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Board 107: Emergency Sun-Tracking Solar Generator

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Emergency Sun-Tracking Solar Generator

Abstract

In recent years, due to the growing electricity demand in modern societies and unforeseen natural disasters and catastrophic events, the number of power interruptions and outages has increased. The proposed emergency sun-tracking solar generator is designed and developed to address such power failure issues. The components used in this project and their functionalities are listed as follows: (i) A photoresistor array measures the luminosity level of the sun; (ii) a microcontroller (Arduino UNO) acquires the luminosity level data, calculates the desired solar photovoltaic panel angles for maximum sunlight energy absorption, and sends commands to servo motors; (iii) two servo motors control the tilt and rotation angles of the solar photovoltaic panel to orient it in the direction of maximum sunlight energy; and (iv) a stand-alone solar photovoltaic system collects the sunlight energy and generates electrical power for the entire system and external power outlets to be used in emergency situations. This senior design project is sponsored by the National Science Foundation and conducted by a group of undergraduate students in the Electrical and Computer Engineering Technology (ECET) program at New Jersey Institute of Technology (NJIT).

Introduction

The extensive development of solar photovoltaic (PV) systems has given rise to a highly lucrative business and job market in the field of power systems. On the other hand, as scientists and engineers become increasingly concerned about climate change, the necessity for emission-free energy increases. Recent catastrophic events such as Kahramanmaras earthquake in Turkey and Syria necessitate the need for more efficient and on-demand emergency power generation systems. The disaster has caused severe power outages and widespread damages to the people of Turkey and Syria. According to CNBC's report on February 9, 2023, the earthquake has affected 23 million people and their access to electricity [1]. This project was motivated by such emergency power generation needs. Figure 1 illustrates the average duration of total annual electric power interruption in the US [2], which shows an increasing trend. The primary usage of the sun tracking device is in cases where normal power generators are forced to go offline for an extended period of time due to unforeseen events such as natural disasters. The main feature of this generator is to automatically adjust the angle at which the solar panel faces the sun to maximize the power generation efficiency specifically during peak sunlight hours. The solar panel's angle is changed to face the optimum direction based on the measurements from the photoresistor array. The power generated by the solar tracking system is stored in a battery and used to supply DC power to the tracking system itself and AC power to emergency loads.

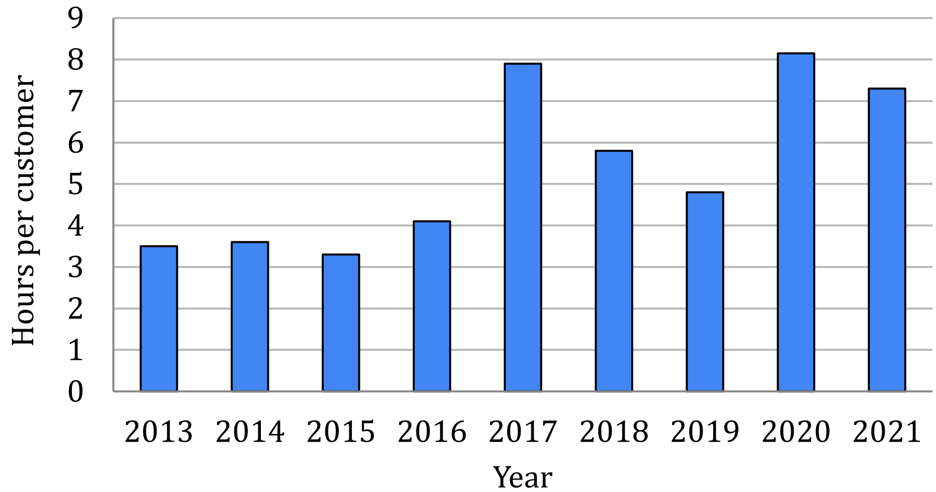


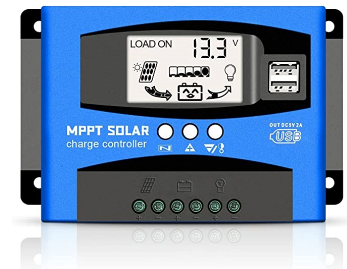
Figure 1. Average duration of total annual electric power interruptions in the US [1].

