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Research Article

Fuzzy Theory Applied in Identification System for Tiny Self-Driving Cars

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ABSTRACT

In this paper, a fuzzy theory based identification system has been developed to improve the self-driving image recognition technology. The Raspberry Pi microprocessor is used as the main controller of the car. The author writes a Python program to deal with the image recognition problem. The image processing techniques include grayscale, binarization, morphology, image cutting and so on. There are four main functional tests in the scenario setting. It includes road identification, conversion of lane turning arc into front wheel turning angle, intersection identification, and traffic light identification. The purpose is to verify the functionality of fuzzy-based identified self-driving cars. The experimental results show that the developed recognition system based on fuzzy theory can successfully improve the recognition effect and reduce the probability of self-driving walking errors.

1 INTRODUCTION

Image recognition technology in the 21st century has been applied to life. In particular, image recognition combined with automatic driving systems can bring people more convenient and safer driving. In the past 10 years, many good related studies have been presented.

In 2016, Felipe Jiménez et al. [1] proposed an algorithm based on vehicle dynamics mathematical model to improving the lane reference detection for autonomous road vehicle control. The following year, Toan Minh Hoang et al. [2] proposed a method to overcome various lighting problems. Especially severe shadows, these authors obtain better road lane detection results by using fuzzy system and line segment detection algorithm. For the problem of traffic light detection, in 2018, Manato Hirabayashi et al. [3] presented a ROI extraction method for traffic light images based on the current location on a 3D map. Moreover, the authors also proposed two methods to identify traffic light states on the extracted ROIs. This method can indeed tolerate calibration and localization errors to a certain extent. However, when the error is too large, the classification is incorrect. After two years, Kento Yabuuchi et al. [4] proposed a method to detect traffic lights from images captured by high-speed cameras that can recognize flashing traffic lights. The proposed method can handle more than 1000 fps. In 2021, Syeda Shahista et al. [5] proposed a vision-based traffic light structure detection and convolutional neural network (CNN)-based state recognition method that is robust to different lighting and weather conditions. Not only that, the authors presented a deep fusion network for robust fusion without the need for a large amount of labeled training data covering all asymmetric distortions. The following year, Qingyan Wang et al. [6] presented a new YOLOv4 algorithm by using the shallow feature enhancement mechanism and the bounding box uncertainty prediction mechanism. Its main purpose is to improve the network's ability to locate small objects and color resolution, and then improve the accuracy of traffic light detection and recognition.

Based on the above, in order to develop teaching-type autonomous vehicles, Chun-Chieh Wang [7] proposed a smart identification technology to complete road identification, conversion of lane turning arc into front wheel turning angle, intersection identification, and traffic light identification. However, the experimental results show that the swing of the vehicle during walking is too large, so that the trajectory of the vehicle often exceeds the sides of the road. Therefore, this paper proposes a road identification system with a fuzzy theoretical framework. In addition, the author also makes moderate improvements to the tiny self-driving car and its power supply.

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2 TINY SELF-DRIVING CARS (TSDC)

2.1 TSDC Platform

The tiny self-driving car body in this article uses the steering gear to drive the direction of rotation of the vehicle. Actual view of the car is shown in Fig. 1. In general, the mechanism design of the car body is similar to the mechanism of [7]. Therefore, this article will not go into details.

It is worth noting that mobile power supply is utilized to provide stable power to keep the testing process at its best in this article. Not only that, a transformer (5V, 2.5A) can provide stable voltage and current to the Raspberry Pi. The two upper and lower lenses on the front of the car are used to identify the road and identify the traffic lights, as shown in Fig. 1-B.

