Improving The Accuracy and Controlling The Shooting Power in a Wheeled Soccer Robot

Amre Syamsudin1), Iwan Kurnianto Wibowo2), Mochamad Mobed Bachtiar3)

1,2,3Informatic and Computer Department
Politeknik Elektronika Negeri Surabaya
Surabaya, Indonesia
amresyamsudin9@gmail.com1), eone@pens.ac.id2), mobed@pens.ac.id3)

Abstract*— Middle Size League (MSL) is one of the divisions in the Robocup competition. Robocup is an international research organization that focuses on developing soccer robots. This organization aims to build a soccer robots team and will be competed with the winner of the world cup in 2050. In mobile soccer robot the ability to perform a kick mechanism is a basic thing that must be owned by soccer robot. Therefore, the focus of this research is to improve the accuracy and control of power shooting in kicking the ball, so that the robot can make decisions when doing the process of flat and lob shoot with a varied kick power that is controlled by Fuzzy Logic Controller. This method serves to improve the accuracy of the kick, so that the ball can fall at a specified point. Giving two inputs consisting of the distance of the ball goal and the opponent's distance with the robot will generate power kicks and kick angles that are used as its output. The power of shooting are divided into five variations. First, very fast kick which using 500V and 40 degree angle will reach distance of 8.5 meters and height of 2.2 meters. Second, fast which use a voltage between 300V-475V. Third, medium which use a voltage of 250V-425V. Fourth, slow use a voltage 175V-300V. Last, very slow use a voltage between 150V-250V.

Keywords: Soccer Robot, Fuzzy Logic, Accuracy, Control Shooting.

I. INTRODUCTION

The match between robots and humans in a soccer game that will be held in 2050 is a dream of the great goals of the Robocup developers or the world robot race. Wheeled soccer robots have various abilities such as searching the ball, goal point determination, avoiding obstacles or opponents, feeding the ball, until kicking the ball that have been obtained. All of these capabilities are automatically linked without any user control. The use of CC or Couch Computer is only for the start and stop buttons while for other function it is automatic.

This study focus to improve accuracy and control the power shooting in kicking the ball towards the goal or feeding the ball to a fellow team. There are various ways for kicking the ball that can be applied such as using a motor actuator, using a spring, and using a solenoid. Using solenoid [2] is very commonly in mobile soccer robot. In this solenoid use a coil and a solid piece of iron, where the iron is placed in a pipe that has been given a coil. When the coil is electrified, then the iron will automatically be drawn into the pipe. The movement of the incoming iron can be used to kick a ball that already exist in the kicking area. This technique uses the principle in the coil gun on the shooting game [3].

There are many another ways that can be used besides the way that have been mention before. Using that methods also have their own disadvantages and advantages, so it can not be said that one of these methods is the best and in its application also has the application of changing mechanical principles. There are several factors that influence the way or media that have been mentioned above, such as kick force, weight of the kicker, required area, time required, safety, ease, and also the cost of making the kicker.

II. THEORY

A. Mobile Soccer Robot

Mobile Soccer Robot is one of the development of soccer robot. In a Robocup game for the mobile soccer robot division there are two categories: Small Size League (SSL) and Middle Size League (MSL). For the small size category, the diameter of the robot is 18 cm and the maximum height is 15 cm (Figure 1), while the middle size league category the maximum size is 52 cm x 52 cm x 80 cm (Figure 2).

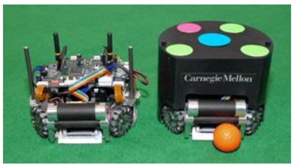

Figure 1. The Small Size of Mobile Robot Soccer

Figure 2. Middle Size Mobile Robot Soccer

The most visible differences between the two categories are from the size of the robot, use of the ball and the use of the camera. The main drivers of both is wheel with different numbers of each developer and the strategy used. If the small size using the top camera as the main vision, while for the middle size use the camera on the robot body.

B. Solenoid Kicker

This solenoid use the principle of magnetic out due to induction on the coil. When a current is flowed into a copper wire coil, a strong magnetic field will be built. An electromechanical solenoid can be the main alternative to be used in the shooting mechanism [2].