Before delving into the technical part of this project, a literature review is presented about the previous solar generation systems. In [3], a sun-tracking system was developed and constructed using standard cylindrical aluminum hollow and Polyurethane. The control system was programmed in a microcontroller with auxiliary devices such as an encoder and Global Positioning System (GPS). The astronomical equation and GPS information was utilized to determine the sun path trajectory. In [4], a sun-tracking system was designed to adjust the solar panel's orientation to generate the maximum amount of power from solar energy. A hybrid controller was designed in which an open-loop sun monitoring system was combined with a dynamic feedback controller. In [5], a closed-loop sun-tracker was developed and fabricated by using a PIC microcontroller based on the Flowcode programming language. The position of the sun was detected by using a photo-sensor. Moreover, an H-Bridge driver was employed to regulate two DC motors. In [6], a sun-tracking system was designed by using an AtMega 328p microcontroller, an array of photo resistive sensors, a double H-Bridge driver, and two geared motors. In [7], a sun-tracker system was developed by utilizing an Arduino UNO microcontroller. The control program activated the servo motor in the direction of the maximum sunlight intensity detected by a pair of light dependent resistor (LDR) sensors. In [8], a sun-tracking system was designed by using a deep recurrent neural network with long-term short-term units. The prediction algorithm could predict the best solar path for each day of the year based on location. In [9], a dual-axis sun-tracking system was designed by using a fusion-based technique of an astronomical-based estimation, and a visual sensor-based feedback to continuously locate and track the position of the sun.

Electrical Components

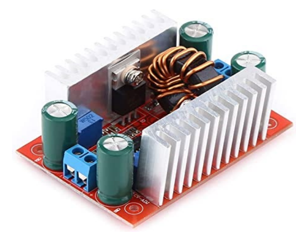
In this section, the electrical components used in this project are explained in detail and demonstrated in Figure 2.

(a) Solar Panel

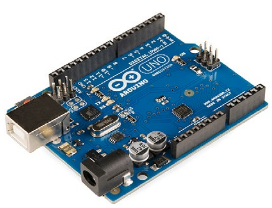


(b) Charge Controller

(c) Battery



(d) DC to DC Converter



(e) Arduino UNO

(f) Photoresistor

(g) DC to AC Inverter

(h) Servo Motor

(i) DC Disconnect

Figure 2. Electrical components.

100(W) 12(V) Renogy Flexible Solar Panel (Figure 2-(a)):
This flexible PV panel receives energy from the sunlight and turns it into a direct current. It utilizes MC4 connectors that are rated for 30 (A) and 1000 (V) DC. The main electrical specifications of the solar panel are as follows:

- Maximum Power Output: 100 (W)
- MPP Voltage (Vmp): 18.9 (V)
- MPP current (Imp): 5.29 (A)
- Open Circuit Voltage (Voc): 22.5 (V)
- Short Circuit Current (Isc): 5.75 (A)
- Dimensions: 47.9” × 21” × 0.08”
- Weight: 1.80 (lb)

WERCHTAY 12(V)/24(V) 30(A) MPPT Charge Controller (Figure 2-(b)):
This charge controller increases the lifespan of the battery, and also charges it more effectively by adjusting the voltage provided to the battery bank. It increases the battery life by cutting off loads when the battery is low to protect against undercharging damage of batteries. It also protects against overcharging. It allows for 99% efficiency from the solar panel.