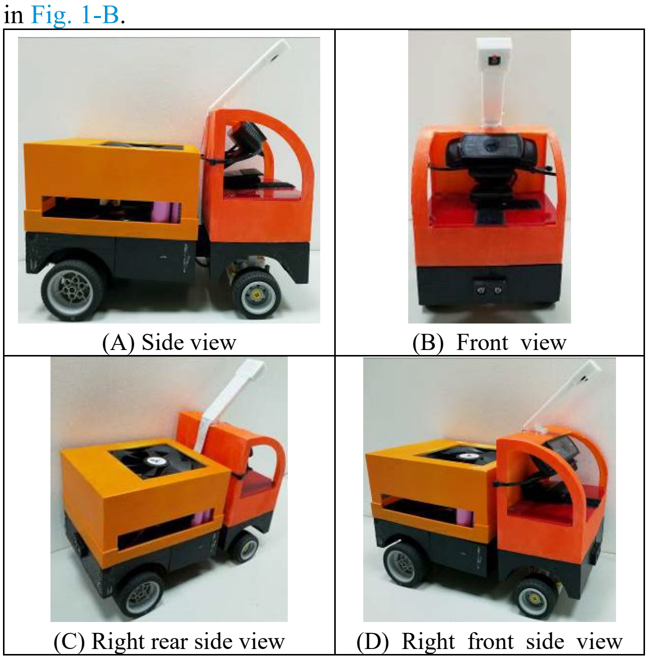


Fig.1. Actual view of the car

2.2 Controller and Peripheral Devices

The Raspberry Pi is used as the main controller for this article. It is a microcontroller based on the Linux operating system. The steering of the car is controlled by the 360-degree rotating servo motor-SG90 and the 180-degree high torque servo motor-MG996R. As for road recognition and traffic light recognition, Raspberry Pi Camera V1.3 and Logitech C920 cameras are used respectively. For actual photos of all the above equipment, please refer to [7].

3 FUZZY THEORY BASED IDENTIFICATION SYSTEM (FTBIS)

3.1 Setting Method of Road Coordinate Points

This paper sets the coordinate positions on both sides of the road to keep the car in the center of the road. The coordinate position of the road width is used to obtain the center point to ensure that the car's route is in the center of the road. If the car turns when it is walking, it will obtain the center point position according to the road width in the lens, so as to control the turning range of the steering gear.

The coordinate points x_1 and x_3 on both sides of the track are taken to calculate the center point (Q) of the road. Equation 1 is used to calculate the Q point coordinates of Fig. 2. Then, the coordinate points on both sides of the road are locked, which are $A(x_0,y_0)$, $B(x_1,y_1)$, $C(x_2,y_2)$, $D(x_3,y_3)$ four coordinate positions.

The controller needs to determine the turning range in advance to prevent the vehicle from exceeding the driving trajectory. Because of this, the coordinates A and C are additionally set in this paper. Coordinates B and D are where the car needs to get the center point. When the subtracted distance between points B and D cannot be directly expressed as the coordinates of the center point, the x1 coordinate needs to be added to the correct position of point Q.

$$Q = x_1 + \frac{x_3 - x_1}{2} \tag{1}$$

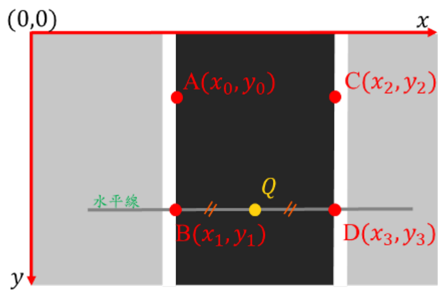


Fig.2. The central position of road recognition

$$\boldsymbol{\theta} = \boldsymbol{tan}^{-1}\frac{|x_n - x_{n+1}|}{|y_n - y_{n+1}|} \tag{2}$$

$$\boldsymbol{\theta_0} = \frac{\theta_L - \theta_R}{2} \tag{3}$$

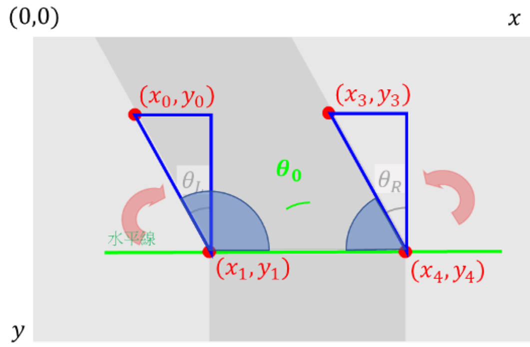


Fig.3. Angle range of θ_L and θ_R

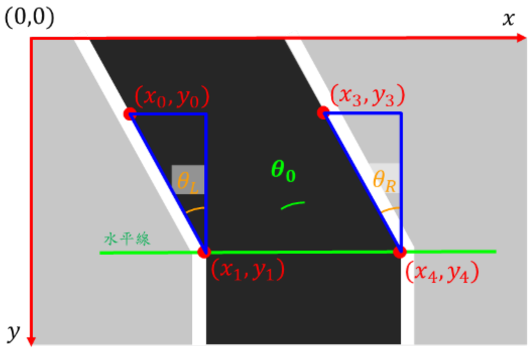


Fig.4. Schematic diagram of the coordinates of the road turning

The green area in Fig.3 is the suitable turning range. Equation 2 is used to calculate the angle of $\theta_\circ$ to adjust the magnitude of the steering gear. As shown in Fig.3, θ_L is the amplitude of the left wheel steering and θ_R is the amplitude of the right wheel steering. It should be noted here that the $\theta_\circ$ generated by the coordinate changes on both sides may be different. Therefore, Equation 3 is used to ensure that the correct $\theta_\circ$ can be obtained. Fig.4 is the coordinate position on the road. According to the curvature and direction of the road, an appropriate angle $\theta_\circ$ is generated to control the vehicle to drive along the road.

