

Implementation of high-voltage kicker system for “ROSTU” middle-size league robot soccer

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ABSTRACT

Middle-size robot soccer is one of the divisions that competed in national events such as the National Indonesia Robotics Competition and international competitions such as the middle size league (MSL). One of the main components in soccer robots is the kicker system. The kicker system is expected to be high torque, robust, and safe. In this work, a high voltage kicker system is designed and evaluated to substitute ROSTU's previous kicker system. This high voltage solenoid-based kicker system works at 380V and uses the electromagnetic force principle to move a ball. The performance criteria of the kicker system are it can move a ball with a mass of around 1 kg for a minimum range of 3 m and control the charging and discharging process in high voltage conditions. The experiment results show that the kicker system can move a ball with a mass of 1.06 kg, a difference kick distance from 100cm to 350cm, and a monitoring system that can show information about the capacitor voltage and system status.

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1. INTRODUCTION

This paper is the development of our previous research. Early research on wheeled soccer robots began in 2016 [1], 2017 which based on [2], and 2018 [1]. The first version of the ball kicker system for a small soccer robot system [3] was based on solenoid 24V in [4], [5]. Figure 1 shows our previous ROSTU robot soccer system. ROSTU stands for Robotic Soccer of Telkom University which represent one of Telkom University robotic team in The National Indonesian Robot Competition (known as KRI). Type of the ball used in the match was ping pong balls [6]. This system works as follows: Arduino Mega 2560 will receive position data from Raspberry Pi [7] in real-time [6], [8]-[10]. This position data is processed in raspberry pi from digital image processing. The raspberry pi processor was chosen due to its open-source characteristic [11]. Digital image processing is a process to identify the position of the ball in a mapped camera frame [9], [12], [13]. After the position of the ball is received, Arduino Mega 2560 will turn on the dc motor to chase the ball according to the data. Furthermore, Arduino Mega 2560 will read the compass sensor and direct the ball to the goal position and turn on the solenoid to kick the ball [14].

In the 2017 version, the soccer robot design is based on the National Indonesian Robot Competition 2017 rules [15], [16], which uses FIFA's standard futsal ball. The ball's weight is 500gr. Because of the weight, the kicker system is changed to the electro-pneumatic system, which has a greater thrust force. However, the kicker based on electro-pneumatic has several disadvantages, such as the dimension of the electro-pneumatic system is more significant than the previous one; the process of air reloading time takes

some time. Moreover, the power and direction of the kick and the number of available kicks are very dependent on existing pressure. Based on this background, a kicker system-based high-voltage solenoid system is chosen. The high voltage solenoid (± 380 V) kicker system has an advantage in the number of kick styles it can produce. The design of this kicker system has to consider the number of solenoids turns (n), the supply voltage, and the electrical current to produce the optimal force (F). Moreover, the safety of a high voltage system has to be designed to protect the low voltage system inside the ROSTU soccer robot [17]. Based on this background, the primary purpose of this paper is to design a high voltage kicker system with a solenoid.

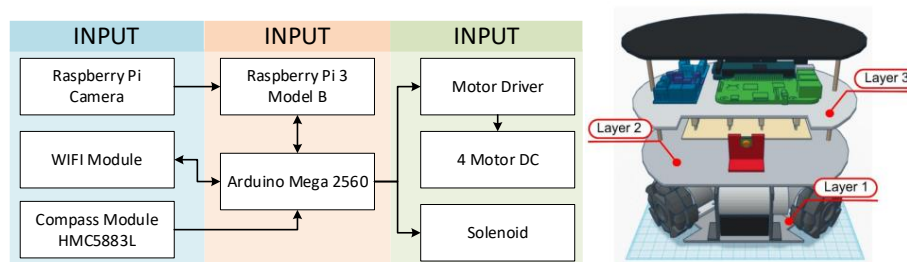


Figure 1. Previous robot soccer system [14]

2. ELECTRICAL DESIGN

The solenoid-based kicker is one of the research challenges in the MSL Competition [18]. In a high voltage solenoid-based kicker system, there are ten main components based on [19]. The block diagram of the ROSTU's Kicker System is shown in Figure 2. The description of how the system works is as:

