Visual-Based Fuzzy Navigation System for Mobile Robot: Wall and Corridor Follower

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Abstract – **This paper presents the development of a visual–based fuzzy navigation system that enables a mobile robot in moving through a corridor or following a wall. The system employs a camera to detect the existence of walls on the left, the right, and the front of the robot. A mamdani-type fuzzy logic controller uses the information gathered by the camera to determine the turning angle and the speed of the robot. The fuzzy system is tested using an OpenGL-based 3D simulator that capable in animating the movement of the robot as well as generating the images captured by the camera. The results of the test confirm that the controller shows a good performance in navigating the robot.**

Keywords: **fuzzy controller, mobile robot, navigation, visual-based system**

I. Introduction

Nowadays, robots play important roles in industries and manufacturing. Many robots have been built to help in enhancing productivity and capacity along production lines. They appear in various forms and sizes, including mobile robots. Among many different types of robots, mobile robots have unique characteristics that they are capable in moving from place to place. Therefore, they can be utilized to autonomously handle many human daily tasks, particularly for dangerous or monotonous tasks. In order to successfully move from one place to another, mobile robots require certain navigation system that incorporates several features. These features may include self-localization [1]-[3], path planning and tracking [1], [4], [5], corridor following [2], [4], [6], clearance maintenance [7], collision or obstacle avoidance [2], [5], [7], [8], [9], as well as target detection and recognition [8], [10], [11].

Mobile robots make use of various sensors to provide the above features, e.g. ultrasonic and infrared sensors, GPS device [3], as well as camera as visual sensor [1]-[2], [4]-[14]. The latter is more preferable since it can be used for almost all of the mentioned features. The type and the number of the camera for each application are also varied. Self localization is mostly performed using landmark detection, utilizing either ordinary planar camera [4], [11] or panoramic camera [1], [2]. Corridor following and clearance maintenance can be done using single camera [2], [4], [7] or 3 cameras comprising central and peripheral cameras [6], whereas to avoid obstacle some work used 2 cameras configures as stereo cameras [12].

The movement of the robot using is determined using certain control technique based on the above mentioned features [12]. Sometime, it needs to employ Artificial Intelligence techniques to solve the problem, such as Genetic Algorithm [9], Artificial Neural Network [8], [10], [12], [14], and Fuzzy Logic [7]. Fuzzy Logic based navigation system for mobile robots has been developed by many researchers; however most of them used several distance sensors, such as sonar and ultrasonic sensors [15]-[19]. This paper presents the use of vision means using camera for the input of the fuzzy controller.

The architectures of the developed fuzzy logic controller mostly consisted of obstacle distance [15], [18], obstacle angle [17], [19], and error angle [18], [19] as inputs; and turning angle [15], [18], [19] or individual wheel speed [17] as output. This paper uses visual sceneries gathered from a camera to determine the existence of walls on the left, the right and the front of the robot as inputs and turning angle and speed as outputs.

II. Design Concept

A. System Design

Fig. 1 shows the schematic diagram of the system which consists of two subsystems: a mobile robot and a fuzzy logic controller. A camera is attached heading forward on the front of the robot (Fig. 2). As the robot roaming around the field, the scenery captured by the camera will change. The image grabbed by the camera is processed. The existence of the walls are quantified and supplied into the fuzzy logic controller to calculate the turning angle and the speed of the robot.

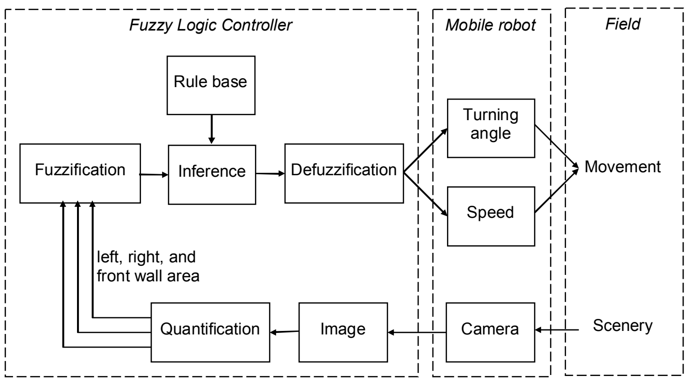

Fig. 1. Schematic of the system

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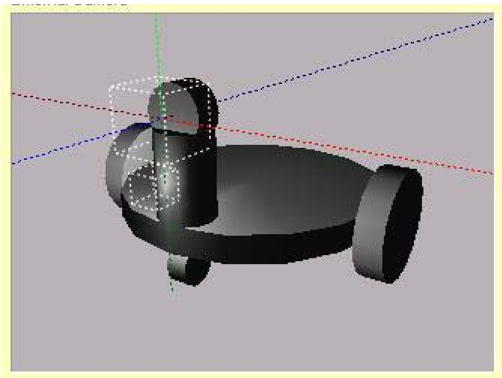


