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"Design and Implementation of a Service Mobile Robot for Cleaning the Curbstones Autonomously"

[1]Saad A. Al-Kazzaz and [2]Amer A. Al-Shaabany

[1]Lecturer, Mechatronics Department, University of Mosul, Kirkuk, Kirkuk, Iraq.
[2]Student, Electrical Department, University of Mosul, Kirkuk, Kirkuk, Iraq.

Address For Correspondence:
Amer A. Al-Shaabany, Mosul University, Electrical Department, Faculty of Engineering, Kirkuk, Iraq.
E-mail: ameraldery2@gmail.com

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ABSTRACT

The developing service robots have engaged by many investigators for different applications, since they provide a significant service and comfort for human. One of the practical problems that cause car accidents, the curbstone of pavement is covered by dust and dirt. For this reason, a differential drive wheeled mobile robot, with a fixed arm carrying the cleaning brushes and water nozzles for cleaning the curbstones has been designed and built. To make the robot follow the curbstones with desired distance and angle, wall following algorithm has been employed. That is a significant and useful way for mobile robot movement in unknown environment. Two ultrasonic sensors have been installed on the right side of robot to get information about mobile robot location, distance and angle from the wall. The robot motion is controlled by using PID-Fuzzy Logic Controller for smooth movement with acceptable error and good response. A Mamdani-type fuzzy inference has been used to get the precise value of output for given inputs, which is the most popular type of fuzzy inference. A famous Center of gravity method to evaluate the defuzzification has been used. The robot is implemented practically and the implementation is executed on 32-bit Atmel microcontroller. The experimental results show that FLC gives a smooth movement without overshoot and P-FLC reduced the error due to the effectiveness of proportional controller but not be zero while PI-FLC leads the error to zero with longer time to reach steady state. It was concluded that PID-FLC has significant effectiveness to improve transient response and steady state error together. Where the rise time and settling time have been reduced and the error has reached to zero as well as the error has been corrected with time.

INTRODUCTION

As noted recently, the robots perform a lot of different jobs rather than human for several reasons, including reduce costs, increase productivity, high precision and work around the clock without human intervention. Many researches are engaged in developing service robots for different applications. Shiu and Lin (2008) develop an optimal path planning scheme for autonomous lawnmowers, including the minimum working time, the minimum energy consumption mode and the mixed operation mode, as well as presented an algorithm for multitask operation. Sgorbissa and Zaccaria (2012) presented navigation subsystem of a mobile robot, which operates in human environments to carry out different tasks, such as transporting waste in hospitals or escorting people in exhibitions. Usually workers push carts around warehouses and manually handle orders, which is not very cost-effective, to this end, Faisal *et al.* (2013) presented a potential method to control a swarm of mobile robots in a warehouse with static and dynamic obstacles and the fuzzy logic control approach has been chosen. Bulgakov and Sayfeddine (2016) provide a study about using a wheeled mobile robot known as Telerobotics for inspection and cleaning the air conditioning ducts. One of the practical problems which facing municipal services in most countries of the world are expose the curbstones of pavement to layers of dust and dirt cover

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the curbstone coating, which leads to the inability of the drivers to see the pavements especially at night, this may result accidents and collision cars to pavement. For this reason, a differential drive wheeled mobile robot supported by fixed arm with cleaning brushes and water nozzles has been designed and implemented. The robot contains four wheels, two wheels for drive the robot and two caster wheels as a support for robot balancing. The robot will follow the curbstone by wall following algorithm and clean it. To do this job the robot should move parallel with curbstones in desired distance and angle. Robot position information has provided by using two ultrasonic sensors on the right side of robot. The robot motion has been controlled by using fuzzy logic controller. The effectiveness of fuzzy logic controller in mobile robots is proved in many of previous studies (Farooq *et al*. 2010; Paykari *et al*. 2013; Sahu *et al*. 2015). In addition, a PID controller is applied to improve the system response and reduce the steady state error. Where P term will reduce the error, I term will lead the error to zero and D term will reduce the settling time and rise time to improve the transient response. The implementation is executed on Arduino board based on 32-bit Atmel microcontroller.

