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Dual axis solar tracker and monitoring system based on internet of things

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ABSTRACT

In this paper, the application of internet of things (IoT) technology in development of a dual-axis solar tracking system is presented. Sting capacity of piezoelectric material is applied a footstep energy generation system. Using Arduino MEGA as the main controller for the system, light-dependent resistors (LDRs) have been used for sunlight detection and maximum light intensity. Two servo motors have been employed to rotate the solar panel towards the position of the sun as detected by the LDR. Ethernet Shield is used as an intermediary between the hardware device and the IoT monitoring system through the Cayenne platform. Alert notifications are included to inform a remote user through phone or mail (or both) when a sensor has reached a certain predefined event. There is a 21.97 increased energy output buy the proposed system as compared to the single-axis solar tracker. Further test results of the manufactured prototype indicate that solar tracker data can be transmitted simply and monitored directly online, and the solar tracker is capable of receiving commands from the IoT monitoring application.

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1. INTRODUCTION

Solar energy is the power generated by the sun. It is the technology that converts sunlight directly into electricity [1], [2]. Data shows that Malaysia can yield 1.4 times more electricity if all the roofs in Malaysia are featured with solar panels [3]. Since solar systems contributed 0.55% of Malaysia's overall electricity gain ratio of 30,875.23 MW [4], the nation now perceives solar energy as one of the most useful renewable sources of energy. Malaysia has higher solar irradiance that can be used to generate electricity. The climate in Malaysia is ideal for producing electricity from solar power [5]. It has a strong solar energy radiation potential with an average of six to eight hours of exposure per day. The feasibility of building a photovoltaic (PV) system can be determined using statistics on solar irradiation. Data on solar irradiance can aid in making forecasts for future energy yield, performance, efficiency, and maintenance [6], [7]. These crucial factors will help in deciding whether to start up a PV system at a particular site [8].

To optimize solar energy absorption and subsequently enhance energy production, it is necessary to integrate solar tracker systems into conventional solar energy systems, where a structure that moves by the direction of the sun can be fixed with solar panels [9]. However, by upgrading from conventional systems to solar tracker systems that follow the sun's path, 10–50% more output energy can be garnered [10]. Solar tracker devices can be classified as single-axis or dual-axis depending on the techniques employed to orient the solar panels. Single-axis devices can only track sunlight in one direction, either the horizontal axis (toward South and North) or the vertical axis (toward East and West). While a dual-axis solar tracker can rotate in both directions to retain the solar panels perpendicular to the sun [11], [12].

Solar tracker systems can be categorized based on five tracking approaches: sensor-based tracker, open or closed-loop-based, artificial intelligent-based, geometric and astronomical equation-based, and a combination of two or more of these approaches [10]–[12]. It is plausible that solar tracker systems have exhibited tremendous potential to boost the production efficiency of solar panels. Additionally, creating a solar tracker device using internet of things (IoT) technologies can be more viable and beneficial [13], where the user can utilize an IoT platform to remotely view the device's data, including the electrical and environmental parameters related to the solar panels. These data can be employed to examine the PV energy potential, the operation of the solar tracker, the early identification, and diagnosis of electrical faults, the consequences of weather variations, and preventive maintenance.

Several single-axis and dual-axis solar tracker systems have been outlined in the literature, and they differ depending on the tracking techniques. The fuzzy logic controller and proportional–integral–derivative (PID) controller were built and compared for a single-axis tracker [14]. The fuzzy logic controller achieved an efficiency, higher than that of the PID controller by 2.39%. While the single-axis rotation is a major drawback, the implementation requirements such as large memory, high speed and flexibility are prohibitory. Other single-axis solar trackers were investigated. The use of arduino microcontroller achieved an increased efficiency of 1.43% [15], but the solar panels face the challenge of reduced sunlight via shading. The technique applied in [16], combined the single-axis tracking with a maximum power point (MPPT) charge controller. This achieved a 43% power gain. This is an expensive technique in addition to charge controllers having shorter lifespan. Another single-axis investigation with MPPT made use of polycrystalline solar cells with a controlled gear motor [17]. This achieved more about 110% increase in output energy. The gear motor made the system quite heavy.

