Design of Ground Vehicle System Semi-autonomous Preceder Type for Straight Path and Circular Path using Fuzzy Logic Method

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Abstract: The development of the robotics system increase significantly. Recently, robotics become an opportunity for people to use those in many activities, for instance, automatic control systems in the land, which can be referred to as Unmanned Ground Vehicle (UGV). Unmanned Ground Vehicle (UGV) has several categories based on autonomous systems provided, namely teleoperated, semi-autonomous, platform-centric, and network-centric. In this study, the prototype of the UGV system is a semi-autonomous type using the fuzzy logic method as a control system. The input of fuzzy logic is the distance between the prototype and obstacle. However, the output variable is the action of UGV to control the safe distance from the obstacle. The design fuzzy logic system has been integrated with the robotdyn UNO microcontroller device as a controller of UGV. The test results showed that the prototype could keep tracking to control the distance according to rule base fuzzy logic. The setpoint has been set up at 10 cm - 15 cm from the obstacle and the results of the semi-autonomous system movement that has been applied in-ground vehicle prototype. The average error is 9 cm. This number still intolerance in tracking control.

1 INTRODUCTION

The autonomous ground vehicle has a wide scope of research consisting of the short, medium, and long-range robots that have small and large sizes with the aim of supervision in small sectors, surveys, and others. In vehicles that have a large size, it is usually controlled by a combination of artificial intelligence and human operators at a considerable distance. So far in Indonesia, the land vehicle movement system is still fully controlled by humans with the value of Human-Robot Interaction (HRI) of 100% or level 0, especially in fields where the land has bad conditions such as bumpy, uneven, there are many obstacles and others. The autonomous ground vehicle has profound theoretical-practical significant in an intelligent transport system (Kiencke, 2001). In autonomous ground vehicle technologies, longitudinal control keeps it moving at the desired speed by controlling throttle and brake coordinately. However, the non-linearity and uncertainty in the dynamic model of the vehicle introduce difficulties in the design of a longitudinal controller with high precision (Xiaolon, 2011).

In this paper, as an extension of an autonomous ground vehicle designed and developed for the user, the control system by fuzzy logic presented. This vehicle used a fuzzy control system to the desired track. Fuzzy logic has the ability to transform human sematic processes into numerical machine processes. Fuzzy logic provides a link between human intuition and machine expression. Fuzzy control methods are known as powerful, intelligent tools that can be used for controlling complex nonlinear systems. Performances of fuzzy controllers have been presented in commercial products and industrial control applications (Kim, 2013). In this paper, a fuzzy control system has simulated to the straight and circular path.

2 FUZZY LOGIC CONTROL

2.1 Fuzzy Logic

Fuzzy logic was first discovered by Prof. Lotfi Asker Zadeh at a seminar at the University of California, Berkeley, United States. Fuzzy logic is made on the grounds that there is uncertainty in which members cannot only be separated into

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members (1) or not members (0). There are several definitions of fuzzy logic, including:

1. Fuzzy logic is a logic used to explain ambiguity and explain the logic of a set that resolves the ambiguity.
2. Fuzzy logic provides a way to convert linguistic statements into a numeric (Hirulkar, 2014).

