

## **Fuzzy Logic Control for Pneumatic Excavator Model**

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### **Abstract**

This research aims to design and create a model excavator with a pneumatic system. Besides that, it is described the use of fuzzy logic control (FLC) for the pneumatic system on the excavator models. Stages of research started from the design and manufacture of excavator models. When the work plan which includes the selection of materials, actuators, determine the dimensions, ways of working, mechanism, control method. At this stage of the modeling includes the manufacture of mechanical systems, actuators installation and programming. Before starting a program is preceded by using kinematics formulation excavator models, while the method used is a manipulator with four degrees of freedom and a mobile robot as a base with 2 degrees of freedom. Tracking trajectory selected in the test wheel excavator models. As for the arms, there is a boom, arm and bucket and the base of frame of the excavator that arm can rotate. Tests performed on the rotational motion actuator is a DC electric motors and straight motion of pneumatic cylinders. A microcontroller Arduino mega-actuators are used to control the rotation and rectilinear motion, then modeled using fuzzy logic control type mamdani, mult input multi output (MIMO), comprising 3 inputs and 2 outputs. In this study, fuzzy control model of excavator with a pneumatic system with membership function as a Gaussian function is simulated. Then, the author chose this system is simulated using Matlab software to test its performance.

Keywords: Pneumatic, control techniques, fuzzy logic control, excavators, models.

### **Introduction**

Excavators are heavy equipment consisting of a boom as shoulder, arm as well as the bucket and driven by a hydraulic power-driven by a diesel engine and is above the chain wheel (trackshoe). Excavators are heavy equipment most versatile because it

can handle a wide variety of other heavy equipment jobs. This machine has a primary function for excavation work. But not limited to that, excavators can also do construction work such as making the slope, loading, rock breaker, and so on. [1].

All systems using the stored energy the compressed air to produce a work called the pneumatic system. In its application, the pneumatic system is widely used as an automation system. Many examples of machines in industrial process and production utilizing pneumatic systems, such as pressing machines, brakes, door opening, and etc. Recently, pneumatic is begun to be used for control and utilization of machinery and means of production. Currently in use pneumatic much combined with the electrical system. Electrical circuit in the form of a switch, solenoid, and a limit switch is used as a part of the control system. For applications that are quite complicated to use a PLC (Programmable Logic Controller) is a programmable controller system [1].

Our previous of topics in the Artificial intelligent can be find below, Syam et.al [2] describes a control method for mobile robots represented by a nonlinear dynamical system, which is subjected to an output deviation caused by drastically changed disturbances. Syam is assumed that a neural network (NN)-based feed forward controller is constructed by following the concept of virtual master-slave robot, in which a virtual master robot as a feed forward controller is used to control the slave (i.e., actual) robot. Another application of adaptive actor critic algorithm to mobile robot already introduced using simulated experience as a kind of temporal difference [3][4].

Today's technological advances make modern industry seeks to improve the quality, quantity and effectiveness of the products they produce. Therefore, the modern industry requires continuous and automating systems are widely used at the present time is pneumatic. This is because the pneumatic have some advantages that are not owned by any other system. Although today's industry in the achievement of high efficiency, combining pneumatic systems with electrical systems, electronic, hydraulic, and mechanical.

In the development of the pneumatic system combined with an electric system to facilitate the operation of the so-called Electro pneumatic System. Advantages of the use of electronic components as the control of pneumatic system is an electrical signal can be transmitted through cables easily and quickly with distance. As for the mechanical signal or pneumatic transmission signal is more complicated.

The use of compressed air in the pneumatic system has several advantages, among others, the availability of unlimited, easily distributed, temperature flexibility, safe, clean, transfer of power and speed is very easy to set up, can be stored, easily to implemented[5].

