Real-Time Obstacle Avoidance and Fuzzy Dynamic Steering Control for an Unmanned Ground Vehicle

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In real situation, the motion planning of the vehicle does not rely on accurate static models of the environments. It can perceive its environments, react to unforeseen circumstances, and plan dynamically in order to achieve its mission. This paper describes the autonomous obstacle avoidance system for a mobile robot in an unmapped and changing environment. The developed algorithm uses a fuzzy logic approach and is conducted using an autonomous mobile robot platform including three sets of ultrasonic sensors. The environment information surrounding the robot detected by the ultrasonic sensors is firstly fuzzified, and then input into fuzzy control system. The output of the fuzzy control system is used to drive the robot. In the real-time performance tests, the system is able to guide vehicle around obstacles.

Keywords: Mobile Robots, Fuzzy Logic, Obstacle Avoidance, Steering Control, UGV
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INTRODUCTION

Obstacle avoidance is one of the key issues to successful applications of unmanned ground vehicles (UGV). There are some classic obstacle avoidance methods such as edge-detection, certainty grids, and potential field method and Virtual Force Field method. These methods have required a vast number of calculations and so significantly increase the response time of robot [1]. The problem of mobile vehicle navigation particularly through a dynamically changing environment is a challenging one.

In the real environment, the path orientation, road flatness, obstacle position, road surface friction, etc. could be varied. There are many uncertainties in conditions that will occur during its operation. Fuzzy logic is one of the solutions for these conditions. The best arguments supporting fuzzy logic control are the ability to cope with imprecise information in heuristic rule based knowledge and sensor measurements. Another advantage of fuzzy logic control is to use fuzzy logic for representing uncertainties, such as vagueness or imprecision which cannot be solved by probability theory [2].

This paper addresses the obstacle avoidance control system for a UGV. Three ultrasonic sensors measure the distances from the obstacles around the vehicle and offers precise ranging information from roughly 3 cm to 3 m. The fuzzy logic controller is implemented on the 16-bit microcontroller and it drives the dc motors and the servo motor to control the speed and heading of UGV. Obstacle encountered on or near the path of the vehicle is avoided according to the information obtained from ultrasonic sensors attached on the vehicle and the decision making Fuzzy controller.

VEHICLE SYSTEM

The commercial off-the-shelf Radio Control (RC) car is used to design unmanned vehicle as shown in figure 1. It has four identical parallel wheels (attached to both sides of the vehicle) and only rear wheels are controlled by a dc geared motor. The dc motors in the original RC were replaced by a servo motor and a new powerful dc motor. The servo motor is used for steering control.

The speed of the dc motor is controlled by pulse width modulator (PWM) and an H-bridge driver and, both motors are powered by 11.1V Li-poly battery. To detect the obstacles on-the-fly the vehicle is equipped with ultrasonic sensors. These sensors are mounted on the fiber stand to avoid the echo from the ground and they are positioned so that their acoustic axes make angle of 45° each other.

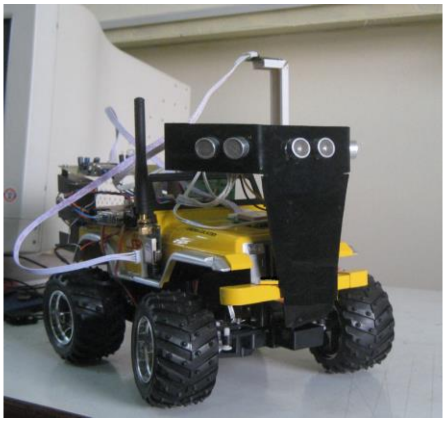

FIGURE 1. UGV system

Vehicle Electronics

The PIC 24FJ128GA010 microcontroller board is the major component of vehicle hardware and the control algorithm is embedded in the program memory of this unit. Three ultrasonic sensors (SRF04s) are connected to the microcontroller's I/O pins and input captured inputs. The microcontroller generates 1ms trigger signal for each ultrasonic sensor. The pulse width of the returning echo signal is detected from input captured pins of microcontroller. The input capture module of microcontroller calculates the time interval between rising and falling edges of an echo signal. The microcontroller activates only one ultrasonic sensor at a time to avoid overlapping the signals among the sensors.