For dual-axis solar tracker systems, the fuzzy logic controller was investagated in [18]. A combination of MATLAB fuzzy toolbox and LabVIEW, pulses were used to drive a stepper motor on a worm gear reducer. The system achieved a 36% improvement compared to fixed axis panels but is very complex and expensive. The design and implementation using Arduino UNO was investigated in [19], [20]. The authors succeeded in establishig the regular curve of the output power in a dual-axis solar tracker setup but there were no verified performance results. The innovative technique of attaching stainless steel reflective sheets was proposed [21]. The Arduino UNO microcontroller was used and this increased overall power output by 17.46%. Apart from costing more, the undulation of the reflective sheets caused uneveness and slight distortion. Nguyen and Ho [22] used the Arduino UNO R3 microcontroller and achieved a 20.77% increased performance. The AVR microcontroller used with solar panel covered by hued cellophane was investigated and achieved a 19.91% increased power [23].

While some of the previously critiqued works achieved results that are consistent with the literature, they lack the added utility of IoT or remote display and monitoring. Such IoT based remote monitoring has been investigated in [24] where the ESP 8266 WIFI module was integrated on the ubidots platform. The authors claimed to achieve a 45.11% increased power compared to the single-axis tracker in [15]. Arduino Nano microcontroller was conbined with Node MCU platform for real time data monitoring and achieved a 2 second response time [25]. The EPS 32 IoT board was used with a web application for monitoring in [26]. The author claimed a 58.02% improvement in the a specific battery charging scenario.

With the performances of these works, less emphasis was placed on the IoT or monitoring aspects aspect of the dual-axis solar trackers. It can also be observed that Arduino UNO is a most commonly used microcontroller for this family of solar trackers. This work will attempt to investigate using another Arduino microcontroller type and an alternative monitoring platform.

In this research, the IoT-based dual-axis solar tracker and monitoring system is developed. The Cayenne platform is used for remote monitoring and alert notifications. The developed system consists of PV panel, light-dependent resistors (LDR), sensors, and servomotors as assembled. An Arduino MEGA microcontroller is employed for smart control and display. The developed system is described, justified, tested, and discussed.

2. METHOD

The block diagram of the proposed IoT-based dual-axis solar tracker and monitoring system is presented in Figure 1. The blocks can be classified as input, processing unit and output. The flow begins with input unit which contains the solar panels detecting irradiation from the sun. The solar panels convert the irradiation into electrical energy, generating voltage. The data from the sensors are forwarded to the electronic processing unit. The electronic processing unit converts the voltage as desired to serve the output unit. The output unit controls the servomotor and display the relevant data. They are described in the following subsections.

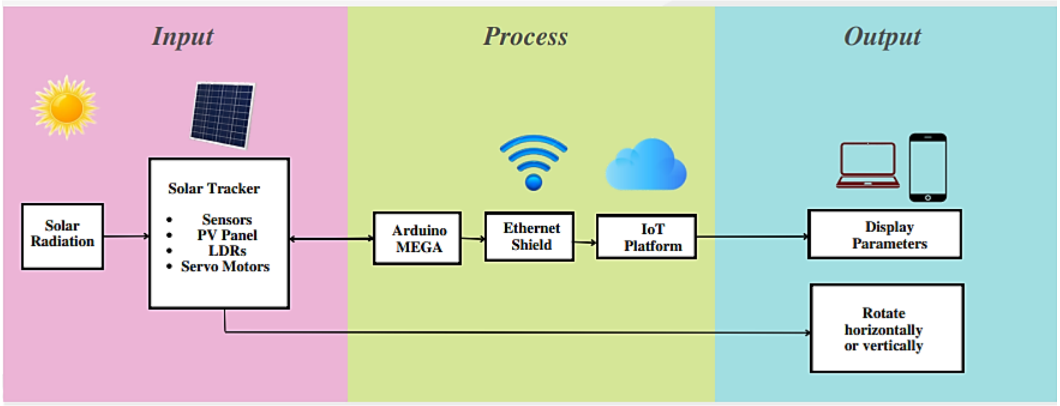


Figure 1. Block diagram of the proposed IoT-based dual-axis solar tracker and monitoring system

2.1. Input unit

The input unit consists of the solar panel, current sensor, voltage sensor, temperature sensor, humidity sensor, and the LDRs. The components and properties/ratings of the input unit are briefly explained hereafter.