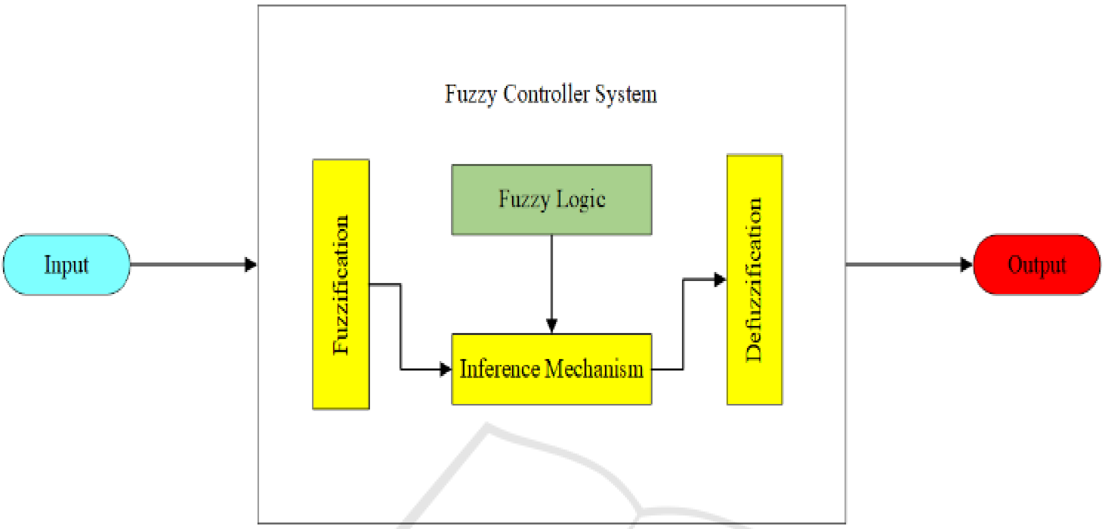

Figure 1: Fuzzy Controller

Fuzzy logic systems, which can be referred to as Fuzzy Logic Control, have a composition of the main setting components consisting of fuzzification, rule base, mechanism of inference, and defuzzification with each Fuzzy Logic Control having input and output (Maghfiroh, 2016).

2.2 Membership Function Fuzzy Logic Controller

Fuzzy logic also has a membership function, namely a curve that shows the mapping of input data points into the value of its membership. There are several types of curves used to define membership functions, namely Triangle Membership Function Curve The function of triangle membership is determined by three parameters, namely {a, b, c} by following the rules as follows:

$$(x;a,b,c) = \max\left(\min\left(\frac{x-a}{b-a},\frac{c-x}{c-b}\right),0\right) \quad (1)$$

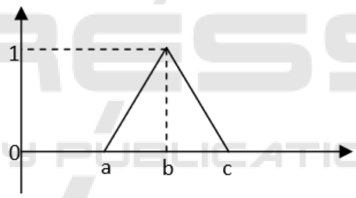

Figure 2: Triangle Membership Functions

Parameters {a, b, c} with a < b < c determine the x coordinates of the three angles of the triangle membership function (Franck, 2013). The Mamdani method is often also known as the Max-Min Method. To get the output, four steps are needed:

1. Fuzzy Set Formation
2. Application Function Implications
3. Component Rule
4. Affirmation or Defuzzy

The input from the defuzzification process is a fuzzy set that is obtained from the composition of fuzzy rules, while the resulting output is a number in the fuzzy set domain, so if given a fuzzy set in a certain range, a certain crisp value must have been taken as the output. There are several defuzzification methods in the composition of Mamdani rules, including the COA method, the bisector, MOM, LOM, and SOM.

1. COA Method; In this method, the crisp solution is obtained by taking the center of the fuzzy region.
2. Bisector Method; In this method, the crisp solution is obtained by taking values in a fuzzy domain, which has a half membership value from the total membership value in the fuzzy area.
3. MOM; In this method, the crisp solution is obtained by taking an average value of the domain that has the maximum membership value.
4. LOM; In this method, the crisp solution is obtained by taking the largest value from the domain that has the maximum membership value.
5. SOM; In this method, the crisp solution is obtained by taking the smallest value from the domain that has the maximum membership value.

Fuzzification is the first phase of fuzzy calculation, which changes input whose definite truth value is in the form of fuzzy input in the form of membership level/level of truth. Thus, this stage takes crisp values and determine the degree to which they become a member of each corresponding fuzzy set (Pramudijanto, 2018). The inference is reasoning using fuzzy input and fuzzy rules that have been determined to produce fuzzy output.

A variable is a symbol or word that refers to something that is not certain in the universe of the discourse. If it's the discourse universe is a set of numbers, then the variable is called a numerical variable, whereas if the discourse universe is a set of words or terms from everyday language (for example high, fast, young, etc.), then the variable is called the linguistic variable. The universe of discourse or universe of words is the whole value allowed to operate in a fuzzy variable (Basjaruddin, 2016). The universe words are a set of real numbers which always increases monotone from left to right or vice versa. The universe word value can be either positive or negative numbers.

3 METHODOLOGY

Based on the results of the literature study, system design has been determined aimed at controlling the action of Ground Vehicle movements realized in the form of a simple prototype. The block diagram of the Ground Vehicle movement control system design system is shown in figure 3. The design of the Ground Vehicle movement system consists of 4 actions that will be output when the Ground Vehicle position with the obstacle is at a safe distance or 10 cm - 15 cm, which stops, goes forward, turns right, and turns left. The design of the movement system also consists of three main frameworks, namely, input (input), process (process), and output (output). The working method of this system itself is where the input value given by ultrasonic in the form of distance value to the obstacle will be forwarded to the *robotdyn* UNO microcontroller which has been integrated with fuzzy logic to be processed by the applied coding, after that the data from *robotdyn* UNO has been completed processed will be forwarded to the output value, which will then give an order to the motor driver to adjust the DC motor rotation according to the results of the data that has been given from the *robotdyn* UNO. This is different from the process carried out by GPS where input originating from the signal transmission to the satellite will be sent back to the GPS module which will then be processed by the *robotdyn* UNO microcontroller with coding that has been applied and clearly different from previous coding (without fuzzy logic), after that the result of the *robotdyn* UNO process will be forwarded back to the GPS module as an output by providing a value in the form of coordinate position or point of location of the Ground Vehicle.