3.2 Control Flow Design

Camera lenses are turned on for image recognition to identify images of road and traffic signs. First, the image captured by the camera lens is judged whether it is the entrance of the starting point. Secondly, the controller will judge according to the system flow chart shown in Fig. 5 to make sure that the driving route is correct. As for flowchart of road identification and flow chart of traffic light identification, please refer to [7].

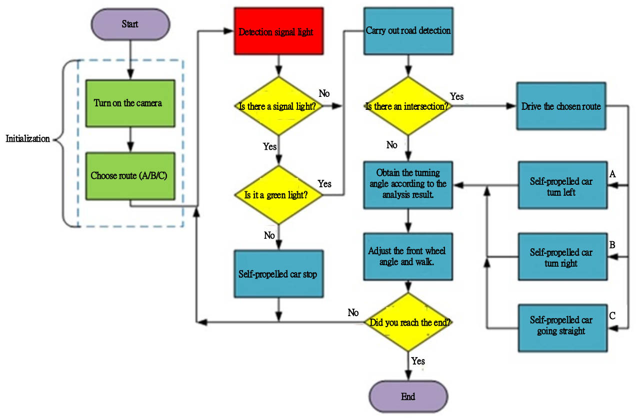
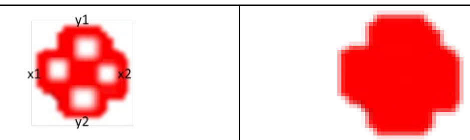


Fig.5. System flow chart

3.3 Traffic Light Detection

To identify the status of the R, Y, and G colors of the traffic lights, it is necessary to obtain the grayscale value of each light first. In addition, to obtain an accurate light status, it is necessary to remove the bright spot in the middle of the LED light to facilitate color judgment. Not only that, the coordinates of x1, x2, y1 and y2 are set to obtain the position of the light signal. Next, the position of the light spot is processed and the parts that may affect the recognition are removed. Dilation needs to be performed after the light spot is removed. Fig. 6 is the result before and after processing the light spot for traffic lights.



(A) 4 coordinate settings | (B) The processed light

Fig.6. The result before and after processing the light spot

3.4 Road Boundary Detection

To make road recognition more accurate, this section firstly plans the judgment conditions for road recognition. The way to judge the turn is to transmit the image of the camera to the Raspberry Pi to get the boundary points of the road so that the width of the road can be calculated. The judgment method will be divided into the calculation formula of the right boundary (line_R) and the left boundary (line_L). Taking Fig.7 as an example, if the X coordinate of line_R minus line_L is less than 120, it means that the captured boundary area appears as a straight line. If the X coordinate position of line_R is less than 10, the trajectory is deviated and a right turn is required. If the X coordinate of line_L is greater than 120, it means that the car is too far to the right and must turn left to return to the center of the road.

When encountering a fork like Fig.8, Fig.9 and Fig.10, the counter will change from 0 to 1. For example, assuming that the self-driving route is A2, in Fig.11, it can be determined whether to turn or go straight at the next intersection.

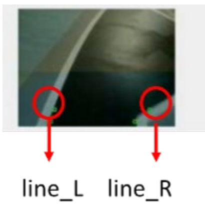


Fig.7. Road boundary detection point

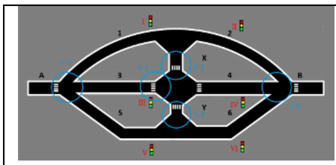


Fig.8. Straight curve detection position

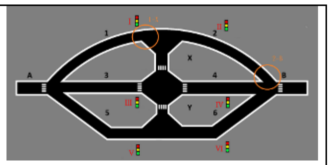
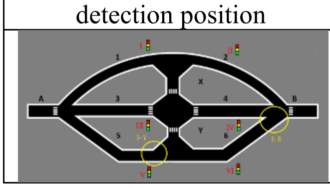


Fig.9. Curved corner detection position



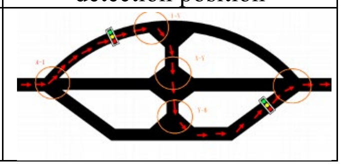


Fig.10. T-shaped corner detection position	**Fig.11.** A2 route curve detection position

3.5 Fuzzy Theory Based Identification Rule Design

To reduce the probability of the vehicle's trajectory going beyond the sides of the road, this paper proposes a road recognition system with a fuzzy theoretical framework. Once the center point of the track is determined by visual recognition, the fuzzy controller is activated immediately, so that the car can be corrected back to the original middle of the road in the shortest time.