2.1.1. Solar panel

The solar panel chosen is a monocrystalline 9 V, 1.6 W panel measuring 120 mm by 80 mm. A typical solar panel consists of a layer of semiconductor material, such as silicon, that is exposed to sunlight [27]. The mono crystalline panel was chosen over the polycrystalline panel due to the fact that monocrystalline panel performed better in low light conditions and is better resistant to change in temperature [28]. Regarding size and power rating, cost, accessibility and availability were the factors that determined the choice. When the semiconductor material is exposed to sunlight, the energy of the sunlight is absorbed by the semiconductor, causing the semiconductor to release electrons. These released electrons flow through an electrical circuit, generating an electric current.

2.1.2. Current and voltage sensors

The ACS712 is a current sensor that is used to measure the current flowing through an electrical conductor. It consists of a Hall effect sensor that is integrated with a linear amplifier and a current transformer [29]. The Hall effect sensor detects the magnetic field that is generated by the current flowing through the conductor, and the amplifier and transformer convert this detection into an output voltage that is proportional to the current. The ACS712 is used in a variety of applications, including current sensing, current measurement, and overcurrent protection. It is commonly used in motor control, power conversion, and other applications where accurate measurement of current is important.

The ADS1115 is a 16-bit analog-to-digital converter (ADC) that is used to measure small differential voltages [30]. It consists of a delta-sigma ADC, an amplifier, and a programmable gain amplifier (PGA). The delta-sigma ADC converts an analog input voltage into a digital output, the amplifier amplifies the input voltage, and the PGA allows the user to adjust the gain of the amplifier.

2.1.3. Temperature and humidity sensor

The DHT22 is a digital temperature and humidity sensor that is used to measure the temperature and humidity of the environment [31]. It consists of a humidity sensor and a temperature sensor, which are integrated into a single package. The humidity sensor is a capacitive sensor that measures the humidity of the air, and the temperature sensor is a thermistor that measures the temperature of the air. Powered by between 3.5 V to 5 V, the DHT11 has a temperature and humidity range of 0 ^{o}C to 50 ^{o}C and 20% to 90% respectively.

The DHT22 communicates with a microcontroller or other device using a single-wire digital interface. It sends a pulse to the microcontroller to request a measurement, and the microcontroller sends a pulse to the DHT22 to initiate the measurement. The DHT22 then sends a stream of digital data back to the microcontroller, which contains the measured temperature and humidity values.

2.2. Processing unit

The processing unit consists of Arduino MEGA microcontroller, Ethernet Shield. and the IoT platform. The components of the electronic processing unit are briefly described hereafter.

2.2.1. Arduino MEGA microcontroller

Arduino MEGA is a microcontroller board based on ATmega 2560. It has a total number of 54 digital input and output pins. Among those 54 pins, 14 of the pins can be used as PWM outputs. There are 16 analog inputs, 4 UARTs (hardware serial ports), a 16 MHz crystal oscillator, an ICSP header, USB connection, a power jack, and a reset button in the Arduino MEGA [32]. It is supported by the microcontroller. To get started, it is connected to a computer with a USB cable or with an AC-to-DC adapter or battery.

The microcontroller will process all the signals sent by the sensors and command the servomotor to rotate the PV panel perpendicularly towards the sun. Then, from the received signal, the Arduino MEGA will control the principle of the solar tracker either to operate it manually or automatically. Arduino MEGA is selected because it consists of much more digital and analog pins if compared to other Arduino board. Therefore, Arduino MEGA is a better choice to implement in the system.

2.2.2. Ethernet Shield

An Ethernet Shield is a hardware module that connects microcontrollers or single-board computers to the Ethernet network, such as the Arduino or Raspberry Pi. It typically comprises an Ethernet controller chip, associated circuitry, as well as an RJ45 Ethernet connector [33]. The Ethernet Shield enables devices such as Arduino to connect to a LAN or the internet through an Ethernet cable. It includes the hardware and software required to establish a network connection, allowing the device to communicate with other network devices and access internet resources.

