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# Design Navigation Error Reduction Algorithm for Mobile Robot Based on Fuzzy Logic Control

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**ABSTRACT**

This paper presents about the development of navigation error reduction algorithm for nonholonomic mobile robot based on fuzzy logic control. For mobile robot, the different armature resistance, actuator constraints or even friction of gear and wheels effect the navigation. To overcome the mentioned problems, we design a fuzzy logic control (FLC) algorithm to reduce the navigation error. Before developing the algorithm, it is important to do preliminary experiment to verify both velocity of DC motors that control the wheels rotation. The experiment is conducted by finding the difference velocity of left and right wheels with and without control the duty cycle of DC motors. In this preliminary experiment, we found that after change the duty cycle to a proper value, it get the least difference in velocity of the left and right wheel. Based on the result and data from the preliminary experiment, we design the algorithm to reduce error by using fuzzy logic controller. The algorithm gave positive result where the error had been significantly reduced.



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## INTRODUCTION

A mobile robot is an automatic machine that built with two or more wheels and it is capable to navigate in designated environment. Usually, the wheels are driven by one or more DC motors which the speed of the motor can be controlled by an electrical circuit. The circuit that can control DC motor is called motor driver which is consist of H-bridge circuit to control direction of electric current. The electric current is supply to the DC motor whether to rotate in CW (Clockwise), CCW (Counter Clockwise) or to brake. DC motor will rotate when a power supply or voltage is supplied to it terminals and amount of current supplied will be determined the rotation speed of motor. Since constant power and voltage is supplied to the DC motor, the rotation speed is controlled by Pulse-Width-Modulation (PWM) that applied to motor driver. This PWM value or duty cycle is whether pre-defined in mobile robot's navigation control algorithm or varies by the time to move the mobile robot directed to its target with minimum or less error (Sulaiman,N.A, 2007 and Rudzuan, M.Nor, 2012).

### 2.*Kinematic Model of Mobile Robot:*

Refer to Fig. 1, the robot is only have two degrees of freedom which are linear velocity, v and rotational velocity, $w$ for locomotion control. However in term of positioning, it has three degrees of freedom which are $x$, $y$ and $\Theta$. Therefore, the system is nonholonomic if the controllable degrees of freedom are less than the total degrees of freedom (Sulaiman, N.A.,2007; Saifizi M.,*et.al*., 2011 and Fierro, R.,1996).

Mathematical model that will be used to develop mobile robot controller is a kinematic model. A kinematics deals with the relationship between the control parameters and behavior of the system in state space (Lee C.C., 1990). For two wheeled mobile robot, wheel rotation is limited to one axis and the navigation is determined by the speed of change in both sides of robot (Jiang, X.,*et al*.,2005). So, the kinematic scheme of the mobile robot can be described as Fig.1.

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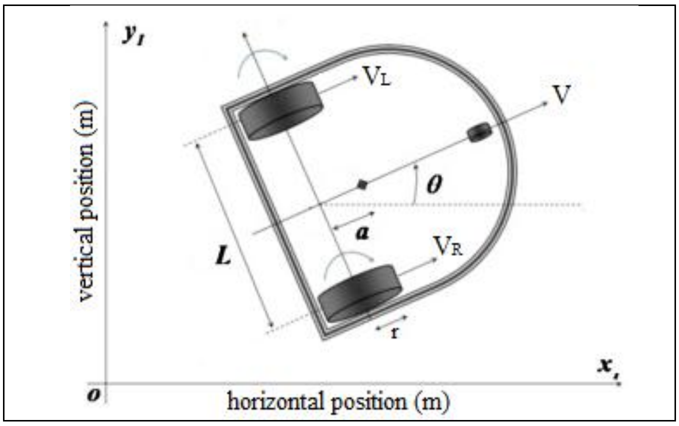


**Fig. 1:** Nonholonomic mobile robot

V is the velocity of robot centroid, $V_R$ is the velocity of the right wheel, $V_L$ is the velocity of the left wheel, L is the distance between two wheels, r is the radius of wheel, x and y is the robot's location in the world coordinate frame while θ is the robot's heading in the real world coordinate frame where counterclockwise is positive angles. Equation (1) and (2) below describe the kinematic model of a wheeled robot.

