquired information from the ultrasonic sensors shows that there are no obstacles around robot, its main reactive behavior is target steer. Here, we list the first and second for realizing this behavior as follows:

If (left_obs is far and front_obs is far and right_obs is far and head_ang is Z) Then (left_v is fast and right_v is fast).

If (left_obs is far and front_obs is far and right_obs is far and head_ang is N) Then (left_v is slow and right_v is fast).

These fuzzy logic rules show that the robot mainly adjusts its motion direction and quickly moves to the target if there are no obstacles around the robot.

4 BEHAVIOR FUSION BY FUZZY REASONING

A key issue of behavior-based control is how to efficiently coordinate conflicts and competitions among different reactive behaviors to achieve a good performance. In section 2, we discuss the deficiencies of the priority strategy. In the proposed control strategy, reactive behaviors are formulated by fuzzy sets and fuzzy rules, and these fuzzy rules are integrated in one rule base. The coordination of different reactive behaviors 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, $left\_obs=d_1$, $front\_obs=d_2$, $right\_obs=d_3$, $head\_ang=\theta_1$, 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 [6].

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 the behaviors

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5 SIMULATIONS

To demonstrate the effectiveness and the robustness of the proposed method, here we report several simulation results on robot navigation in unknown environments using ultrasonic sensors, such as avoiding obstacle in real-time, decelerating at curved and narrow roads, escaping from a U-shaped object and moving to target and so on.

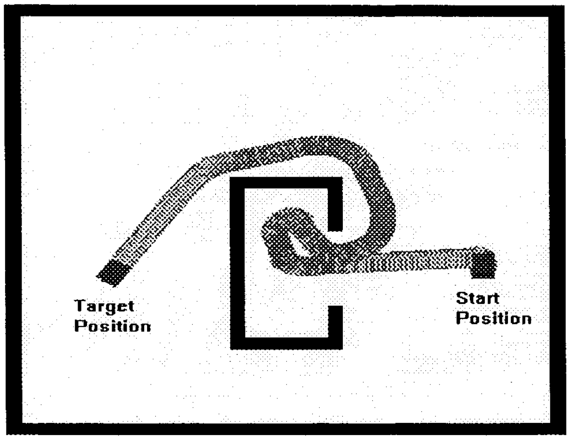

Fig.6: Robot escaping from a U-shaped object

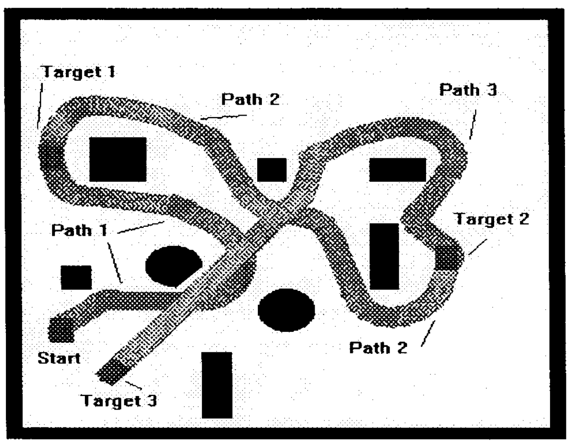

Fig.7: Robot motion to reach multiple targets in a cluttered environment

5.1 Escaping from a U-Shaped Object

Fig.6 shows a robot start position is located to the entry side of the U-shaped object and a target position is located to the back side of the U-shaped object. In this case, using artificial potential fields the robot is usually trapped inside the U-shaped obstacle due to local minimum. Using the fuzzy navigation algorithm, the robot moves to the target with a high speed at start stage since there is a large free space around the robot . When it is trapped inside the U-shaped object, the robot is moving along the edge of the U-shape object by increasing the weight of the "following edge" behavior as so to escape the U-shaped object. When the robot goes around the U-shaped object, it drives to the target with a high speed again.

