Design and Development of Fuzzy-PID Controller for Four-Wheeled Mobile Robotic Stability: A Case Study on the Uphill Road

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***Abstract*— Design intelligent control to maximize the performance of the Four-Wheeled Mobile Robot (FWMR) in case of uphill road problems. The variation of slope angle and load variation on the uphill road is applied to know the performance of the automatic control system on FWMR. The research is divided into three two covering, system identification, design system and simulation testing. The Rotary speed control system response with fuzzy-PID control method has a good performance by anticipating various tilt angle 5^o. The system can through uphill with loads 11N with a steady time and fast travel time. The best travel time in the 5^o tilt angle condition is 2 seconds with a 4m circuit length. This research concludes that fuzzy-PID control can be implemented and increase the dynamic response of the FWMR effectively on the uphill road problems.**

***Keywords*—Four-Wheeled Mobile Robot (FWMR), Fuzzy-PID control, Inclined Terrain, Tilt angle trajectory**

I. Introduction

Mobile robot technology becomes an extraordinary potential in the development of automation and instrumentation systems. The advantages gained are very much, from the side of the application of everyday life, such as examples in automotive fields such as Audi's mobile parking vehicles [1] or the research of autonomous parking control seen in the study [2]. Research [3] mobile robot as a substitute for manual work into automatic work with Robot, which is transporter technology in the industry. Other utilization of electric car electric vehicle technology [4], which implements speed stability control in the autonomous four-wheeled electric vehicle. The mobile robot also develops in agricultural technology in [3] research and still many other field technology applications. Tracking incline or road uphill in mobile robot performance is a research opportunity that is not much touched. The weakness of electric motor drive performance as a wheeled mobile robot actuator is when operating on the uphill road. The weakness of dynamic and non-linear system conditioning on DC motors becomes the core of problems. This dynamic condition results from the changing tracks travelled like uphill, ramps, and even downhill [5].

The wheeled robot that will be built is a branch of mobile robot technology with a simple mechanical system and widely applied in-vehicle technology. The main actuator which is widely used in rolling robot technology is an electric motor with DC motor type that has more reliable and cheaper than other electric motors [6]. The control method with a constant algorithm will not be effective especially when this wheeled mobile robot runs at a predetermined pace [7]. It has been strongly proven that the reliability of the control method PID also remains used in DC motor control technology [8][9].

Fuzzy logic control is an effective method when used in complex systems, especially systems that have difficulty to build analytical mathematical models [10][11]. Fuzzy logic has also been widely developed for the FWMR control, as in research [12] that has developed the design of fuzzy-PID controller gain scheduling for DC motor speed settings resulting in a system response preformation good control with overshoot ± 1%, rise time 2, 6s, and slurries time 3, 6s, so that the control method can be developed in the control of four DC motors in FWMR system. Research [10] has developed a Sugeno fuzzy method [13] on the balance application of two-wheeled mobile robots with independent performance principles on each motor, [11] research that has designed and implemented FWMR using systems fuzzy controls. Research [14] has examined the performance of fuzzy-PI combined control methods on mobile robots with Omni-directional actuators getting optimal results for robotic actuators input drivers. Utilizes a new approach to planning fuzzy-PID controllers in the four-wheeled rolling robot with a DC motor. The objectives of the research are to know the performance of the FWMR in the various angle of the uphill circuit with various loads using the desired controller.

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II. METHOD

A. *Novel Design Control of the Four-Wheeled Mobile Robotic (FWMR)*

The problem of this mobile robot research performance is the dynamic conditions when operating on the uphill track. The best control in controlling the drive motor, which is DC motors is a priority in this research, with the dynamic conditions that are lived by a mobile robot. The coordinates of the robotic body and geometric parameters are displayed in Figure 1 of the wheeled thrust style for each axis consisting of normal components and longitudinal components. It is assumed that the mass of the robot body is located in the center of gravity, hence the dynamics of the robot can be described as follows [15].