- The power supply is using a 4S battery with 5200mah. This component provides a kicker system voltage suppression to perform kicks.
- Display system. This section consists of a 16x2 LCD, three pushbuttons, and two LEDs. The function of this section is to monitor the kicker system condition.
- Relay. This component serves as a switch from battery to Current limiter. So it allows for on/off the step-up transformer as needed and to avoid the step-up transformer overheating due to continuous work.
- Step-up Transformer. This component works to increase the voltage from 16v to 400v battery. This component is vulnerable to damage. Damage occurred due to the backflow of capacitors, Overheat due to continuous work, and overcharge. To overcome this, the safety diodes were installed between step up and capacitor with a cooling fan to control the temperature of the step-up transformer.
- Switch 1. This component uses the G80N60 transistor. This component works for:
- Connect the power flow from step up to the capacitor in the charging process.
- To decide the power flow from step up to capacitor when in charging process is fully charged (390v), the maximum voltage of the capacitor must not exceed 390v.
- Capacitor. This component serves as an electrical charge bank which needed to supply electrical current for the kicking process. This capacitor specification is 6200uF 400v. It takes 20 seconds to fill the capacitor. Under full charge conditions, the one-time shot kick will reduce the voltage to 50%.
- Switch 2. This component uses the G80N60 transistor. This transistor works to connect and disconnect electricity from the capacitor to the solenoid during the kicking process.
- Solenoid. This component serves to convert electric energy into motion energy. The solenoid is made of a 0.4mm diameter copper wire welding. The 0.4 mm diameter is chosen to facilitate the process of solenoid winding. To increase the value of the inductance of the solenoid is done by multiplying the number of wires wrapped simultaneously.
- Voltage sensor. This component works to measure the voltage in the capacitor. The voltage value will be sent to Arduino to be a parameter in the system.
- Arduino. This component works to control the kicker system. Algorithms used are:
 - Arduino reads voltage sensor values.
 - If the voltage is less than 360, the Arduino will turn on the relay and switch one for the charging process.
 - If the voltage is more than or equal to 380, the Arduino will turn off switch one and the relay.
 - If the voltage is more than 200 and the Arduino receives the command from the image processing system to do the kick, then the Arduino will turn on switch two.

- If the voltage is less than 200 and the Arduino receives the command from the image processing system to perform kick, then Arduino will not turn on switch two until the voltage value is more than or equal to 200.

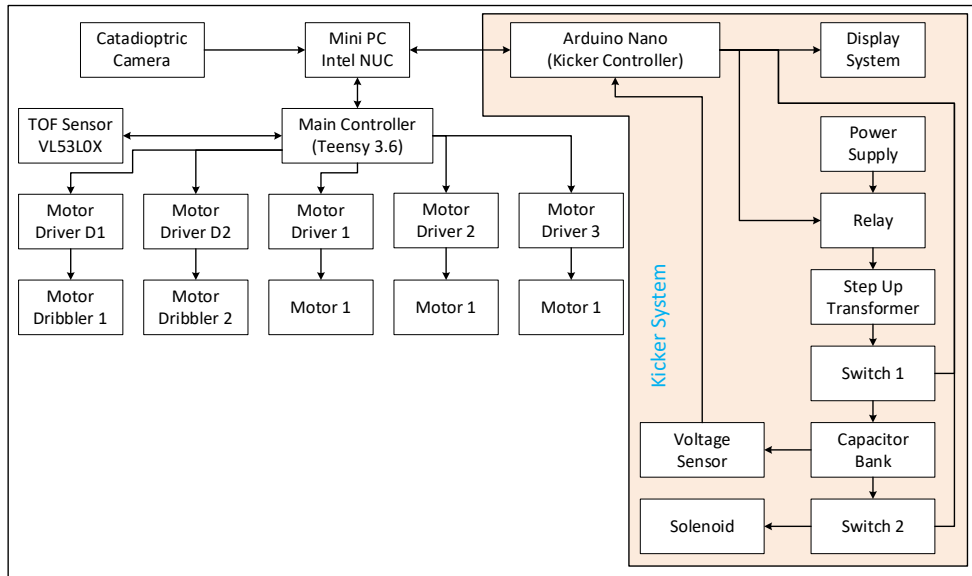


Figure 2. Design of ROSTU kicker controller module system

Figure 3 shows ROSTU internal component for the kicker mechanism. ROSTU uses three DC 24 V motors with an Omni wheel to control the motion. Moreover, the dribbler system uses two 24V DC motors with a worm gearbox. The catadioptric camera lens at the top of the robot is used to maximize the camera view angle for computer vision. All components of the controller and mini PC are positioned at the top (far from the solenoid and DC motor) to avoid the damage caused by the electromagnetic pulse from the solenoid during the kicking process. All electronic components are protected by a casing made of 3d print (plastic) [20].