Mobile Robot Architecture:

The Robot is designed in dimensions of 50 * 50 * 70 cm. It consists of the robot body hold on four wheels. The two wheels in front of robot are connected to two DC motors independent each from the other, for robot drive. While the other two wheels in the back are caster wheels, which have free movement in all directions and they work as a support for robot balancing as shown in fig. 1 (b). The cleaning arm is fixed on the robot body and it is designed of welded metal strips to form the total cleaning arm as shown in Fig. 1 (a). The cleaning brushes is connected to the arm, which are joined to a metal shaft inserted in a spherical ball-bearing and connected to the DC motor to rotate the brushes and perform the cleaning job. As well as, the arm is equipped with four water nozzles to wash the curbstones before and after cleaning brushes. The upper cleaning brush is used to clean the top side of curbstone while the other cleaning brush is used to clean the front side of curbstone as shown in fig.1 (a). Furthermore, the cleaning arm can be adjusted according to the height of curbstones for appropriate work on different types of pavements, which have height greater or less than others.

(a) (b)

Fig. 1: The mobile robot (a) fixed cleaning arm (b) Robot body.

Wall Following Algorithm:

The wall following algorithm is an effective technique to control the movement of the mobile robots in unknown environments. The algorithm guides the robot to move along the wall with required distance between the wall and robot. There are many devices has been used to follow the wall, the most popular one is the ultrasonic sensors which is used to get information about the wall. In many researches the ultrasonic sensors are used to keep track the wall in different ways. For example, Antoun and McKerrow (2010) use a single ultrasonic sensor to follow the wall. While Duan *et al*. (2010) use two groups of ultrasonic sensors (two sensors per group). Also Hanafi *et al*. (2013) installed two ultrasonic sensors in the left side of the robot to sense the wall. In this research work two ultrasonic sensors are used, fixed on the right side of robot body; one sensor in the back U1 and the other sensor in the front U2 as shown in fig. 2 (a), where d_a refers to the actual distance from the wall, d_d represents the desired distance and d_e is the error of distance. The error in distance can be calculate as follow:

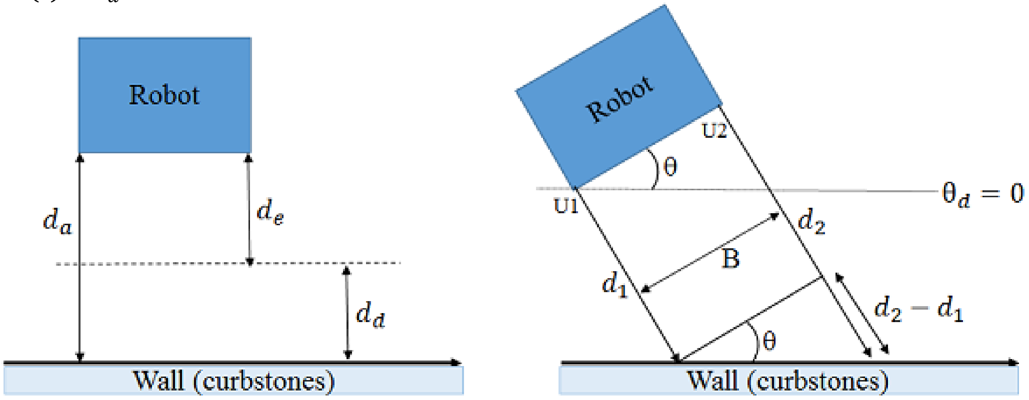
$$d_e(t) = d_a(t) - d_d$$

From the fig. 2 (b), d_1 the reading distance from the sensor U1 and d_2 is the reading distance from the sensor U2, while B is the distance between the two sensors. The desired angle θ_d should be zero and the actual angle between the robot and the wall θ which can be calculated from the equation bellow:

$$\theta(t) = tan^{-1}\left(\frac{d_2(t) - d_1(t)}{B}\right)$$

The angle error θ_e is the different between the actual angle and the desired angle as shown below:

$$\theta_e(t) = \theta(t) - \theta_d$$

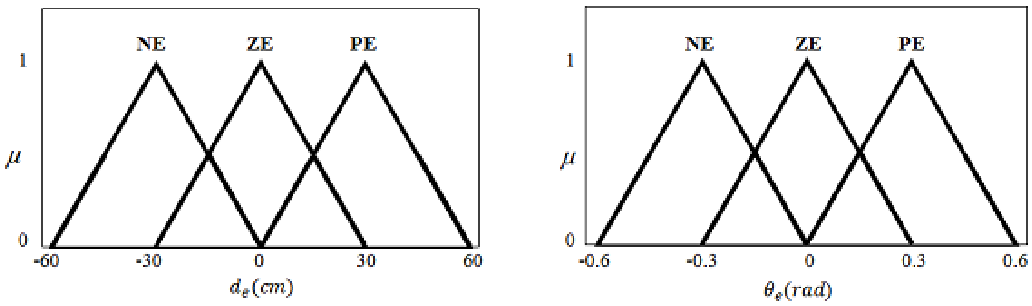


(a) (b)

Fig. 2: Position representation of robot from the wall (a) distance representation (b) angle representation

Fuzzy Logic Controller Design:

After fuzzy logic concept is introduced by Lotfi Zadeh in 1965, which simulates the human worker experimental in dealing with the systems. Fuzzy logic play an important role in practical applications and appeared many of the machines that depends on it. It has an active role in the movement of robots of all kinds, including wheeled mobile robots. In this work, fuzzy logic controller (FLC) with Mamdani-type fuzzy inference process has been used, which is consist of five steps: input variables fuzzification, fuzzy operator generation, implication method implementation, aggregation method implementation, and defuzzification. To control the robot motion for curbstones following, the FLC is designed with multi input and multi output (MIMO). The input variables of the FLC are the distance error d_e, which is divided into three linguistic variables as shown in fig.3 (a), and the angle error θ_e, which is divided into three linguistic variables as shown in fig.3 (b). While the FLC outputs are right and left wheel speeds, which is controlled by using PWM technique, the outputs are divided into a three linguistic variables as shown in fig.4. The fuzzy rules shown in table 1, where the desired speed is MS at 125 of the Arduino PWM parameter range (0-255). Table 2 contains the definition of abbreviations, which are used in the fuzzy logic controller.



(a) (b)

Fig. 3: Membership functions for the FLC inputs (a) distance error (b) angle error

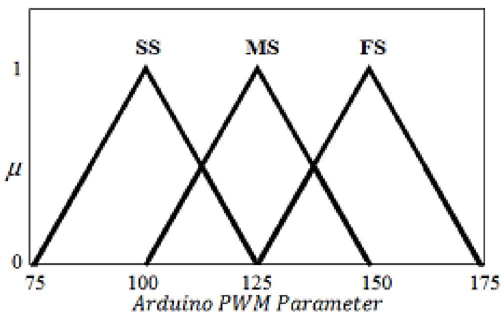


Fig. 4: Membership function for the FLC outputs (right and left motor speed)

Table 1: Fuzzy rules of the left speed and right speed of the motors

θ_e \ d_e	NE	ZE	PE
NE	RM_{FS}	RM_{FS}	RM_{MS}
	LM_{SS}	LM_{SS}	LM_{MS}
ZE	RM_{FS}	RM_{MS}	RM_{SS}
	LM_{MS}	LM_{MS}	LM_{MS}
PE	RM_{MS}	RM_{SS}	RM_{SS}
	LM_{MS}	LM_{FS}	LM_{FS}

Table 2: Fuzzy rules of the left speed and right speed of the motors

NE	Negative Error	SS	Slow Speed
ZE	Zero Error	MS	Medium Speed
PE	Positive Error	FS	Fast Speed
RM	Right Motor	LM	Left Motor

Pid Controller:

To improve the transient response and the steady state error of the system PID controller with the fuzzy logic controller is used. It consists of three expressions; proportional expression (P), Which is used to adjust the basic gain value in the controller, the integrative expression (I) which ensures that the steady state error go to zero, and differential expression (D) that predict the future error in the system and improve the transient response.