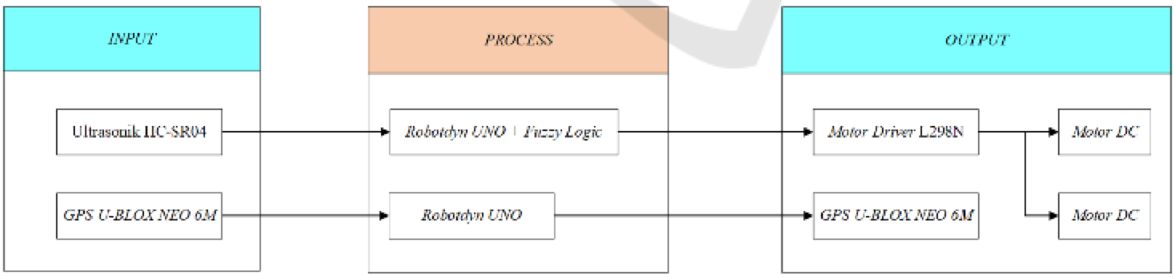

Figure 3: Design System of Controller

This design is the initial design carried out to find out how the composition of each component that will be used is in accordance with the place or not.

Ultrasonic Sensors are attached to the *robotdyn* UNO with the trigger pin and echo pin configuration inserted into the analog header pin. The continuous track wheel used has 2 DC motors as the drive, and the Motor Driver functions to adjust the speed and speed of the DC motor. After that, the GPS module will also be paired according to the analog header pin specified in the *robotdyn* UNO separately supplied by the 11.1 Volt 1000 mAh LithiumPolymer (LiPo) battery power supply.

The hardware design that has been completed will be adjusted again with the next coding, which will be explained in the system design. The hardware design is also included with the wiring activity, as shown below

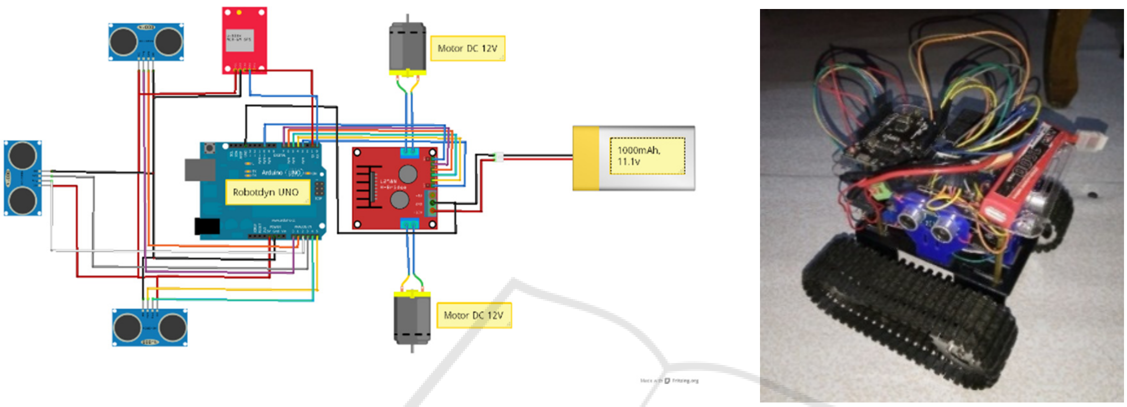

Figure 4: Ground Vehicle

4 RESULTS

The rule base of fuzzy logic is used to process input values, which afterward will be output values as commands in the form of decisions. This rule base also has components in the form of certain Variables which will then be used in the prototype system. The variables needed to increase the accuracy of the programming process are three inputs named input values of the front direction, values of the right side direction, and values of the left side direction.