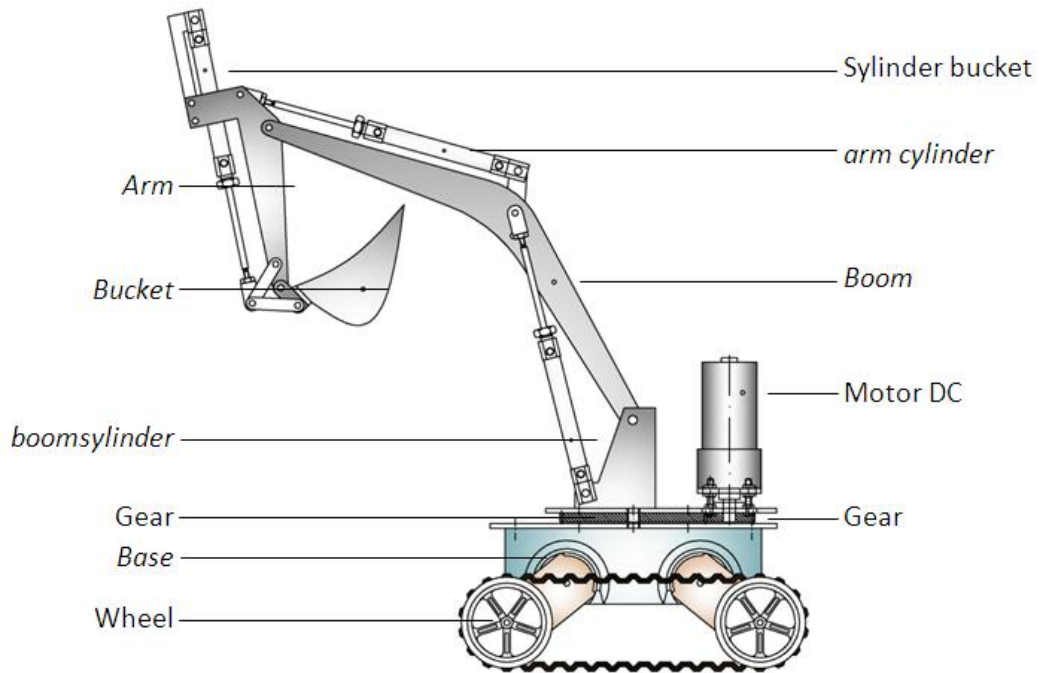
## **Research Method**

The design and several stages of research in this study can be explained as follows:

### ***Design models of excavators with a pneumatic system***

From Figure 1 shows an image of excavator models to be created. Of the overall

picture, there are several components obtained by buying that piece wheels, gears, DC motors and pneumatic cylinders. Other components are made of thick aluminum plate material 3.2 mm and 1.6 mm thick with dimensions adapted to the existing components.



**Figure 1 Model of excavator with pneumatic system**

**Formula's motion of excavator model**

Denavit Hartenberg [6] as shown in table 1 below

**TABLE I. CONTOH DH PARAMETER**

$i - 1$	$i$	$\alpha_{(i-1)}$	$a_{(i-1)}$	$d_i$	$\theta_i$
0	1	0°	0	0	30°
1	2	90°	0.307	0	39°
2	3	0°	0.105	0	-20°
3	4	0°	0.097	0	40°

Matrix transformation for frame 1:

$${}^0T_1 = \begin{bmatrix} c_1 & -s_1 & 0 & 0 \\ s_1 & c_1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} = \begin{bmatrix} 0.866 & -0.5 & 0 & 0 \\ 0.5 & 0.866 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

Matrix transformation for frame 2

$${}^1T_2 = \begin{bmatrix} c_2 & -s_2 & 0 & L_1 \\ 0 & 0 & -1 & 0 \\ s_2 & c_2 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} = \begin{bmatrix} 0.777 & -0.629 & 0 & 0 \\ 0 & 0 & -1 & 0 \\ 0.629 & 0.777 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

Matrix transformation for frame 3

$${}^2T_3 = \begin{bmatrix} c_3 & -s_3 & 0 & L_2 \\ s_3 & c_3 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} = \begin{bmatrix} 0.939 & 0.342 & 0 & 0.307 \\ -0.342 & 0.939 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

Matrix transformation for frame 4

$${}^3T_4 = \begin{bmatrix} c_4 & -s_4 & 0 & L_3 \\ s_4 & c_4 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} = \begin{bmatrix} 0.766 & -0.643 & 0 & 0.105 \\ 0.643 & 0.766 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