Depending on the shield design, the shield communicates with the microcontroller or single-board computer using various communication protocols such as serial peripheral interface (SPI) or inter-integrated circuit (I2C). It encapsulates the low-level complexities of Ethernet connection, allowing developers to integrate network connectivity into their projects more easily. The connection speed of the Ethernet Shield is 10/100 Mb. The ethernet controller is a W5100 with internal 16K buffer. It is powered by a 5 V input and can take a maximum of 8 individual sockets. The Ethernet Shield sends the data that has been processed by the Arduino to the IoT Platform which is Cayenne application. It enables the device to send and receive data packets over the network, allowing it to participate in networked communication and internet connectivity. Hence, allow users to keep track of their data processing and other activities online or from a long range.

2.2.3. Internet of thing platform

Cayenne myDevices is an IoT program that provides a user-friendly platform for creating and controlling IoT projects. It enables users to establish a connection and control numerous IoT devices, sensors, and actuators through a single interface. Cayenne enables real-time monitoring and visualization of sensor data. It provides dashboards that can be customized to display sensor readings, graphs, and charts. Users can easily configure widgets to display sensor data and customize alerts and notifications according to certain circumstances [34].

Through its interface, Cayenne enables users to remotely control IoT devices and actuators. Custom controls, buttons, sliders, and switches can be designed by users to interact with their connected devices. In addition, it provides automation capabilities, enabling users to set up protocols and triggers for automatic operations according to data from sensors or predefined conditions.

To interface the hardware prototype with the IoT application on the Cayenne platform, message queuing telemetry transport (MQTT) credentials are used. The credentials were subsequently integrated into the Arduino source code. Cayenne log outputs are displayed on the Serial monitor of the Arduino IDE after the source code has been successfully compiled and uploaded.

2.3. Output unit

The output unit consists of the servomotors and computer or phone displays. The SG-90 servomotor has a torque of 2.5 kg.cm. With an input voltage of 5 V, it has an operating speed of 0.1s/ 60°. The angle of rotation is 0° to 180° [35]. Servo motors are high torque motors which are commonly used in robotics and several other applications due to the fact that it's easy to control their rotation. Servo motors have a geared output shaft which can be electrically controlled to turn one degree at a time. For control, unlike normal DC motors, servo motors usually have two power pins (VCC and GND) which is the signal pin. The signal pin is used to control the servo motor, turning its shaft to any desired angle. Servo's have high current requirement so when using more than one servo motor with the Arduino, it is important to connect their power connections to an external power supply as the Arduino may not be able to source the current needed for the servo.

2.4. Schematic circuit

The schematic circuit is shown in Figure 2. The schematic diagram shows the connections for all equipment and materials that can be conducted before designing the actual prototype. The Ethernet Shield is mounted on top of the Arduino MEGA. Both power and ground pin of Arduino MEGA and Ethernet Shield are connected to the positive and negative terminal of the breadboard. Then, four LDRs are connected to Ethernet Shield and Arduino through analogue pin A1, A2, A3, and A4. Each LDR is connected to 330 Ω resistor. All four LDR are indicated by four directions which are top-left, top-right, bottom-left, and bottom-right.

