Journal of Industrial Automation and Electrical Engineering
Vol. 02, No. 02, December 2025, pp. 82~ 90
ISSN: 3089-1159

Stepper motor control for single axis solar tracker based on Arduino

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Article Info

Article history:

Received July 21, 2025
Revised August 25, 2025
Accepted September 29, 2025

Keywords:

Solar Tracker
Stepper Motor
Grbl Controller
Arduino
Real Time Clock

ABSTRACT

The need for electrical energy continues to increase along with technological developments, so the utilization of solar energy as an alternative source is important. However, the efficiency of solar panels is greatly affected by the angle of incidence of sunlight which changes due to the rotation of the earth. To overcome this problem, a solar tracker is used. Solar tracker is a system designed to optimize the absorption of solar energy by adjusting the position of solar panels to keep them facing the direction of incoming sunlight. This research develops a stepper motor-based one-axis solar tracker to increase the efficiency of solar energy absorption. The system uses five main tracking positions that are adjusted to the movement of sunlight in the equatorial region. The stepper motor control is implemented using Arduino IDE and uses G-code program to simplify programming, while Real Time Clock (RTC) is used for scheduling automatic movement based on time. Results show the system has high accuracy in its positional displacement, making it an effective solution for tropical applications.

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1. INTRODUCTION

Along with the development of increasingly modern times, technology is also increasingly sophisticated, all of which require energy sources, especially electrical energy. This causes the need for electrical energy to continue to increase. Therefore, scientists are competing to find and utilize alternative energy sources in meeting the needs of electrical energy [1]. Solar energy can be converted into electrical energy that can be utilized by humans to meet the energy needs that are very necessary at this time. Indonesia is a tropical country traversed by the equator with abundant sunlight throughout the year. This makes Indonesia very suitable for utilizing solar energy as an alternative energy [2],[3].

Solar panels are devices that can convert sunlight energy into electrical energy [4]. The energy produced by solar panels is influenced by several factors, one of which is the angle of sunlight. The angle of sunlight changes every time due to the rotation of the earth [5]. To maximize the energy of sunlight, the position of solar panels must always face the direction of sunlight. Therefore, it is necessary to develop an automatic drive that can adjust the position of the solar panel to always face the direction of sunlight. Solar tracker is a device that can move solar panels in the direction of incoming sunlight [6]. One of the keys to increasing the solar energy received by solar panels is the actuator used in the solar tracker system [7].

In this research, a stepper motor is used as a driver in the solar tracker system. This research uses a one-axis tracking system because the research location is in the equatorial region, where the apparent movement of the sun does not experience significant changes throughout the year [8], [9]. This study uses five tracking positions to balance the efficiency of sunlight capture with system power consumption. The selection of five main points (morning, midday, afternoon, evening, and dusk) is based on the relatively stable characteristics of the sun's movement at the equator, so it does not require continuous tracking.

Stepper motors are a great choice due to their ability to provide accurate position control with smooth motion [10]. Stepper motors can position solar panels with high accuracy, thereby improving the overall efficiency of the system. The stepper motor adjusts the position of the solar panel by moving the metal load to reach the desired position. Stepper motors are controlled using Arduino IDE software with complex programs. In order to make the program simpler, G-code is used to adjust the displacement of the stepper motor position by determining the coordinate points. Stepper motors and microcontrollers use very low power, so they can minimize the power consumed by the solar tracker drive and produce optimal output power. In this system, Real Time Clock (RTC) is used for storing and reading time [11], so that the stepper motor will move according to the time and position that has been determined automatically.

2. METHOD

This research was conducted in several stages, including the system design stage. At this stage, the needs of the Arduino-based stepper motor control system were analyzed. The system is designed by utilizing the Arduino UNO microcontroller as the main controller which is used specifically to upload the Grbl library in order to control the stepper motor using the G-code system. Several supporting components are also integrated in this system including Buck Converter, CNC Shield, A4988 Driver, Arduino Nano, and Real Time Clock (RTC). To clarify the relationship between these components, a system block diagram is used which can be seen in Figure 1.