First, the error (e) between the center point (Cm) captured by the camera and the road center point (Q) is defined as the input of the fuzzy controller. That is, e=Cm-Q. e>0 means the car is to the right. Conversely, e<0 means that the car is to the left. The output of the controllers are set as the rotation angles of the motor (θ_L, θ_R). In addition, the error (e) is divided into small positive error (SPE), medium positive error (MPE), large positive error (BPE), small negative error (SNE), medium negative error (MNE) and large negative error (BNE). Similarly, the output (θ_L, θ_R) are also divided into small positive error (SPA), medium positive error (MPA), large positive error (BPA), small negative error (SNA), medium negative error (MNA) and large negative error (BNA). Here, the symbols of the forward and reverse rotation of the motor are defined as P for forward rotation and N for reverse rotation. The membership function of the input and output range are designed in Mamdani type. Combining the above, the design of Fuzzy IF-THEN rules are expressed as follows.

If e is BPE, then θ_L is BNA and θ_R is BPA.
If e is MPE, then θ_L is MNA and θ_R is MPA.
If e is SPE, then θ_L is SNA and θ_R is SPA.
If e is SNE, then θ_L is SPA and θ_R is SNA.
If e is MNE, then θ_L is MPA and θ_R is MNA.
If e is BNE, then θ_L is BPA and θ_R is BNA.

4 EXPERIMENTAL SCENARIO DESIGN

The position and number of traffic lights in this article are as shown in Fig.12. During the experiment, only two traffic lights will be placed on each path for testing.

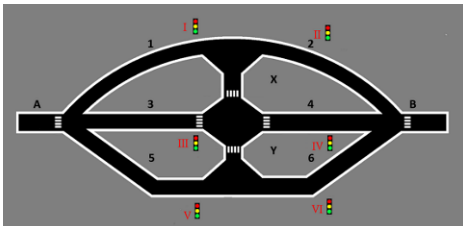


Fig.12. Road site simulation map (6 traffic lights)

5 EXPERIMENTAL RESULTS

Please refer to the following URL directly for the experimental results. https://youtu.be/hZut2Adu0Rw

Fig.13-Fig.30 are screenshots (including schematic diagrams) of self-driving walking pictures of 9 routes.