$$\omega_R = \frac{1}{r}V + \frac{L}{2r}\omega \quad , \quad \omega_L = \frac{1}{r}V - \frac{L}{2r}\omega \tag{1}$$

$$\begin{bmatrix} \dot{x} \\ \dot{y} \\ \dot{\theta} \end{bmatrix} = \begin{bmatrix} \cos\theta & 0 \\ \sin\theta & 0 \\ 0 & 1 \end{bmatrix} \begin{bmatrix} V \\ \omega \end{bmatrix} \tag{2}$$

Controlled variable of the model is position and orientation of mobile robot. The control variables are the angular velocities of the left wheel and the right wheel (Jiang, X.,*et al*.,2005). The velocity along the plane is considered perpendicular to point of contact between wheel and the ground is zero (Saifizi M.,*et.al*., 2011).

### *3. Fuzzy Logic Controller:*

Fuzzy control has appeared as one of the most active areas of research in the usage of fuzzy set theory (Zadeh, L.A., 1965). Fuzzy control is based on fuzzy logic or logical systems that are closer in spirit to human thinking and natural language than traditional logical systems (Lee C.C., 1990). The application of fuzzy logic principles in control is known as Fuzzy Logic Control (FLC). FLC is based on fuzzy logic to provide the algorithm to change the language of the control strategy based on expert knowledge into automatic control strategy. So, fuzzy logic control may be seen as a step towards correspondence between conventional accurate mathematical control and human-like decision making (Gupta, M.M, 1980).

Fuzzy Logic Theory -Traditional logic is based on two values, one (true) and zero (false). This is not enough to close the human decision making process (Harisha, S.K., *et al*., 2008). Fuzzy logic uses the whole interval between zero and one, and hence can be used to close resemble human thinking (Nearchou, A.C., 1999). Design process of fuzzy logic systems generally can be divided into three stages:

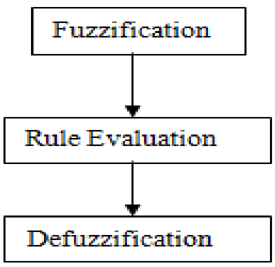


**Fig. 2:** Stage in fuzzy logic controller

Fig. 2 shows the fuzzification stage fuzzy inputs delivered to the fuzzy controller. For the first stage, we apply the membership function to fuzzified the input. Then, the membership functions are changing the input values into degree values of membership for each function. Afterwards, the rules are applied to define the response to the inputs when the inputs are fuzzified. In the last stage, the results of the rule evaluation changed to discrete outputs. This can be done in any proper ways by using a variety of algorithms. Plain and simple approach to defuzzification is Centre-of-Gravity (COG) method (Nearchou, A.C., 1999).

## MATERIALS AND METHODS

This section is to understand and also develop the programmed that using LabVIEW software and create a fuzzy controller for the mobile robot. As for the methodology, 3 preliminary experiment was conducted to find the difference speed of left and right DC motor by record the position of mobile robot from pathway after navigate in fixed time travel. Then, algorithm based on fuzzy logic controller was constructed to reduce the remaining error.

### 1. *LabVIEW Programming:*

In this project, the mobile robot is mainly controlled by using LabVIEW program. LabVIEW program for this project consist of two main parts which are robot motion control and fuzzy logic controller. Robot motion control is functioning as motor controller for the left and right wheels while fuzzy logic controller acting as error reduction in mobile robot. The block diagram for this project is as shown in Fig. 3.