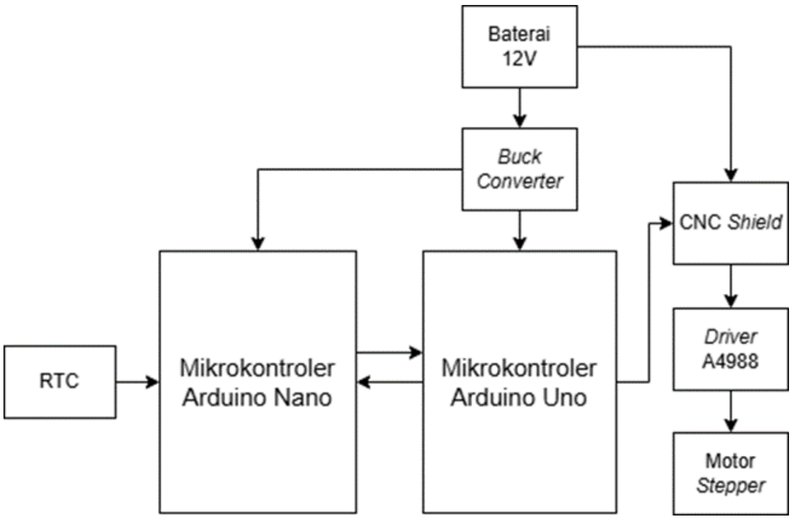

Figure 1. Block Diagram

Figure 1 displays a block diagram of an Arduino based stepper motor control system that illustrates the relationship between components in the system. The system gets power from a 12 volt battery connected to the CNC Shield and the 12 volt power is converted using a buck converter to adjust the voltage level needed by the microcontroller. The following is a more detailed explanation for each component block in this system as follows:

2.1 Accumulator

Figure 2. Accumulator

Accumulator in solar power plants are used to store the power generated by solar panels before being used for load operations [12]. The accumulator used has 12V 5A specifications with a size of 15.1 x 9.8 x 9.5 cm which can be seen in Figure 2.

2.2 Buck Converter

Figure 3. Buck Converter

Buck Converter is one type of DC to DC converter that has a role to reduce DC voltage to a voltage that suits your needs. By adjusting the duty cycle, the buck converter can produce a lower output voltage compared to the input voltage. This duty cycle setting is done through the use of a PWM (Pulse Width Modulation) signal [13]. The Buck Converter used is the LM2596 buck converter which can be seen in Figure 3.

2.3 Arduino UNO Microcontroller

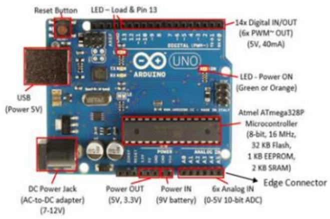

Figure 4. Arduino UNO ATMega328P

Arduino UNO is an electronic board based on ATMega microcontroller. This board fulfills the microcontroller minimum system so that it can operate independently [14]. The Arduino used is Arduino UNO ATMega328P R3.0 as the main controller.

2.4 Arduino Nano Microcontroller


Figure 5. Arduino Nano

Arduino Nano is a mini microcontroller board based on the ATmega328 or ATmega168 chip that is popular because of its compact size and practical for various electronics projects [15].

2.5 Real Time Clock (RTC)

Figure 6. Real Time Clock (RTC)

Real Time Clock (RTC) is an electronic clock equipped with a battery to supply power to the chip so that the module continues to run and the clock is always up-to-date even if the computer is turned off. The chip can calculate time accurately and store time data in real time [16].

2.6 CNC Shield Board

Figure 7. CNC Shield V3.0

CNC Shield V3 is an Arduino expansion board that functions as an expansion board for the A4988 IC Driver. This module has 4 slots for IC drivers and can control 4 stepper motors simultaneously [17]. The type of CNC Shield used is CNC Shield V3.0.

2.7 A4988 Driver Module

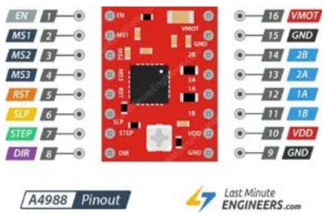

Figure 8. A4988 Driver

IC A4988 is a driver IC to drive a stepper motor with only two input pins, namely pin DIR and pin STEP, and has five step settings: full step, half step, quarter step, eight step, sixteenth step [17].

2.8 Stepper Motor

Stepper motor is a type of electric motor that rotates based on discrete steps. This motor receives input from electrical pulses and can convert these electrical signals into regular mechanical movements. The movement produced by a stepper motor is known as a step, which moves regularly [18]. The stepper motor used is the NEMA 17HS4401 stepper motor which is controlled using the G-code programming language.

