Fuzzy Logic-Based 'Perception-Action' Behavior Control of a Mobile Robot in Uncertain Environments

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Abstract

This paper presents a method for fuzzy logic-based 'perception-action' behavior control of a mobile robot in uncertain environments. A key problem in 'perception-action' behavior control is to coordinate and integrate more reactive behaviors when the mobile robot executes tasks in complex environments. The main idea of the paper is to formulate 'perception-action' behaviors and to coordinate their conflicts and competitions by fuzzy sets and fuzzy rules. An advantage of this method is that the coordination of more reactive behaviors is very robustness (nearly independent of dynamic environments). The simu-lation results show that the proposed method, only using dynamic information acquired by ultrasonic sensors, can perform robot navigation in complex and uncertain environments by efficiently weighting reactive behaviors, such as avoiding obstacle, follow-ing edge, and moving to the target and so on.

1 Introduction

A key issue in autonomous robot is robot navigation in uncertain and complex environments. If a mobile robot moves among unknown obstacles to reach a specified target without collisions, sensors must be used to acquire information about real world. Obviously, using such information it is very difficult to build a precise and entire world model in real-time for preplanning a collision-free path. On the basis of reactive behaviors, 'perception-action' behavior control [1][2][3] has been proposed to realize robot navigation. For example, robot wandering behavior can be described by the following two simple perception-actions: if obstacles are located to the left side, the robot turns to the right; if obstacles are located to the right side, the robot turns to the left. Since this method does not need building an entire world model and complex reasoning process, it is suitable for robot navigation in dynamic environments. In practice, more perception-action behaviors must be supplemented, so a key problem in the method is how to coordinate these perception-action behaviors efficiently. In [1], the coordination of more perception-action behaviors is done by inhibiting those reactive behaviors with lower levels according their priority. However, this strategy is not very efficient when a mobile robot executes tasks in complex environments. The example in Fig.1 shows that the robot must efficiently weight more reactive behaviors according to dynamic information, such as avoiding obstacle, following edge, and moving to the target ect., when it reaches a target inside a U-shaped object. The usual approach for implementing perception-action behaviors is artificial potential field [4][5][6]. A drawback to the approach is that during preprogramming much effort must be made to test and to adjust some thresholds regarding potential field for avoiding obstacle, wandering, and moving to target ect. Besides, these thresholds frequently depend on environments.

This paper presents a new method for 'perception-action' behavior control based on fuzzy logic [10]. Unlike 'perception-action' behavior control based on artificial potential field [1][2][3], this method is to compute weights of more reactive behaviors in dynamic environments by the fuzzy logic algorithm rather than simply to inhibit those reactive behaviors with lower levels 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 by the use of the idea of 'perception-action' behaviors and are directly oriented to a dynamic environment to improve real-time response and reliability. To demonstrate the effectiveness and robustness of the proposed method, we report a lot of 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.

2 Fuzzy Logic Control Scheme for a Mobile Robot

In order to acquire information about dynamic environments, 15 ultrasonic sensors are mounted on the THMR-II mobile robot with 1.0m length and 0.8m width. These ultrasonic sensors are divided into three groups to detect obstacles to the left, front, right

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locations, as shown in Fig.2, respectively. The THMR-II mobile robot is equipped with two driving wheels and one driven wheel. The velocities of the driving wheels are controlled by a motor drive unit. The input signals to fuzzy logic navigation algorithm are 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.3(a). 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.3(b). According to acquired dynamic information, reactive behaviors are weighted by the fuzzy logic algorithm to control the velocities of the two driving wheels of the robot, 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*. In analogy to artificial potential field, distances between the robot and obstacles serve as a repulsive force for avoiding obstacle, while the heading angle serves as an attractive force for moving to target.

3 Description of 'Perception-Action' Behaviors Using Fuzzy Logic

In order to reach a specified target in a complex environment, the mobile robot must at least have the following reactive behaviors: 1. obstacle avoidance; 2. following edges; 3. target steer; 4. decelerating at curved and narrow roads. Because a real world is very complex, using ultrasonic sensors it is very difficult to acquire precise information about dynamic environments. In this case, a set of fuzzy logic rules is used to describe the perception-action behaviors mentioned above. Now, we list parts of fuzzy rules from the rule base to explain, in principle, how these the perception-action behaviors are realized (in fact, much more fuzzy logic rules have been used in our navigation algorithms).