Motion of the arms from the base until the 4th axis can be seen in the following equation:

$${}^0T_4 = {}^0T_1 \cdot {}^1T_2 \cdot {}^2T_3 \cdot {}^3T_4$$

$$\begin{bmatrix} x_T \\ y_T \\ z_T \\ 1 \end{bmatrix} = \begin{bmatrix} 0.445 & -0.741 & 0.5 & 0.292 \\ 0.257 & -0.428 & -0.866 & 0.168 \\ 0.856 & 0.514 & 0 & 0.227 \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} 0.097 \\ 0 \\ 0 \\ 1 \end{bmatrix}$$

$$x_T = 0.097 \cdot 0.445 + 0.292 = 0.335 \text{ m}$$

$$y_T = 0.097 \cdot 0.257 + 0.168 = 0.193 \text{ m}$$

$$z_T = 0.097 \cdot 0.856 + 0.227 = 0.310 \text{ m}$$

So the position of  $x$ ,  $y$  and  $z$  at end effector could be found below:

$$\begin{aligned}
 x_T &= 0.335 \text{ m} \\
 y_T &= 0.193 \text{ m} \\
 z_T &= 0.310 \text{ m}
 \end{aligned}$$

### Result and Discussion

In the figure 3 shows the design of the mechanical model of the excavator with a pneumatic system in a three-dimensional image. In general, this excavator models is divided into two parts, namely the base as mobile robot with crawler wheels and the arm as manipulator robot. At the base there are two left and right wheels which serves as navigation for the forward and backward, turn left and right.

The top of base serve as a rotational motion and stand for all components, electronic, mechanical or pneumatic. Rotational motion is driven by a DC motor. On the arm there are four pneumatic cylinders those serves as the actuator straight movement. As shown in Figure 3 the two cylinders to move the boom, the arm and the bucket.

In figure 4 shows control scheme or control model of excavator with a pneumatic system. Excavator models is controlled by an open loop control system, wherein the input signal is given via a remote control that is subsequently processed in the microcontroller, then continued on the motor and solenoid valve driver then actuators will move in accordance with the instructions given on the remote control which has resulted movement in the arm excavator models and the direction in which the rover 5 forward, backward, turn left and right.

### Fuzzy Logic Control

Motion system excavator models pneumatic system can be shown in Figure 3, where the motion of arm excavator models derived from the combination of three pneumatic cylinder motions to generate the position of the bucket [7].

Working range can also be seen in Figure 5 R1 is the furthest distance or radius obtained from the movement of the boom cylinder, arm cylinder produces and L4 R2 obtained from the bucket cylinder. In Table 1 are shown the basic rules for determining the position of the bucket as a result of the movement of a pneumatic cylinder.

From Figure 5 visible range of variation obtained the motion of boom, arm and bucket.  $L_2$  is formed radius of the boom motion with 307 mm length,  $L_3$  of arm motion with 105 mm length,  $L_4$  of motion bucket with 98 mm length. While  $R_1$  is the radius of the base of the furthest length of 500 mm,  $R_2$  is formed of arm motion and bucket with a length 191 mm.