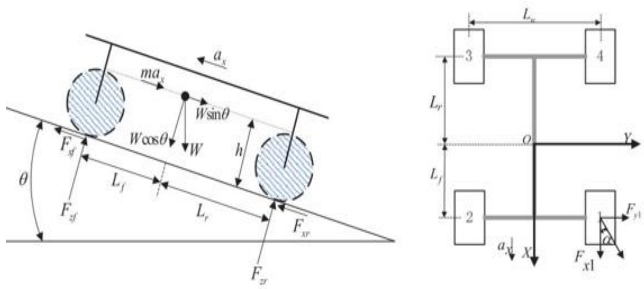

Figure. 1. Robotic dynamics on uphill roads [15]

B. *Hardware & Software Design*

Designing and developing the automatic control system requires a basic system through block diagrams. This block diagram is represented by the variables and the instrumentation needed to create the automatic control system. figure 2 and figure 5 shows a block diagram without an open-loop system, this block diagram is created to test the performance of the FWMR system without a control system. Figure 3 is a block diagram with a system of control (close loop system) using fuzzy logic control for PID parameter tuning.

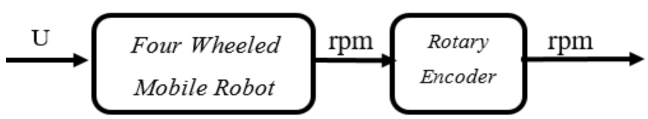

Figure. 2. Open-loop block diagram

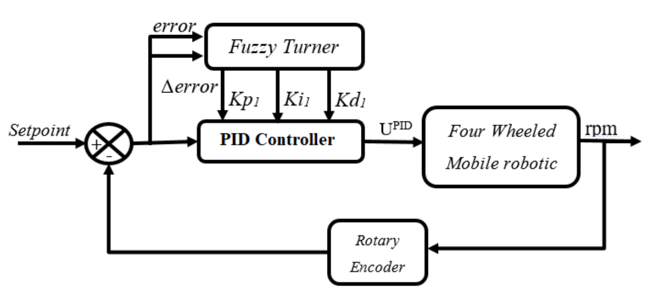

Figure. 3. Closed-loop block diagram

FWMR designed in this study is 25cm length and 15cm width. FWMR is a DC motor used by four in a couple with a wheel [12]. The biggest problem of this study is that four DC motors are independently controlled and operated on inclined terrain. This problem is a non-linear uncertainty or system when the mobile robot operates on the inclined terrain [5][11][16].

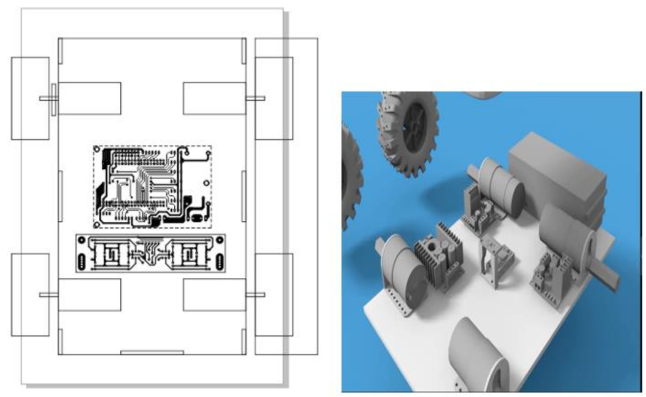

Figure. 4. FWMR Body Design

The development of the Human Machine Interface (HMI) system on the FWMR was initiated from the embedded system HMI using Visual Studio 2010 software. HMI is used to know the response data interface of the control methods (Fuzzy-PID and PID) and the DC motor data interface (RPM) showed in Figure 16.

