Mobile Robot Speed Control using Fuzzy Logic Controller

Mutita Songjun

***Abstract*— *This paper presents a mobile robot speed control system using the fuzzy logic controller. Fuzzy rules embedded in the controller of a mobile robot enable it to regulate its speed to be stable if the load is varied. A fuzzy logic system is designed with a speed regulation behavior. The inputs to the fuzzy controller are the change of load and the current load on the mobile robot measured from the load cell. The outputs from the fuzzy controller are the speed of the mobile robot and the speed regulator parameter. The speed control system has been experimented on an actual mobile robot. Under the proposed fuzzy controller model, a mobile robot is capable to stably remain the desired speed if the load is changed.*

***Keywords*— Fuzzy logic controller, speed control, mobile robot, load.**

1. INTRODUCTION

Mobile robots are widely used in a present time since they are able to work in many areas and able to do their jobs perfectly as human commands. Their working places are not only in the factories however it is expanded to our homes and also to the office building, department stores, and hospitals. The design of a controller for a mobile robot is the important part to achieve the desired target. The specific movement of the mobile robot is controlled by the desired controller under the specific conditions. Sometimes the speed of the movement is also considered in the tasks that require the constant speed level. There are many approaches for designing the speed controller.

Fuzzy logic is one of the approaches that is able to deal with the approximating mode under uncertainty condition [1]. Fuzzy logic is based on the simulation of human decisions and perceptions to control the system. The expert operator develops the flexible control mechanism using linguistic concept. The linguistic words in the fuzzy logic design are frequently used in human life. Fuzzy logic control is constructed on the logical relationships without requiring the precision mathematical model. Fuzzy set are used to show the designed linguistic variables. Fuzzy sets theory was firstly introduced in 1965 by Lotfi Zadeh to express and process fuzzy knowledge [2], [3]. The classical controllers depend on the accuracy of the system model and parameters but fuzzy logic controller uses the different strategies. Fuzzy logic controller process is basically based on experiences and linguistic definitions instead of system model. The fuzzy logic controller for mobile robot has been investigated by many researchers. For the robot navigation, [4], [5], [6], and [7] proposed the fuzzy logic controller model to force the mobile robot to avoid the obstacles on the desired path. [8] and [9] also dealt with robot navigation but they used the neurofuzzy-based controller. [10] and [11] presented the fuzzy logic controller for a speed control of dc motor.

The goal of designed fuzzy logic controller in this paper is to regulate the mobile robot speed when the load is varied. The desired robot speed value is set and remains at the same value even the load is changed more or less. The inputs of the fuzzy controller are the output from the sensor system. The outputs from the fuzzy controller are the speed of mobile robot and speed regulator parameter. The linguistic fuzzy sets and the designed rules are developed to implement the desired target. The experiments prove that the mobile robot with the proposed fuzzy logic controller has the stably constant speed movement when the load is changed.

2. MOBILE ROBOT

The mobile robot is designed and constructed in a rectangular shape with four wheels. The actual mobile robot configuration is shown in Figure 1. Two wheels at the back are independently controlled by two dc motors on a common axis. Other wheels are provided for support on a free direction. The dimension of the mobile robot is 0.21 m wide, 0.27 m long and 0.25 m high. The sensor systems consist of a load cell and an encoder. The load cell is equipped in the middle of the robot to measure the weight which will be loaded on the top of the robot. The encoder is equipped at the right back wheel to measure the number of the wheel rotation. The speed of the robot can then be calculated and displayed in m/s unit on the LCD screen at the front part of the robot.