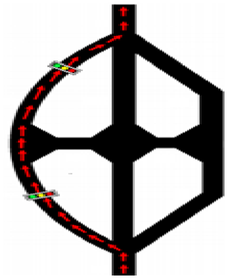


Fig.13. Schematic diagram of route A

Fig.14. Actual walking screen of Route A

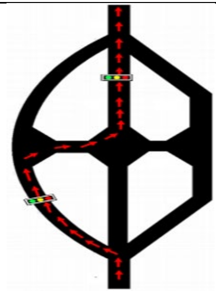


Fig.15. Schematic diagram of route A1

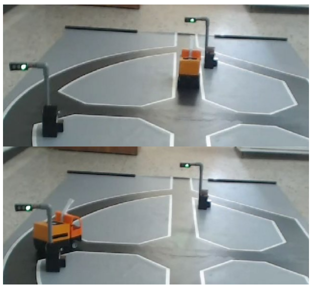


Fig.16. Actual walking screen of Route A1

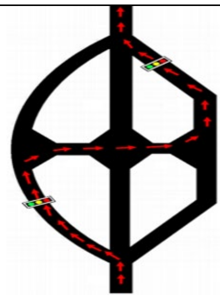


Fig.17. Schematic diagram of route A2

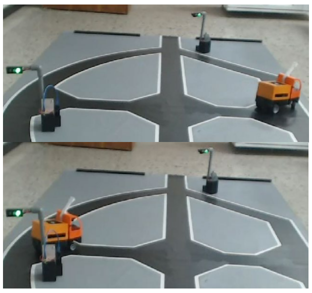


Fig.18. Actual walking screen of Route A2

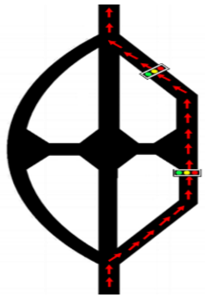


Fig.19. Schematic diagram of route D

Fig.20. Actual walking screen of Route D

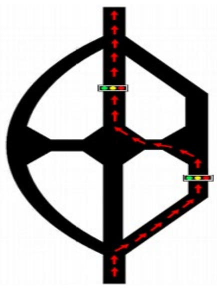


Fig.21. Schematic diagram of route D1

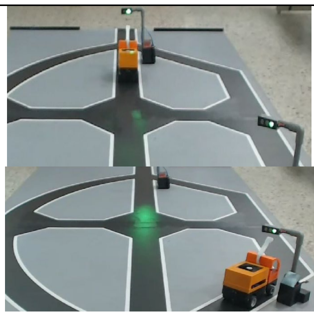


Fig.22. Actual walking screen of Route D1

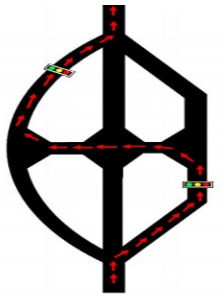


Fig.23. Schematic diagram of route D2

Fig.24. Actual walking screen of Route D2

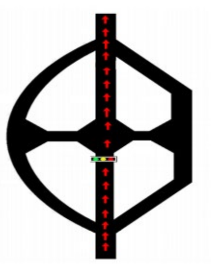


Fig.25. Schematic diagram of route S

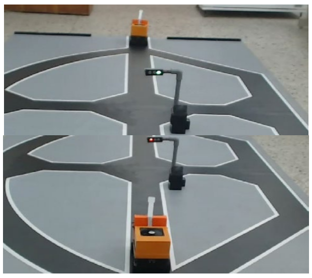


Fig.26. Actual walking screen of Route S

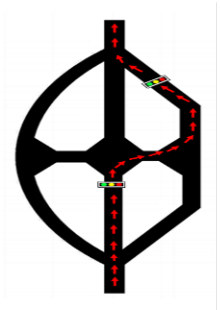


Fig.27. Schematic diagram of route S1

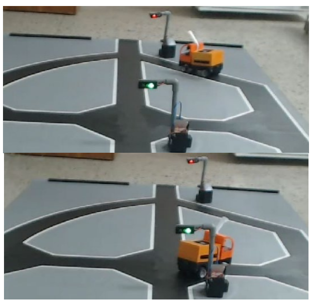


Fig.28. Actual walking screen of Route S1

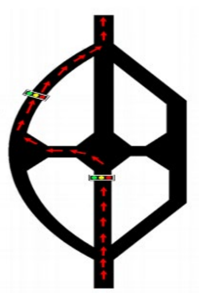


Fig.29. Schematic diagram of route S2

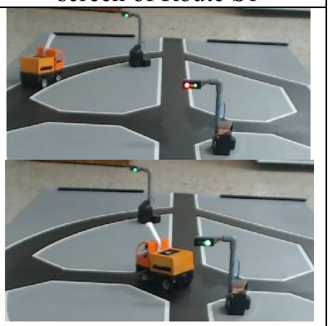


Fig.30. Actual walking screen of Route S2

6 CONCLUSION

This article successfully developed a tiny self-driving car with fuzzy based identification system. In order to test whether it is fully functional, the experimental field is planned, in which 9 different paths are designed to allow the tiny self-driving car to perform visual identification based on different paths.

In addition, to reduce the probability of the vehicle's trajectory going beyond the sides of the road, a road recognition system with a fuzzy theoretical framework is proposed. When the trajectory of the tiny car crosses any side of the road, the fuzzy controller will be activated immediately. The purpose is to make the car correct the trajectory and return to the middle of the original road in a very short time.

To realize the function of self-driving cars, there are four main functional tests in the scenario setting. It includes road identification, conversion of lane turning arc into front wheel turning angle, intersection identification, and traffic light identification. The test results prove that the developed fuzzy-based recognition system can effectively improve road recognition and reduce the probability of self-driving derailment.

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Authors Introduction

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He is a professor of Department of Automation Engineering and Institute of Mechatronoptic Systems of Chienkuo Technology University. His areas of research interest include robotics, image detection, electromechanical integration, innovative inventions, long-term care aids, and application of control theory. He is now a permanent member of Chinese Automatic Control Society (CACS) and Taiwan Society of Robotics (TSR). He is also a member of Robot Artificial Life Society.