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. To realize this behavior, we use such fuzzy logic rules 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*)
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*)
If (*left_obs is near and front_obs is med and right_obs is near and head_ang is any*) *Then* (*left_v is med and right_v is med*)

Such fuzzy rule represents that the robot only pays attention for 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 inside a room (Fig.1) or escaping from a U-shaped obstacle, it must reflect following edge behavior. In order to describe this behavior, we use the following fuzzy rules:

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*)
If (*left_obs is far and front_obs is med 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 med 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 left (or right) of the robot and the target also is located to the left (or right).

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 use the following fuzzy rules to realize this behavior:

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

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.

3.4 Coordination of Reactive Behaviors

In 'perception-action' behavior control based on artificial potential field [1][2][3], the velocities of the driving wheels *left_v* and *right_v* are controlled by a reactive behavior that is determined by inhibiting reactive behaviors with lower levels according their priority. In doing this, much effort must be made to test and to adjust some thresholds during preprogramming. Besides, these thresholds usually depend on environments. In our 'perception-action' behavior control, reactive behaviors are formulated by fuzzy rules and the velocities of the driving wheels *left_v* and *right_v* are determined by weighting all reactive behaviors. This is done by the Min-Max inference algorithm and the centroid defuzzification method. Obviously, this strategy for the coordination of reactive behaviors is not to inhibit reactive behaviors with lower levels according their priority, so this is more reasonable for robot navigation.

4. Simulations

To demonstrate the effectiveness and robustness of the proposed method, here we report several simulation results on robot navigation in dynamic 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.

4.1 Moving to a Target inside a U-Shaped Object

Fig.1 illustrates robot motion to a target inside a U-shaped object. At start stage, the robot moves to the target with a high speed since the "moving to target" behavior is strong due to the large free space around the robot. When the robot approaches to the U-shaped object, it is decelerating by automatically reducing the weight of the "moving to target" behavior and increasing the weight of the "avoiding obstacle" and "following edge" behaviors. When the robot finds out the entry of the U-shaped object, it slowly reaches the target by integrating the "avoiding obstacle" and "moving to target" behaviors.

4.2 Escaping from a U-Shaped Object

Fig.4 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 field the robot is usually trapped inside the U-shaped obstacle due to local minimum. Using our 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.

4.3 Moving in a Cluttered Environment

Fig.5 shows robot motion in a cluttered environment. We choose at random several targets that are located among different obstacle distribution. Path 1 in Fig.5 represents robot motion from the start position to target 1 located in a narrow road; Path 2 in Fig.5 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 more 'perception-action' behaviors using the proposed fuzzy logic navigation algorithm.

4.4 Following Wall Edges

In some applications, a mobile robot should be able to move from a room to another room. Fig.6 shows that a start position and a target position are located in different rooms. Using artificial potential field, it is difficult for the robot to reach the target in absence of complete information about the environment. Using our navigation algorithm, however, 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.

4.5 Decelerating at Curved and Narrow Roads

When the mobile robot operates in outdoor environments, it should be able to tack roads to reach a target. The example in Fig.7 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.

4.6 Moving Obstacle Avoidance

Fig.8(a)-(d) shows the simulation of robot motion in an uncertain environment with avoiding a moving obstacle. In the example, we set a moving obstacle nearby the target whose speed is lower than that of the mobile robot. Its motion direction is along the wall and just blocks the robot motion to the target in Fig.8(a). In this case, the robot only pays attention for avoiding this obstacle by making right turn, as show in Fig.8(a)-(b). After the robot goes round the moving obstacle, it moves directly to the target in Fig.8(c)-(d)

5. Conclusions

In this paper, we use fuzzy logic to realize the perception-action behavior control for robot navigation. Since this method is to weight more reactive behaviors by the fuzzy logic algorithm rather than simply to inhibit those reactive behaviors with lower levels according their priority, it may be more efficient than traditional perception-action behavior control. 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 more 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. However, this method does not guarantee to reach a target in some case since complete information is not available. This can be improved by adding a vision system.

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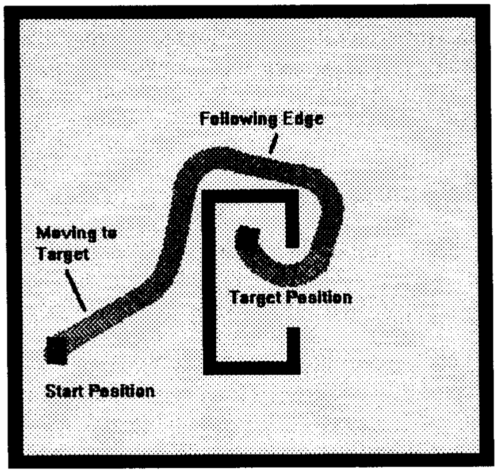