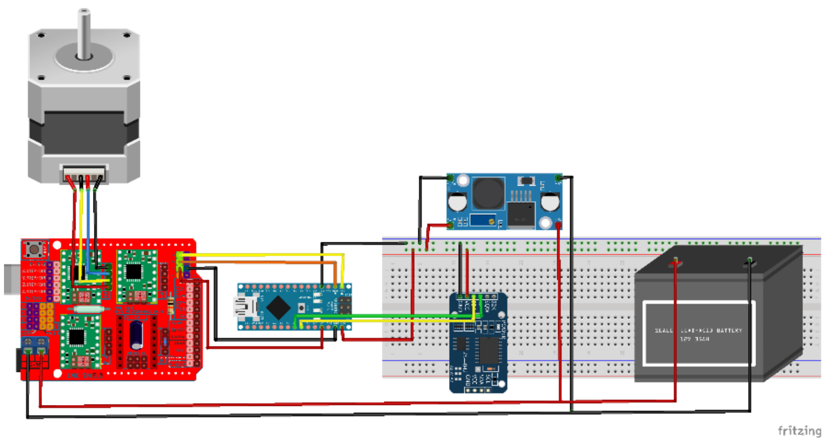

Figure 9: Stepper Motor Control System Schematic

Figure 9 shows the Arduino based stepper motor control system scheme. The system power source comes from a 12 Volt accumulator. This voltage is then reduced to 5 Volts using a Buck Converter module, to match the needs of the microcontroller [19]. The Arduino UNO in this system is connected to the CNC Shield, which functions as a link between the Arduino UNO and the A4988 Driver. This A4988 Driver is used to control the stepper motor, where this stepper motor will move the load so that the solar panel moves in five positions. Arduino Nano communicates with CNC Shield through serial communication pins (RX and TX). The Arduino Nano runs a program that executes G-code (which is on the Arduino UNO), based on a predetermined time. To support time scheduling, an RTC (Real Time Clock) module is used. Next will be described the flowchart of this system. Flowchart is a graphical diagram that describes the steps and sequence of procedures of a program systematically [20].

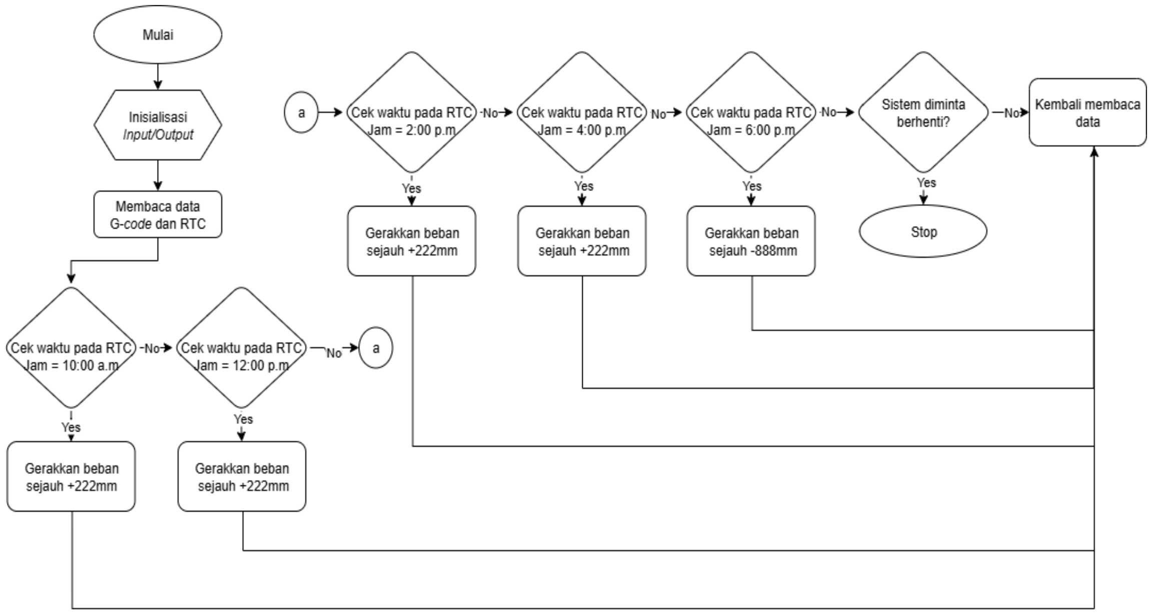

Figure 10. System Flowchart

Figure 10 explains how the system works on the program in controlling the stepper motor. The process begins with input/output initialization and reading all the necessary libraries. Next, the program checks the RTC connection. If detected and readable, the system will retrieve the time data from the RTC. If the time read is as desired, the program will execute the G-code, which then moves the stepper motor according to the command in the program. This process will continue to repeat until the device is turned off.