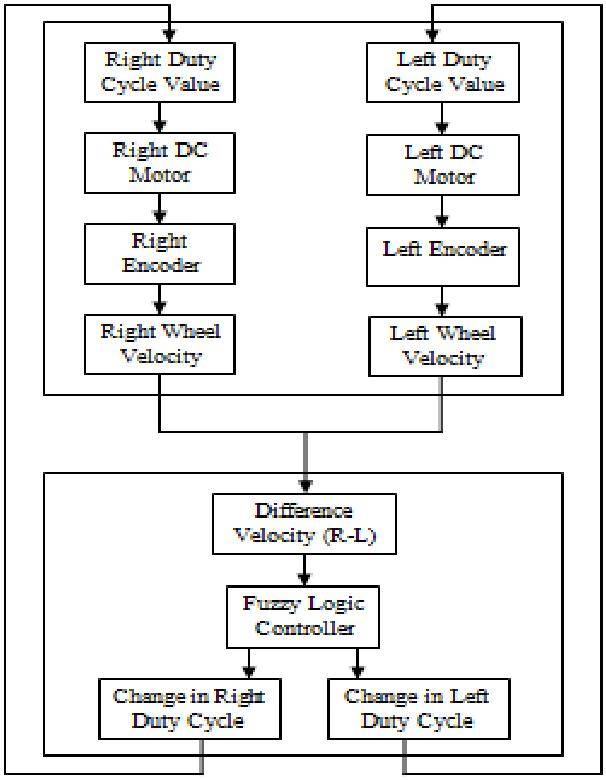


**Fig. 3*:*** Overall block diagram in LabVIEW program

### *2. Robot Identification:*

Fig. 4 is the actual picture of the mobile robot was used in this project. The needed measurement was taken where width of the robot, L=50 cm and radius of wheel r=5 cm.

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**Fig. 4:** Nonholonomic mobile robot

### *3. Preliminary Experiment:*

There were three preliminary experiments that have been conducted where it's very important before develop the lgorithm. Fig. 5 shows the mobile robot is set on the pathway. The robot should move in the straight line, but due to the difference speed rotation of the wheels, mobile robot may move slightly to the left or to the right. The set time is 15 seconds. The distance travel of the left wheel and right wheel will be recorded. The steps are repeats 10 times to get the accurate result.

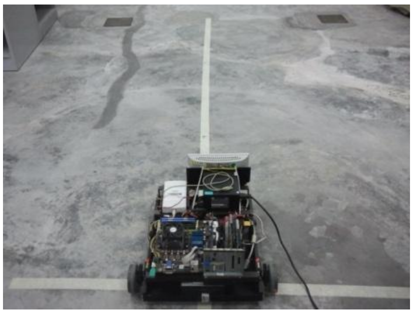


**Fig. 5:** Mobile robot on the pathway

Experiment 1: The experiment was done to confirm whether left and right DC motors are moving in same speed without applied any speed control to the DC motors.

Experiment 2: The purpose for this experiment is to find the best duty cycle value for both DC motor in order to reduce the speed different for both DC motors. In this experiment, the right wheel duty cycle was fixed to 100% and the left wheel duty cycle was manipulated to match the speed of the right wheel.

Experiment 3: Experiment was preceded by using the duty cycle that gain from experiment 2. Mobile robot was once again tested to navigate on the pathway to determine the difference speed of left and right wheel

Experiment 4: Fourth experiment was conducted to test the difference velocity of wheels mobile robot based on algorithm developed.

### *4. Algorithm Development:*

After all the preliminary experiment carried out, the algorithm that based on Fuzzy Logic Control (FLC) was developed. In designing FLC, three main parts were considered which is fuzzification, fuzzy inference and defuzzification.

Fuzzification:

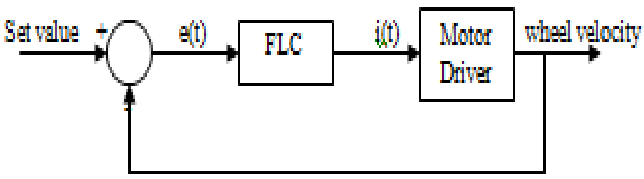



**Fig. 6:** Simple block diagram of the system

This project is using single input and multiple output (SIMO) system.

**Input**: Difference Wheels Velocity $(V_R - V_L)$

**Output**: Changes in Left Duty Cycle and Changes in Right Duty Cycle

UoD for the - **input** $(V_R - V_L)$: {-30, 30} mm/s
- **output** (DC_Left): {-30, +30} %
(DC_Right): {-30, +30} %

Then membership functions for input and output were selected and shown in the graph as in Fig. 7 to Fig. 9.