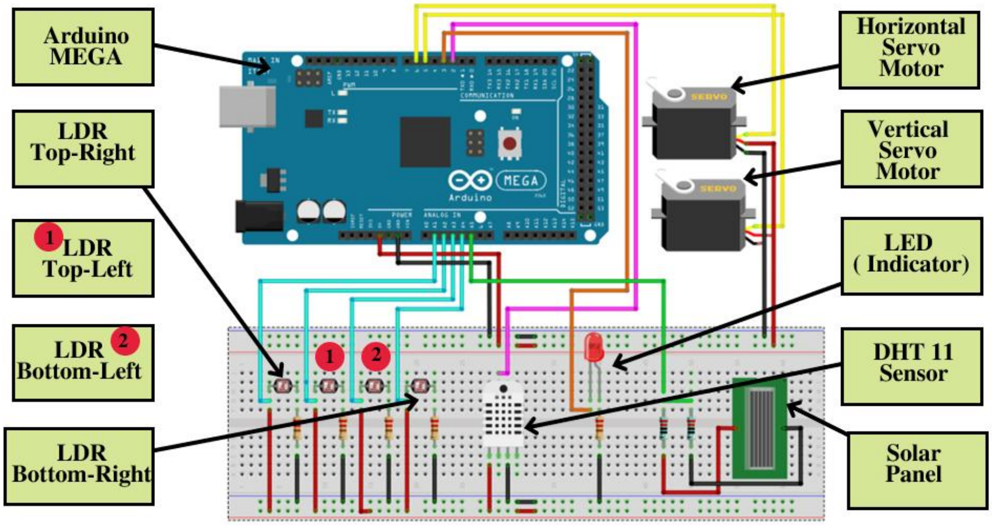


Figure 2. Schematic circuit of the proposed dual-axis solar tracker

The DHT11 temperature and humidity sensor has its VDD and GND pins, connected to the positive and negative terminal of the breadboard, respectively. The data pin of the DHT11 is connected to the digital pin of Arduino MEGA and Ethernet Shield. The signal wire (PWM) of the horizontal servo motor is connected to the Arduino MEGA and Ethernet Shield through digital pin 6 while signal wire for vertical servo motor to digital pin 5, respectively. GND and VCC pins of both servo motors are connected to the to the Arduino MEGA and Ethernet Shield. Two series resistors of 10 Ω were added to the circuit whereby it acts as voltage divider circuit. Both positive and negative terminals of the solar panel are connected to the previous circuit. The output of the voltage divider circuit is connected to the Arduino MEGA and Ethernet Shield through analog pin A5.

2.5. Functional modes

The IoT-based solar tracker has two functional modes: manual and automatic. A button created in the Cayenne dashboard has a role to switch between the two modes. When it is inactive, the manual mode is selected, otherwise automatic mode. When the manual mode is selected, the user can directly control the positions of the servomotors to orient the PV panel from east to west by the horizontal servomotor or from south to north by the vertical servomotor. The control is made from the associated widgets of servomotors in the dashboard of the Cayenne application. The system is programmed to send all data from the device regardless of the tracker mode (manual or automatic). The flowchart of the automatic mode is presented in Figure 3.

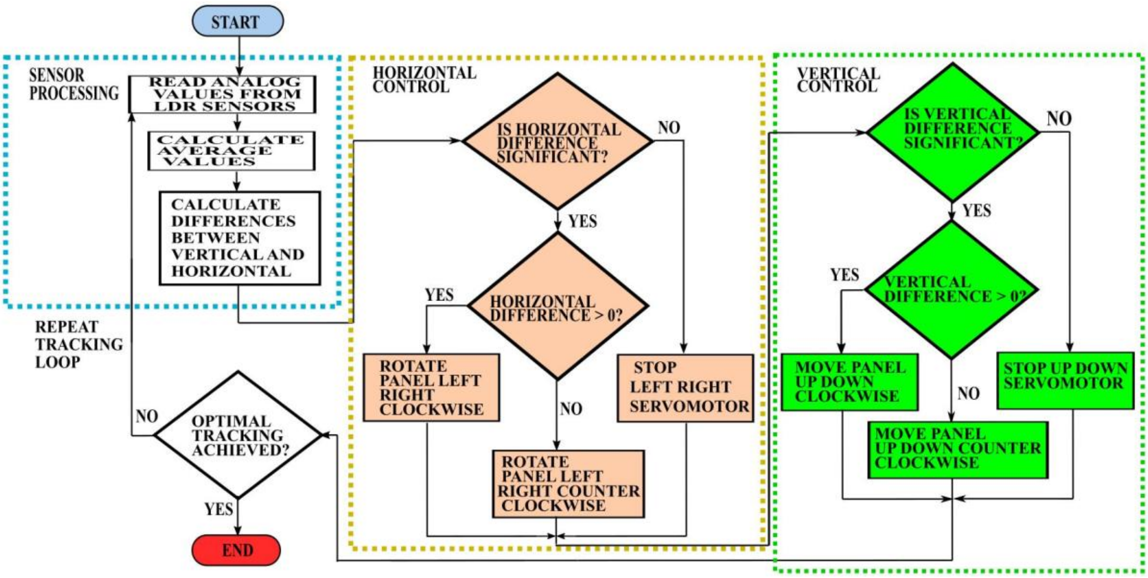
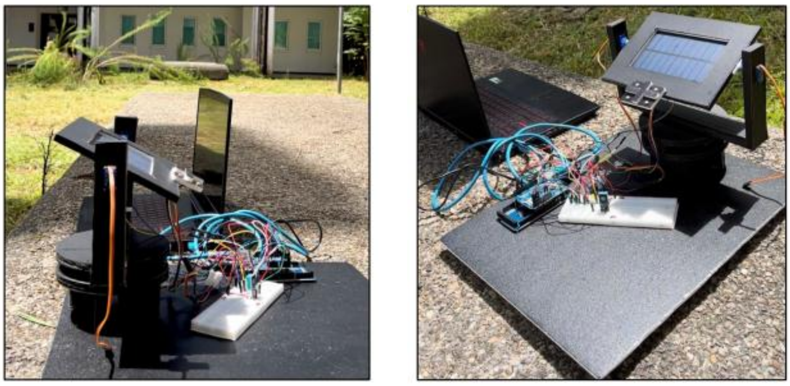