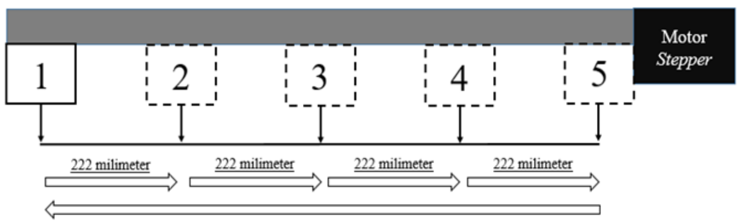

Figure 11: Load Movement Position

Figure 11 shows the distance between each load position is 222 millimeters. The stepper motor will move a metal load weighing 2 kg attached to the ballscrew and then regulate its movement using a stepper motor. The length of time the load is in each position is 7,156 seconds and the length of time the load moves to the next position is 44 seconds. Meanwhile, the displacement distance of the fifth position to the starting position or position one is 888 millimeters long with a displacement time of 176 seconds. By moving the position of the load using a stepper motor as a driver on the solar tracker, five solar panel positions will be obtained which can be seen in Figure 12.

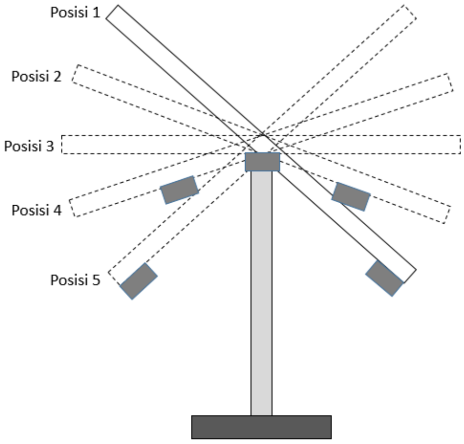

Figure 12. Five Solar Panel Positions

3. RESULTS AND DISCUSSION

In this study, system programming was designed using Arduino IDE software. And to control the stepper motor using the G-code system, the Grbl Controller is used, namely by connecting the Arduino with the CNC Shield then connected to the stepper motor, then the circuit is connected to the PC using serial communication. Testing is done to ensure that the stepper motor can move after the program on the Arduino is run. The program that will be entered into the arduino to move the stepper motor is uploaded from the Grbl Controller. The motor is set to be in the desired position by calibrating.

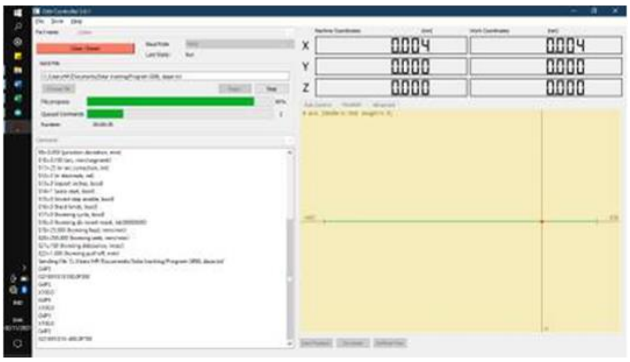

Figure 13. Grbl Controller Experiment

By using the program created in the Grbl Controller by setting the coordinate points, the motor can move according to the position of the desired point. Comparison of coordinate points in the Grbl Controller program, namely:

Position Distance (cm) = Coordinates / 10

From the measurement results, the distance of the load crossing position is 88.8 cm so that in the program we will create a coordinate value of 888. Arduino UNO is used as the main controller to upload the Grbl library so that stepper motors can be controlled using the G-code system. The Grbl library on Arduino is as follows.

```
#include <grbl.h>
```

In addition, a calibration process is carried out on the Real Time Clock (RTC) to ensure the time keeping on the system is in accordance with the actual time. The program to calibrate the RTC is as follows.

```
rtc.setTime(10, 34, 00);
rtc.setDate(4, 7, 2025);
rtc.setDOW(5);
```

The initial calibration process carried out on the RTC before operational use aims to ensure the precision of time recording in accordance with real conditions. The results of this RTC test can be seen in Table 1.