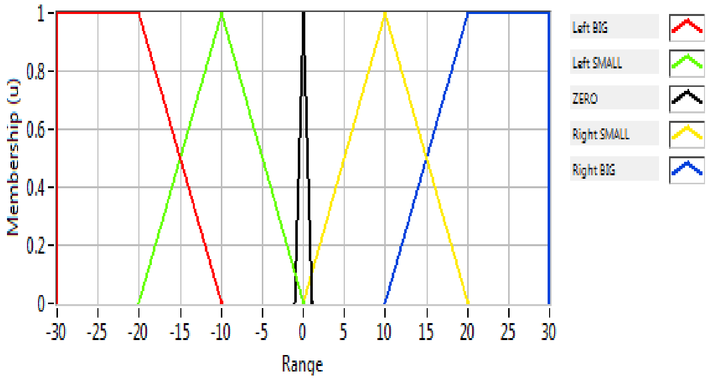



**Fig. 7:** Input variable membership functions $(V_R - V_L)$

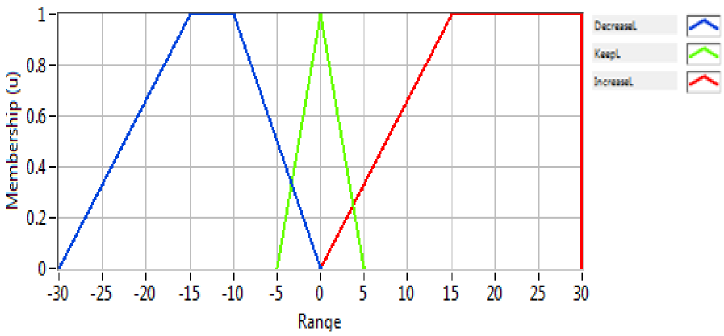



**Fig. 8:** Output variable membership functions (DC_Left)

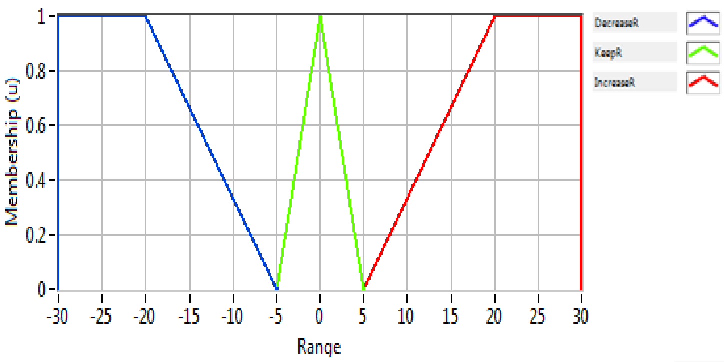
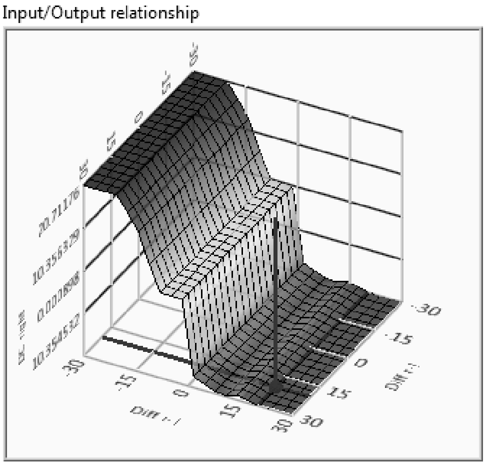



**Fig. 9 :** Output variable membership functions (DC_Right)

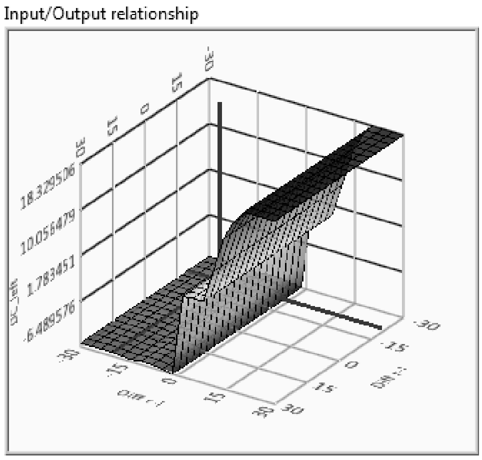
Fuzzy Inference:
So there were 5 rules had been chosen:

1. IF '($V_R$-$V_L$)' IS 'Left BIG' THEN '(DC_Left)' IS 'DecreaseL' ALSO '(DC_Right)' IS 'IncreaseR'.
2. IF '($V_R$-$V_L$)' IS 'Left SMALL' THEN '(DC_Left)' IS 'DecreaseL' ALSO '(DC_Right)' IS 'KeepR'.
3. IF '($V_R$-$V_L$)' IS 'ZERO' THEN '(DC_Left)' IS 'KeepL' ALSO '(DC_Right)' IS 'KeepR'.
4. IF '($V_R$-$V_L$)' IS 'Right SMALL' THEN '(DC_Left)' IS 'KeepL' ALSO '(DC_Right)' IS 'DecreaseR'.
5. IF '($V_R$-$V_L$)' IS 'Right BIG' THEN '(DC_Left)' IS 'IncreaseL' ALSO '(DC_Right)' IS 'DecreaseR'.

Defuzzification:
The last step is defuzzification to get the crisp value of the FLC output. This part will be described at every rule fired. Fig. 10(a) and 10(b) below shows the defuzzification graph for output.




(a)




(b)

**Fig. 10:** (a): Defuzzification for output (DC_Left) , (b): Defuzzification for output (DC_Right)

## RESULT AND DISCUSSION

### *Experiment 1 Result:*

As shown in Table 1 the robot was 10 times moved to the right side of the pathway line. This thing happen because left wheel moved faster than right wheel as shown in table 4.0 where the average velocity of the left and right wheel are 14.37 cm/s and 12.43 cm/s respectively.

**Table 1:** Experiment 1 data

| Test | Distance Travel by (cm) | | Wheels Velocity (cm/s) | | |
|---|---|---|---|---|---|
| | Left Wheel | Right Wheel | Left | Right | Forward |
| 1 | 222 | 193 | 14.80 | 12.87 | 13.83 |
| 2 | 215 | 188 | 14.33 | 12.53 | 13.43 |
| 3 | 218 | 188 | 14.53 | 12.53 | 13.53 |
| 4 | 207 | 180 | 13.80 | 12.00 | 12.90 |
| 5 | 207 | 180 | 13.80 | 12.00 | 12.90 |
| 6 | 208 | 179 | 13.87 | 11.93 | 12.90 |
| 7 | 209 | 182 | 13.93 | 12.13 | 13.03 |
| 8 | 227 | 194 | 15.13 | 12.93 | 14.03 |
| 9 | 222 | 190 | 14.80 | 12.67 | 13.73 |
| 10 | 221 | 191 | 14.73 | 12.73 | 13.73 |
| Average | 215.6 | 186.5 | 14.37 | 12.43 | 13.40 |

Fig. 11 shows that left wheel obviously faster than right wheel.

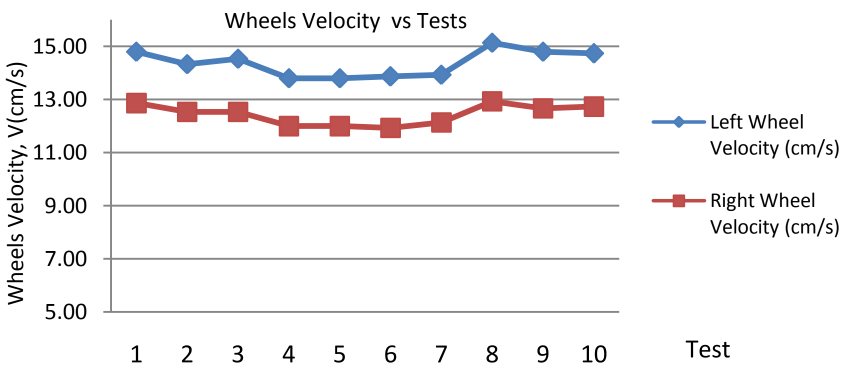



**Fig. 11:** Comparison between left wheel and right wheel velocity

### *Experiment 2 Result:*

Table 2 shows that the robot was tested 10 times with 50% and 60% left duty cycle were only tested once and 70%, 69%, 68%, 67% were tested twice. 50% and 60% duty cycle were tested once due to the bigger value of difference velocity. Table 3 is built to show the average of left and right wheel velocity based on tested duty cycle.