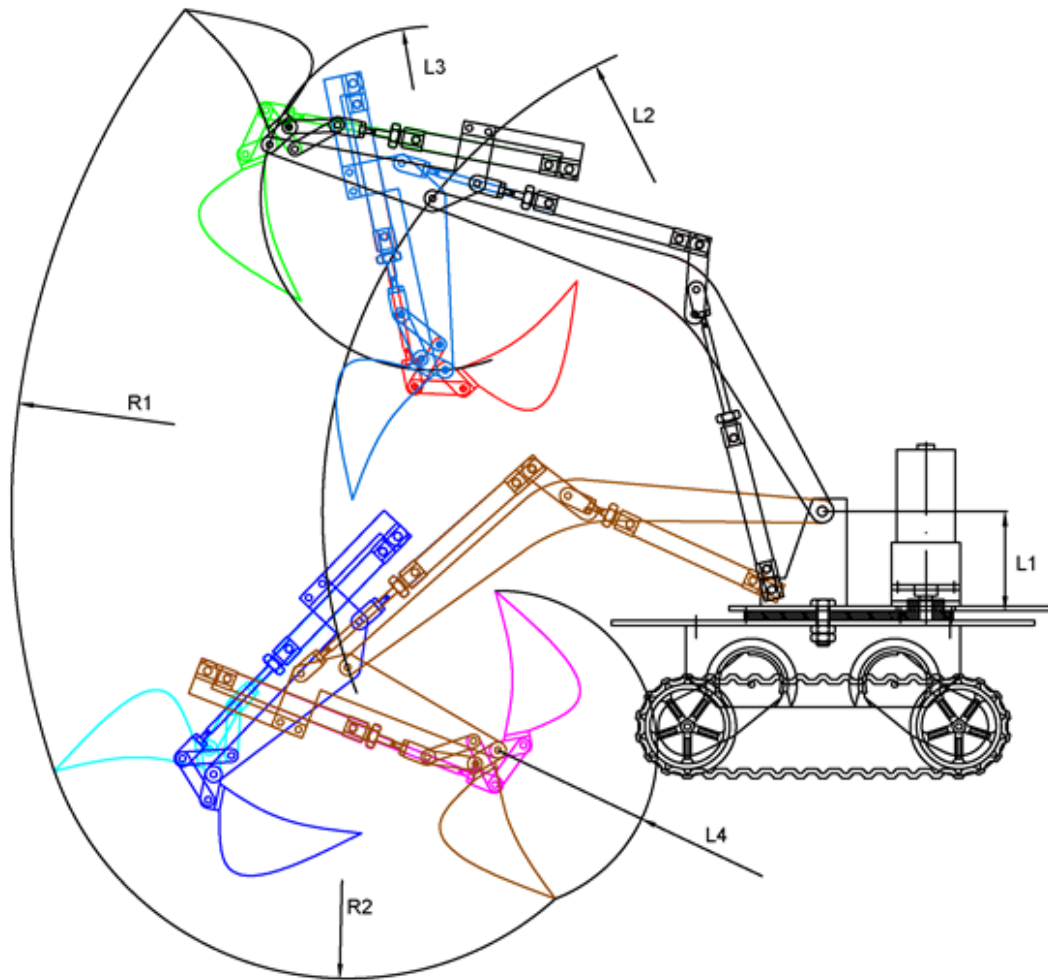


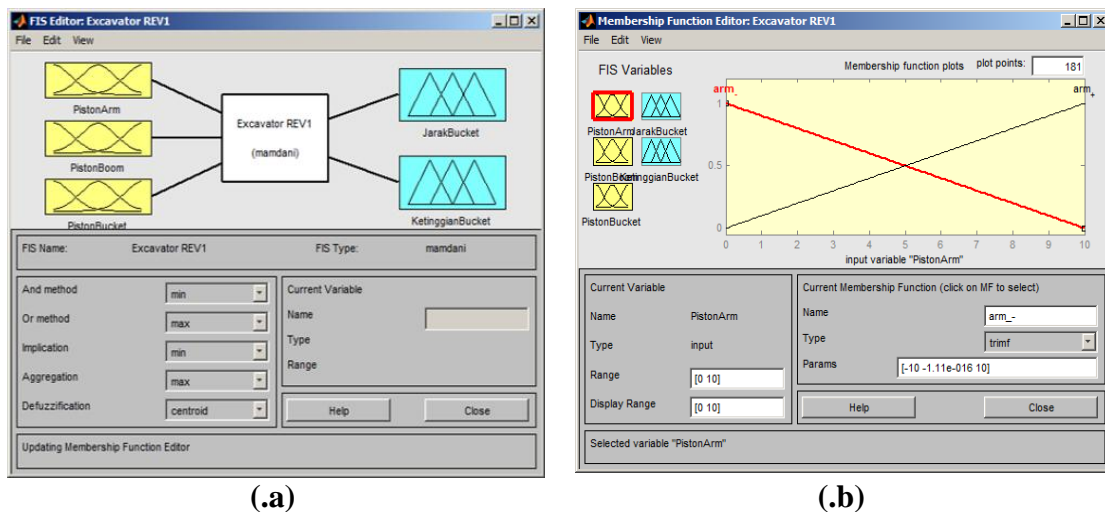
Figure 5. Work Area Jarak of *excavator model*

Table 1. Rule of Fuzzy Logic Control

Rules	Cylinder			Bucket position	
	<i>boom</i>	<i>arm</i>	<i>bucket</i>	distance	Vertical distance
1	+	+	+	X1	Y6
2	+	+	-	X4	Y5
3	+	-	-	X7	Y8
4	-	-	-	X8	Y3
5	-	-	+	X5	Y2
6	-	+	+	X3	Y4
7	+	-	+	X6	Y7
8	-	+	-	X2	Y1