Table 1. RTC Testing

No.	Date and time on computer	Date and time on RTC	Time difference
1.	June 26, 2025 12:30:00	June 26, 2025 12:30:02	2 seconds

Based on the results obtained from the comparison of time and date from the computer and RTC, it can be concluded that the RTC can work properly. Then testing the stepper motor control program using the G-code system through the Arduino IDE software.

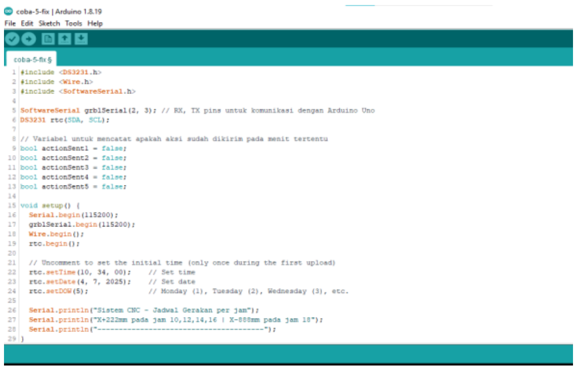

Figure 14. Arduino IDE Program

Figure 14 shows the stepper motor control program used in the system. The G-code used to move the stepper motor is as follows.

G91 G21 G1 X222 F300

In this program, several words are used to become a stepper motor starting program. The combination of several words or also called blocks in this program consists of G21 which serves to show the coordinate units used, namely in millimeters, G91 serves to regulate the movement and lock the 91 start position in order to know the movement of the stepper motor, G1 serves to move the stepper motor linearly, X222 serves to determine the size of the movement coordinates, F300 serves to adjust the speed of the stepper motor. The stepper motor moves a load weighing 2 kg. By adding a mass of 2 kg, it is able to move the solar panel with a maximum angle of 26.5°. The angle of the solar panel obtained by moving the load in five positions can be seen in Figure 15.

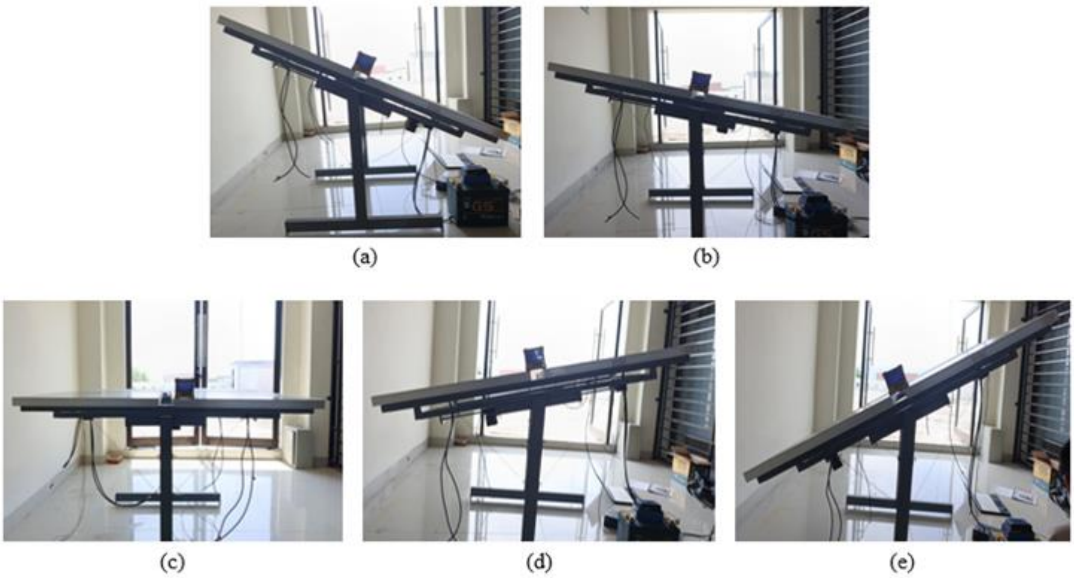

Figure 15. (a) Position 1 (b) Position 2 (c) Position 3 (d) Position 4 (e) Position 5