12(V) 100(Ah) Renogy Lithium Deep Cycle Battery (Figure 2-(c)):
This battery stores the energy generated from the solar panel. The main specifications of the battery are listed below:

- Nominal Voltage: 12 (V)
- Charging Voltage: 13.5 - 13.8 (V)
- Rated Capacity: 100 (Ah) at 77°F
- Dimensions: 13.1” × 6.9” × 8.6”
- Weight: 63.9 (lb)
- Maximum Continuous Discharge Current: 9.14 (A)
- Maximum Permanent Discharge Current: 1100 (A) in 5 (sec)
- Maximum Continuous Charge Current: 30 (A)
- Operating Temperature: Discharge: 5 ° (F) to 122° (F); Charge: 5° (F) to 104° (F)

400(W) DC-DC Step-up Converter Driver 8.5/50(V) to 10/60(V) (Figure 2-(d)):
This converter is used to convert the output voltage of the charge controller (from the solar panels and battery) to the 18 (V) and 5 (A) electricity needed to power the servo motors continuously. It is rated to handle up to 400 (W), which helps prevent any damage to the step-up converter when under loads.

Elegoo Arduino UNO R3 (Figure 2-(e)):
This microcontroller is used to control the servo motors by using the data it receives from the photoresistors. The photoresistors act as sensors to adjust servo motors’s angle based on the side of the photoresistor array which detects more sunlight. The Arduino UNO is chosen due to its lower power consumption (compared to a Raspberry Pi). The operating voltage of the Arduino UNO is 5 (V) and its operating current is 685 (mA).

Hilitchi 5(mm) Light Dependent Resistor (Figure 2-(f)):
The light dependent resistor (LDR) measures the luminosity level of the sun. It uses 5 (V) power and a fixed 1000 (Ω) resistor to give an analog input to the Arduino UNO. These measurements are used within the code to determine how the solar panel is to be moved to stay aligned with the sun.

ROARBATT Pure Sine Wave Inverter 12(V) DC to 110(V)/120(V) AC (Figure 2-(g)):
This inverter is chosen since it provides continuous DC to AC power output and twin 120 (V) AC outlets. It also comes with an on/off switch to stop current flow. The inverter takes 12 (V) DC and transforms it to 120 (V) AC.

DOCYKE 350(kg-cm) 12(V)-24(V) Servo Motor (Figure 2-(h)):
This servo motor powers the adjustable joint that turns the panel, and is chosen due to its high maximum torque of 350 (kg-cm). The operating voltage of the servo motor is 18 (V), while the maximum voltage that the motor can utilize is 24 (V). Its maximum input current is 5 (A). It can meet any torque requirements that adjusting the panel might bring about.

DIHOOL DC Disconnect (Figure 2-(i)):
This DC Disconnect is an emergency on/off switch for the solar PV system. It provides a safety precaution in the case of short circuit or overload current. The DC disconnect can handle up to 400 (V) and 60 (A).

Mechanical Structure Design

Autodesk Inventor software is utilized to design and generate 3D models of the mechanical structure including the generator system and the photoresistor array, whose designs and dimensions are depicted in Figures 3 and 4, respectively.

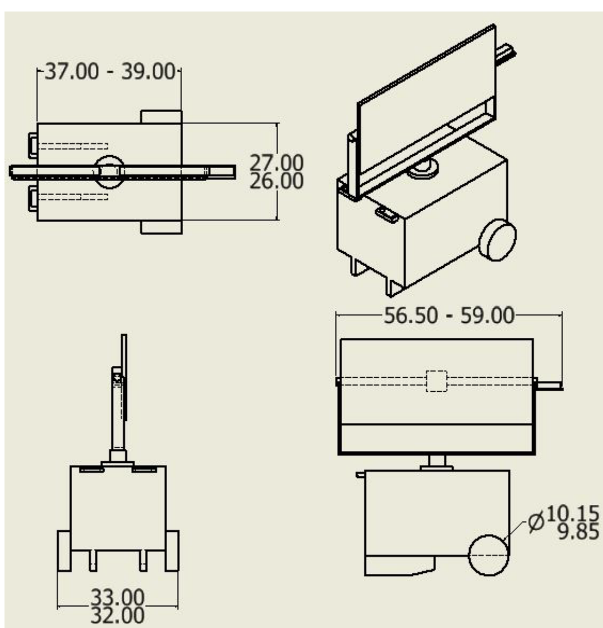


Figure 3. Mechanical structure: generator system design.