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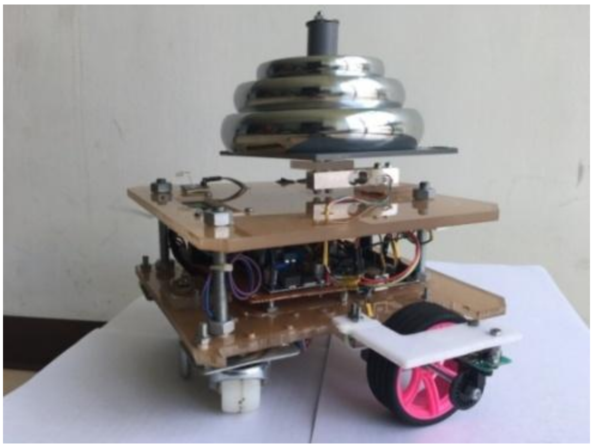

Fig.1 Mobile robot configuration.

3. FUZZY LOGIC CONTROLLER DESIGN

Fuzzy logic is an alternative method for designing the controller which the inputs to the controller can be determined as the uncertainty values. It is a tool that uses the human expertise to generate the various decisions. Traditional logic permits conclusions based on two values which are either true or false. This solution sometimes is not enough to accomplish the process. Fuzzy logic uses the entire interval between zero and one to make the solution close to the human reasons. The design process of fuzzy logic control generally consists of three stages: fuzzification, fuzzy inference, and defuzzification.

In the fuzzification stage, the inputs to the fuzzy logic controller are in the membership function values which are converted from the crisp data. The membership functions change the actual input values into degree values. Once the inputs are fuzzified, the fuzzy rules are applied to decode and analyze the inputs under the designed conditions and determine a relative response to the inputs. The results obtained from fuzzy inference cannot be use directly. They have to be translated to crisp signals in the defuzzification stage. There are various ways using different kind of algorithm to evaluate the crisp data. A common and easy approach for defuzzification is center of gravity (COG) method.

The fuzzy controller designed in this paper is to control the speed of the mobile robot depending on the weight loaded to the robot. The inputs to the fuzzy controller are the outputs from the load cell which are the change of load and the current load on the mobile robot. The outputs from the fuzzy controller are the change of speed and the speed regulator parameter at the current load. The fuzzy inference system with two inputs and two outputs is shown in Figure 2.

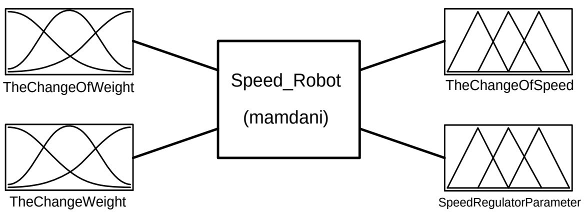

Fig. 2. The fuzzy inference system of the proposed controller.

Fuzzification

The fuzzification procedure maps the crisp input data to the fuzzy terms with membership values between zero and one. Two fuzzy membership functions are designed to fuzzify the data from load cell. The membership functions for the terms of the input variables of this controller are shown in Figure 3 and Figure 4.

The membership functions considered here are triangle and trapezoid function. The input of the change of load is defined with linguistic variables which are negative very small (NVS), negative small (NS), negative medium (NM), negative large (NL), negative very large (NVL), positive very small (PVS), positive small (PS), positive medium (PM), positive large (PL), and positive very large (PVL). The other input is the current load on the mobile robot. This input is defined as the least load, very small load, small load, medium load, heavy load, and the heaviest load which are denoted by variable w0, w1, w2, w3, w4, and w5 respectively.

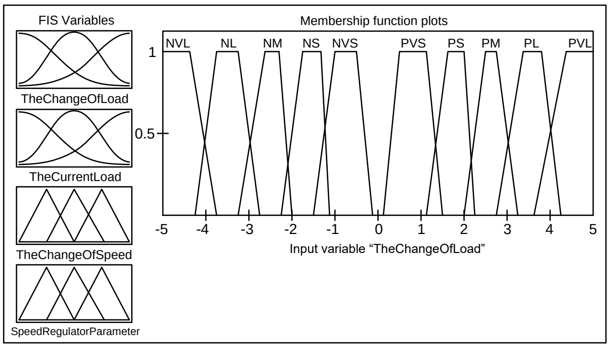

Fig. 3 The membership function for the input the change of load.