Figure 3. Flowchart of the automatic function mode

3. RESULTS AND DISCUSSION

In this section, the results of the experiments will be presented. Thereafter, the results will be examined and discussed to determine the viability of the project. The experimental setup is depicted in Figure 4. Figure 4(a) portrays a view of the experimental setup from the side while Figure 4(b) is the view of the experimental setup from the top. The Arduino board is powered by the computer via a USB cable, and the Ethernet Shield is linked to the Arduino board by an RJ-45 cable. The side view and the front view of the experimental setup can be seen.



(a) (b)

Figure 4. Experimental setup of the prototype; (a) side view and (b) top view

All the measured parameters and data received from the Arduino are presented in the Cayenne dashboard. This will allow us to check whether the data recorded from the Arduino is being transferred accurately and in real time. The data have been examined to evaluate the performance of the solar tracker and its ability to transmit real-time data to the IoT platform.

Figure 5 illustrates that the difference between the lowest and maximum data obtained does not seem substantial. This is due to the short duration of the evaluation. It would be possible to execute a prolonged test period to evaluate the performance of the solar tracker over an extended time frame.

The data recorded from the solar tracker was obtained by using a multimeter whereby it is used to measure current, voltage, and power. On the other hand, temperature and humidity are measured by using

Therma-hygrometer. According to Table 1, it can be verified that the data obtained from the solar tracker and data received from the Arduino on the Cayenne dashboard are transmitted in real time. It shows that the percentage error for all parameters is not exceeding 5%. In summary, a percentage error of not more than 5% generally indicates a reasonably accurate measurement or prediction, which is considered acceptable in many scientific and engineering scenarios.

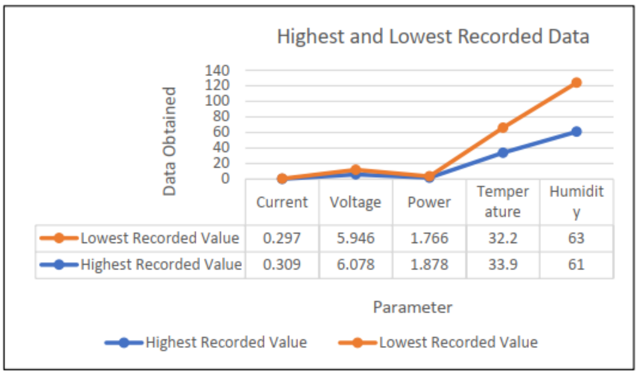


Figure 5. Highest and lowest recorded data

Table 1. Data recorded by solar tracker vs data received on Cayenne

Parameters	Measured data	Data on cayenne	Percentage error (%)
Current, A	0.299	0.289	3.34
Voltage, V	5.973	5.860	1.89
Power, W	1.784	1.756	1.57
Temperature, ºC	33.5	32.20	3.88
Humidity, %	64.7	62.5	3.40

Figure 6 shows that the output power gradually increases from the beginning of the experiment from 8:00 am. until around 12 pm. From midday time, the output power continues similarly and is stable at its maximum values until around 2:00 pm. After that, the power begins to decline from around 2 pm until the end of the experiment at 6:00 pm. This scenario could be deduced due to the location and the solar irradiance exposure on the solar panel whereby as the temperature increases, the output power also increases.

