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Dual-Axis Solar Energy Tracking and Monitoring System with Arduino as a Microcontroller

Siti Sufiah Abd Wahid[1], Mohd Sufian Ramli[1*], Nur Idayu Zabidin[1]

[1]School of Electrical Engineering, College of Engineering, Universiti Teknologi MARA Cawangan Johor, Masai, Malaysia

[*]Corresponding Author's E-mail:sufian6037@uitm.edu.my

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ABSTRACT

As an inexhaustible and non-polluting energy source of the future, solar energy is improving to meet the world's ever-increasing energy demands. In this project, the solar panel is made movable to absorb energy in different directions based on the direction of the sun to maximize the amount of energy generated by solar photovoltaic system. Four Light Dependent Resistors (LDRs), a voltage sensor and a set of humidity and temperature sensor are acting as inputs. Meanwhile, two servo motor outputs are placed in the horizontal and vertical axes to maximize power absorption by orienting the PV panel towards the varying sun directions. The Arduino Mega2560 was used as the microcontroller that controls the inputs to make sure the outputs are operating as required. Apart from the servo motors, another important feature of the project includes the monitoring unit for the system which comprises of the LCD display and Microsoft Excel Data Streamer.

Keywords: Solar; Arduino; Tracking; Monitoring

INTRODUCTION

Recent trends have seen a global effort of renewable resources adoption in power generation industry. Solar energy has gained increasing popularity among other green options due to its abundance and cost-free resources despite its significantly high installation cost. Besides, the flexibility of the installation size and numerous incentives support by the government have further boosted the solar energy growth [1]. With high solar radiation received in a year, similar situation can also be observed in Malaysia, especially after the government had announced the new renewable energy capacity target of 31 % by 2025. In the end of 2020, 33 large scale solar (LSS) projects were already operating while another 12 LSS plants have commenced commercial operations in 2020. Furthermore, several other projects is set to be operating in the following few years [2].

There are several factors that contribute to the performance of a solar photovoltaic (PV) such as level of solar irradiance, photovoltaic material, panel orientation, temperature as well as soiling. In addition, shading factor is also affecting the solar production [3,4]. Therefore, in order to maximize the solar energy production, a tracking mechanism known as maximum power point tracking (MPPT) is vital in orienting the solar panel accurately towards the solar radiation as the direction continuously varies over a day. Overall, there are electrical and mechanical (solar tracker) MPPT techniques whereby electrical MPPT operates by tracking the optimal operative point based on power, voltage and current curves [5]. The MPPT for this type is installed between PV panels and converters [6]. Meanwhile, it has been found that a mechanical MPPT (solar tracker) is able to result in energy increase of more than 40 % on average [7]. Therefore, various solar tracker systems were proposed and implemented in order to increase the power conversion efficiency.

A sun-tracker mechanism for a case study in coastal area was performed for both fixed and dual-axis system. Two microcontrolllers; Raspberry Pi3 and Arduino Uno were controlling the system with a number of inputs parameter being measured every minute, including solar radiation, light intensity, temperature, short-circuit current and open-circuit voltage [8]. The measurements were made via three sensors namely voltage, current and temperature sensors before the data is sent via i2C protocol communication to an interconnected Automatic Weather Station (AWS). Ponce-Jara et al have found that the project has successfully produced 19.62 and 8.62 % more energy than the static and one-axis tracking system, respectively [8]. Another solar tracker system was designed into three main blocks; electronic control block equipped with a relay module provided by the Arduino card, mechanical movement block and electrical power block [9]. In the system, two LDRs are used as inputs to detect light in East-West direction other than another current sensor input to measure the current level. Meanwhile, the output of servo motor is used to support metallic servo bracket for the solar panel. The author has found that the system increased the efficiency of solar energy collection compared to fixed mechanism.