In Figure 3, there is a projectile or commonly called iron plunger, the iron that will be drawn by the coil that has been made of copper wire. The pull makes the iron can go forward or retreat, so that phenomenon is used in the principle of solenoid. The forward pullback of the plunger makes a change of the induction coil, which is a measure of the amount of magnetic flux that has been formed for a given electric current flow. The magnitude of the inductance is influenced by the position of the plunger or the iron of the rod, this plunger serves to provide mechanical strength in kicking the ball.

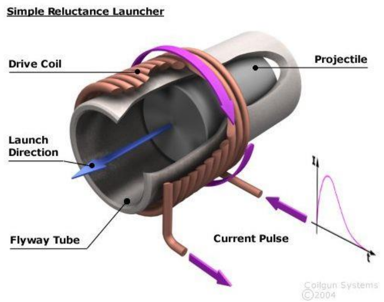

Figure 3. Solenoid Principal

This plunger has a force proportional to the copper coil proportional to the instantaneous current changes, the radius and length of a copper coil and plunger will continue to move in the direction which have a high inductance. Solenoid has a typical time constant with value:

$$\tau = L/R \qquad \text{(Eq.1)}$$

where, τ is Time Constant, L is Inductance, and R is Electrical Resistance of the Coil.

C. Optimization

In making a new solenoid there are several parameters that must be noticed. There are characteristics that must be met if we want to get the maximum results. Such as the characteristics of the component, like as iron kicker (plunger), shield, and coil [3].

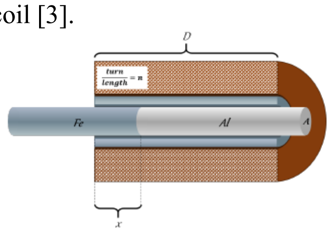

Figure 4. Optimization Solenoid

- Iron Length
- Kicker Material
- Protector
- Number of spin coils
- Number of layers
- The length of coil winding
- The thickness of the coil wire

D. Fuzzy Logic

Soft Computing is a new innovation in building intelligent systems. This intelligent system is a system that has expertise like humans in a particular domain, able to adapt and learn in order to have better work in the event of environmental changes. The main elements in Soft Computing are: Fuzzy Systems, Artificial Neural Networks, Probabilistic Reasoning, Evolutionary Computing. Generally there are 5 fuzzy systems in doing reasoning, these are the following possibilities;

1. Define fuzzy input.
2. Apply fuzzy operators.
3. Apply the method of implication.
4. Composition of all outputs.
5. Defuzification.

Fuzzy systems have several advantages when compared to traditional systems, for example the number of rules used. The initial processing of a large number of values into a value of membership degree in the fuzzy system reduces the number of values to a value of membership degree in the fuzzy system reducing the amount of value that the controller must use to make a decision. Another advantage is that fuzzy systems have reasoning abilities that are similar to human reasoning abilities. This is because the fuzzy system has the ability to provide responses based on information that is qualitative, inaccurate, and ambiguous. There are several reasons for using fuzzy logic:

1. Fuzzy logic is very flexible.
2. Fuzzy logic has tolerance.
3. The concept of fuzzy logic is easy to understand. The mathematical concepts that underlie fuzzy reasoning are very simple and easy to understand.
4. Fuzzy logic is capable of modeling very complex nonlinear functions.
5. Fuzzy logic can build and apply the experiences of experts directly without having to go through the training process.
6. Fuzzy logic can work in conventional control techniques.
7. Fuzzy logic is based on natural language.

III. DESIGN SYSTEM

In this chapter we will discuss about tool design starting from designing control, systems. and kicker mechanism from mobile soccer robot. It is intended that the results of each design can be integrated with the subsequent design and the results obtained more optimally. The design of the program formulation that will be used to kick the ball, whether it's a flat shoot or a lob shoot on mobile soccer robot.

