Real-Time Fuzzy Logic Controllers for Autonomous Robot Navigation with U-Shaped Obstacles

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Abstract

A robot navigation system based on combined two fuzzy logic controllers is developed for a mobile robot. Eight ultrasonic sensors, a GPS sensor and two fuzzy logic controllers with separate 81 rules were used to realize this navigation system. The data from sensors are used to the input of each fuzzy controller. The outputs of fuzzy controllers control the speed of two servo motors. The robot with this navigation system chooses one of two controllers based on the information from the sensors while navigating for the targets. Fuzzy controller1 has functions which are target steering, avoiding obstacles and following the edge of obstacles. Fuzzy controller2 has a function which makes the robot keeps following the edge of obstacles. Simulation results show that a mobile robot's escaping ability from U-shaped obstacle was improved and steering ability for a target by avoiding obstacles was also improved with this combined fuzzy logic controller.

Keywords: Robot navigation, fuzzy logic controller, U-shaped obstacle

1 INTRODUCTION

A main issue in mobile robots is robot navigation in an uncertain and complex environment and considerable research has been done for making an efficient algorithm for the mobile robot navigation. Among them, one of the most popular control algorithms is behavior-based control [1]. Behavior-based control shows a good performance in making a robot to take motions which are instructed from each behavior unit corresponding to the information obtained from the surroundings; however, it has two major problems: the combination of behavior units, and the integration of behaviors with higher-level processes [2]. A useful approach to implementing behavior-based control is the use of fuzzy logic. Fuzzy logic provides many advantages to mobile robot navigation because of its robustness in dealing with large variability and uncertainty of parameters. This characteristic can satisfy the need of navigation system where many navigation skills can be combined to show good performances in uncertain and complex environment [1 - 4]. A drawback of using fuzzy logic in mobile robot navigation is that a robot tends to get trapped inside U-shaped obstacles [5 - 6]. Once a robot enters a U-shaped obstacle, it keeps roaming because of conflict of the behavior rules that instruct the robot to move toward target and to avoid or follow obstacles at the same time. In this paper, a combined fuzzy logic controller is designed for a mobile robot's navigation system to solve the problem of trapping inside U-shaped obstacles and to improve navigation ability of the mobile robot.

2 SENSORS

The sensors perceive surroundings. Eight ultrasonic sensors and 1 GPS sensor are mounted on the robot. While the robot navigates in an unknown environment, ultrasonic sensors measure the distance from the obstacles, and a GPS sensor detects the present position of robot. Eight ultrasonic sensors are divided into 3 groups. Two ultrasonic sensors are placed on the front of the robot and three ultrasonic sensors are placed on each side of the robot to measure the distances from the left and right obstacles, respectively. Firstly, among the value of data from each sensor group, the smallest value in each group is used as inputs of fuzzy controller, which are denoted by L_distance, F_distance, R_distance, as shown in Fig. 1. Secondly, the difference angle between robot's heading direction and target position is calculated and it is used to an input to a fuzzy controller. The positive and negative value of the difference angle is denoted by θ. If θ has a positive value, it means the robot is on the right side of a target. If θ has a negative value, it means the robot is on the left side of a target. This process is illustrated in Fig. 2.