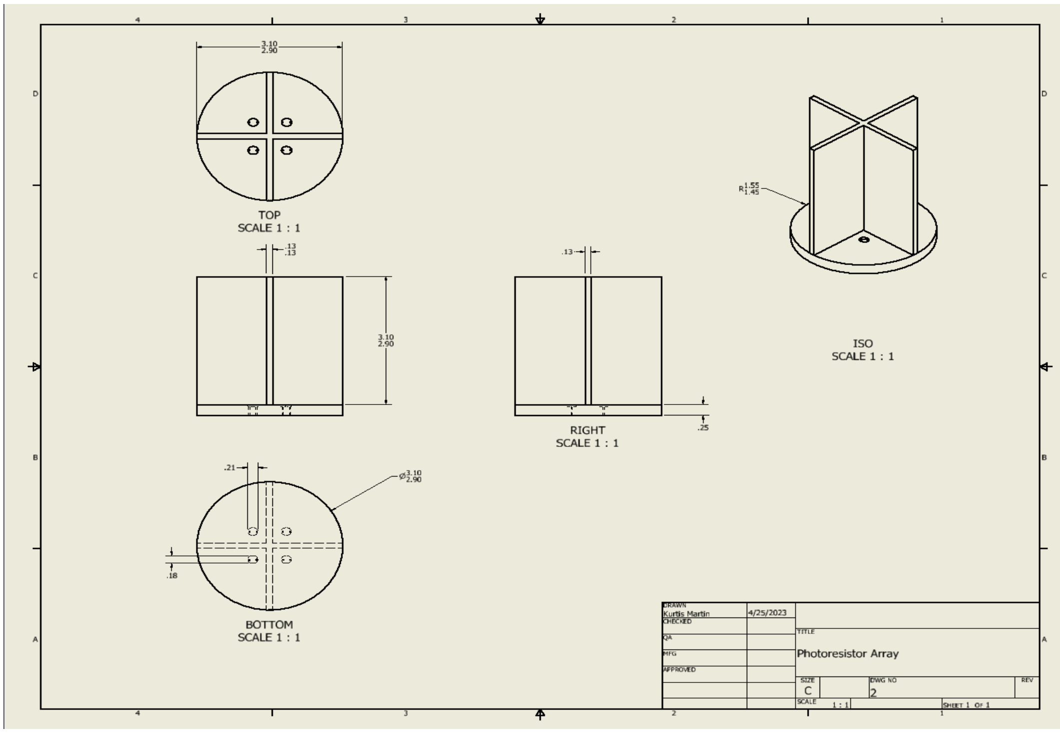


Figure 4. Mechanical structure: the design of the photoresistor array.

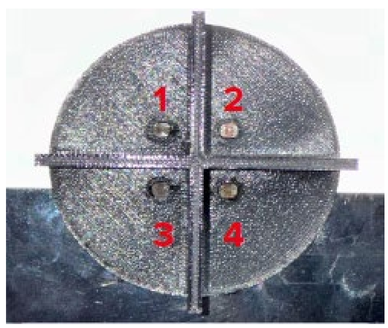


Figure 5. Mechanical structure: the 3D printed photoresistor array.

The photoresistor array (designed in Figure 4) is 3D printed with polyethylene terephthalate glycol (PETG) as demonstrated in Figure 5, which has a temperature-resistance rating of 185°(F). The photoresistors embedded in the array are connected using 20-gauge wires, which are soldered to the ends of each resistor lead. The shadows that the walls between the photoresistors cast allow to determine the direction of angle deviation from the maximum light angle. The measurements from photoresistors are fed down into the enclosure and as inputs to the Arduino UNO for data processing. The generation system can be transported to any location by using its wheels and handles. The exterior of the enclosure as pictured in Figure 6 has vinyl siding to help bolster its overall weather-resistance. The enclosure's skeleton is made of galvanized slotted steel and plywood as the floor and ceiling. The U-Bracket sits on the 10" bearing for rotation. The servo motor is inserted into a dowel that can control the tilt angle of the U-Bracket. The custom-designed 3D-printed photoresistor array is placed at the top-middle of the solar panel assembly for the most accurate luminosity measurements.