Fig. 2 Mobile robot

B. *Fuzzy Logic Controller Design*

The rules of the fuzzy inference engine are determined heuristically using the knowledge of a human driver. In order to perform corridor and wall follower navigation, the following considerations are taken into account in developing the rules:

1. The distance between the robot and the wall is represented by the area of the wall captured by the camera. The closer the robot to the wall, the bigger part of the wall captured by the camera, and hence, the bigger area of the wall in the grabbed image.
2. If walls are detected both on the left and the right sides, the robot keeps its position in the middle of the corridor.
3. If a wall detected only on one side, either left or right side, the robot maintains certain distance to that wall.
4. If no wall detected at all, the robot moves forward.
5. If the robot is completely blocked by walls on the three sides; left, right, and front sides; the robot will turn back by turning to the right and follow the path behind.

Some examples of the visual patterns those are used to construct the fuzzy knowledge base are given in Fig. 3, which shows the images gathered by the camera and their processed results when the robot is

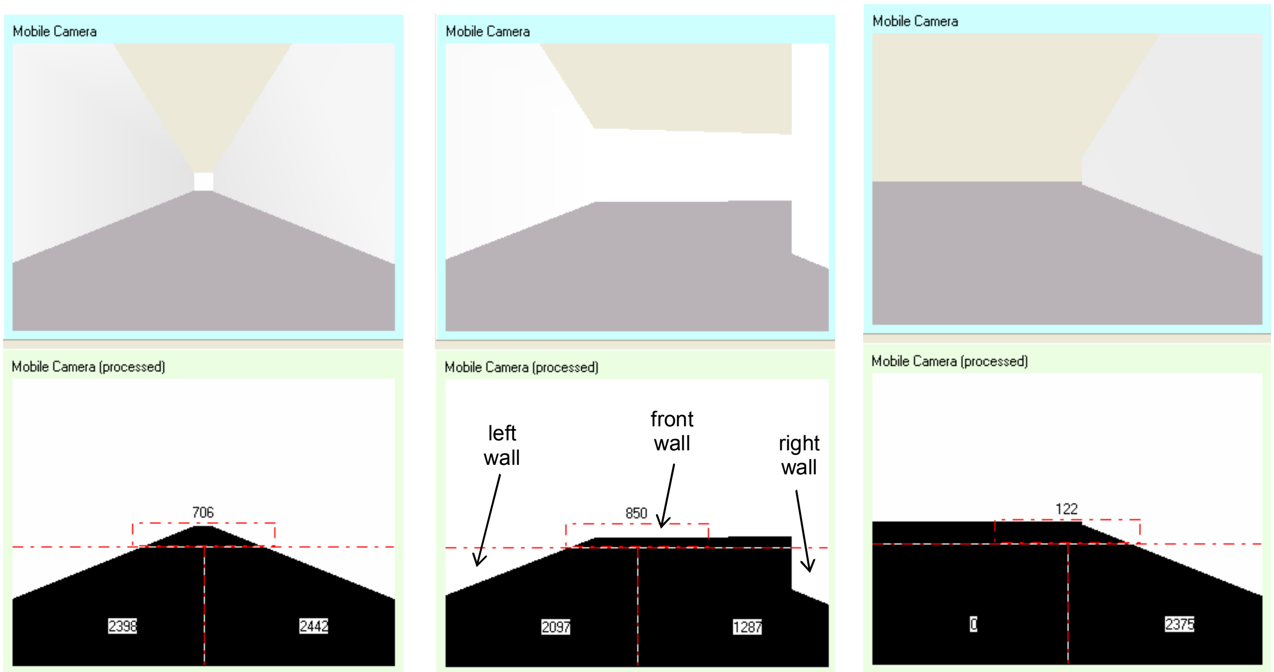
(a) running straight through a corridor,
(b) turning to the right, and
(c) following right wall.

Based on these visual patterns the processed images are divided into four regions representing the area of left wall, right wall, front wall and unused regions. The walls are discriminated from the floor using simple thresholding operation to the original image. The area of the wall is measured by counting the number of pixels which are part of the wall in those regions. Depend on their number of pixels, these areas are then classified into zero, small, medium, or large area for left and right walls, as well as zero, small, or large area for the front wall.