Fig.1: Robot motion to reach a target inside a U-shaped object

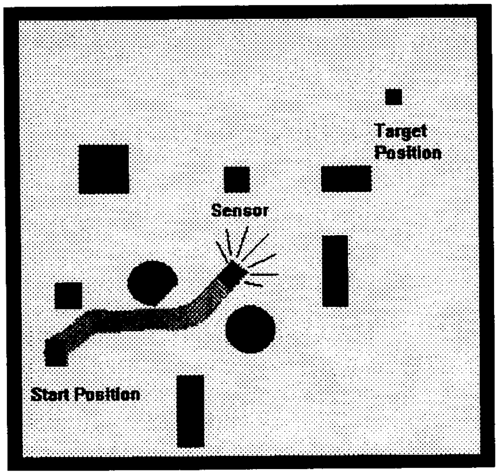
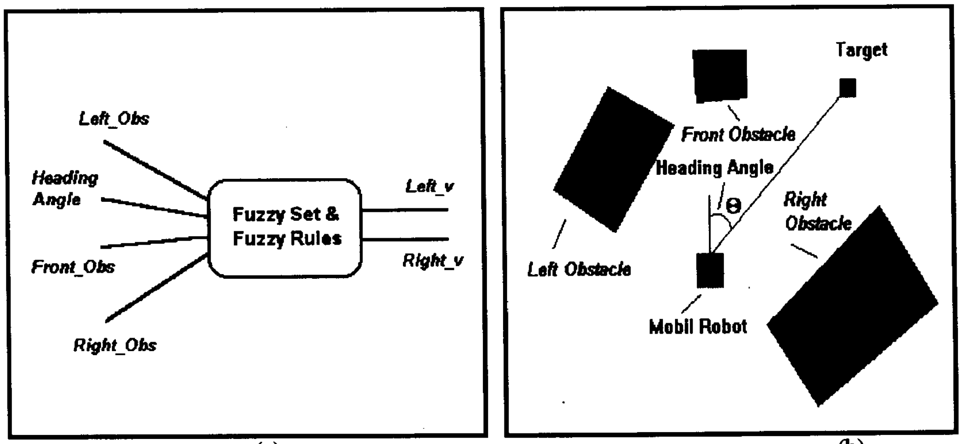


Fig.2: Ultrasonic sensor-based robot motion



(a) (b)