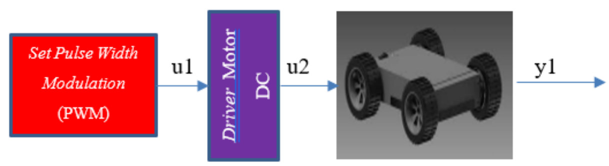

Figure. 5. Open loop identification system

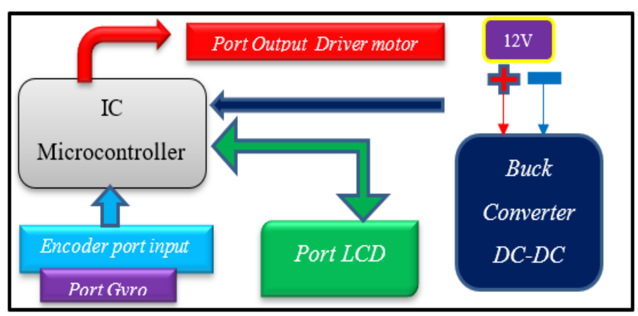

Figure. 6. Hardware in main controller

Communication of FWMR with the HMI system uses wireless communication. Figure 6 and figure 7 shows rotary encoder sensor is used in this research. Rotary encoder converts the rotary positions or angles into electronic signals. To understand the principle behind a rotary encoder, first consider a basic optical rotary encoder. An optical encoder has a disk with specific patterns mounted to the shaft. The patterns on the disk either blocks light or allows it to pass through. Then it can be determined the rotational speed of the shaft [18].

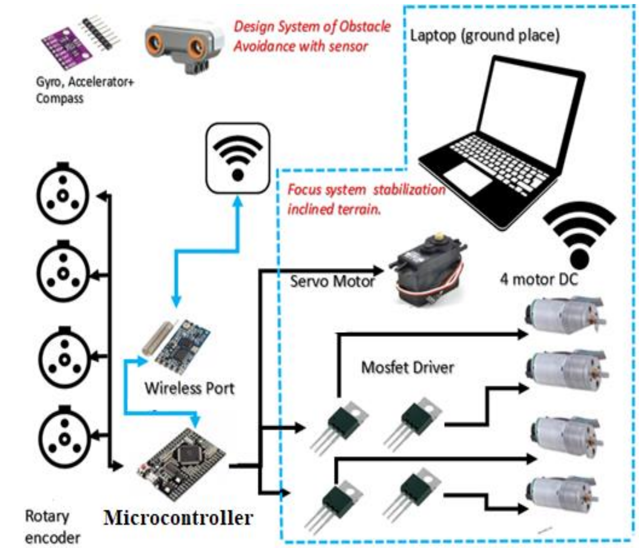

Figure. 7. FWMR Hardware Structure

C. Design of Fuzzy Logic

Conventional PID control is the control that has the characteristics of a fixed-gain feedback controller. Therefore, the PID controller cannot compensate for variations in the parameters of the process and can't adjust changes the environment. The system is controlled by the PID controllers are less responsive to changes in a relatively quick and real, so that the system requires a longer time to reach set point. Therefore, the algorithm with fuzzy controller is used to solve these problems [19]. Fuzzy-PID logic control system is a closed-loop system with the Mobile Robot swivel speed set point. Two fuzzy logic inputs of this research are variable error and variable delta error. The delta error is obtained from the current error value with the previous error value [20]. Fuzzy logic inputs and outputs are expressed in membership functions to group the existing variables [21]. The variable output is Kp, Ki, and Kd. Figure 8 and figure 9 shows a five-part distribution of variable error membership functions.

Negative Big (NB)	= [-1 -1 -0.25]
Negative Small (NS)	= [-0.25 0.2 0.5]
Zero (ZE)	= [0.2 0.5 0.8]
Positive Small (PS)	= [0.4921 0.7921 1.242]
Positive Big (PB)	= [1.25 2 6.5]

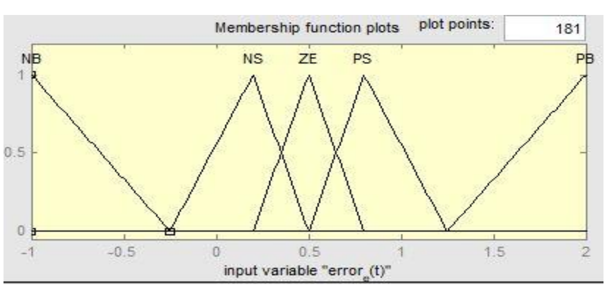

Figure. 8. Variable error membership function

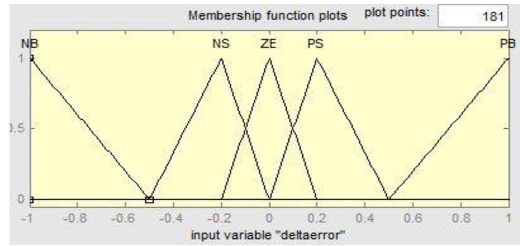

Figure. 9. Membership function variable Delta error.