**Table 2:** Experiment 2 data

| Test | Left Duty Cycle | Distance Travel by (cm) | | Wheels Velocity (cm/s) | | |
|---|---|---|---|---|---|---|
| | | Left Wheel | Right Wheel | Left | Right | Forward |
| 1 | 50% | 150 | 176 | 10.00 | 11.73 | 10.87 |
| 2 | 60% | 158 | 177 | 10.53 | 11.80 | 11.17 |
| 3 | 70% | 179 | 171 | 11.93 | 11.40 | 11.67 |
| 4 | 70% | 175 | 168 | 11.67 | 11.20 | 11.43 |
| 5 | 69% | 180 | 177 | 12.00 | 11.80 | 11.90 |
| 6 | 69% | 179 | 177 | 11.93 | 11.80 | 11.87 |
| 7 | 68% | 176 | 176 | 11.73 | 11.73 | 11.73 |
| 8 | 68% | 180 | 181 | 12.00 | 12.07 | 12.03 |
| 9 | 67% | 172 | 175 | 11.47 | 11.67 | 11.57 |
| 10 | 67% | 166 | 168 | 11.07 | 11.20 | 11.13 |

Table 3 shows that six duty cycle were tested to find the best and suitable duty cycle. The best duty cycle is defined as the smallest value of difference velocity. So, the smallest value of difference velocity is at 68% duty cycle.

**Table 3:** Average of left and right wheel velocity based on tested duty cycle

| Left Duty Cycle | 50% | 60% | 70% | 69% | 68% | 67% |
|---|---|---|---|---|---|---|
| Left Wheel Velocity (cm/s) | 10.00 | 10.53 | 11.80 | 11.97 | 11.87 | 11.27 |
| Right Wheel Velocity (cm/s) | 11.73 | 11.80 | 11.30 | 11.80 | 11.90 | 11.43 |
| Difference Velocity (cm/s) | 1.73 | 1.27 | 0.50 | 0.17 | 0.03 | 0.17 |

### *Experiment 3 Result:*

Table 4 shows the mobile robot was six times moved to the right side and four times move to the left side. The highest wheel velocity is 12.20 cm/s while the lowest is 10.4 cm/s. The difference between highest and lowest wheels velocity is 1.8 cm/s.

**Table 4:** Experiment 3 data

| Test | Distance Travel by (cm) | | Wheels Velocity (cm/s) | | |
|---|---|---|---|---|---|
| | Left Wheel | Right Wheel | Left | Right | Forward |
| 1 | 183 | 176 | 12.20 | 11.73 | 11.97 |
| 2 | 182 | 173 | 12.13 | 11.53 | 11.83 |
| 3 | 165 | 174 | 11.00 | 11.60 | 11.30 |
| 4 | 162 | 174 | 10.80 | 11.60 | 11.20 |
| 5 | 170 | 180 | 11.33 | 12.00 | 11.67 |
| 6 | 156 | 170 | 10.40 | 11.33 | 10.87 |
| 7 | 183 | 177 | 12.20 | 11.80 | 12.00 |
| 8 | 180 | 172 | 12.00 | 11.47 | 11.73 |
| 9 | 177 | 171 | 11.80 | 11.40 | 11.60 |
| 10 | 169 | 167 | 11.27 | 11.13 | 11.20 |
| Average | 172.7 | 173.4 | 11.51 | 11.56 | 11.54 |

The graph was plotted to see the comparison between left wheel and right wheel velocity as shown in Fig. 12.