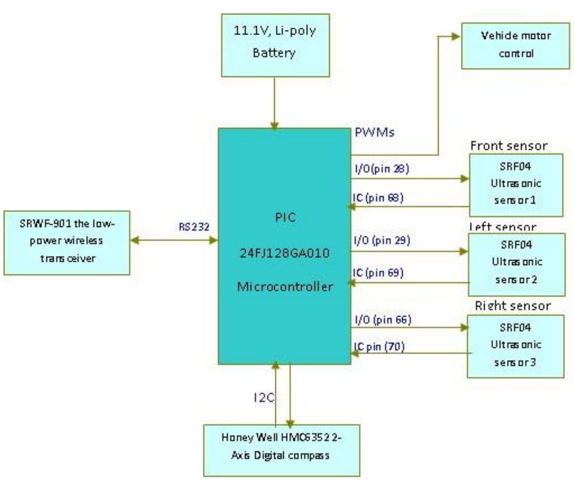

FIGURE 2. UGV electronics

The SRF04 detects objects by emitting a short burst of ultrasound and listening for the echo, and it operates at 40 kHz sound wave. This pulse travels through the air at about 1.125 feet per millisecond (the speed of sound) and bounces back from the object. By measuring the time between the transmission of the pulse and the returning echo, the distance to the object can be determined [3].

The speed controller is designed to move the vehicle with different speeds both forward and reverse directions. The steering actuator can turn vehicle up to eighteen degrees from the centre position. The H-Bridge circuit is used as a power driver for the dc motor. The PWM drives the H-bridge input to alter the speed of the dc motor and it has a frequency of 65Hz and 8µs resolution for the pulse duration.

The wireless connection between UGV and PC is established to transfer the data between them and to send the command to the UGV. The wireless transceivers are interfaced to the serial ports of the microcontroller and PC.

FUZZY LOGIC CONTROLLER FOR OBSTACLE AVOIDANCE

A fuzzy logic controller (FLC) has the advantage that it allows intuitive nature of sensor-based navigation and can easily transform linguistic information into control signals[2]. The proposed FLC uses the sensory information from three ultrasonic sensors as inputs and controls the speed of the dc motor and position of the servo motor for the steering angle control.

The FLC scheme is shown in figure 3.The fuzzification process maps crisp input into a fuzzy set, being input to the inference engine. The inference engine combines rules and gives mapping from fuzzy input sets for fuzzy output sets. The defuzzification process produces crisp output from a fuzzy set. Defuzzification method used in this work is Center of Gravity (COG) method.

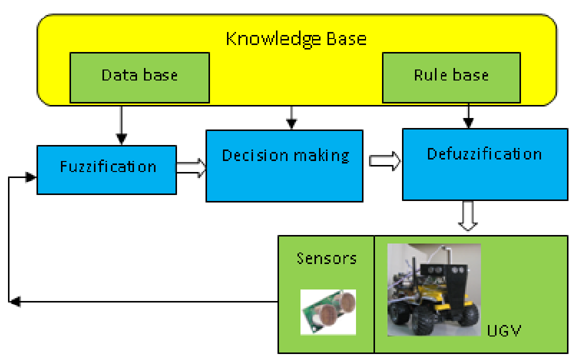

FIGURE 3. FLC scheme

Defining Membership Functions

The membership functions are used for converting the real data from the ultrasonic sensors into a fuzzy value between zero and one, or converting the fuzzy output values into real values for motor outputs. There are three sets of input membership functions for three ultrasonic sensors (US): left US, right US and front US. Two membership functions are used for each sensor as show in figure 4 and they are identical for all inputs.

The controller variables for inputs are $(\text{Left})_k$, $(\text{Front})_k$ and $(\text{Right})_k$. The linguistic terms for input variables are assigned as

$(\text{Left})_k = (\text{Front})_k = (\text{Right})_k = \{\text{Near, Far}\}$.

The range (or universe of discourse) of each variable lies between 0 and 160 cm.