Five-part distribution of variable delta error membership functions:

Negative Big (NB)	= [-1 -1 -0.25]
Negative Small (NS)	= [-0.25 0.2 0.5]
Zero (ZE)	= [0.2 0.5 0.8]
Positive Small (PS)	= [0.4921 0.7921 1.242]
Positive Big (PB)	= [1.25 2 6.5]

The value of the output membership function is created to obtain the value of Kp, Ki, Kd. The process to obtain the value of Kp, Ki, Kd must be through the rule base and the retrieval decision (Defuzzification).

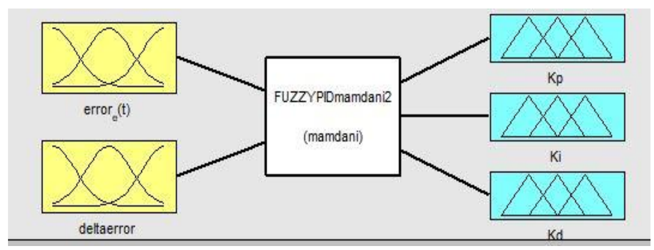

Figure. 10. Toolbox fuzzy mamdani

The design of the Fuzzy-PID logic control with Mamdani's reasoning method has a fuzzy set in the system output, which is a triangular-shaped base (trims) for determining the output you want to achieve. After creating the membership function, next, create a rule base for action determination based on error input and delta error. Creation of a rule base to determine the action of error input and delta error is based on previous research by [22].

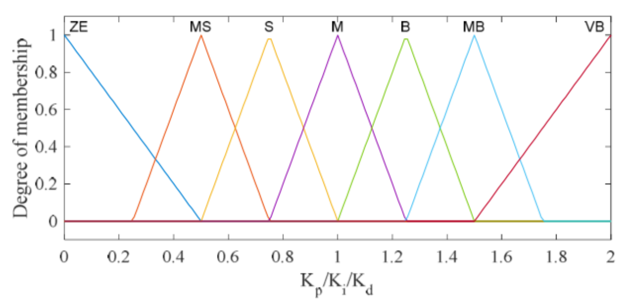

Figure. 11. Output membership functions Kp, Ki, and Kd

III. RESULTS AND DISCUSSION

A. Four-Wheeled Mobile Robot Design Results

The DC motor driver series uses the H-bridge power MOSFET IRF540 seen in Figure 12. The series is designed with a length of 11cm and a width of 3.5 cm, composed of two upper and lower circuits. The circuit at the top position uses 8 power MOSFET IRF 540 for the front motor driver. Bottom series using 8 power MOSFET IRF 540 for rear motor driver.

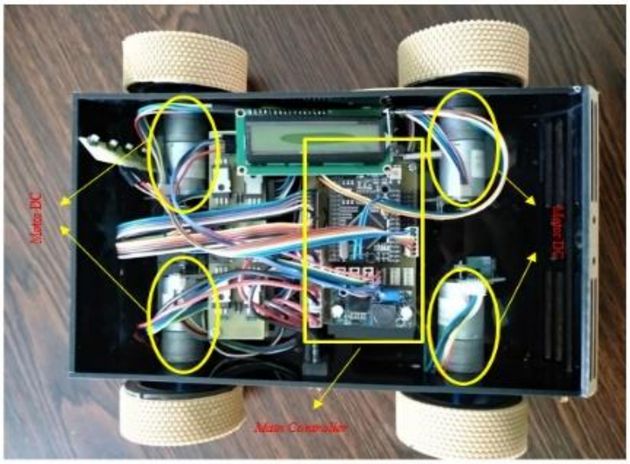

Figure. 12. Four Wheeled Mobile Robot display (looks in)