In addition, for data recording purpose, the Arduino Xd05 is used which is equipped with a real-time clock to provide time data for the solar energy production in another proposed solar tracker [10]. Besides, in detecting the solar orientation, this project adopted partial derivative, a Proportional Derivative (PD) controller to control the angle due it's quick response to small variations. A current sensor becomes the input for the microcontroller Arduino UNO R3 used. The ability of the system in increasing the power delivered by as low as 19 % to as high as 19.5 % is verified with simulation performed in PvSyst software. Another dual-axis solar tracker controlled by Arduino Uno R3 used LDR and temperature sensor as the inputs [11]. However, a satellite motor with better performance and lower power consumption is chosen as the actuator device to substitute the stepper motor. The result shows that the proposed system produced higher solar power as compared to the system without tracking mechanism. In [12], the role of a gearbox is highlighted as a speed-reducing gear to further increase torque of mechanical movement as well as the accuracy of solar tracker positioning towards solar direction. The gearbox is embedded in two dc servomotor outputs. Each servomotor consists of four main parts namely electrical dc motor, gearbox, position-sensing device and an electronic card to control the motor. Both outputs and input of LDRs are processed by ATMEGA328P microcontroller. Meanwhile, an MPPT controller is applied for another dual-axis solar tracker which has proved that the system with tracking feature generated more power than the fixed angle panels [13].

This study aims to simulate the Dual-axis Solar Energy Tracking and Monitoring System with Arduino as a Microcontroller by using Proteus software as the modern tool. The second aim of this study is to develop a Dual-axis Solar Energy System that is capable to track the sunlight and monitor the solar voltage generated. In previous studies, most of the solar tracking system proposed did not emphasize on the data monitoring process of the solar production as the main output. This process is important as it provides a series of trend if the data collection is done over a fixed duration which is very useful in examining the performance of the solar tracking mechanism. Besides, the analysis of the monitored and visualized real-time data in the form of graphs is capable in giving the exposure to the users not only about green solar energy but also the technology of the microcontroller embedded-system itself.

EXPERIMENTAL DETAILS

This section explains the block diagram, system flowchart and schematic diagram of the Dual-axis Solar Energy Tracking and Monitoring System.

Block diagram

Figure 1 depicts a Dual Axis Solar Tracking System block diagram, which includes the inputs, microcontroller, and outputs. LDR sensors, voltage sensors, and DHT11 sensors make up the input while the project's microcontroller is an Arduino Mega 2560. On the other hand, servo Motors, an LCD display, and a Microsoft Excel Data Streamer comprise the output. When sunlight strikes the surface of the LDR sensors, it reacts by rotating the solar panel board based on the amount of light intensity received. On the solar panel, four LDR sensors are installed perpendicularly for the bottom left, bottom right, top left, and top right. Voltage sensors function as a voltage divider circuit, measuring the output voltage of the solar panel. The DHT11 Sensor, on the other hand, can monitor the temperature and humidity levels around solar panel areas. Meanwhile, the Arduino IDE will be used as one of the software tools to code all of the sensors connected to the Arduino Mega 2560 microcontroller. The input data from the sensor to be displayed can be selected according to the project's requirements using C programming. The system will control all of the data that appears in the system's output section using this microcontroller. The goal is to be able to demonstrate the effectiveness of the sensors incorporated into the system in order to determine its performance. For the output, servo motors move in dual axes because it has two servo motors operating horizontally and vertically. Both will move the solar panel based on the input, which is provided by LDR sensors. The servo motor's movement is determined by the light intensity measured by the four LDR sensors. When the solar panel is perpendicular to the sunlight, the output voltage is generated. Next, for the project's monitoring unit, an LCD display and Microsoft Excel Data Stream are used to display live data from the project. This project is capable to display the output parameters, which are temperature, humidity, and output voltage generated by the solar panel.

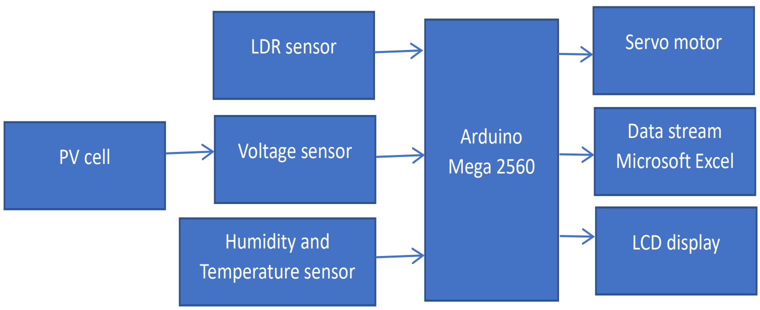

Figure 1: Block diagram of Dual-axis Solar Energy Tracking and Monitoring System

System Flowchart

To begin with, the project's algorithm starts by reading the analogue values returned by the four LDR sensors as shown by the flowchart of the system in Figure 2. It then instructs servomotors to shift the PV panel in the direction of the sun after processing this data. When considering vertical axis-based solar tracker movement, the average values of the two LDRs on the left and the two LDRs on the right are compared, and if the lefts receive more light, the PV panel will move in that direction (clockwise) via the L-R servomotor.