The areas of the walls determined the speed and the turning angle of the robot to move around the field. The fuzzy rules based on the visual patterns given in Fig. 3 are:

(a) if left wall area is large and right wall area is large and front wall area is small then turning steer is straight and speed is high (for straight through corridor)
(b) if left wall area is small and right wall area is large and front wall area is large then turning steer is small right and speed is low (for turning right corridor)
(c) if left wall area is zero and right wall area is medium and front wall area is zero then turning steer is straight and speed is medium (for following right wall)

The complete set of fuzzy rules used in this paper is given in Table I.



(a) Straight through corridor (b) Turning right (c) Following right wall

Fig. 3. Visual patterns to construct fuzzy knowledge base

TABLE I. FUZZY RULES

No	Input			Output	
	Left area	Right area	Front area	Turning angle	Speed
1.	S	S	Z	ZE	HI
2.	M	M	Z	ZE	HI
3.	L	L	Z	ZE	HI
4.	S	S	S	ZE	HI
5.	M	M	S	ZE	HI
6.	L	L	S	ZE	HI
7.	S	M	Z	LS	ME
8.	S	L	Z	LB	LO
9.	M	L	Z	LS	ME
10.	S	M	S	LS	ME
11.	S	L	S	LB	LO
12.	M	L	S	LS	ME
13.	M	S	Z	RS	ME
14.	L	S	Z	RB	LO
15.	L	M	Z	RS	ME
16.	M	S	S	RS	ME
17.	L	S	S	RB	LO
18.	L	M	S	RS	ME
19.	Z	S	Z	RS	LO
20.	Z	M	Z	ZE	ME
21.	Z	L	Z	LS	LO
22.	Z	S	S	LS	LO
23.	Z	M	S	LS	LO
24.	Z	L	S	LB	LO
25.	Z	S	L	LS	LO
26.	Z	M	L	LS	LO
27.	Z	L	L	LB	LO
28.	S	Z	Z	LS	LO
29.	M	Z	Z	ZE	ME
30.	L	Z	Z	RS	LO
31.	S	Z	S	RS	LO
32.	M	Z	S	RS	LO
33.	L	Z	S	RB	LO
34.	S	Z	L	RS	LO
35.	M	Z	L	RS	LO
36.	L	Z	L	RB	LO
37.	Z	Z	S	RL	ME
38.	Z	Z	L	RB	LO
39.	Z	Z	Z	ZE	HI
40.	L	L	L	RB	LO

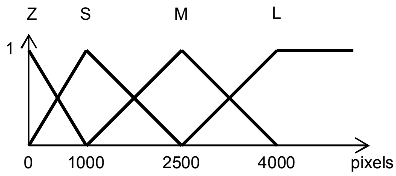
Those rules can be categorized as follows

1. Following straight corridor, rules 1-18
2. Following right wall, rules 19-27
3. Following left wall, rules 28-36
4. Heading normally to a wall, rules 37-38
5. No wall detected, rule 39
6. Blocked by walls from the three sides, rule 40

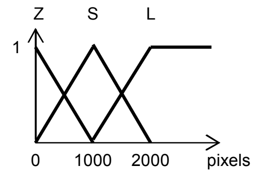
The fuzzy model used in this paper is a mamdani type fuzzy inference system (FIS). In order to simplify the calculation, triangular and semi trapezoid membership functions are used for the inputs; whereas for the outputs, singleton type is used. Fig. 4 and 5 show the membership functions for the inputs and the outputs, respectively.

The FIS implements minimum operator for the implication method and maximum operator for the aggregation of the outputs, as shown in (1).

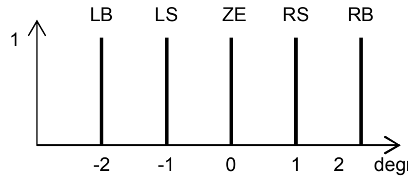
$$\mu_j(z_j) = \max\left(\min(\mu_{Li}(x_{Li}), \mu_{Ri}(x_{Ri}), \mu_{Fi}(x_{Fi}))\right)_j \quad (1)$$



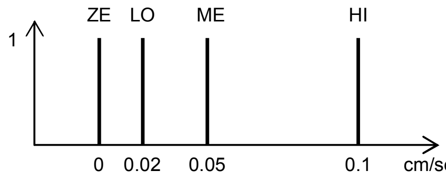
(a) Left and right wall area (Z = zero, S = small, M = medium, L = large)



(b) Front wall area (Z = zero, S = small, L = large)
Fig. 4. Input membership functions



(a) Turning angle (LB = left big, LS = left small, ZE = zero, RS = right small, RB = right big)



(b) Speed (ZE = zero, LO = low, ME = medium, HI = high)
Fig. 5. Output membership functions

where μ is the membership of the fuzzy sets, z_j denotes the output set, and L_i, R_i, and F_i, denote the left area, right area, and front area sets.