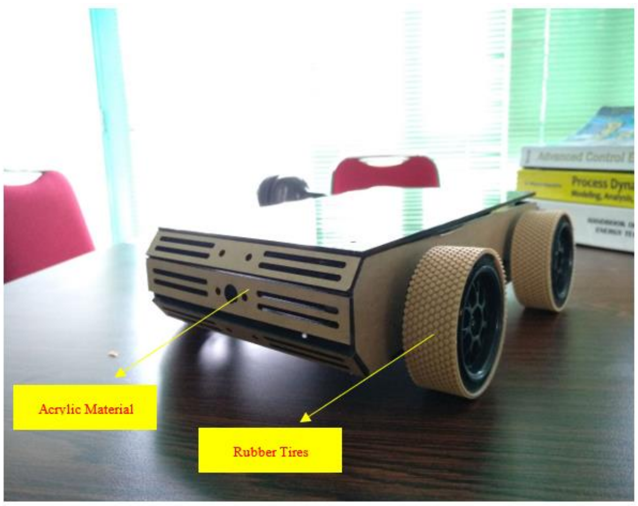

Figure. 13. Four Wheeled Mobile Robot display (looks out)

B. *Simulation Results of the Full Fuzzy-PID Comparison with Fuzzy-PI*

This test is a comparative stage, to prove the best control method, fuzzy-PID or Fuzzy-PI control system. Fuzzy-PID and fuzzy-PI control methods will be compared and selected based on the performance index based on the FWMR models that have been examined in [19]. A comparison of this method is made based on that fuzzy-PI method is already considered fast enough in resolving system errors and resulting in a stable control system, but the parameter capabilities of Kd also affect overshoot being smaller, so Kd is also indispensable in the control system.

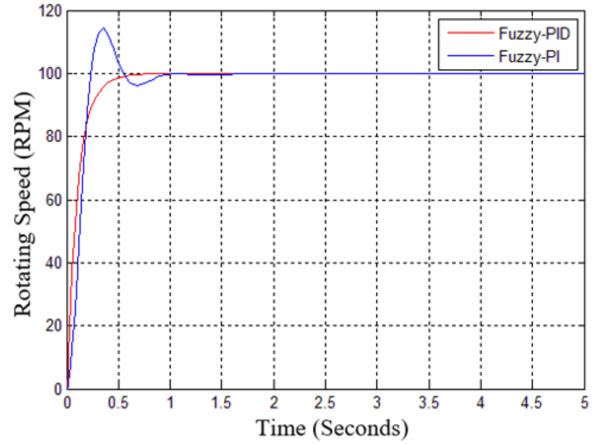

Figure. 14. Simulation results of a comparison of fuzzy-PID control methods with Fuzzy-PI.

Comparison simulation results of this control method seen in Figure 14, that fuzzy-PID control method is better compared to fuzzy-PI control method, the results of fuzzy-PID response indicate a faster stable time compared to fuzzy-PI. A comparison of this method was made based on that of the fuzzy-PI method which was considered fast enough in resolving system errors and resulted in a stable control system, but Kd is parameter capability accelerates system responsiveness, so Kd is also indispensable in the control system. Kp, Ki, Kd, is the initialization value of the gain parameters with the price of Kp = 2.25, Ki = 0.05, Kd = 0.005 on Fuzzy-PID and eliminates the Kd parameter on the Fuzzy-PI control system.

TABLE 1.
RESULTS OF FUZZY-PID SYSTEM RESPONSE PERFORMANCE WITH FUZZY-PI

Parameters	PI Controller	Fuzzy-PI Controllers
Time Delay (s)	0.091	0.117
Rise Time (s)	1.133	0.235
Peak Time (s)	-	0.353
Steady Time (s)	0.353	0.494
Maximum Overshoot (%)	0	14.260

A comparison of the best control methods on DC motor systems has been attested in research [23] and in this study, the fuzzy-PID control method is the best compared to fuzzy-PI control method or PID in the control system DC motor swivel speed.

C. *FWMR Test Results on Road Slope Angle 5^0*

FWMR test results on road slope angle 5^0 four DC motor swivel speed control system is obtained from the feedback value of the measured optocoupler sensor in each motor in FWMR. The result of fuzzy-PID control method applied is through language programming conversion C, so it can be in the microcontroller and run the FWMR system. The study of the problem in this subchapter is the performance variation of the tilt angle in the trajectory. The 5^0 slope case study was successfully performed with the FWMR criteria through well-slope.