Figure 15 shows the five load positions that adjust the elevation angle of the solar panel. At 8:00 a.m. the load will be in position 1, at 10:00 a.m. the load will be in position 2, at 12:00 p.m. the load will be in position 3, at 2:00 p.m. the load will be in position 4 and at 4:00 p.m. the load will be in position 5. At 6:00 p.m. the motor will rotate to move the load from position 5 back to position 1. For the load position transfer mechanism, the stepper motor will move for 222 steps in each position transfer with a speed of 70 rpm. From the first position, the motor will move closer to the second position by 222 steps according to the set time and will stop at the fifth position with a set point step of 888 steps. The results of testing the displacement of the load position using a stepper motor can be seen in Table 2.

Table 2. Load Testing Using a Stepper Motor

Position	Moving Time (s)	Tilt Angle (°)
1-2	44	26,34°
2-3	44	13,16°
3-4	44	0°
4-5	44	13,18°
5-1	176	26,50°

The load will move from position one to position two after two hours and so on until the fifth position. Moving from position 1 to the next position takes 44 seconds. After arriving at the 5th position, the length of movement from position 5 to position 1 takes 176 seconds.

4. CONCLUSION

From the test results, research on stepper motor control on a single axis solar tracker with five Arduino based positions was successfully carried out. This system integrates the Arduino microcontroller as the main controller. CNC Shield and A4988 Driver are used to control the stepper motor with G-code Grbl Controller system. And RTC is used as the real time scheduling stepper motor movement to move the load that regulates the tilt angle of the solar panel. The test results show that the solar tracker drive system using Arduino and G-code has high accuracy in moving its position. By using a metal load with a mass of 2 kg as a heavy point on the solar tracker that will move the solar panel, the tilt angle obtained in the first position of the solar panel is 26.34° , the tilt angle in the second position is 13.16° , the tilt angle in the third position is 0° , the tilt angle in the fourth position is 13.18° , and the tilt angle in the fifth position is 26.50 .°

REFERENCES

[1] D. Sepannur Bandri, "Pengaruh Intensitas Cahaya Matahari Terhadap Tegangan Dan Arus Yang Dihasilkan Panel Surya," *J. Tek. Elektro*, vol. 10, no. 2, pp. 106–113, 2021.

[2] M. Yuhendri, A. Aswardi, and H. Hambali, "Implementasi Pompa Air Otomatis Tenaga Surya Untuk Rumah Ibadah," *JIPEMAS J. Inov. Has. Pengabdi. Masy.*, vol. 3, no. 2, p. 166, 2020, doi: 10.33474/jipemas.v3i2.6758.

[3] M. S. Alim, S. Thamrin, and R. L. W., "Pemanfaatan Pembangkit Listrik Tenaga Surya sebagai Alternatif Ketahanan Energi Nasional Masa Depan," *J. Pengabdi. Kpd. Masy. Nusant.*, vol. 4, no. 3, pp. 2427–2435, 2023.

[4] R. Mayangsari and M. Yuhendri, "Sistem Kontrol dan Monitoring Pembangkit Listrik Tenaga Surya Berbasis Human Machine Interface dan Internet of Thing," *JTEIN J. Tek. Elektro Indones.*, vol. 4, no. 2, pp. 738-749–738 – 749, 2023.

[5] M. Nurdiansyah, E. C. Sinurat, M. Bakri, I. Ahmad, and A. B. Prasetyo, "Sistem Kendali Rotasi Matahari Pada Panel Surya Berbasis Arduino UNO," *J. Tek. dan Sist. Komput.*, vol. 1, no. 2, pp. 40–45, 2020, doi: 10.33365/jtikom.v1i2.14.

[6] M. A. Nugraha, "Enhancing electricity production in Photovoltaic systems using a double-axis solar tracker," *Journal of Industrial Automation and Electrical Engineering.*, vol. 02, no. 01, pp. 52–58, 2025.

[7] S. Helena, J. Hamka, and K. UNP Air Tawar Padang, "Unjuk Kerja Single Axis Solar Tracker Berdasarkan Perubahan Waktu Pergerakan Matahari," *MSI Trans. Educ.*, vol. 03, no. 04, p. 2022, 2022.