RESULTS AND DISCUSSION

After the training of the FLC and tune the proportional gain a response without overshoot as shown in fig. 5 at Kp = 1.05 is obtained. Our design should not contain overshoot because it makes the cleaning arm crash with the curbstone. Using P-FLC the error is reduced but not zero, also it has been noticed the error is increased with time until reach 5 cm which is not acceptable. To get zero error and eliminate the error that increased with time, PI-FLC is used, where the integral controller lead the error to zero and integrate the error with time to eliminate the error occurred with time (Golnaraghi and Kuo, 2010). The response is reached to zero error as shown in fig. 6 as well as the error continuously eliminated with time. But the integral controller affect the transient response as shown in table 3, the rise and settling time are increased and yield longer time than P-FLC. To reduce this increased time and get better response, PID-FLC is employed. Where the derivative controller improve the transient response as shown in fig. 7. The effectiveness of integral controller still keeping, as well as the response has improved and as shown in table 3 the rise and settling time reduced. The PID-FLC leaded to response and steady state error better than P-FLC and PI-FLC.

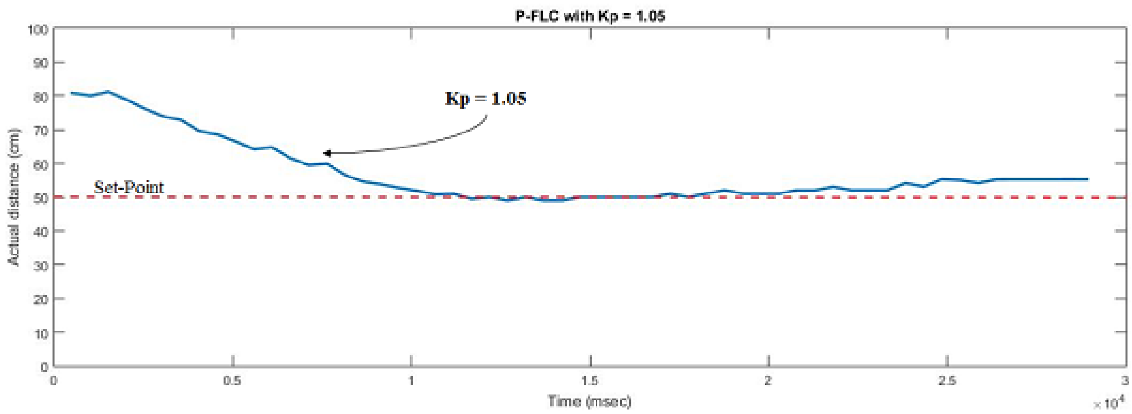


Fig. 5: Actual distance with time curve by using P-FLC.