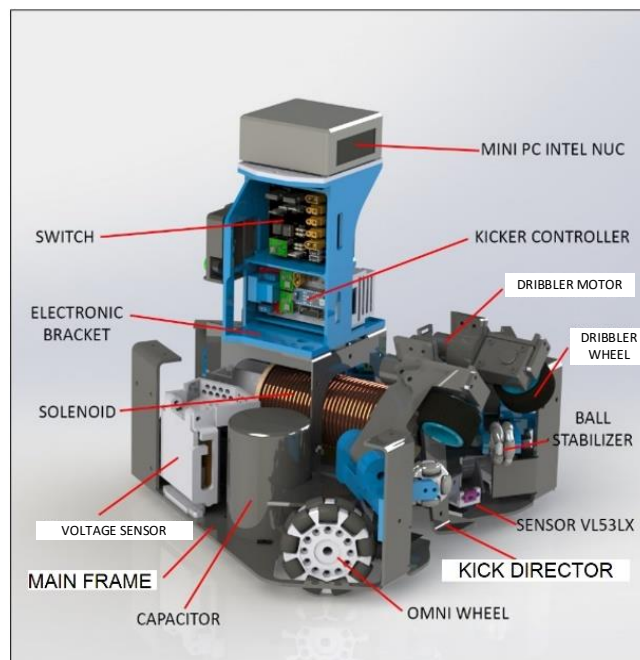


Figure 3. Rendered mechanical design of ROSTU robot soccer system

3. MECHANICAL DESIGN

Figure 4 shows the kicker solenoid-based design. The design enables the kicker system to do push the ball in front of the robot and avoids ball friction with the floor when the robot moves [21], [22]. The kicker system works as follows: the copper coil is energized with an electrical current to produce induction force, induction force will push the ferromagnetic-based plunger, and the plunger will push the ball. This kicking system was designed to push the ball with an elevation angle of 40.46°. Figure 5 describes the detailed design of the solenoid system. The solenoid system consists of an isolating frame, a copper wire coil, and a ferromagnetic-based plunger. The number of wire windings on a copper wire coil depends on the designed force.

One value that affects the force produced by a solenoid system is the resistance value of the coil. This resistance value will affect the value of the electric current. Increasing or decreasing the number of wires in the parallelized winding wired will vary the solenoid resistance value. Table 1 shows the welding scheme for the solenoid system for the ROSTU robot.

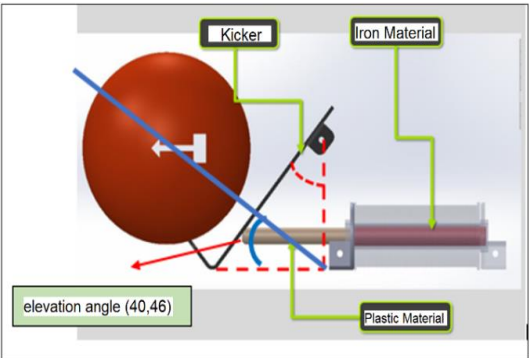


Figure 4. Kicker design of ROSTU robot soccer system

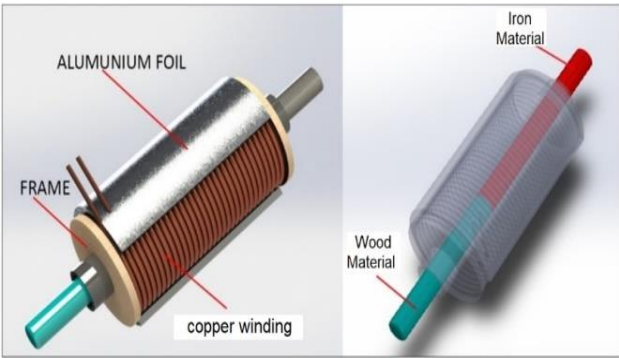


Figure 5. Solenoid design of ROSTU robot soccer system

Table 1. Winding scheme for selenoid system	
Number of paraleed winding	Illustration of winding
1 (Single wire winding)	
2 (Wire windings simultaneously then both ends of the wire are united)	
3 (Wire windings simultaneously then both ends of the wire are united)	