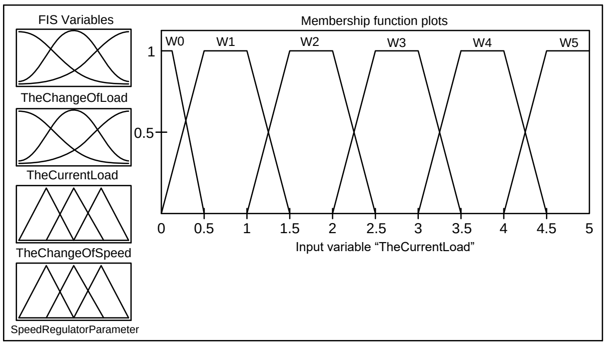

Fig. 4 The membership function for the input the current load.

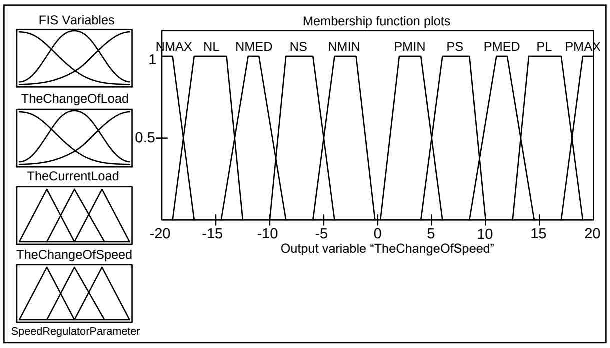

Fig. 5 The membership function for the output the change of speed.

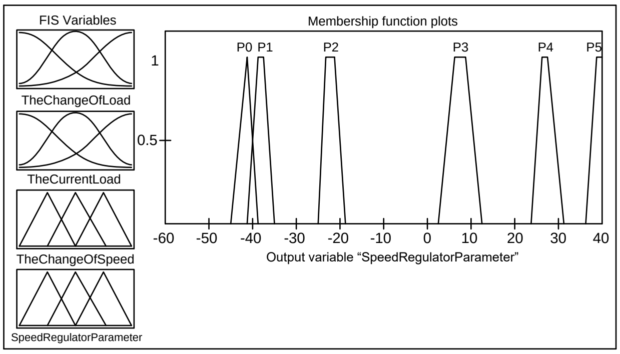

Fig. 6 The membership function for the output the speed regulator parameter.

The membership functions of the output variables are shown in Figure 5 and Figure 6. The first output is the change of speed depended on the change of load. They are denoted by linguistic variables as negative minimum (NMIN), negative small (NS), negative medium (NMED), negative large (NL), negative maximum (NMAX), positive minimum (PMIN), positive small (PS), positive medium (PMED), positive large (PL), and positive maximum (PMAX). The second output is the speed regulator parameter at each load which are denoted as parameter at the least load (P0), parameter at very small load (P1), parameter at small load (P2), parameter at medium load (P3), parameter at heavy load (P4), and parameter at the heaviest load (P5).

Fuzzy Inference

The fuzzy inference is the procedure in the fuzzy controller that using approximate human reasons and experiences for making the decisions. The designed rule base in the controller contains the possible rules that are governing the inputs and the outputs relationship. The inference rules can be written in the general form as

IF (The change of load is positive very small (PVS))

THEN (The change of speed is positive minimum (PMIN))

Sixteen rules formulated for the proposed controller are given in Table 1 and Table 2. There are two possibilities rule base: the change of speed behavior when the load is changed (Table 1), and the speed regulator parameter at the current load (Table 2). The change of speed behavior is used to regulate the speed of the mobile robot depended on the change of load. For example, if the load is heavier, in general, the speed of the mobile robot will decrease. So the controller has to gradually increase the robot speed to reach the desired speed. On the other hand, if the load is smaller, the speed of the mobile robot will be faster. Consequently, the robot should be automatically controlled to reduce the speed to the desired point.