The defuzzification process uses center of singleton method, which can be calculated using (2).

$$output = \frac{\sum \mu_j(z_j) z_j}{\sum \mu_j(z_j)} . \quad (2)$$

C. Simulator

A 3-D computer simulator has been developed using OpenGL programming language to simulate the robot itself (including light sources and a camera) and the walls. The simulator also generates hypothetical image captured by the camera attached on the mobile robot. The simulator is equipped with the aforementioned fuzzy controller to navigate the robot movement.

Fig. 6 depicts the simulator interface showing the image gathered from the camera as well as its processed image, as well as robot movement image captured by an external camera.

III. Results and Discussion

Fig. 7 shows the tracks of the mobile robot while following a corridor from the right entrance to the left. It can be seen that the robot tries to maintain its position in the middle of the corridor and make smooth turns without colliding the wall. Fig. 8 shows the deviation between the actual positions of the robot normal to the center of the corridor. The error can be minimized along the straight path of the corridor. There is a slightly small error of around 0.2 cm at the leftmost corridor. However it is relatively small compare with the width of the corridor. The high values of error (up to 2 cm) are because the robot tries to turn smoothly while following the 90 degree turn corridor.

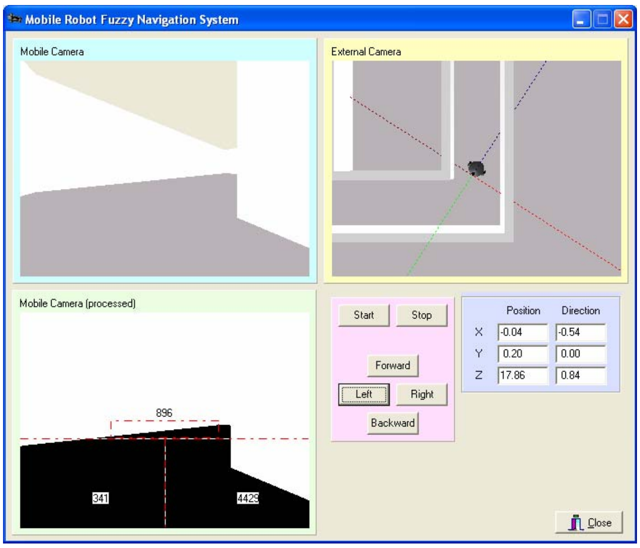


Fig. 6. Simulator interface

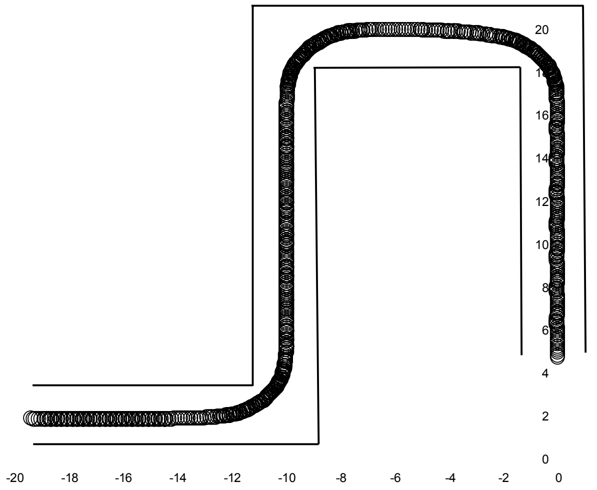


Fig. 7. Tracks of the robot moving through a corridor

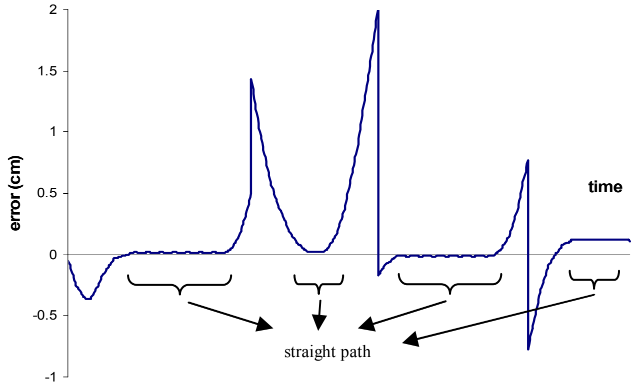


Fig. 8. Error normal to the center of the corridor

IV. Conclusions and Future Work

The visual-based fuzzy logic controller in this work is capable in implementing wall and corridor follower. However, more navigation features, such as obstacle avoidance, path planning, self localization, and target recognition, need also to be included into the system. This will enable the mobile robot to perform various tasks autonomously and intelligently. The developments to implement such features are still in progress parallel with this work.

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