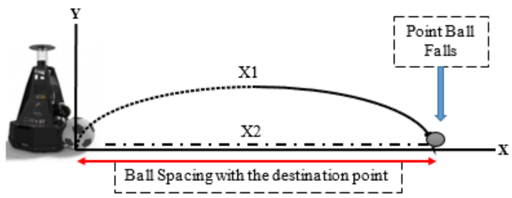

Figure 5. Illustration Ball Input Distance

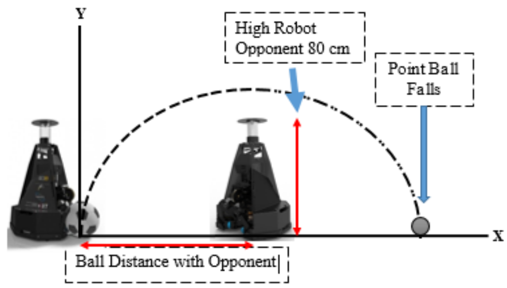

Figure 6. Illustration There is Obstacle

Based on the above case, to get an accurate kick is influenced by several parameters, these are the following possibilities; the power solenoid, kick angle, distance of the falling point of the ball to be aimed at and the distance of the opponent blocking the kick.

A. Diagram Control

Figure 7 shows the flow of control of a mobile soccer robot from the beginning of receiving the ball to the final execution of kicking, which is the title of this final project.

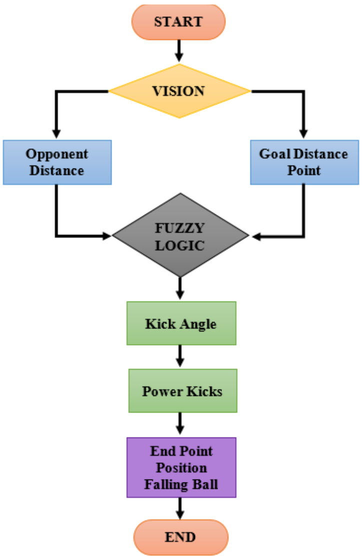

Figure 7. Diagram Control

The function of the fuzzy method is as the execution of each robot which gets the ball. The input from this method comes from two parameters, the position of the opponent's robot and the destination of the ball point to be kicked. In the first parameter, the destination point of the ball point to be kicked works after the robot knows the starting position to kick, then the robot will find the point where the ball will be kicked. The second parameter is the position of the opponent is useful to determine whether the kick to be taken in the form of a lob shoot or just a flat shoot. After all parameters are obtained, they will be entered into the Fuzzy Logic method, where later the output of the fuzzy output will be in the form of the kick angle that will be executed (40 degrees to 90 degrees) and how many kicks will be used in order to reach the desired point.

B. *Kicking Mechanism*

Kicking mechanism is the part used to kick the ball, where in this section there are several parts, the solenoid control and kick handle control. For more details, consider the structure of the kicking mechanism in figure 8.

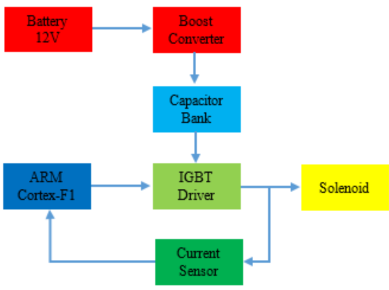

Figure 8. Solenoid Control Structure

The process in Figure 8 aims to control the power produced by the solenoid. Firts, the 12V battery increased its voltage to 530V with boost converter which aims to fill the bank capacitor with a capacity of ± 500V 4000uF. Then after the bank capacitor has been fully charged, it will be distributed using the IGBT driver. This driver functions to control the outflow of voltage in the capacitor of the bank so that the solenoid power can be controlled. The addition of a current sensor is used to determine whether the voltage and capacity of the capacitor is in accordance with the power produced. The current sensor data obtained will be processed by a microcontroller using ARM Cortex-F1 to determine and evaluate whether the voltage distributed by IGBT is as desired. In addition, from this current sensor the power generated by the solenoid can be calculated.

Figure 9 shows the structure of the kick handle control. This handle is used to determine the angle of the kick from which ball area to kick. Control here is a control to adjust the motor rotation so that it can match the kick angle of the ball to be kicked.