Table 1. Rule base for the change of speed behavior

Rule no.	Input	Output
	The change of load	**The change of speed**
1	NVS	NMIN
2	NS	NS
3	NM	NMED
4	NL	NL
5	NVL	NMAX
6	PVS	PMIN
7	PS	PS
8	PM	PMED
9	PL	PL
10	PVL	PMAX

The surface analysis of the relationship between the input variables and the output variables for the change of speed behavior is shown in Figure 7. It is shown that the change of speed only depends on the change of load as the change of load is higher the change of speed will be higher. The surface analysis of the relationship between the input and output variables for the speed regulator parameters is shown in Figure 8. It is shown in the same way as in Figure 7 that the speed regulator parameter only depends on the current load. As the current load on the mobile robot is heavier, the designed value of speed regulator parameter is higher.

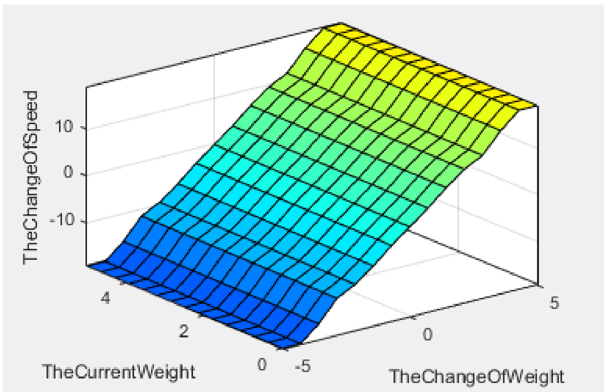

Fig. 7. The surface analysis for the change of speed behavior.

Table 2. Rule base for the speed regulator parameter

Rule no.	Input	Output
	The current weight	The speed regulator parameter
11	W0	P0
12	W1	P1
13	W2	P2
14	W3	P3
15	W4	P4
16	W5	P5

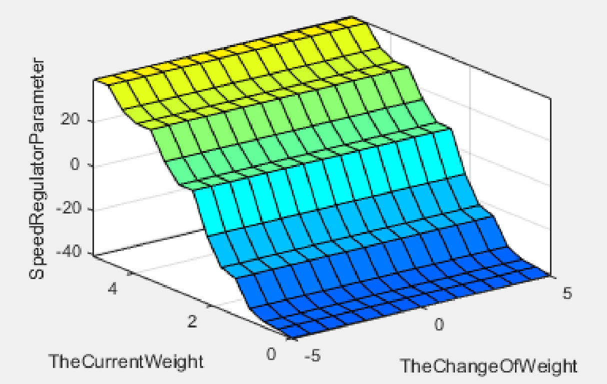

Fig. 8. The surface analysis for the speed regulator parameter.

Defuzzification

Since the results from the inference mechanism are in the fuzzy values, the defuzzification procedure is used to map the fuzzy output to a crisp signal. There are many methods used to convert the output results of the inference mechanism into the actual output of the fuzzy controller. The most convenient and commonly used method is the center of gravity which is chosen in this proposed controller. The COG method combines the outputs represented by the fuzzy set from all rules to generate the gravity centroid of the possible values for control action. The COG for defuzzification method can be expressed to calculate the output of the controller as follow

$$Y = \frac{\sum_{x=1}^{m} \mu_A x}{\sum_{x=1}^{m} x} \qquad (1)$$

where μ_A is the output from each rule
x is the membership value of each output
m is number of rules
Y is output of the controller

The value of the output variables the change of speed (CS) and the speed regulator parameter (SRP) are given in equation (2) and (3).

$$CS = \frac{\sum_{m=1}^{16} \mu_1 x_m}{\sum_{m=1}^{16} x_m} \qquad (2)$$

$$SRP = \frac{\sum_{m=1}^{16} \mu_2 x_m}{\sum_{m=1}^{16} x_m} \qquad (3)$$

where, μ_1 and μ_2 denote the values related to the membership functions of the output variables provided by the *m*th rule. x_m is the membership for input contributing to the *m*th rule. m is the number of rules.