The latter will come to a halt when the difference between -10 and 10 is attained. This range is recommended for reducing servomotor power consumption and stabilizing the controller. If the right pair of LDRs does not receive enough light, the PV panel will rotate in the opposite direction (anticlockwise) through the L-R servomotor until the difference is between

[-10, 10]. The horizontal axis-based solar tracker movement operates on the same principle, determining the average value of the top and bottom LDRs. The voltage sensor monitors the output voltage created by the solar panel when power is generated by it. The DHT11 Sensor will also be used to read the current temperature and humidity, and all data from the project will be transferred to and shown on the LCD display and Microsoft Excel Data Streamer.

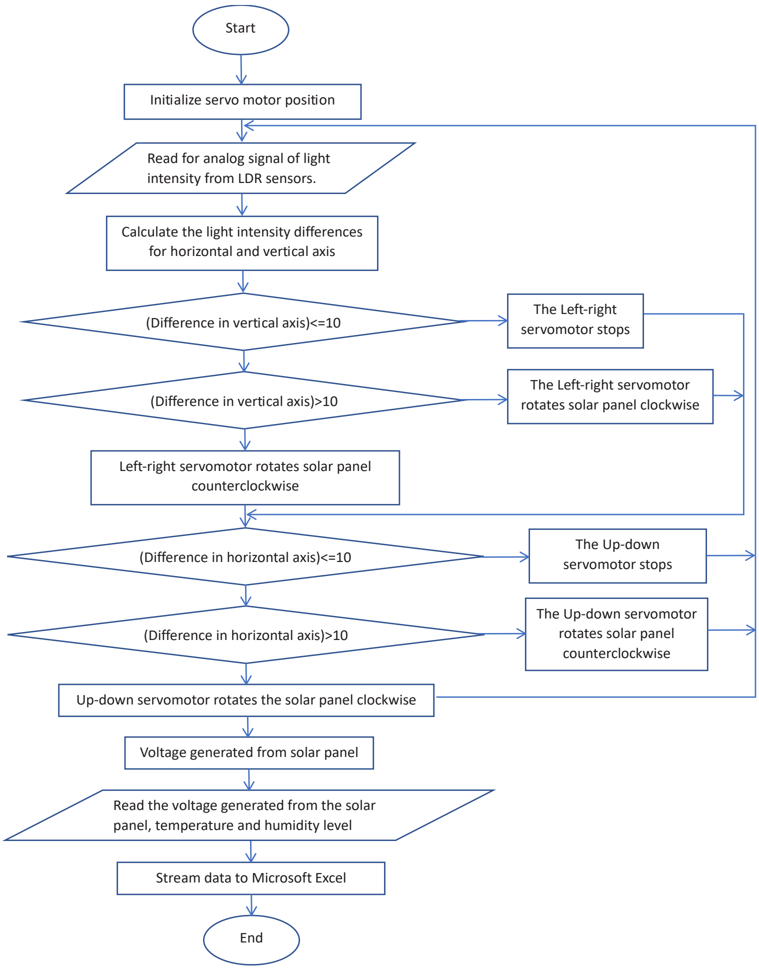

Figure 2: Flowchart of Dual-axis Solar Energy Tracking and Monitoring System

Schematic Diagram

The complete schematic diagram of the Dual-axis Solar Energy Tracking and Monitoring System is shown in Figure 3. While the output is connected to GND, the data is sent to the Arduino via the Analog Pin of the Arduino, A6. The horizontal and vertical servo motors are then connected to Digital Pin 3 and Digital Pin 4, as well as Arduino's GND and VCC, for the project's output. To display data on an LCD display, an I2C module is interfaced with the LCD.

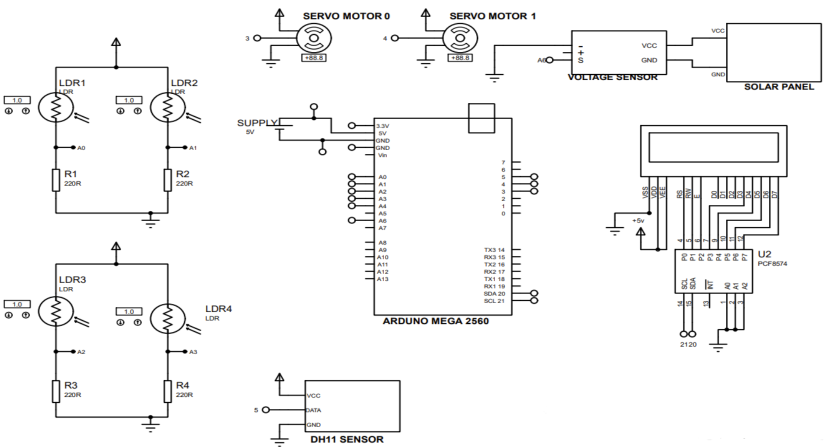

Figure 3: Schematic diagram of Dual-axis Solar Energy Tracking and Monitoring System