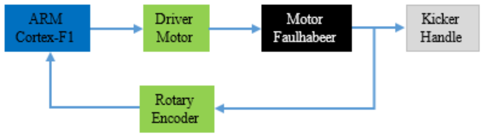

Figure 9. Control Structure of Kicking Handle

C. *Mechanical Solenoid Design*

Inside the solenoid there is a copper wire that is rolled in a way wrapped around a certain thickness (figure 10). On the inside of the solenoid there is a plunger like a cylinder made of iron or steel. If this wire coil is flowed by an electric current it will produce a strong magnetic field. This strong magnetic field will produce a magnetic force and will attract the plunger. If the magnetic field is turned off, the spring or sponge will return the plunger to its original state with the reflection obtained from the collision or pulling the plunger.

Figure 10. Design of Kicker Components

The kicker is in front of the robot (figure 11). The kicker has a flat shoot mechanism and a lob shoot. To produce a kick will be used a gear banding or handle that can be moved up and down which aims to not only do one kick angle. The robot will use a kicking mechanic with the help of a motor at the end of the gear banding or handle so that it can move the lever up and down so that the kick angle can be determined and varied. The initial angle range provided by the system is between 40 to 90 degrees.

Figure 11. Kicker Installed On Robot

D. *Hardware Design*

In the design of this hardware is used as a solenoid controller and faulhabber motor. It also takes a microcontroller which is also used to control the driver and also for the serial communication of the USART microcontroller pin to the PC to send commands to the microcontroller and execute it through the driver. For a bank capacitor charger controller, a DC-DC boost converter is needed and for the Faulhabber motor controller, the BTN motor driver and rotary encoder are used as feedback.

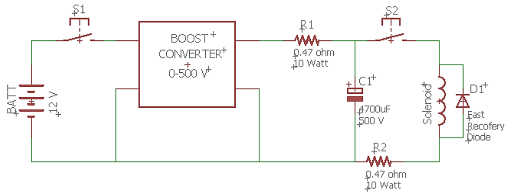

Figure 12. Schematic Hardware Solenoid

The first step is to increase the 12V battery input voltage with boost converter to fill the capacitor up to ± 500V voltage. Furthermore, the electrical power of this capacitor is used to supply the solenoid. A strong current will be able to flow from the capacitor in a short time.

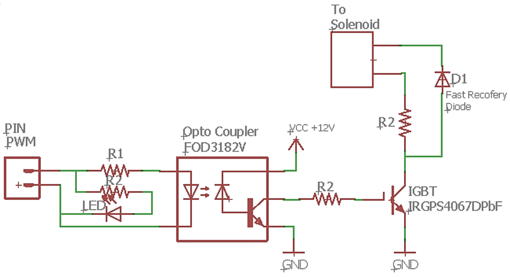

Figure 13. Schematic Control Solenoid

The next step is to remove the electrical power stored in the capacitor using a solenoid driver with an IGBT circuit that has a current capability up to 120A (figure 12). Optocouplers are used to isolate digital systems with system drivers.

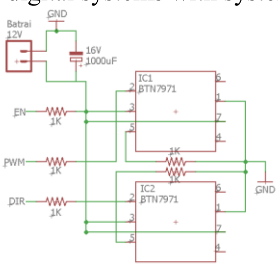

Figure 14. Schematic BTN7971

The design of the microcontroller and motor driver is the main driver to be created. The microcontroller will be connected to a PC or Laptop with a USART serial that functions to send commands that have been inputted and monitor all hardware whether it is appropriate or not.

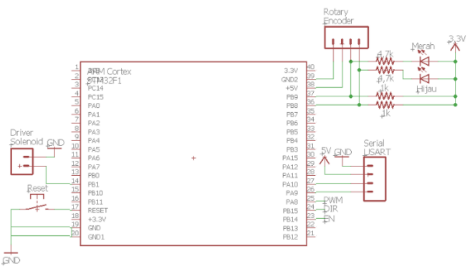

Figure 15. Schematic Microcontroller Pinout

E. Control Power and Angel Shooting

Power control and kick angle can be done through the selenoid driver that has been made in the previous design, and also by controlling the handle shaft from the kicker from top to bottom to produce a kick angle on the ball point to be kicked. The control is done to get the accuracy of the kick that can be arranged.