5.2 Moving in a Cluttered Environment

Fig.7 shows robot motion in a cluttered environment. We choose at random several targets that are located among different obstacle distribution. Path 1 in Fig.7 represents robot motion from the start position to target 1 located in a narrow road; Path 2 in Fig.7 represents robot motion from target 1 to target 2 that is behind more obstacles; and path 3 represents robot motion from target 2 to target 3 that is placed in the region where start position is located. It can be observed that, only using ultrasonic sensors to acquire dynamic information, the robot can successfully reach all targets by efficiently weighting multiple reactive behaviors using the proposed fuzzy logic algorithm.

5.3 Following Wall Edges

In some applications, a mobile robot should be able to move from a room to another room. Fig.8 shows that a start position and a target position are located in different rooms. Using the fuzzy navigation algorithm, the robot can automatically act "following edge" behavior (in our algorithm the right-oriented principle is implemented) as so to reach the target when it "hits" the wall.

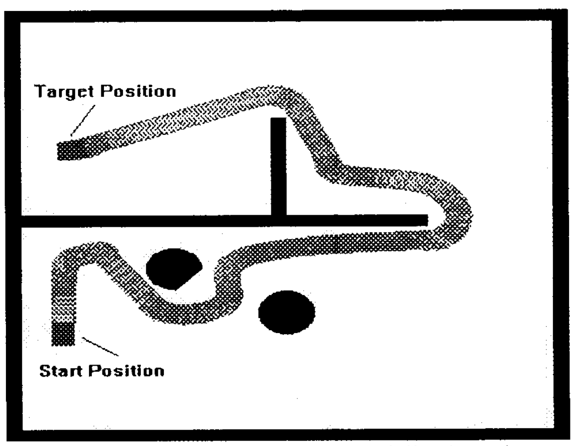

Fig.8: Robot reaching a target by following edge behaviors

5.4 Decelerating at Curved and Narrow Roads

The example in Fig.9 shows robot navigation at curved and narrow roads. The robot begins from its start position and is automatically decelerating at the first curved road with 90°. Then it moves into a very narrow road with a slow speed. At the following curved roads with 90°, the robot automatically makes turns to keep on the roads. Finally, the robot gets the road where the target is located and move to the target with obstacle avoidance by the use of distance information between the robot and obstacles and their heading angle.

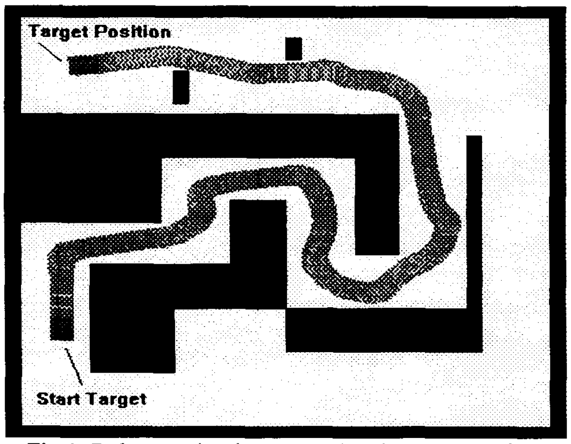

Fig.9: Robot motion in a curved and narrow corridors with slow speed

6 CONCLUSIONS

In this paper, we present a new method for behavior fusion for robot navigation using fuzzy logic. Since this method is to weight multiple reactive behaviors by fuzzy reasoning rather than simply to inhibit those reactive behaviors with lower levels, it is more efficient than traditional reactive behavior control using artificial potential fields. The navigation algorithm has better reliability and real-time response since perception and decision units are integrated in one module and are directly oriented to a dynamic environment. The simulation results show that the proposed method, only using information acquired by ultrasonic sensors, can perform robot navigation in complex and uncertain environments by weighting multiple reactive behaviors, such as avoiding obstacles, decelerating at curved and narrow roads, escaping from a U-shaped object, and moving to target and so on. This method is suitable for robot navigation by multisensor integration [13][14].

ACKNOWLEDGMENT

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