4. ROSTU KICKER SYSTEM METHOD

Based on the electrical design in section 2, Figure 6 shows the flowchart of the solenoid-based kicker system. Arduino nano communicates with the mini PC in serial communication [23]. Arduino nano will send capacitor voltage information to a mini PC. The ROSTU Robot will give orders to Arduino nano to trigger a kick motion. The ROSTU robot is run under the robot operating system (ROS) framework [24]-[26]. To communicate between Arduino nano and mini PC, the system must use the Serial ROS library. A program, which runs under Arduino nano, must act as a node (subprogram) that publishes or transmits data. The node in the main program reads the capacitor voltage information as parameters in the robot's main program algorithm. Arduino nano receives a kick command from the main program by doing a subscribe protocol (receive data) in the form of a PWM value. The Arduino obtain the PWM value and uses it as a parameter to determine the power of the kicker system.

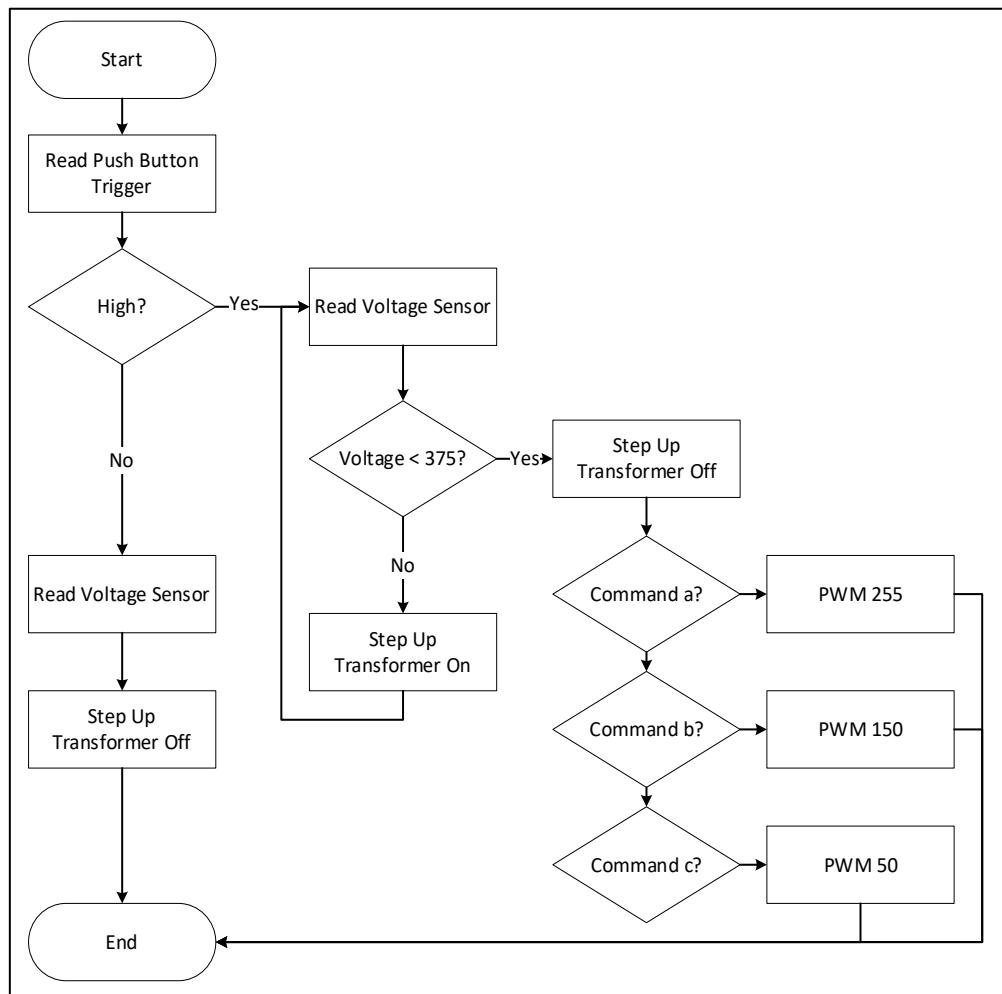


Figure 6. Proposed kicker controller flowchart

5. RESULTS AND DISCUSSION

5.1. Kicker controller module experiment results

The kicker controller, as shown in Figure 7, has several testing scenarios as follows. There are two buttons to run the experiment. Table 2 shows the experiment using the two-button in the kicker controller module. The experiment result in Table 2 shows that the kicker controller module works as in the proposed design.



Figure 7. Kicker controller module

Table 2. Experiment result of kicker controller module

Scenario	Experiment Result	Respond
The push button is pressed for the first time	Relay is On, Step up is On, and Red LED is On	As designed
The push button is pressed for the second time	Relay is Off, Step up is Off, and Red LED is OFF	As designed
The system charges the capacitor up to 380V	Charging process stop and Buzzer is sounded for 1 second	As designed

5.2. Monitoring display module experiment results

The experiments on display systems, as shown in

Figure 8, show the display system can receive manual commands via a push button. Moreover, the display system can represent the kicker system status (charging or discharging) and the capacitor voltage values. Built-in LEDs can provide a simple status indicator of the kicker system. Table 3 describes The experiment scenario and experiment result for the kicker monitoring display system.