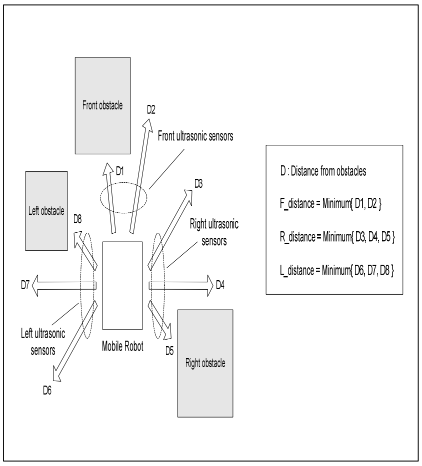


Fig. 1. Scheme of data processing of ultrasonic sensors

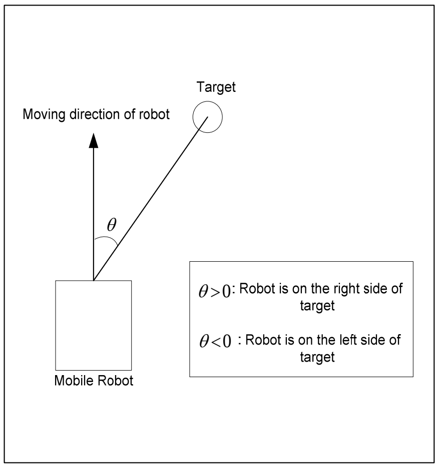


Fig. 2. Scheme of data processing of GPS sensor

3 NAVIGATION SYSTEM WITH A COMBINED FUZZY CONTROLLER

In order to reach a specified target, a mobile robot needs the following navigation skills: target steering, avoiding obstacles and following the edge of obstacles. A conventional robot possessing the above skills has a good navigation performance in unknown and uncertain environment; however, the robot usually gets trapped in U-shaped obstacles and it is directly connected to navigation failure. Once a robot gets trapped in a U-shaped obstacle, it oscillates between target steering rules and following edge rules [5]. Fig. 3 illustrates this situation with a U-shaped obstacle configuration.

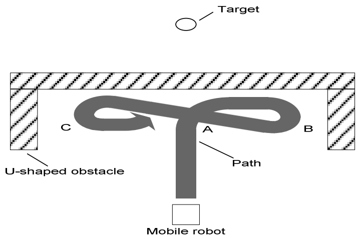


Fig. 3. Example of navigation failure in U-shaped obstacle

To improve this drawback, a navigation system based on two combined fuzzy logic controllers is designed. Fig. 4 shows the schematic diagram of this navigation system.

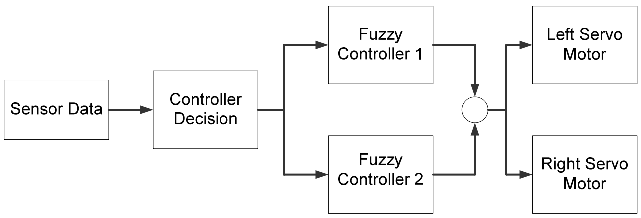


Fig. 4. Scheme of navigation system with a combined fuzzy controller

In the navigation system, a controller decision process is conducted based on the data from two front ultrasonic sensors.

When the mobile robot with Fuzzy controller1 is surrounded by obstacles or the robot's path is blocked by an obstacle, the robot quickly tries to make big turns to avoid collision. While Fuzzy controller2 is operating, the robot only follows the edge of obstacles without taking any action of target steering and avoiding obstacles.

4 FUZZY CONTROLLERS

Two fuzzy controllers have the same input and output membership functions. The difference between two controllers is the rule evaluation part. After a fuzzy controller is chosen based on the information obtained from the surroundings, the fuzzy controller has a process, which consists of three stages: fuzzification, rule evaluation and defuzzification.

The outputs of fuzzy controllers control the velocity of two wheels of the mobile robot and they are denoted by L_velocity and R_velocity as linguistic variables in fuzzy rules.

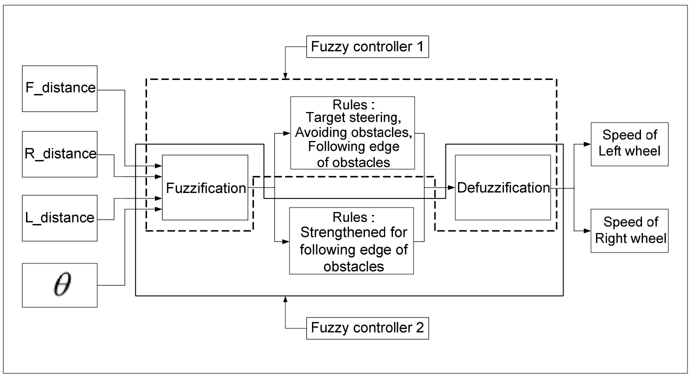


Fig. 5. Scheme of combined fuzzy controller

5 FUZZIFICATION

Two fuzzy membership functions are designed to fuzzify the data from sensors. Membership function shown in Fig. 6 is used to fuzzify the value of variables “F_distance, R_distance, L_distance” from the ultrasonic sensors.