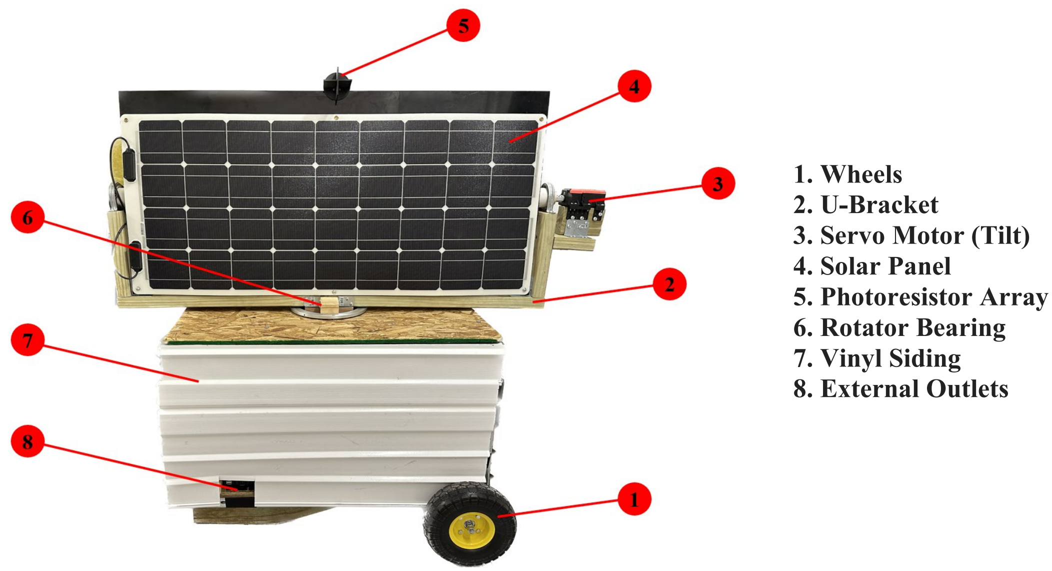


Figure 6. Mechanical structure: the exterior of the generator.

Electronics and Electrical Structure Design

The solar panel is connected in series with the DC disconnect, while the charge controller is connected in parallel with the solar panel, battery, AC inverter (external outlets), and DC step-up converters. The servo motors are connected to the DC step-up converters, which provide the correct voltage for the two motors to control the rotation and tilt angles. The Arduino UNO is powered by the charge controller USB port. The wiring block diagram of the generator system is depicted in Figure 7.

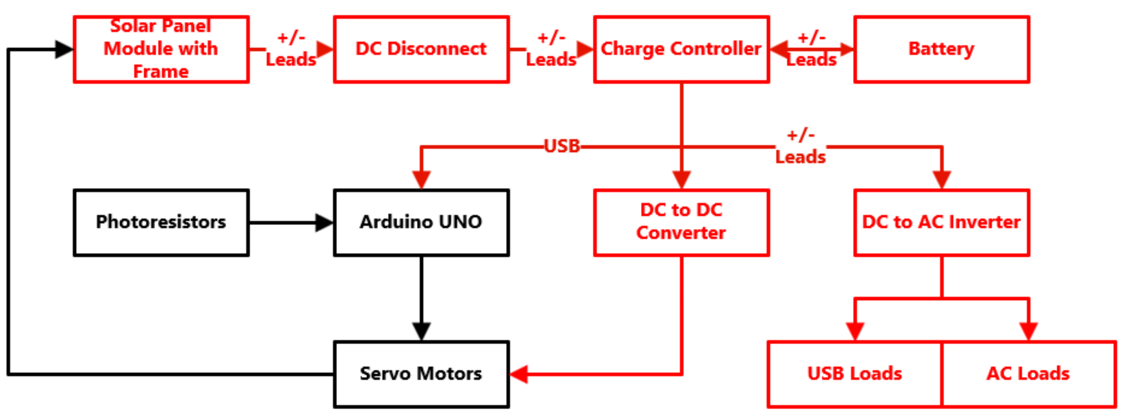


Figure 7. Wiring block diagram (power source and supply are highlighted in red).