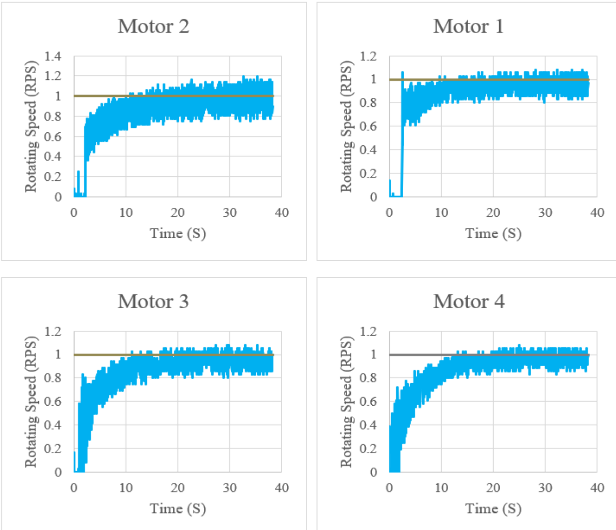

Figure. 15. Graphics response system fuzzy-PID control at tilt angle 5°

The performance characteristics produced are seen in Figure 15, showing the ripple response rate a considerable speed measurement below the set point value. Analysis obtained is the data that is read by the encoder sensors on each DC motor has a very fast response time of 0.1 second, ± 10 data in each 1 second so that there are readings that are missed and do not correspond to the real state. The data presented in figure 15 graph shows that fuzzy-PID control system generates 0% overshoot and fast-paced time. Figure 16 shows result software for the Four-Wheeled Mobile Robot System. The results of this software were created using Visual Studio 2010. The result of this software is a browser system on the personal computer with wireless communication from hardware HC-12. The results of the software are shown in figure 16.

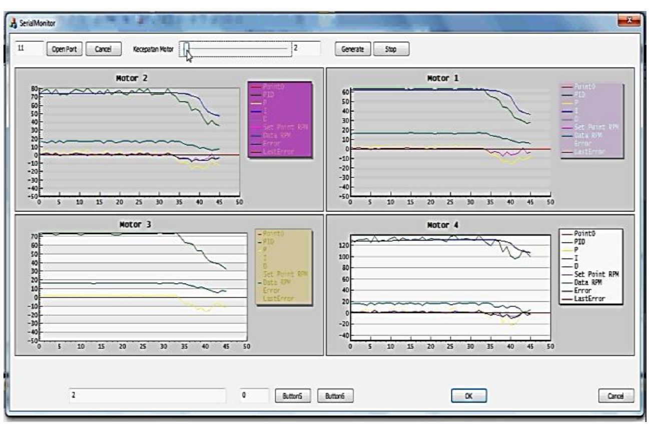

Figure. 16. Software interface Results

The built-in system interface will show the response of the four control systems of the DC motors used on the Four-Wheeled Mobile Robot. The details of the information that will be revealed in this interface include point 0, PID value, parameter P-value, parameter I, D parameter, RPM set points, RPM Data, Error, and Last Error is seen in figure 17.

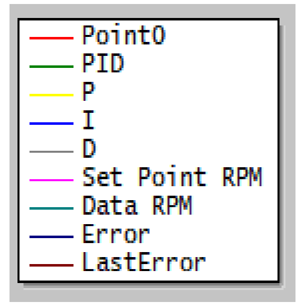

Figure. 17. The interface information will be displayed

The software aims as a performance response interface of the Four-Wheeled Mobile Robot. This Interface is called system display system are shown in figure 16.

Figure. 18. FWMR documentation test result in the track ramp

IV. Conclusion

The development control of four DC motors independently for the application of an FWMR has finished, and obtained the following conclusion:

- The comparison of fuzzy-PID control with fuzzy-PI control shows that fuzzy-PID has better system response, based on an undetectable peak time control system and overshoot, a faster delay time with a 0.091 S value, and a steady time of 0.353 S.
- The result of the development of fuzzy-PID control method in the study [15] by changing the defuzzification method into the LOM method has a good performance control system in the implementation of the real plant system namely FWMR. Fuzzy-PID method implemented precisely in anticipation of road problems with fast-paced time and < 15 second travel time based on testing of road slope angles and load variations, and the documentation test results in the real track ramp shown in figure 18.
- Fuzzy-PID control method is better compared to fuzzy-PI control method, the results of fuzzy-PID response indicate a faster stable time compared to fuzzy-PI.

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