RESULT AND DISCUSSION

This section includes the results based on the outputs of the project in simulation and hardware implementation followed by further analysis on the monitored data collected from the system.

Simulation

The simulation was performed in Proteus software. In order to verify the programming code, two conditions of different light intensity have been set as shown in Table 1 to prove that the project operates accordingly by detecting light from two different directions.

Table 1: Two conditions of different light intensity

Condition	Light intensity of LDR				Light intensity differences	Operating servo motor	Rotation direction	Angle of rotation (°)
	Top left	Top right	Bottom left	Bottom right				
1	151	1	351	1	(Left-Right)>0	Vertical servo motor	Clockwise	83.3
					(Top-Bottom)<0	Horizontal servo motor	Clockwise	98.3
2	21	81	11	41	(Left-Right)<0	Vertical servo motor	Counter-clockwise	117.0
					(Top-Bottom)>0	Horizontal servo motor	Counter-clockwise	67.6

Based on Table 1, for both conditions, firstly, the system will track the higher light intensity between the left or right side of the panel, adjusted by the vertical servo motor. Next, the PV panel is directed towards higher light intensity received either between the bottom or top part of the solar panel which is controlled by horizontal servo motor.

In condition 1, based on the light intensity setting, left LDRs received more light. As the result, the vertical servo motor rotated 83.3° clockwise as shown in Figure 4. Meanwhile, the bottom LDRs sensed higher light intensity, causing the horizontal servo motor to rotate clockwise with an angle of 98.3° as shown in Figure 4. The tracking process is followed by data display on the serial monitor which shows the value of temperature (Temp), humidity (RH) and solar voltage (Vsolar) of 32.6 °C, 74.3 % and 11.94 V respectively.

On the other hand, right LDRs detected more light in condition 2 that causes the vertical servo motor to rotate 117° counterclockwise. The top LDRs also received higher light intensity which leads to the rotation of the horizontal servo motor 67.6° counterclockwise. The rotation direction of both the vertical and horizontal servo motor as well as the respective measurement of the output parameter, Temp=29.3°C, RH = 70.5 % and Vsolar = 7.59 V is shown in Figure 5. After the simulation result is verified, the programming code is uploaded into Arduino for hardware implementation stage.