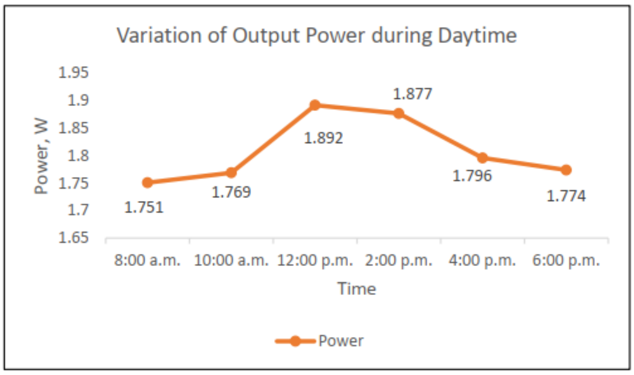


Figure 6. Daytime output power variation

To validate the output power performance of the dual-axis solar tracker, a single-axis solar tracker has also been implemented. The dual-axis solar tracker was the source of all equipment and materials used in the construction. However, only one servo motor was included in the prototype of the single-axis solar tracker. The power readings of the single-axis and the dual-axis solar tracker were taken hourly and recorded in Table 2. As shown in Table 2, the highest percentage gain in output power is 21.97%. The performance of single-axis and dual-axis solar trackers reaches the peak at noon that is because both solar panels are faced almost the same trend (facing the sun at the same time), but with a small difference in angle. The output power reaches maximum values around 12 pm which is 1.963 W. In addition, some fluctuations notable in the data were because of some cloudy sky and atmospheric conditions.

Table 2. Summary of experimental results

Time	Single-axis power reading data (2 W)	Dual-axis power reading (2 W)	Percentage gain (%)
8:00	1.103	1.118	1.36
9:00	1.136	1.219	7.31
10:00	1.208	1.297	7.37
11:00	1.349	1.601	18.68
12:00	1.963	1.963	0.00
13:00	1.860	1.878	0.97
14:00	1.815	1.837	1.21
15:00	1.672	1.796	7.42
16:00	1.461	1.782	21.97

Figure 7 shows the comparison graph of the output power for single-axis and dual-axis solar trackers. Both solar tracking systems were placed for 8 hours from 8 am until 4 pm. Different results can be seen from the data obtained and the graph showing where the output power for the dual-axis solar tracker is higher than the single-axis solar tracker. This is because, the single-axis solar tracker can only move from the east to the west, following the movement of the sun. However, a dual-axis solar tracker can generate more electricity by absorbing more sunlight intensity due to a horizontal servo motor that can detect the sun despite the presence of sun-blocking clouds.

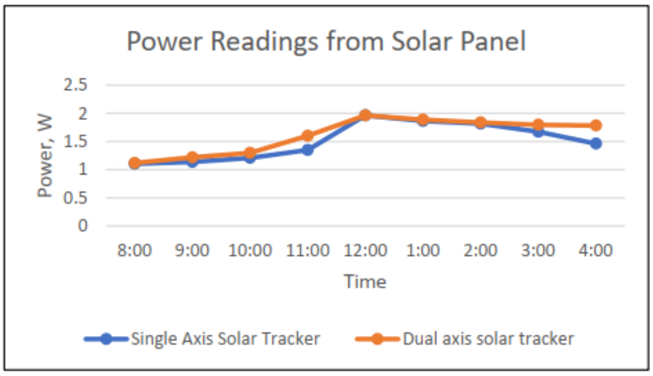


Figure 7. Output power for single-axis and dual-axis solar trackers

The data shows that the output power gradually increases from the beginning of the experiment from 8:00 am. until around 12 pm. From midday time, the output power continues similarly and is stable at its maximum values until around 2:00 pm. After that, the power begins to decline from around 2 pm until the end of the experiment at 6:00 pm. This scenario could be deduced due to the location and the solar irradiance exposure on the solar panel whereby as the temperature increases, the output power also increases.

One of the most essential characteristics of a monitoring system is its ability to send notification alerts to users when an event involving their monitored devices occurs. A temperature alert was created to send an email notification to the user (or recipients) when the monitored temperature is reached a threshold value. In practice, when the temperature exceeds the threshold value, the user will receive an alert notification in their inbox indicating that their MQTT sensor requires attention. Figure 8 depicts the Cayenne interface and alert notification that receives in the email address of the recipient when the temperature exceeds or is equal to the threshold value. In addition, other alerts, such as a sensor or actuator malfunction or a rapid decrease in PV power, can be added to the application.