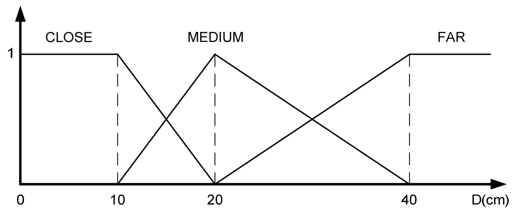


Fig. 6. Membership function for linguistic variables “F_distance, R_distance, L_distance”.

Membership function shown in Fig. 7 is used to fuzzify the difference angle (θ) between robot’s heading angle and target’s position. If θ is bigger than $+90^\circ$ or smaller than -90°, it is denoted by R_position and L_position respectively. If the difference angle is within the range of $\pm 90^\circ$, it will be denoted by S_position.

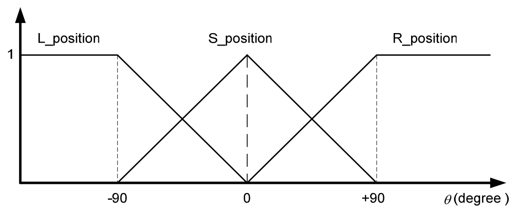


Fig. 7. Membership function for variable “θ”

With these membership functions, the distance information and position information from sensors are converted to fuzzy values.

6 RULE EVALUATION

With 4 fuzzy inputs, each fuzzy controller has two outputs which are denoted by linguistic variables: L_velocity, R_velocity. Those linguistic variables represent the speed of each wheel, and they are classified by three range of speed: SLOW, MED, and FAST.

6.1. Rules in fuzzy controller 1

Fuzzy controller1 has 81 rules for navigation skills: Target steering, avoiding obstacles and following the edge of obstacles. To realize these navigation skills, following rules are designed, for example:

Rule 1: If (L_distance is FAR and F_distance is FAR and R_distance is FAR and θ is S_position) then (L_velocity is FAST and R_velocity is FAST)

6.2. Rules in fuzzy controller 2

Fuzzy controller2 also has 81 rules. Different from rules in Fuzzy controller1, the rules in Fuzzy controller2 are designed for the robot to follow the edge of obstacles in order to find any exit inside obstacles.

These rules are a fortified form of following edge rules in fuzzy controller1. With these rules, the mobile robot approaches to the edge of obstacles, making adequate distance, and keeps following the edge of obstacles without consideration of compensating the difference angle (θ).

With these rules, in most case, the robot moves at low speed. However, when the robot reaches a corner of obstacle, it makes turns towards the obstacle at high speed because the robot usually misses obstacles at that point, so such quick approaching motion toward obstacle prevents the robot from getting away from obstacle. To realize this navigation skill, following rules are designed, for example:

Rule 12: If (L_distance is FAR and F_distance is FAR and R_distance is MEDIUM and θ is any) then (L_velocity is FAST and R_velocity is SLOW)

7 SIMULATION AND RESULTS

The path is represented by the overlapped motion of mobile robot in each step. The dense part of path means that the robot moves at lower speed compared to the other parts of path. Fig. 8. (a) shows robot's motion when it meets scattered obstacles on its way to a target. Fig. 8. (b) shows robot's motion when a target is placed inside a U-shaped obstacle.