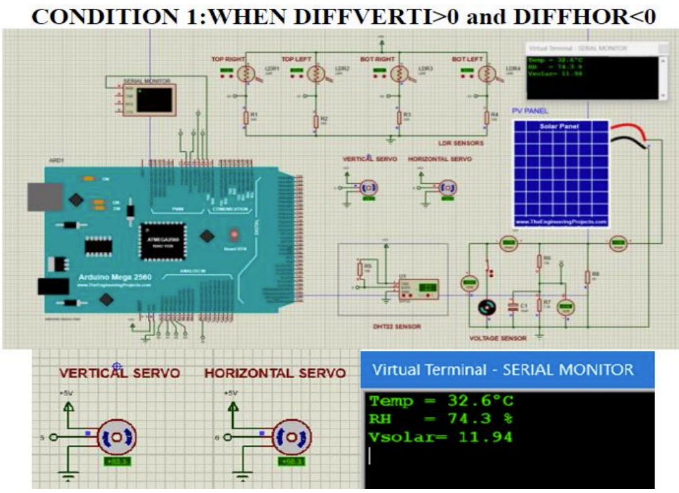

Figure 4: Simulation result for condition 1

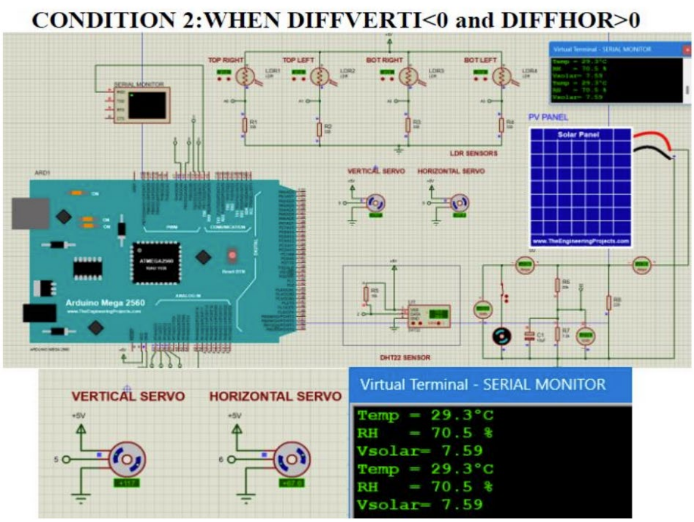

Figure 5: Simulation result for condition 2

Hardware

Figure 6 shows the project hardware assembly whereby there are horizontal and vertical servo motors that move the attached pan tilt of solar cell on it according to the direction of the solar energy level. Four LDRs are placed on the top right, top left, bottom right and bottom left of the solar cell's edges. Figure 7 depicts the process of live data recording that is stored in the excel format.

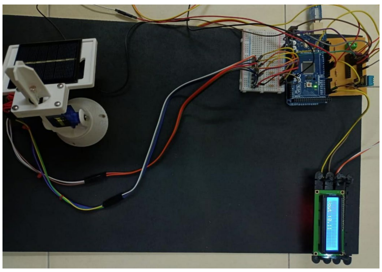

Figure 6: Project hardware assembly

Figure 7: Process of live data recording

Data Monitoring

In this project, the real-time data collection is streamed into Excel as shown in Figure 8 whereby the measurements are continuously taken for every preset time interval. For monitoring and analysis process, the data of all the three parameters which include the temperature, humidity and solar voltage level were collected in UiTM Pasir Gudang, Johor on a daily basis of starting from 10 am to 7 pm with a frequency of one reading for every 10 minutes interval.

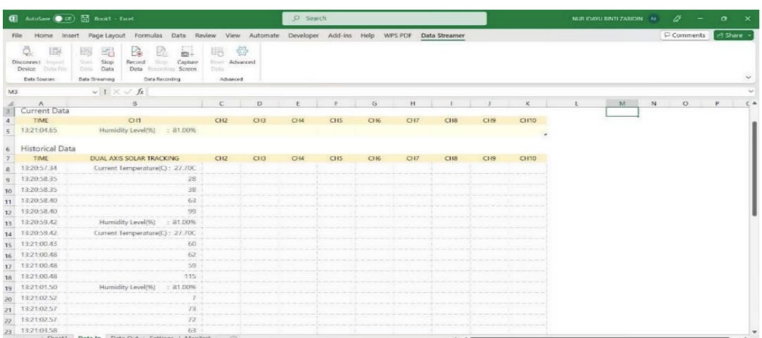

Figure 8: Real-time data collection is streamed into Excel

Figure 9 and Figure 10 visualize the daily graph of temperature and humidity level versus time respectively. The temperature level is recorded at 27 °C at just over 10 am as the sunlight was just about to shine bright. The figure increased to around 27.5 °C before dropping significantly to 26 °C about 30 minutes later. The decrement is due to weather factors as Figure 10 shows high humidity level of 80 % at 10.50 am. However, the dropped humidity level to the lowest level of around 75 % at 11am lead to a sharp increase of temperature level to 29 °C before the reading showed steady figures over the following 5 hours. This is the duration where the solar energy captured is at the highest level. As the time is approaching late evening, the temperature started to drop to 26 °C and this is probably due to the high humidity level recorded around the same time at 6.30 pm. The temperature remains at the same level until 7 pm. Both Figures 9 and 10 verified the expected relationship; as humidity level increases, the temperature level decreases.