4. EXPERIMENTAL RESULTS

The process of controlling mobile robot speed under the variable load can be shown in Figure 9.

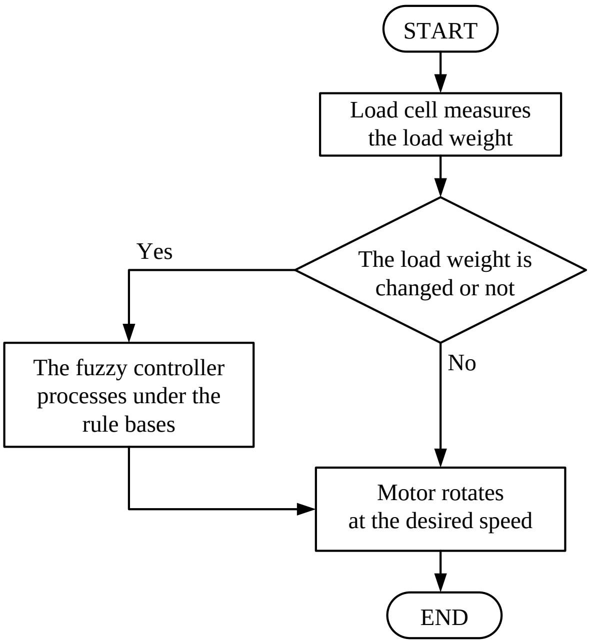

Fig. 9 The flowchart for controlling the mobile robot speed under variable load.

To verify the validity and the effectiveness of the proposed approach, the actual custom-made mobile robot is tested in two scenarios. In the first scenario, the load is gradually added to the mobile robot to reduce the speed. In the second scenario, the load is gradually removed from the mobile robot in order to increase the speed. In order to control the desired direction of the mobile robot, the mobile robot will move in the elliptical track as shown in Figure 10.

Fig. 10 The elliptical track for mobile robot movement.

The maximum speed of the mobile robot with five kilogram load is 0.60 m/s. The constant speed of the mobile robot initially set for the experiment is therefore chosen to be 0.45 m/s, 0.52 m/s, and 0.60 m/s. The mobile robot runs on the track for 5 rounds which approximately equal to 40 meters. In order to see the different behavior of the mobile robot speed when the load is varied, the two experiments with three different values of constant speed are provided. The time that the mobile robot uses to regulate its speed to reach the desired constant speed is collected and compared to each case of experiments. This value of time that the mobile robot uses indicates how fast the mobile robot is able to turn back to the initial constant speed when the load is changed. In the first experiment, the scenario is to add more load to the mobile robot. At the beginning, the mobile robot starts to move with no load. After the speed of the mobile robot is at the desired constant speed, the one kilogram weight is loaded to the mobile robot each time in order to see how the speed of the mobile robot is changed. The procedure of the experiment is the same but the weight loaded to the mobile robot is changed to be two, three, four and five kilogram each time respectively. The results when the load is added to and removed from the robot are shown in Figure 11 and Figure 12 respectively.

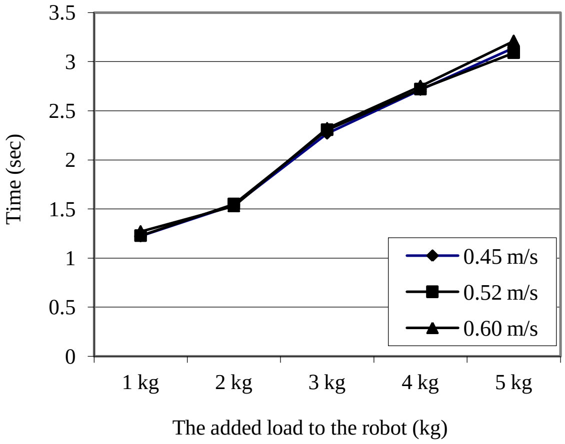

Fig. 11. The time robot uses to regulate the speed when the load is added.