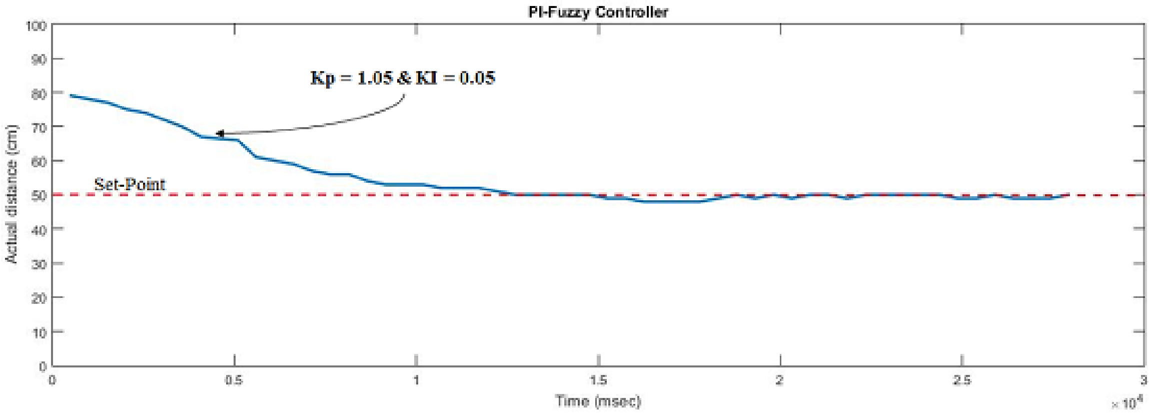


Fig. 6: Actual distance with time curve by using PI-FLC.

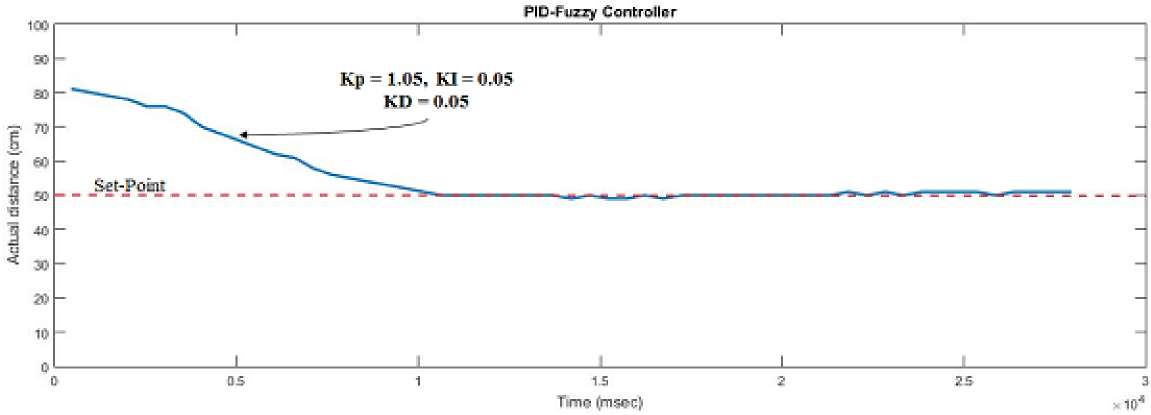


Fig. 7: Actual distance with time curve by using PID-FLC.

Table 3: System response and actual error.

	Rise Time (sec)	Settling Time (sec)	Actual Error (cm)
P-FLC	8.413	10.578	1 - 5
PI-FLC	8.466	12.212	0 - 2
PID-FLC	7.032	10.144	0 - 1

Conclusion

Mathematical analysis and practical implementation of wall following algorithm are conducted in this research. It was concluded that the use of two ultrasonic sensors on the right side of robot, one at the front and the other in the back, give proper information about the robot position, distance and angle with respect to wall. The continuous training of fuzzy rules can be eliminate or remove the overshoot and give smooth response, so the final response of fuzzy logic has smooth response and without overshoot. By using PID-FLC the error reduced to the range 0-1 cm compared to 0-2 and 1-5 for PI-FLC and P-FLC respectively. Moreover, the PID-FLC improve the transient response, where the settling time reduced to 10.144sec compared to 12.212 and 10.578sec with PI-FLC and P-FLC respectively, and the rise time reduced to 7.032sec compared to 8.466 and 8.413sec with PI-FLC and P-FLC respectively. As a result, the PID-FLC can provide significant improvement of transient response and steady state error at the same time. Accordingly, the PID-FLC can be used for wheeled mobile robots with smooth movement and less time to reach the steady state at minimum error.

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