Table 3 shows a comparison between [24], [26] and this work. It can be observed that the increased power output in [24] can be attributed to the use of the poly-crystalline solar cell with larger size and higher rating. In the same vein, the high power rating of the mono-crystalline solar cell in [26] accounted for the high power output. The proposed system has an advantage of temperature/humidity monitoring and control as well as email notifications.

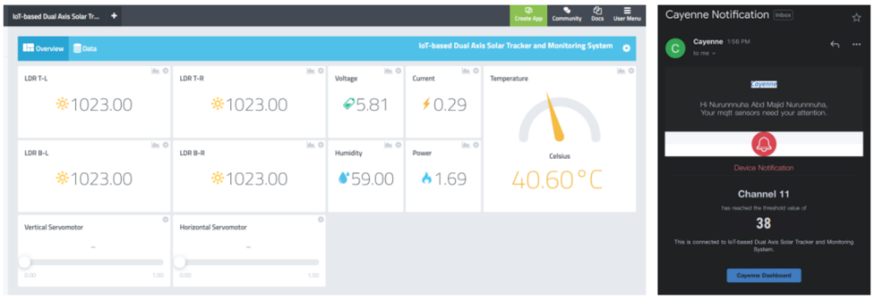


Figure 8. Cayenne interface and temperature alert notification

Table 3. Comparison between related works

Parameters	[24]	[26]	This work
PV Rating, W	3	50	1.6
PV type	Poly-crystalline silicon	Mono-crystalline silicon	Mono-crystalline silicon
PV size, mm	195×125	Not provided	120×80
Power increase, %	45.11	58.02	21.67
IoT platform	Ubidots	Website	Cayenne
Microcontroller	Arduino UNO	Arduino UNO	Arduino MEGA
Temperature/humidity monitor	No	No	Yes
Email notification	Not indicated	Not indicated	Yes

Other notable works generally apply similar principles presented in this work [36]-[41]. Worthy of mention is the design that considered floating solar cells (FPV) [36]. While the FPV design can save land space, the improved efficiency at 5.5% is considerably lower than the 21.97% improved efficiency achieved in this work. In the same vein, the 18% efficiency produced in [37] is lower than that produced in this work. Other investigations focused on the hardware implementation [38]-[40], cost reduction [41], and the advantages of dual axis trackers.

Some limitations of this study like the relatively low power output and size can be attributed to cost implications. Also, the efficiency of 21.97 can be improved by reducing losses. These losses might arise from the use of a breadboard and jumper cables. In such a scenario, loose connections might contribute to losses. A printed circuit board with properly soldered connections can ameliorate this shortcoming.

4. CONCLUSION

In this work, the efficacy of the Arduino MEGA microcontroller along with an alternative remote monitoring and notification system was investigated for a double-axis solar tracker. The solar tracker was designed to absorb solar irradiance from the sun and maximize the energy output of the solar tracker. The respective parts of the proposed system have been described. The implemented double-axis solar tracker delivered a 21.97% improvement in output power over the single-axis solar tracker. The temperature/ humidity sensor was helpful in determining the environmental parameter such as temperature and humidity of surrounding area. The proposed system can be operated in manual or automatic mode whereby all the electrical and environmental parameters can be monitored remotely through an IoT monitoring application developed on the Cayenne platform. This work contributes to the literature for energy harvesting in low cost applications. Future studies may explore scalability and control in diverse environments.

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AUTHOR CONTRIBUTIONS STATEMENT

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Kasumawati Binti Lias		✓					✓	✓		✓	✓	✓	✓	✓

C : **C**onceptualization
M : **M**ethodology
So : **So**ftware
Va : **Va**lidation
Fo : **Fo**rmal analysis
I : **I**nvestigation
R : **R**esources
D : **D**ata Curation
O : Writing - **O**riginal Draft
E : Writing - Review & **E**diting
Vi : **Vi**sualization
Su : **Su**pervision
P : **P**roject administration
Fu : **Fu**nding acquisition

CONFLICT OF INTEREST STATEMENT

Authors state no conflict of interest.

DATA AVAILABILITY

Derived data supporting the findings of this study are available from the corresponding author [YB] upon request.

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