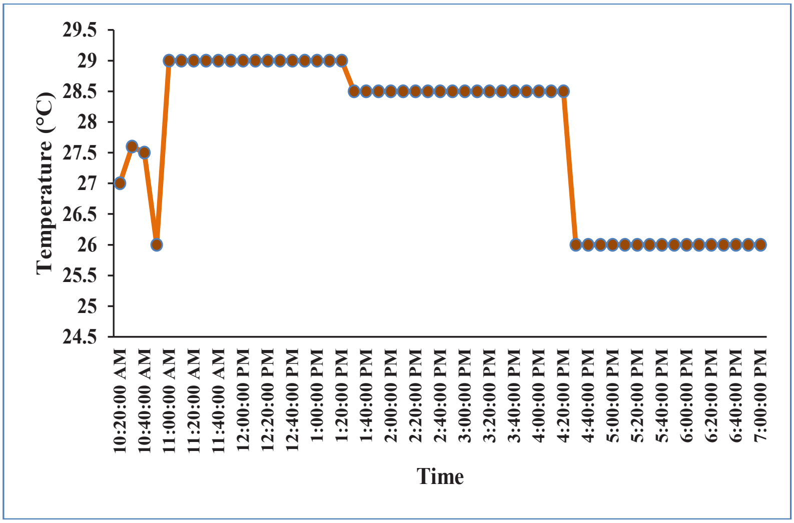

Figure 9: Graph of temperature level versus time

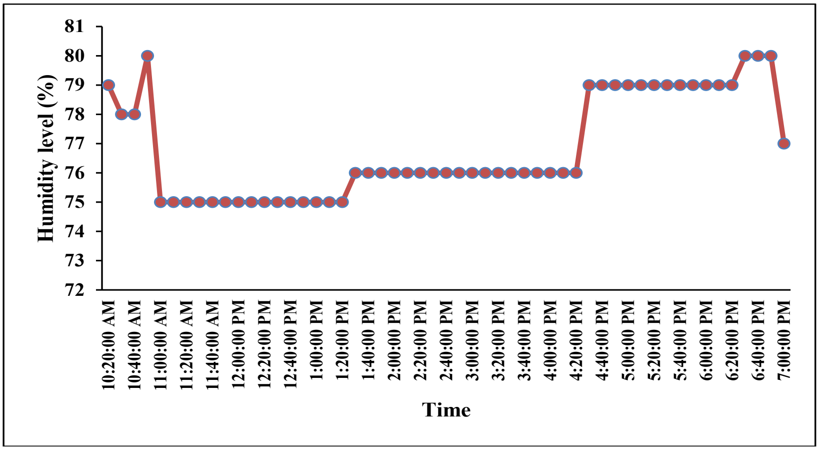

Figure 10: Graph of humidity level versus time

Figure 11 shows the graph of solar voltage level versus time. The voltage level started off at approximately 2.5 V. In general, the amount of voltage shows an increasing trend as the temperature of the day also records a similar pattern especially from 11 am to 4 pm. However, there was voltage drop at around 10.50 am due to the sudden temperature decrement and abrupt humidity increment at about the same time. Overall, this project has successfully tracked the solar direction as the solar output voltage is generated in accordance to the temperature level in a day, with the highest produced voltage of 4.99 V is recorded when a maximum temperature of 29 °C is measured between 11.00 am to 12.50 pm.

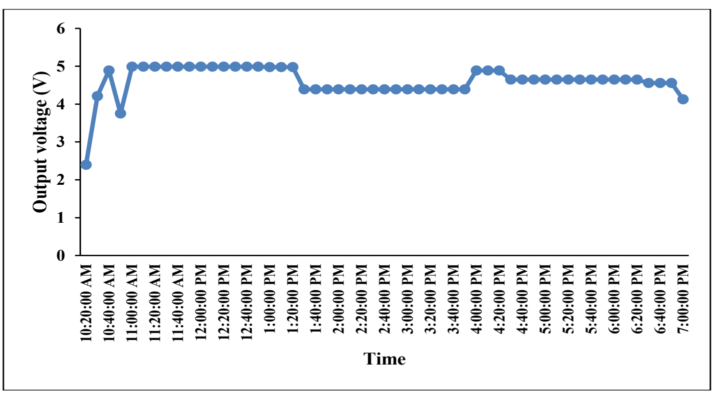

Figure 11: Graph of solar voltage level versus time

CONCLUSION

Overall, this Dual-axis Solar Energy Tracking and Monitoring System with Arduino as a Microcontroller has successfully increased the solar energy production via the sunlight-oriented feature. The generated voltage is in accordance with the level of solar humidity and temperature level. Furthermore, the monitoring unit equips the project with an important feature that continuously ensures a reliable operation of the system. With the application of Arduino technology as the microcontroller along with the data monitoring and analysis processes involved in this embedded-system, this project provides strong exposure towards solar as clean energy. In the future, further improvement such as adding electrical loads to the system that utilize the solar energy generated could provide a relatable and clearer scenario to the students since it is more likely to resemble the real application situation.

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