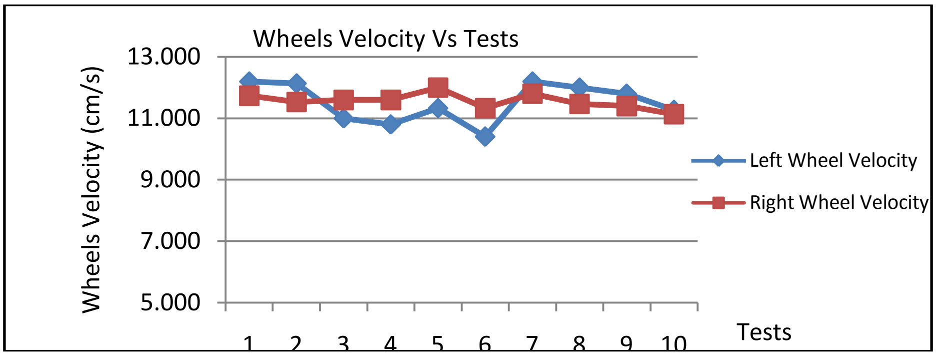



**Fig. 12:** Comparison between left wheel and right wheel velocity

***Experiment 4 Result:***

For this experiment, the mobile robot was five times moved slightly to the right side, four times move slightly to the left side and once time move through straight line. The result is impressed compared to the previous experiment. The result for this experiment is tabulated in Table 5 and the velocity of left wheel and right wheel for each run is compared in Fig. 13.

The highest wheel velocity is 11.40 cm/s while the lowest is 10.73 cm/s. The difference between highest and lowest wheels velocity is 0.67 cm/s.

The highest difference velocity comes in 2$^{th}$ test where 11.20 cm/s – 10.93 cm/s = 0.27 cm/s while the smallest difference velocity comes in 10$^{th}$ test with 11.20 cm/s – 11.20 cm/s = 0 cm/s. The error velocity for this experiment is 0.27 cm/s – 0 cm/s = 0.27 cm/s. This is the value of error after the algorithm was implemented.

When compared to the previous experiment, the difference between highest and lowest wheels velocity was reduced from1.8 cm/s to 0.67 cm/s. Then, the error velocity was reduced from 0.79 cm/s to 0.27 cm/s.

**Table 5:** Experiment 4 data

| Test | Distance Travel by (cm) | | Wheels Velocity (cm/s) | | |
|---|---|---|---|---|---|
| | Left Wheel | Right Wheel | Left | Right | Forward |
| 1 | 166 | 163 | 11.07 | 10.87 | 10.97 |
| 2 | 168 | 164 | 11.20 | 10.93 | 11.07 |
| 3 | 161 | 159 | 10.73 | 10.60 | 10.67 |
| 4 | 164 | 163 | 10.93 | 10.87 | 10.90 |
| 5 | 168 | 167 | 11.20 | 11.13 | 11.17 |
| 6 | 168 | 167 | 11.20 | 11.13 | 11.17 |
| 7 | 164 | 163 | 10.93 | 10.87 | 10.90 |
| 8 | 164 | 165 | 10.93 | 11.00 | 10.97 |
| 9 | 171 | 167 | 11.40 | 11.13 | 11.27 |
| 10 | 168 | 168 | 11.20 | 11.20 | 11.20 |
| Average | 166.2 | 164.6 | 11.08 | 10.97 | 11.03 |

The graph was plotted to see the comparison between left wheel and right wheel velocity as shown in Fig. 13.

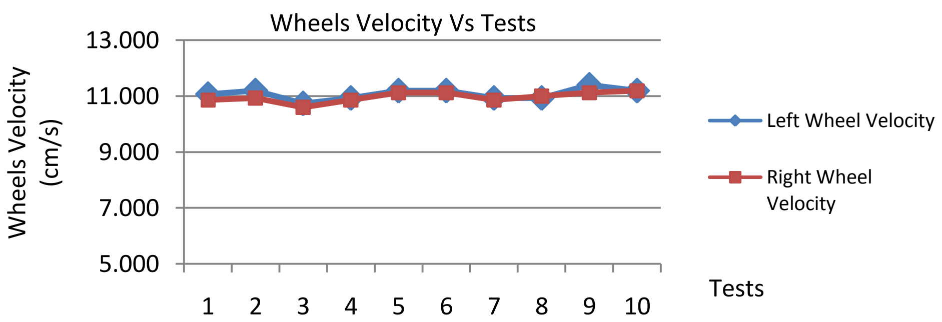



**Fig. 13:** Comparison between left wheel and right wheel velocity

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***Conclusion:***

The research work proposed the use of Fuzzy Logic Controller (FLC) in order to reduce the navigation error of two wheel mobile robot. While navigate to a stable target, the FLC works as the controller to dynamically adjust both the angular velocity of the right and left wheels.

From the result, it can be seen that the proposed FLC algorithm has greatly minimize the navigation error of the mobile robot.

## ACKNOWLEDGMENT

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