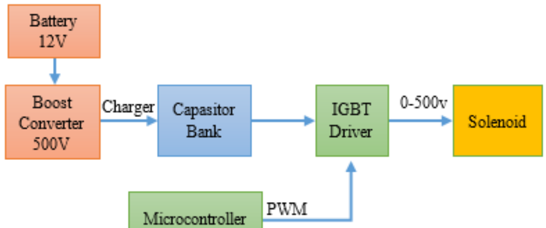

Figure 16. Control Power Shooting

Using the circuit as shown in Figure 17 where the inductance and resistance, L, R, represent the solenoid, using IGBT can be used to adjust the current through the coil. Using the pulse width modulation (PWM) signal to turn on the IGBT serves to adjust the kick force power generated by the solenoid. To avoid voltage surges on the IGBT when shutting down, the flyback diode D is placed parallel to the solenoid.

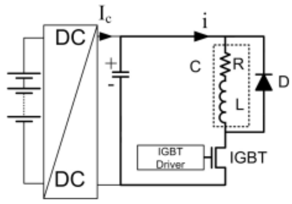

Figure 17. Schematic R/L

To kick the ball, this robot is equipped with an actuator mechanism on the handle to move up and down the kicker. This handle is driven by a faulhabeer motor which is at the end of the lever then there is a belt to the lever, so that when this motor moves and is given a set point value on the encoded value this motor will move to the point set point. In other words, the handle will be pulled by the motor and produce upward and downward movements so that the ball can be kicked in a certain corner. For the kicker handle design can be seen in the figure 18.

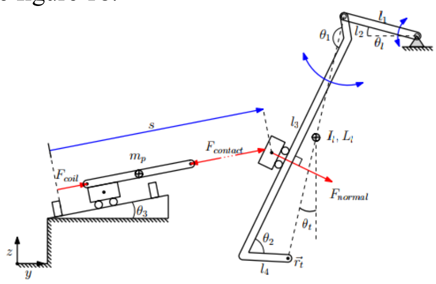

Figure 18. Kicker Handle System

The height of the kicker handle can be adjusted by rotating around the first hinge with an angle θ_l. The dimensions of the handle are determined by l_1-l_4, θ_1 and θ_2. The handle mass is represented by the point mass at the distance l_l from the second hinge, to the moment of mass inertia I_l, and θ_t at the angle of the line connecting the end of the handle with the second hinge with the z axis. Plunger has mass m_p and moves toward s, with angle θ_3 corresponding to horizontal plane. F_{coil}, $F_{contact}$ and F_{normal} represents the magnetic force of the coil on the plunger, the contact force between the plunger and the handle, and the force perpendicular to the handle.

F. Fuzzy Logic Control Design

In this fuzzy logic controller design, there are two inputs and two outputs. The first input is the destination distance of the ball and the second input is the distance of the opponent or obstacle distance. For the first output is the solenoid power output and the second output is the kicker handle angle. In this study, we use Fuzzy Logic non symmetry triangle shape cause this method is a method that produces the best kick accuracy between the other Fuzzy Logic.

1. Ball Destination Distance

The ball goal distance is one of the inputs used in the fuzzy method in this final project. Here are the variables of the membership function. The distance of the ball goal:

- *Near*
- *Medium*
- *Far*
- *V.Far (Very Far)*

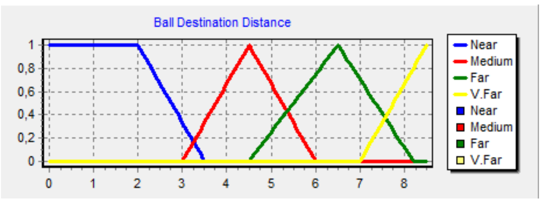

Figure 19. Membership Input Distance Ball Purpose

2. Distance of the Opposing Robot

The distance of the opposing robot is the second input in the fuzzy method in this final project. Here are the variables of the opponent's Robot Distance membership function:

- *N.Obstacle (No Obstacle)*
- *Near*
- *Medium*
- *Far*

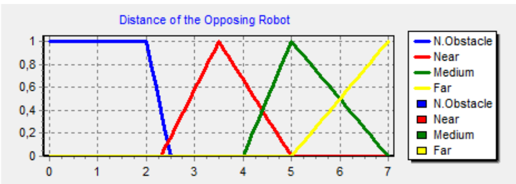

Figure 20. Membership Input Opponent Distance

3. Solenoid Power Decision

The output of this fuzzy method has various forms of kick strength, this power is greatly influenced by the input that has been given. Starting from the goal of the ball to be kicked and the distance of the opponent with the robot. Following are the kick strengths that will be generated:

- *V.Slow (Very Slow)*
- *Slow*
- *Medium*
- *Fast*
- *V.Fast (Very Fast)*

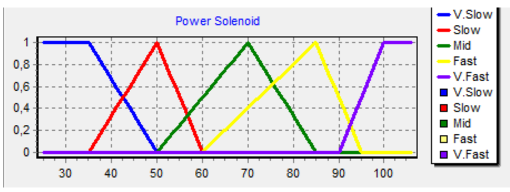

Figure 21. Membership Output Power Solenoid

4. Decision of Kick Angle

The output of the second fuzzy method is the angle of the handle that will be used for how high the lob shoot. This kick angle is strongly influenced by the input that has been given. Starting from the goal of the ball to be kicked and the distance of the opponent with the robot. The following is the kick angle that will be generated:

- *Lob*
- *R.Lob (Rather Lob)*
- *R.Flat (Rather Flat)*
- *Flat*

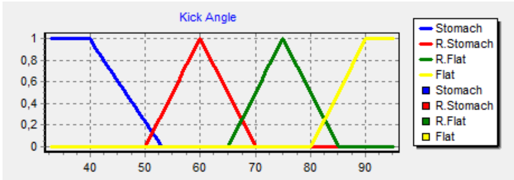

Figure 22. Membership Output Kick Angle

G. Rule Table

The next stage is the creation of a table rule, where all the functions of the membership variabel have been made from the input until the output will be entered in accordance with the provisions already in the making of the table rule. The following table 1 and table 2 create a table rule that will be used in this system.

Table 1. Rule Table of Power Solenoid

		Opponent Distance			
Ball Purpose		N.Obstacle	Near	Medium	Far
	Near	V.Slow	V.Slow	Slow	Slow
	Medium	V.Slow	Slow	Slow	Slow
	Far	Medium	Medium	Fast	Fast
	V.Far	Fast	V.Fast	V.Fast	V.Fast

Table 2. Rule Table of Kick Angle

		Opponent Distance			
Ball Purpose		N.Obstacle	Near	Medium	Far
	Near	Flat	R.Flat	R.Flat	R.Flat
	Medium	Lob	Lob	R.Flat	R.Flat
	Far	R.Flat	Lob	Lob	Lob
	V.Far	R.Flat	Lob	Lob	Lob

IV. EXPERIMENTAL RESULT

In this discussion will discuss the testing of the making of a kicker mechanism soccer robot starting from hardware, solenoid, mechanical development, experiment to control kick angle, kick strength and travel time of the ball. As well as the fuzzy system testing that has been made.

A. Hardware Examination

The battery input from this boost converter is a 12v battery then the voltage is increased to 530v DC so that it can charge a capacitor of 500v / 4000uF. The following is the time data needed to fill the capacitor of 530v.

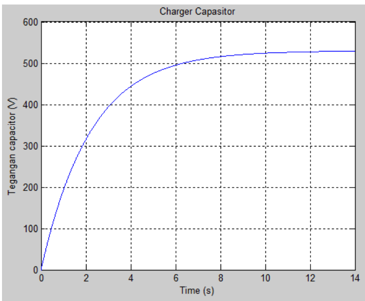

Figure 23. Response Charger Capacitor 500v

Then the testing on the solenoid hardware is carried out by taking current data on the solenoid when the solenoid is active even if only for a moment. From this data can be taken and calculated how much power or electrical power used by the solenoid, with the formula below:

$$P = V \text{ x } I \qquad \text{(Eq. 2)}$$

where, $P$is electrical power (W), V is voltage (V), I is current (A).