Fig.3(a)-(b): Fuzzy logic scheme for perception-action behavior control

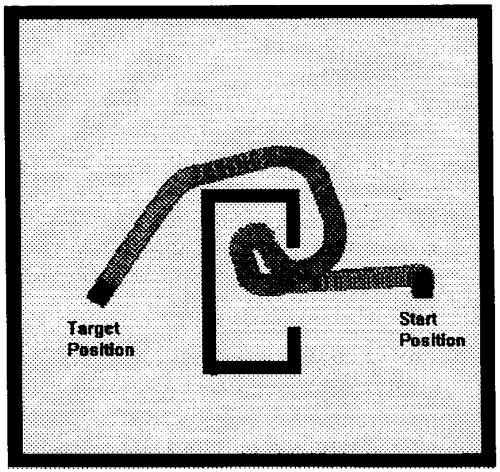


Fig.4: Robot motion to a target with escaping from the U-shaped object

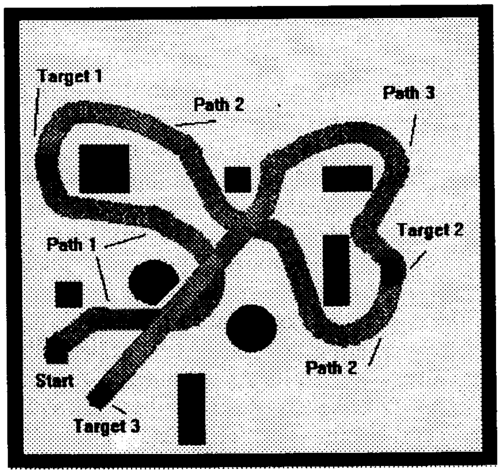


Fig.5: Robot motion to reach more targets in a cluttered environment

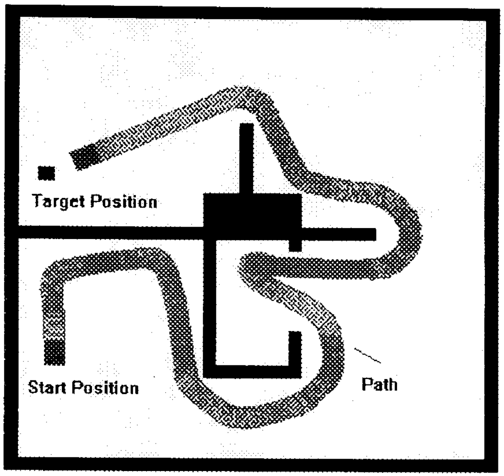


Fig.6: Robot motion to reach a target by following edge behavior

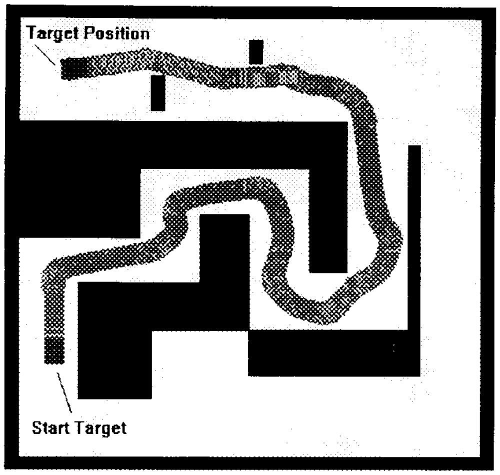
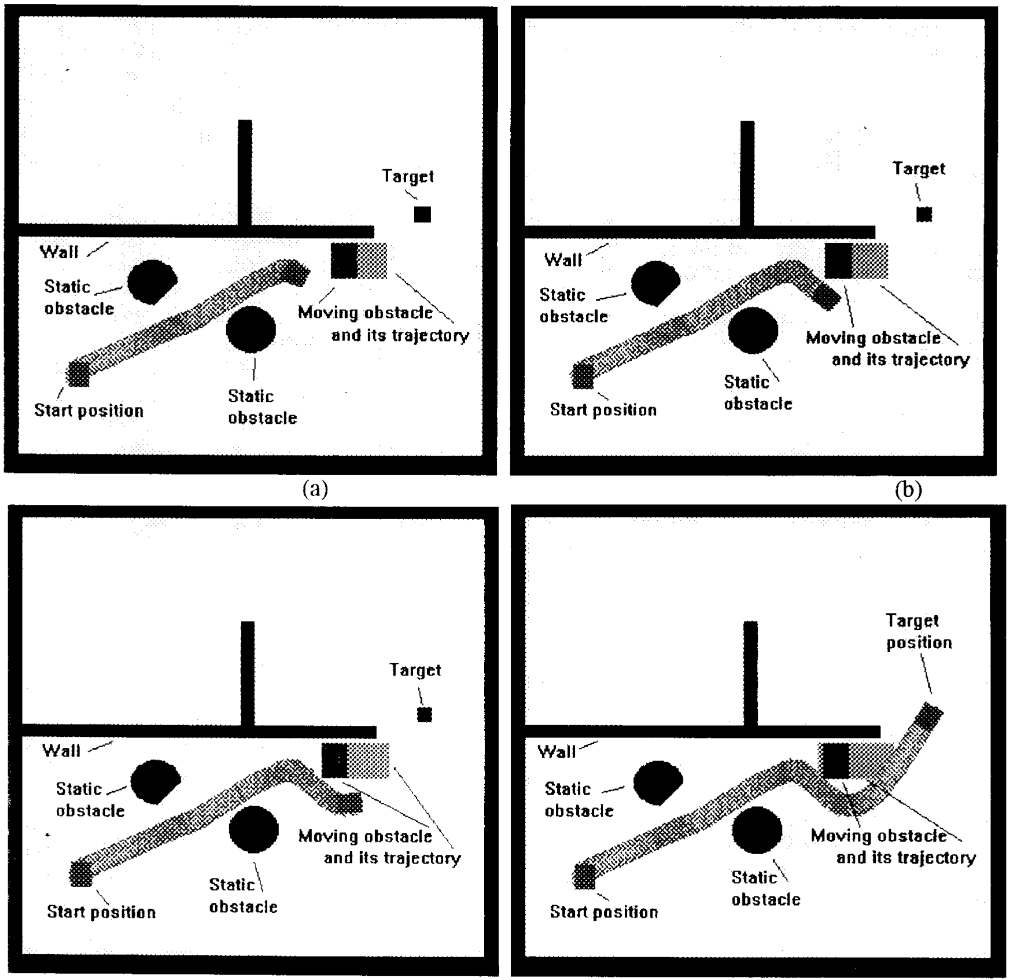


Fig.7: Robot motion with lower speed at curved and narrow roads



(a) (b) (c) (d)

Fig.8(a)-(d): Robot motion with avoiding a moving obstacle