Each linguistic variable is associated with a scaling factor: K_L for the $(\text{Left})_k$, K_F for the $(\text{Front})_k$ and K_R for the $(\text{Right})_k$. Scaling factors enable the use of normalized universe of discourse and play a role similar to that of the gain coefficients in a conventional controller. The control policy is established in the rule-base and expresses the knowledge of the designer about the process.

The distance membership functions allowed the distance measured by the SRF04 ultrasonic range finder to be fuzzified, while the **speed** membership function shown in figure 5 and **turn-angle** membership function illustrated in figure 6 converted fuzzy values back into crisp values.

The singleton are used for the output membership functions instead of triangular membership functions because they greatly simplify the mathematics required in the defuzzification phase and the result obtained from using singletons are almost the same as that obtained from using full membership function. Then the FLC engine performs evaluation of the rule base by looping through the rule-base array one element at a time.

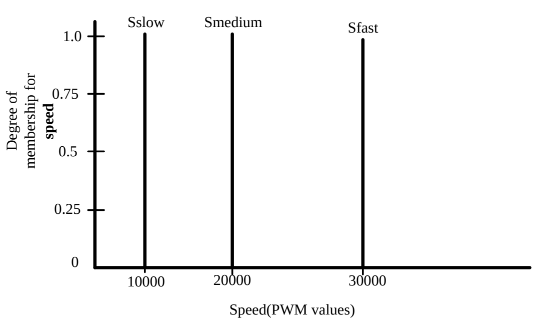

FIGURE 4. Output membership function for speed

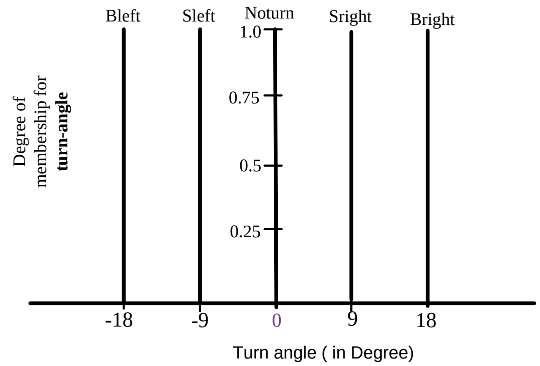

FIGURE 5. Output membership function for turn-angle

Defining Rule-Base

Once the input data was fuzzified, the eight defined fuzzy logic rules in table 1 is executed in order to assign fuzzy values for translational speed and turn angle. One of the rules is seen in the form:

If (Left is Near) AND (Front is Near) AND (Right is Near) then (Speed is S_slow) and (turnangle is B_right)

This results in multiple values for each of the fuzzy output components. It is then necessary to take the maximum of these values as the fuzzy value for each component. Finally, these fuzzy output values are "defuzzified" using the max-product technique and the result is used to update each of the motor speed and turn angle.

TABLE 1. Fuzzy logic rule-base.

Rule	Left	Front	Right	Speed	turn-angle
1	*Near*	*Near*	*Near*	*S_slow*	*Big_ right*
2	*Near*	*Near*	*Far*	*S_ medium*	*Small_ right*
3	*Near*	*Far*	*Near*	*S_slow*	*No_ turn*
4	*Near*	*Far*	*Far*	*S_fast*	*Small_ right*
5	*Far*	*Near*	*Near*	*S_ medium*	*Small_ left*
6	*Far*	*Near*	*Far*	*S_slow*	*Big_ right*
7	*Far*	*Far*	*Near*	*S_fast*	*Small_ left*
8	*Far*	*Far*	*Far*	*S_fast*	*No_ turn*

Defuzzification

The output of the inference mechanism is a fuzzy value and it is necessary to convert this fuzzy value into a real value for actuators, because the physical process cannot deal with a fuzzy value. This operation is called defuzzification and it is also the inverse operation is fuzzification [2].

There are several defuzzification methods to convert a fuzzy value to real value. The COG defuzzification method is used because it is simpler and computationally very efficient. The following equations are used for defuzzification of speed and turn angle of the controller outputs[4],[5].