[8] A. B. Pulungan, Q. Fajri, and I. Yelfianhar, "Peningkatan Daya Keluaran Panel Surya Menggunakan Single Axis Tracker Pada Daerah Khatulistiwa," *JTEV (Jurnal Tek. Elektro dan Vokasional)*, vol. 7, no. 2, p. 261, 2021, doi: 10.24036/jtev.v7i2.113304.

[9] A. B. Pulungan, L. Son, S. Syafii, S. Huda, and U. Ubaidillah, "Low Speed Orientation Control Using

Variable Mass System: Application in Solar Panel," *J. Sustain. Dev. Energy, Water Environ. Syst.*, vol. 11, no. 2, pp. 1–17, 2023, doi: 10.13044/j.sdewes.d11.0456.
[10] A. A. Dilaga *et al.*, "Rancang Bangun Sistem Penggerak Pada GPR (Ground Penetrating Radar) Program Studi Teknik Elektro , Institut Teknologi Kalimantan Rancang Bangun Sistem Penggerak Pada GPR (Ground Penetrating Radar)," vol. 23, no. 1, pp. 44–59, 2025.
[11] R. Fernandes and M. Yuhendri, "Implementasi Solar Tracker Tanpa Sensor pada Panel Surya," *JTEV (Jurnal Tek. Elektro dan Vokasional)*, vol. 6, no. 2, pp. 337–343, 2020.
[12] M. Usman, "Analisis Intensitas Cahaya Terhadap Energi Listrik Yang Dihasilkan Panel Surya," *Power Elektron. J. Orang Elektro*, vol. 9, no. 2, pp. 52–57, 2020, doi: 10.30591/polektro.v9i2.2047.
[13] N. Fuada and I. Husnaini, "Rancang Bangun Buck Converter dengan Kontrol PID Berbasis Mikrokontroller Arduino," *JTEIN J. Tek. Elektro Indones.*, vol. 4, no. 2, pp. 781–791, 2023, doi: 10.24036/jtein.v4i2.513.
[14] A. Nur Alfan and V. Ramadhan, "Prototype Detektor Gas Dan Monitoring Suhu Berbasis Arduino Uno," *PROSISKO J. Pengemb. Ris. dan Obs. Sist. Komput.*, vol. 9, no. 2, pp. 61–69, 2022, doi: 10.30656/prosisko.v9i2.5380.
[15] I. Zulfa, H. Syahputra, and A. Faisal, "Rancang Bangun System Kontrol Alat-Alat Listrik Menggunakan Bluetooth Berbasis Mikrokontroler," *J. Ilm. Elektron. Dan Komput.*, vol. 14, no. 1, pp. 188–199, 2021, [Online]. Available: http://journal.stekom.ac.id/index.php/elkompage188
[16] S. Hutauruk, T. Pangaribuan, and J. H. Sinaga, "Rekayasa Sistem Data Logger Temperature Berbasis Arduino Uno R3," *J. ELPOTECS*, vol. 3, no. 2, pp. 15–21, 2020, doi: 10.51622/elpotecs.v3i2.467.
[17] W. R. Pratama, B. Yulianti, and A. Sugiharto, "Prototipe Smart Parking Modular Berbasis Internet of Things," *J. Teknol. Ind.*, vol. 11, no. 1, pp. 52–60, 2022, [Online]. Available: https://journal.universitassuryadarma.ac.id/index.php/jti/article/view/954
[18] H. Timothy Wijaya, D. Pangestu, M. Timothy Sutjipto, W. Surya Widjaja, K. Octavianus Bachri, and T. Nur, "Simulasi Sistem Pengendalian Motor Stepper dengan Metode Pulse Width Modulation," *J. Elektro*, vol. 15, no. 1, pp. 21–30, 2024, doi: 10.25170/jurnalelektro.v15i1.5120.
[19] D. Rahmawati, M. Ulum, M. Farisal, and K. Joni, "Lantai Pembangkit Listrik Menggunakan Piezoelektrik dengan Buck Converter LM2596," *J. Arus Elektro Indones.*, vol. 7, no. 3, p. 84, 2021, doi: 10.19184/jaei.v7i3.28128.
[20] A. Zalukhu, P. Swingly, and D. Darma, "Perangkat Lunak Aplikasi Pembelajaran Flowchart," *J. Teknol. Inf. dan Ind.*, vol. 4, no. 1, pp. 61–70, 2023, [Online]. Available: https://ejurnal.istp.ac.id/index.php/jtii/article/view/351