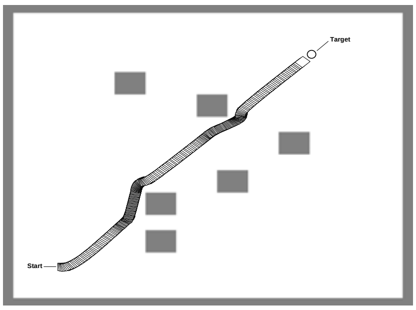


Fig. 8. (a)

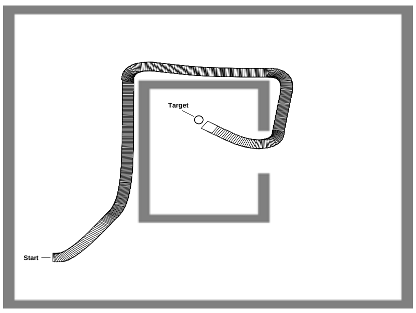
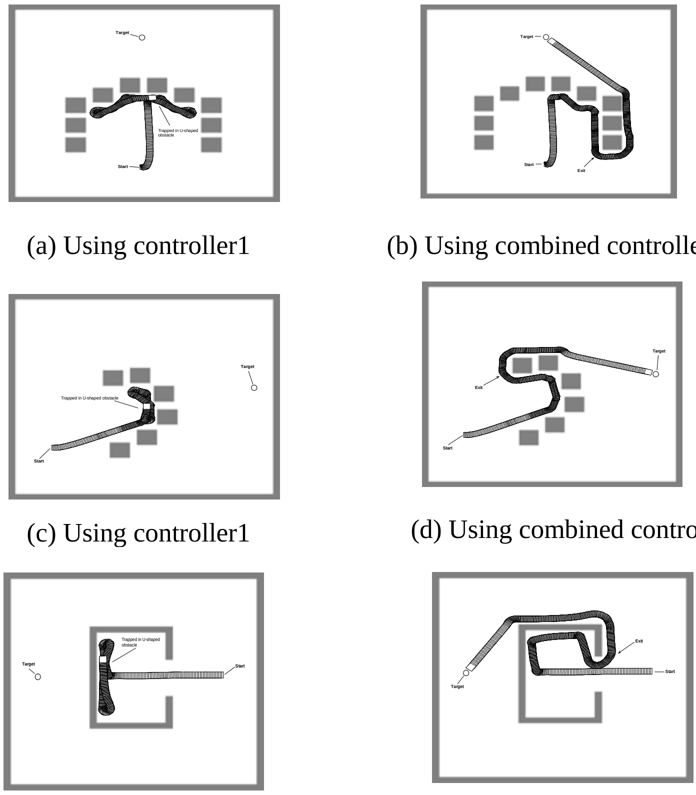


Fig. 8. (b)

From Fig. 9 shows robot's escaping motion for various shapes of U-shaped obstacle. In each case, two simulation results are presented. One is the robot's motion with Fuzzy controller1 only, and the other is the robot's motion with the combined fuzzy controller. In all cases, the robot equipped with Fuzzy controller1 fails to escape from the U-shaped obstacle. On the other hand, the robot equipped with the combined fuzzy controller finds out the exits from U-shaped obstacles and reaches the targets successfully.



(a) Using controller1 (b) Using combined controller

(c) Using controller1 (d) Using combined controller

(e) Using controller1 (f) Using combined controller

Fig. 9. (a)-(f): Robot's motion in various shaped of U-shaped obstacles

8 CONCLUSIONS

A navigation technique using a combined fuzzy controller has been proposed in this paper. From the simulation result, the mobile robot with the combined fuzzy controller demonstrates an improved navigation in unknown or uncertain environment. A number of behavior units are well combined and show good responses to the various sensor data through fuzzy logic. In the complex environment where there are various shaped obstacles, the robot with the combined fuzzy controller reached specified targets without collision with the obstacles, and the robot also showed smooth navigation paths by reducing its moving speed while it bypasses obstacles. This shows that the fuzzy logic, which imitates human's reasoning, is suitable to control the robot's motion in complex environment and thus simplifies the navigation system without using any dynamic equations to generate robot's path corresponding to surrounding information. However, the combined fuzzy navigation system has some drawbacks.

Nonmenclature

L_distancep: distance data from left ultrasonic sensors
F_distance : distance data from front ultrasonic sensors
R_distance : distance data from right ultrasonic sensors
θ : difference angle between robot's heading direction and target position
L_velocity : rotating speed of left wheel of robot
R_velocity : rotating speed of right wheel of robot

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