Table 1 Rule Base Fuzzy Logic Ground Vehicle

No.	Rule Base (Mamdani)				Setpoint
	Input			Output	
	Front Obstacle	Right Obstacle	Left Obstacle	UGV Respons	
1	Near	Near	Near	Stop	10 cm-15 cm
2	Near	Far	Far	Left	
3	Near	Near	Far	Left	
4	Near	Far	Near	Right	
5	Far	Near	Far	Forward	
6	Far	Far	Near	Forward	
7	Far	Near	Near	Forward	
8	Far	Far	Far	Forward	

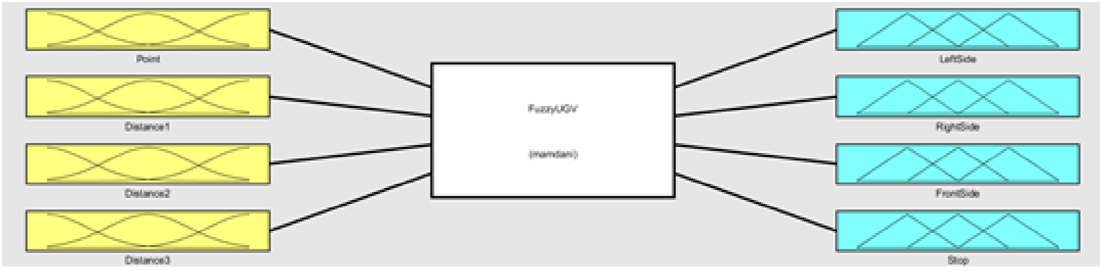

Figure 6: Fuzzy Inference System

The formation of a fuzzy inference system is based on the input, output, and rule base that has been determined and compiles it based on the inference mechanism that has been selected, namely Mamdani's inference mechanism.

Rule readings on the specified member function, as in Figure 7, starting from the input, the process with the inference mechanism to output if it is in accordance with the design plan, the system can be applied.

Figure 7: Fuzzy Inference System

The results of the first experimental data have been reshaped into a graph that provides a clear description of the results obtained, as shown in Figure 8.

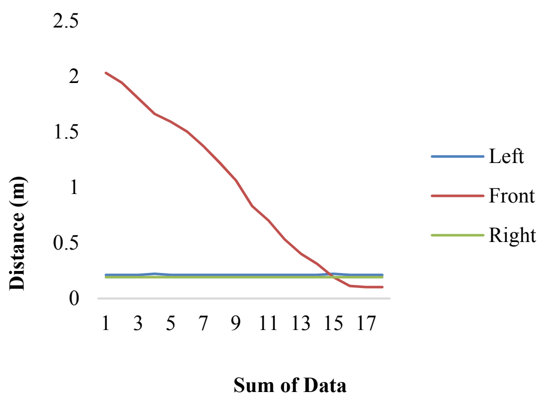

Figure 8: First Experiment Straight Path Without Obstacle Data

The graph shown in Figure 8 can explain how the fuzzy logic system performance is applied directly based on the data obtained for the first experiment. The X-axis on the graph shows the distance between the Ground Vehicle and the obstacle consisting of 3 sides, namely front, left, and right, and the Y-axis on the graph showing the amount of data recorded during the Ground Vehicle functioning from the initial line to the finish line. The data lines for the left and right directions do not have a big difference because the values tend to be the same, so the lines are also almost parallel, but this is different from the frontline data, which has a high initial position in the graph with a large initial value. The value decreases and is almost parallel with the other 2 data lines because the Ground Vehicle position that is getting closer to the destination point will produce a smaller distance value with a maximum setpoint value of 10 cm from the obstacle destination point.

For the second experiment, the graphs formed based on data can be considered in Figure 9 as follows:

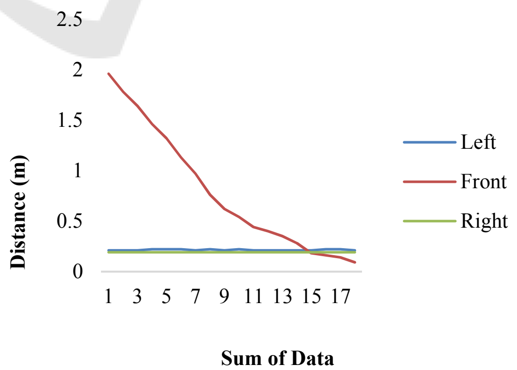

Figure 9: Second Experiment Straight Path Without Obstacle Data

In Figure 9 it can also be seen that the flow from the left, front and right data lines has the same concept as Figure 8 where the left and right data lines have values that are not much different and almost parallel, then for the front line data also has the large initial value continues to change becomes smaller due to the reduced distance between the Ground Vehicle and the obstacle destination point so that the final value is almost parallel to the other 2 data lines.