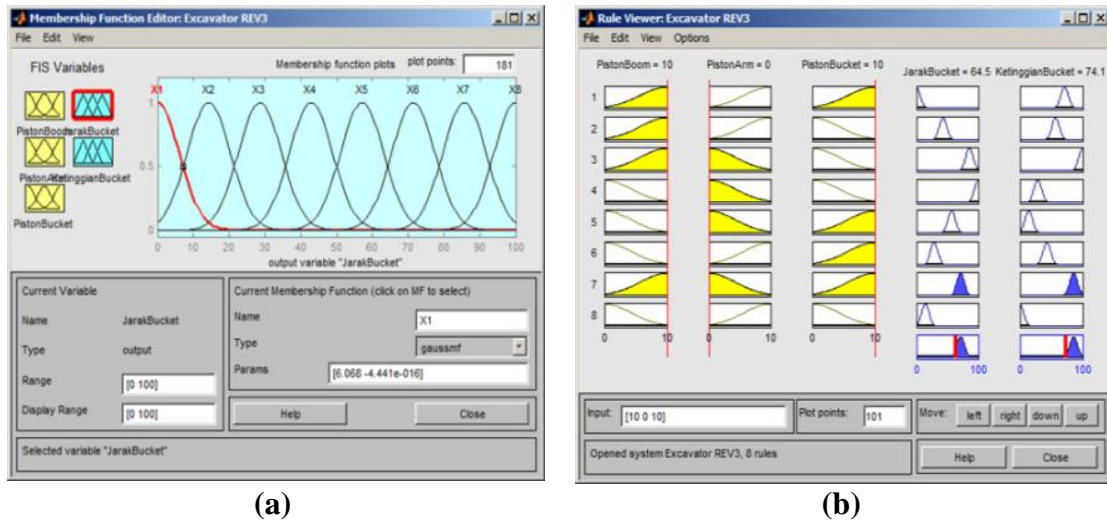
In Table 1 shows the position of the bucket cylinders caused by movement of the boom, arm and bucket. Sign (+) indicates the position of the pneumatic cylinder forward and sign (-) indicates the position of the cylinder backwards. Mark (X) is the distance from the base of the bucket. Height and distance control will be obtained by using fuzzy inference system (FIS) is designed in the rule editor and type mandani using Matlab. Membership functions for input and output is shown in Figure 6-8.

In the Figure 6a shows 3 inputs and 2 outputs fuzzy inference system (FIS) excavator models, the left side there are three inputs obtained from the cylinder boom, arm and bucket. On the right there are two outputs obtained from the variation of the three cylinder pneumatic movement that distance and height of the bucket. In the middle there is a type of fuzzy inference system (FIS) is mamdani system.



**Figure 6. a. Input and output of FIS excavator model b. Membership function as input of boom cylinder, arm and bucket.**

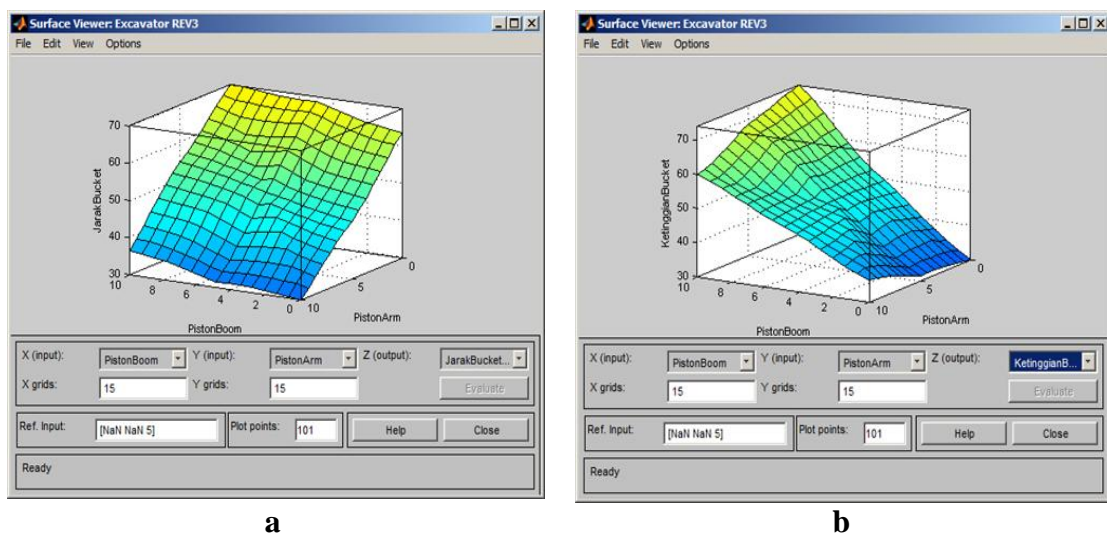
In the Figure 6b shows membership functions for input of “piston boom”, the yellow window to adjust the membership function that is name, range and type. The name for the membership function that is if advanced pneumatic cylinder named if backward boom boom + -. Figures 0-10. states range from the backward position to the forward position or vice versa. Similarly, to set the "Piston Arm" and "Piston Bucket".