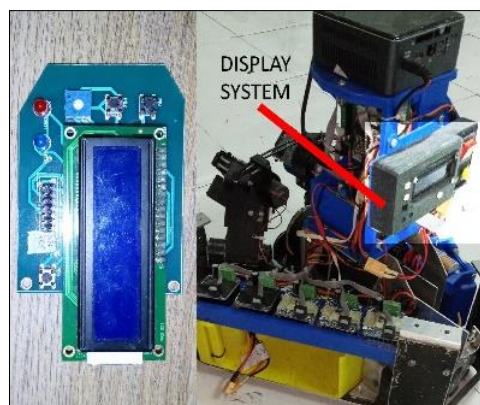


Figure 8. Kicker controller display module

Table 3. Experiment result of kicker controller display module

Push button Scenario	Experiment Result	Experiment result picture
The push button is pressed for the first time	Charging Process is executed, Red LED is On, Blue LED is off. The value of capacitor voltage is detected	
The push button is pressed for the second time	Discharging Process is executed, Red LED is off, Blue LED is on. The value of capacitor voltage is detected	

5.3. Copper coil experiment results

The effect of the difference winding number of copper wire experiment results shown in Table 4. From the experiment, the result shows that the higher number of copper wire winding will increase the electrical current, and will increase the inductance, which yields greater induction force.

Table 4. Experiment result of kicker director module

Wire size	Number of winding	Coil paralleled	Resistance	Kick distance (bounce kick)
0,4 mm	6000	1	120 Ω	1m
0,4 mm	6000	2	70 Ω	1,8m
0,4 mm	6000	4	20 Ω	3m
0,4 mm	6000	6	6 Ω	4 m

5.4. Solenoid switch experiment results

Table 5 shows experimental results with different PWM values. From the results can be concluded that the kick distance can be controlled by variation PWM Trigger value. The greater the PWM value will use greater the electrical current in the same voltage and will yield greater force. The maximum kick distance is 400 cm and the minimum distance with possible PWM value is 130 cm.

Table 5. Experiment result of kicker switch module

PWM value	Voltage	Kick Distance (bounce kick)
255	390V	400 cm
230	390V	350 cm
210	390V	230 cm
190	390V	150 cm
160	390V	50 cm
130	390V	30 cm
100	390V	0 cm

6. CONCLUSION

This paper shows that the high voltage solenoid-based kicker system can kick up the kick with a maximum distance of 4 meters. The maximum spacing produced is shorter than 0.5 meters than the design. The PWM value can control the kick distance. Furthermore, the display system can monitor kicker system conditions with the capacitor voltage value and the system status. In designing a football robot kicker system, it is necessary to consider other factor factors such as friction force, solenoid heat, or transistor current quality. Some improvement that could be done on the future research is by changing step-up transformer with larger output electrical current.

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