For the third experiment in Figure 10, there is a graph formed based on data which can be reviewed as follows:

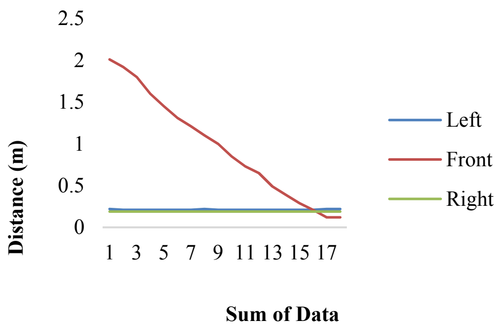

Figure 10: Third Experiment Straight Path Without Obstacle Data

The graphic concept is shown in Figure 10 also tends to be the same as the previous two graphs, namely the data lines in the left and right directions are almost parallel because the values held are not so different while the front data line has a large initial value due to the Ground Vehicle position with obstacle destination point has a long-distance range so that the more Ground Vehicle position with the destination point, then the resulting value is also getting smaller and smaller until the position of the data line is almost parallel to the other 2 lines.

The value of the distance generated at the front for this experiment has a value that tends to be small, and the variations it has are quite large, with a range of distances that are also small. The graph formed can be reviewed in Figure 11 as follows:

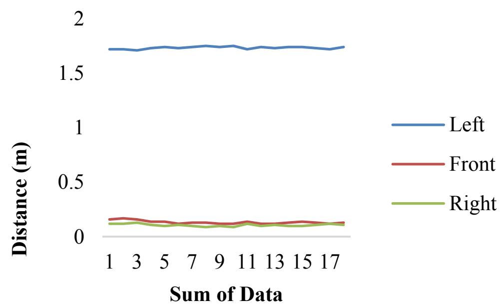

Figure 11: First Experiment Circular Path Without Obstacle Data

The results of the graph on the first trial circular path without obstruction have conciseness different from the graph in the previous experiment, which is located at the position of the left sideline whose value tends to be consistently large starting from the initial position to the final position. The values on the right side and the front side have the same concept as the previous graph, which is almost parallel because the values possessed by both have a difference not so far away.

Then for the second experiment on the circular path, there is a graph that has been formed, as shown in Figure 12 as follows:

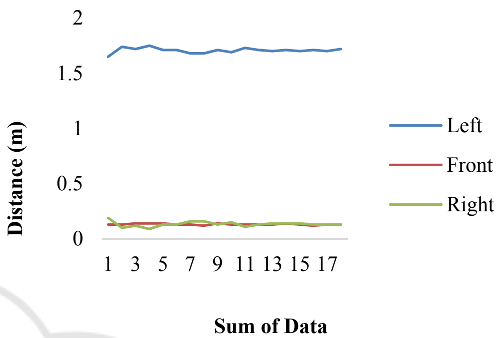

Figure 12: Second Experiment Circular Path Without Obstacle Data

The concept in Figure 12 also has a form that tends to be similar to the previous graph image; that is, on the left side of the data line, it has a beginning to end value that tends to be large when compared to 2 data on the right and front sides. The values on the right and front side also have quite a lot of variations with the characteristics of the value range that is also small, but it is noted in the data on the right side that there is a value below 10 cm which is 9 cm from the obstacle wall arena. The cause is the same as in the first trial circular path without obstruction.

Then for the third experiment on the circular path, there is a graph that has been formed, as shown in Figure 13 as follows:

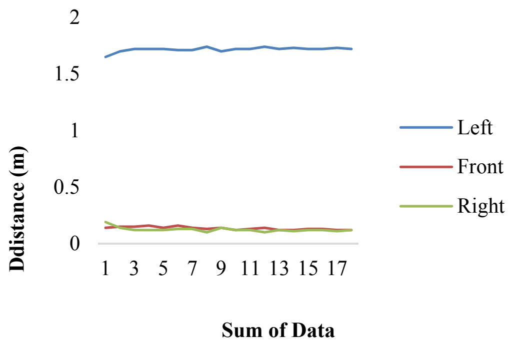

Figure 13: Third Experiment Circular Path Without Obstacle Data

The graphical form in Figure 13 has a conceptual basis, which tends to be the same as the two previous trial graphs where the left side distance value has a large value starting from the beginning of the position to the end of the position. Data values on the right and front also have values that vary with a small range but tend to be consistent so that the data lines shown are also almost parallel starting from the initial position to the final position.

5 CONCLUSION

The conclusion of research of the fuzzy logic control implemented in the UGV prototype is the control system, and the objective was reasonably achieved. The most important in this research is how to design the control system using fuzzy logic. There is a lot of variables that should be involved. However, this research shows a starting point for more advanced research on the topic similarly. Throughout this research, the motion of UGV depends on DC motor as an actuator, the robotdyn UNO microcontroller based on the fuzzy logic rule base as the control system and ultrasonic as a sensor to read the distance between prototype and obstacle.

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