**Figure 7. a.Membership function of output as distance of the bucket b. Rules of FIS system**

In the Figure 7.a shows membership functions for output "Distance Bucket", it shows to adjust the membership function that is range and type. The membership function that is if the distance bucket near named  $X_1$  if far  $X_2$  to  $X_8$ . Figures 0, shows the 100 states range from position  $X_1$  to  $X_2$ ,  $X_2$  to  $X_3$ , and so on. Similarly, to set the output to of FIS that is Altitude Bucket".

In the figure 7.b seen throughout the rule, there are eight rules that can be made, to set the trend bucket whether the farther distance or near, can do to shift the center red line for each input membership functions. In the picture a blue triangle visible tendency bucket position, the full terms of the three is the tendency of the position of the bucket in the position that the greater.



**Figure8. a.The surface of FLC for distance as output of the end effector b. The surface of FLCfor altitude as output of the end effector**



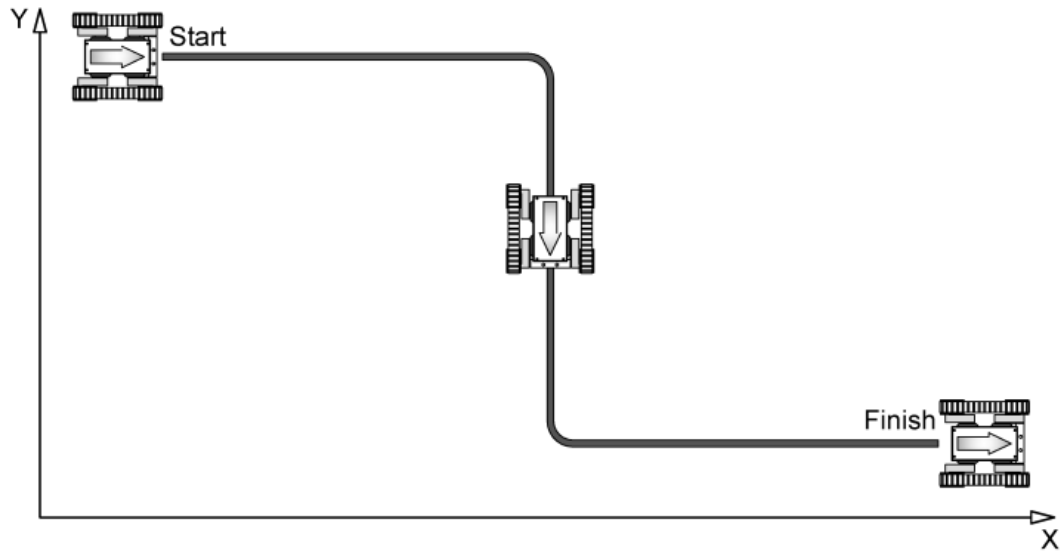
Microcontroller Arduino-Uno is used in this system. To support it, needs program is to determine how the model excavator in accordance with the movement desired. The software used is Arduino 1.5.5 as shown in Figure 8, a program that was created in uploaded to the microcontroller through a USB cable, and then do the test if it is appropriate then proceed with the simulation in the field if it is not checked again until the program that created the program running correctly.

```

gerak_excavator | Arduino 1.5.5
File Edit Sketch Tools Help
gerak_excavator Setup_Gerakan
currentButton1 = debounce1(lastButton1);
if(lastButton1 == LOW && currentButton1 == HIGH)
{
  led0n1 = !led0n1;
}
lastButton1 = currentButton1;
digitalWrite(LedPin1,led0n1);
currentButton2 = debounce2(lastButton2);
if(lastButton2 == LOW && currentButton2 == HIGH)
{
  led0n2 = !led0n2;
}
lastButton2 = currentButton2;
digitalWrite(LedPin2,led0n2);
currentButton3 = debounce3(lastButton3);
if(lastButton3 == LOW && currentButton3 == HIGH)
{
  led0n3 = !led0n3;
}
lastButton3 = currentButton3;
digitalWrite(LedPin3,led0n3);
if(digitalRead(inmundur)==HIGH)
{
  mundur();
}
else
if(digitalRead(inmaju)==HIGH)
{
  void maju()
  {
    analogWrite(enb,255);
    analogWrite(ena,255);
    digitalWrite(kiril,LOW);
    digitalWrite(kiri2,HIGH);
    digitalWrite(kanan1,LOW);
    digitalWrite(kanan2,HIGH);
  }
  void mundur()
  {
    analogWrite(enb,255);
    analogWrite(ena,255);
    digitalWrite(kiril,HIGH);
    digitalWrite(kiri2,LOW);
    digitalWrite(kanan1,HIGH);
    digitalWrite(kanan2,LOW);
  }
  void kiri()
  {
    analogWrite(enb,255);
    analogWrite(ena,255);
    digitalWrite(kiril,HIGH);
    digitalWrite(kiri2,LOW);
    digitalWrite(kanan1,LOW);
    digitalWrite(kanan2,HIGH);
  }
  void kanan()
  {
    analogWrite(enb,255);
    analogWrite(ena,255);
    digitalWrite(kiril,LOW);
    digitalWrite(kiri2,HIGH);
    digitalWrite(kanan1,HIGH);
    digitalWrite(kanan2,LOW);
  }
}
1 Arduino Mega or Mega 2560, ATmega2560 (Mega 2560) on COM6