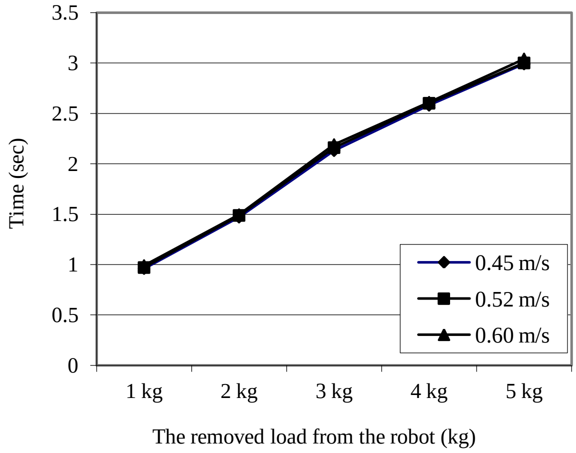

Fig. 12. The time robot uses to regulate the speed when the load is removed.

Figure 11 and Figure 12 show the behavior of the time that the mobile robot uses to regulate its speed to the desired constant speed when the load is increased or decreased. It is obviously seen that both graphs have the same behavior as when the change of load is increased the time used to regulate the speed also increases. This is because when the load is increasingly or decreasingly higher the speed of the mobile robot will be slower and faster respectively. For instance, the speed of the mobile robot when the two kilogram and the five kilogram load are added are both slower than the initial desired speed, but the current speed of the mobile robot when the two kilogram load is added will be faster than when the five kilogram load is added. Consequently, the mobile robot tries to speed up itself to approach the initial desired speed again. Moreover, the speed when the five kilogram load is added decreases more than the others, it therefore have to use more time to accelerate the speed to the target.

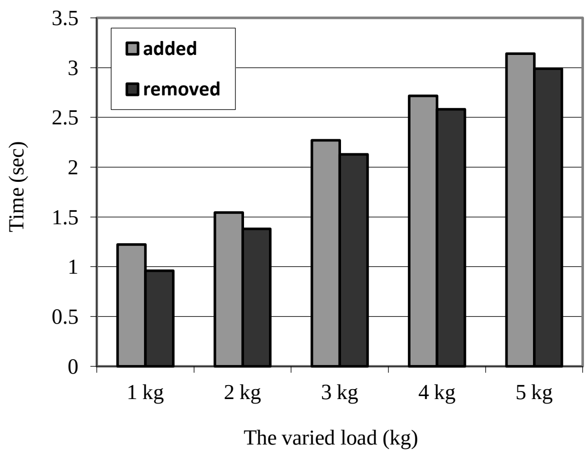

Fig. 13. The comparison of the time robot uses between the added load and the removed load.

Figure 13 shows the comparison of the time that the mobile robot uses to regulate the current speed to the initial desired speed between the added load case and the removed load case. The graph indicates that the time that the mobile robot uses for the added load case is more than the removed load case for every values of the change of load. Since when the mobile robot obtains more load the velocity becomes slower. It is different from the mobile robot when it loses the load as the velocity is getting higher. This means that regulating the velocity up to the higher value needs to use more time than slowing the velocity down.

5. CONCLUSIONS

In this paper, the mobile robot regulates speed using fuzzy rules by means of applying a fuzzy logic controller. A successful way of robot regulation is demonstrated. A fuzzy logic based control system is proposed for speed regulation of the mobile robot when the load is changed. Sixteen fuzzy rules are designed in the proposed model. Fuzzy logic is used to implement two behaviors. The first behavior is to regulate the speed up to the initial desired speed if the speed decreases due to the added load. The other behavior is to regulate the speed down to the desired speed if the speed increases since the load is removed from the robot. Under the control of the proposed fuzzy logic-based model, the speed of the mobile robot can be autonomously regulated to reach the desired target speed precisely with the acceptable delay time.

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