Table 3. Solenoid Power

duty cycle	Analog Write	Voltage	Current	Power
100%	255	530 V	34,03 A	18035,9 W
80%	204	424 V	23,96 A	12698,8 W
60%	153	318 V	14,18 A	7515,4 W
40%	102	212 V	7,00 A	3710,0 W
20%	57	106 V	1,81 A	959,3 W

For the motor response from 40 degrees to 90 degrees the PID formula is used, where the reson is good because it is fast enough that is 1 second. In this kp, and kd experiment the signal that is formed is a signal overdamped response, a response that can reach the input value quickly and not over the input limit. Here is a response signal formed by the motor response of the kicker handle from a value of 40 degrees to a 90 degree value:

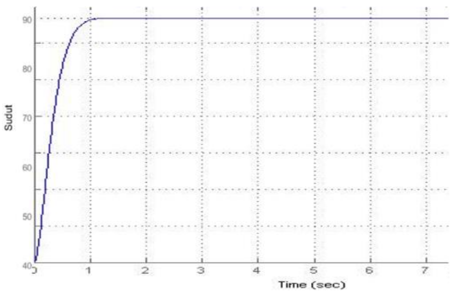

Figure 24. Motor PID Response

After the calculation of the PID control is complete, then the hardware will respond and the motor will rotate so that it will pull the handle up and cause the kicker in figure 25 to be pulled up and get a kick angle in the ball area. The minimum angle from the kicker that can be reached is an angle of 40 degrees to 90 degrees. A 40 degree angle down cannot be used because it has touched the floor and is stuck

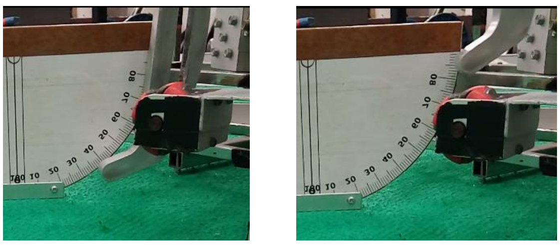
(a) Kick Angle 40° (b) Kick Angle 90°

Figure 25. Kick Angle

B. *Ball Kick Examination*

In the testing phase this time will be tested with a variety of kicks with different angles and with different power solenoid forces. The kick angle experiment aims to find out which angle of the ball when kicked can get the farthest and highest peak distance, while the power solenoid aims to find the value of the power solenoid range that can be controlled for air bait or flat feed. The distance that will be calculated is the starting point of the ball that will be kicked to the point where the ball falls first, the rest of the ball bouncing or moving where it will not be counted. Figure 25 shows the data collection process:

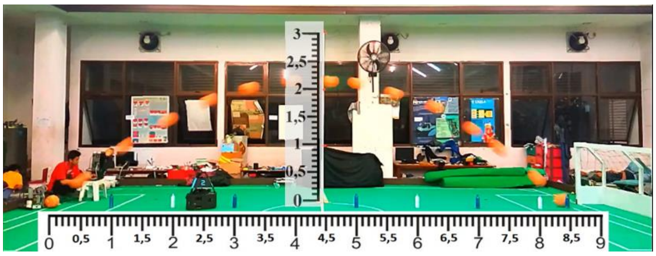
Figure 26. Kick Examination

In the kick angle experiment (figure 26), the power or kick strength used is 18035.9W or equivalent to 530V and 34.03A from the capacitor supplied by the 12v input battery then boost converter is done to increase the voltage to 530v. The Dutty cycle used is 100%, each kick starts from a 40 degree angle then rises every 5 degrees to reach 90 degrees at the point where the maximum lever can move. The data that has been obtained can be seen in the table 4.

Table 4. Kick Examination

Experiment	Angle	Height	Distance
1	40 °	2,22 m	8,52 m
2	45 °	2,03 m	8,32 m
3	50 °	1,80 m	8,10 m
4	55 °	1,62 m	7,73 m
5	60 °	1,50 m	7,50 m
6	65 °	1,29 m	6,53 m
7	70 °	1,00 m	5,00 m
8	75 °	0,68 m	4,57 m
9	80 °	0,20 m	3,32 m
10	85 °	0,06 m	1,78 m
11	90 °	0,00 m	9,00 m

Various lob shoot can be produced using different ball kick angles. To provide varying speeds on flat kicks can be done by giving a variable dutty cycle, so that there will be a change in power on the solenoid. Data from table 4 can also be modeled and seen in the form of kicks through matlab modeling as shown in Figure 27.