```

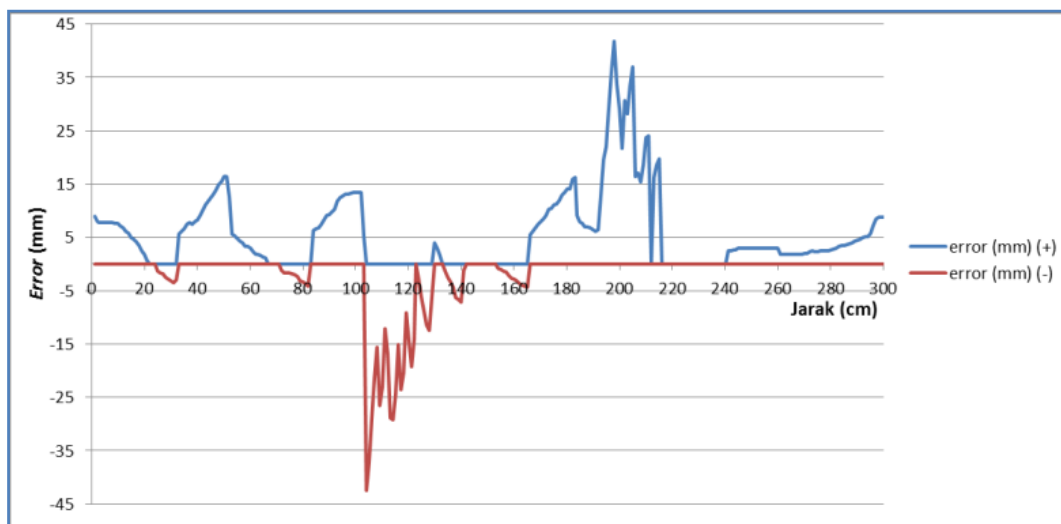
Figure8. Arduino 1.5.5software



**Figure11.Trajectory tracking 1**

In figure 12 shows that the largest errors occur in the first and second turnout.

This is because when a mobile robot mobile robot turn to change the position from vertical to horizontal forming an angle  $90^{\circ}$  that causes the sensor away from the track trajectory resulting in a large error value. In figure 12 there were also errors for tracking 1, data errors are taken at a distance of 1 cm each. Error (+) is the sensor away from the track to the right and errors (-) to the left which is the biggest error on the first turn at a distance of 104 cm at -42.4 mm.



**Figure12.Error vs trajectory with auto navigation**

### Conclusion

In this study, the position of height and distance buckets arranged using fuzzy logic control. Based on simulation results, it appears that the variation motion of three pneumatic cylinders can determine the position of the bucket excavator models.



**Figure18. Model of excavator fill the trucks model with soil material**

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