Below is an example equation created with Word 97's Equation Editor. To move this equation, highlight the entire line, then use cut and paste to the new location. To use this as a template, select the entire line, then use copy and paste to place the equation in the new location.

$$(\Delta \mathrm{Uij})_{\mathrm{speed}} = \frac{\sum_{ij} f_{ij}(c_{ij})_{speed}}{\sum_{ij} f_{ij}}. \quad (1)$$

$$(\Delta \mathrm{Uij})_{\mathrm{tum\text{-}angle}} = \frac{\sum_{ij} f_{ij}(c_{ij})_{turn-angle}}{\sum_{ij} f_{ij}} \quad (2)$$

Where f_{ij} is the firing strength of the rule and c_{ij} is a crisp value (action). $(\Delta U_{ij})_{\text{speed}}$ and $(\Delta U_{ij})_{\text{turn-angle}}$ are control action for the speed and steering angle of UGV.

The main idea of this method is that the larger the firing strength of the rule (fij), the more this rule contributes to the global fuzzy output.

PERFORMANCE TESTS FOR OBSTACLE AVOIDANCE

The constructed vehicle with FLC algorithm was tested along the corridors of Universities' Research Centre building which is 160cm wide. The obstacles are placed in different position along the corridor and the motion of the UGV is recorded with video recorder during the test run. The path travelled by the UGV is drawn using video records and analyzed for particular incidents or collisions. The Fuzzy controller is tuned during the tests until the vehicle travels along the shortest path and smooth trajectories in different obstacles environments.

Performance test results obtained in two different working scenarios (with different obstacle constellations) are presented in figures 7 and figure 8. In all scenarios, the robot moves from the initial point to the target point avoiding the obstacles. The vehicle took 11 seconds to travel along the obstacle free path and its achieved average speed of about 0.45 m/s. In scenario 1 and scenario 2 it took 18 s and 16 s respectively. So, its average speeds for these tests are 0.27 m/s and 0.31 m/s.

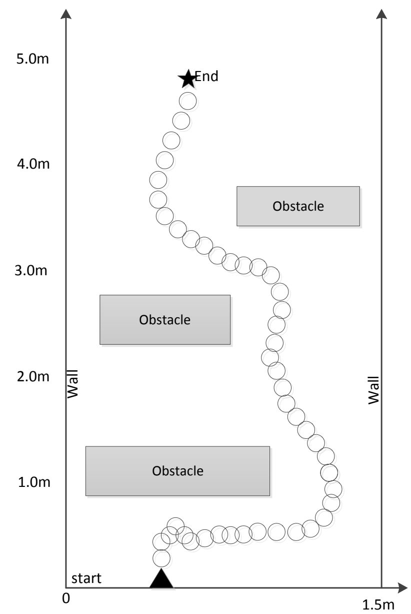

FIGURE 6. Experimental result of scenario 1

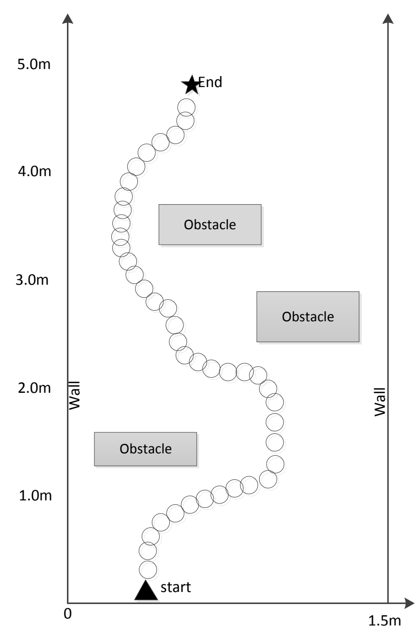

FIGURE 7. Experimental result of scenario 2

CONCLUSION

This paper has addressed the fuzzy logic algorithm in association with the ultrasonic sensors for UGV and it works with a good level of reliability. UGV has been tested in a variety of working scenarios with different obstacle constellations, both static and dynamic, providing each time a collision-free trajectory for the robotic platform. The algorithm is able to guide UGV around obstacles, in simple and complex situations and successfully control the heading and speed of the UGV.

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