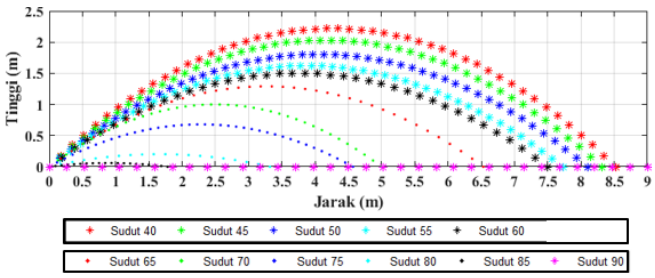

Figure 27. Modeling of Kick Angle

C. *Fuzzy System Examination*

The test on the fuzzy system aims to adjust the kick to fit the robot and make the learning process easier, so that it can determine a good position to kick in accordance with the existing variations, these are teh following possibilities; Very Slow, Slow, Mid, Fast, and Very Fast. In addition, if there is an opponent in front of robot, the robot can also determine how many degrees of lob shoot will be used in order to pass the opponent's robot, so that it is expected to pass the opponent without any errors regarding the opponent so that the ball can bounce back to his own goal. Tables 5 and 6 show data obtained from several experiments.

Table 5. Distance Ball Purpose 8,5m

No.	Expectation and Reality		No.	Expectation and Reality	
	The ball falling point	Error		The ball falling point	Error
1	8,5 m	0 m	**6**	8,5 m	0 m
2	8,5 m	0 m	**7**	8,5 m	0 m
3	8,5 m	0 m	**8**	8,5 m	0 m
4	8,4 m	0,1 m	**9**	8,5 m	0 m
5	8,5 m	0 m	**10**	8,5 m	0 m

From 50 times the experiment will be taken on average per 10 sampling and data will be obtained in accordance with table 5. The results show that only 9 experiments reached the target point perfectly and 1 trial did not meet the target. It is caused by an interfering x factor, such as the absence of dribbling of the ball so that the ball moves slightly and causes the ball to not be straight forward and turn a few inches or milli. The ball shift is very influential for a straight kick in order to get right on target.

Table 6. Distance Ball Purpose 6,5 m

No.	Expectation and Reality		No.	Expectation and Reality	
	The ball falling point	Error		The ball falling point	Error
1	6,5 m	0 m	**6**	6,5 m	0 m
2	6,5 m	0 m	**7**	6,5 m	0 m
3	6,2 m	0,3 m	**8**	6,5 m	0 m
4	6,5m	0 m	**9**	6,3 m	0,2 m
5	6,5 m	0 m	**10**	6,5 m	0 m

Of the 50 experiments that have been carried out, the average values that are in accordance with table 6. The results show that out of 10 average values, only 8 trials have reached the target point perfectly, while the other 2 trials have not met the target due to the x factor disturbing ones, such as the absence of dribbling the ball so that the ball moves a little and causes the ball to not go straight ahead and turn a few centimeters or milli. The ball shift is very influential on the straight kick in order to get right on target.

V. Conclusion

The use of a solenoid in a wheeled soccer robot can produce a kick that can be adjusted to the power settings. Voltage settings on the Boost Converter can affect the kicking power used, and setting the switching output voltage will also affect the kick force generated. The Fuzzy Logic non symmetry triangle shape is a method that produces the best kick accuracy between the other Fuzzy Logic method.

The results of the experiment show that the application of the fuzzy system on the kicker mechanism greatly influences the accuracy of the kick. Before adding a fuzzy system, the accuracy of the robotic kick target is very small, but after adding a fuzzy system to the system, the accuracy of the kick is very accurate at 98%. An error of 2% was obtained due to other factors such as a weak battery, a ball that lacked wind and also no dribel to hold the ball so that the kick could go straight ahead. So that this system will be very useful to be applied to the kicker mechanism.

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