The detailed implementation and integration of electronics and electrical components inside the generator enclosure are shown in Figure 8. The solar panel is connected to the DC disconnect with extended MC4 cables to prevent cable tearing when the system is rotating. Power is then fed into the charge controller, which allows for maximum power point tracking. The charge controller helps the battery charge and discharge in such a way to extend battery life and improve overall battery health.

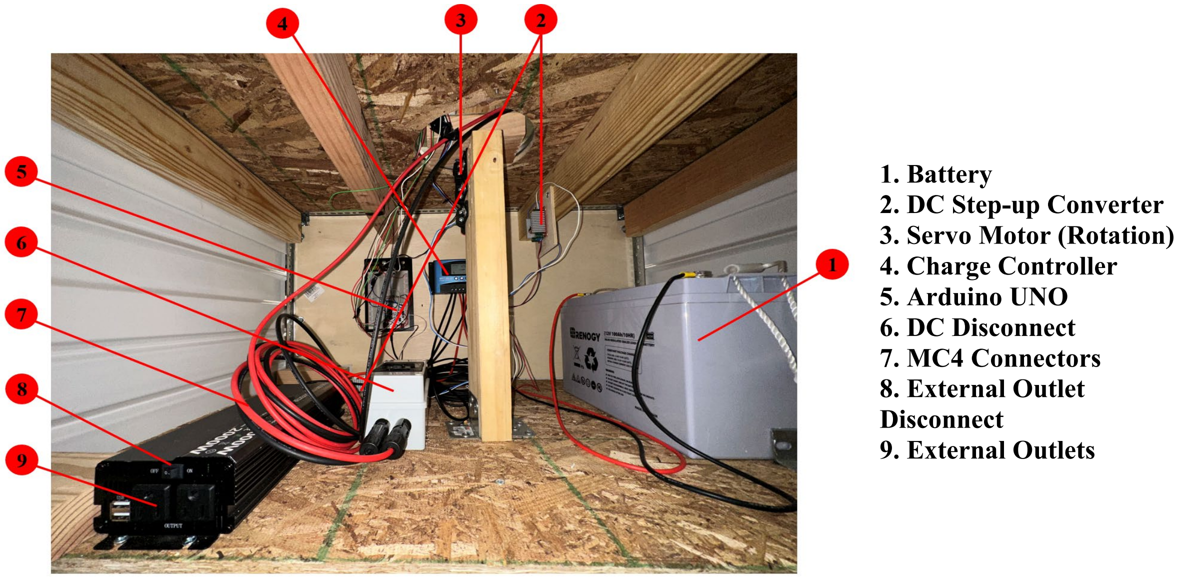


Figure 8. Implementation and integration of electronics and electrical components.

It is crucial to calculate the total power requirement when designing a stand-alone PV system. The total power needed to operate the sun-tracking solar generator components is calculated as follows:

$$\begin{aligned}\text{Total Power} &= 2 \times \text{Servo Motors} + \text{Arduino UNO} \\ &= 2 \times 18\ (\text{V}) \times 1\ (\text{A}) + 5\ (\text{V}) \times 0.685\ (\text{A}) = 39.425\ (\text{W})\end{aligned}$$

The PV system in this project is required to provide the above total power to ensure the generator system is operable. The excess power is then used to charge the 100 (Ah) battery throughout the day. The 100 (W) lightweight solar panel allows for constant generation of power, provided that sufficient sunlight is available over the span of peak sunlight hours.

Software Development

The top-level data flow diagram is depicted in Figure 9, which shows how the data is received, processed, and sent to output as usable information.

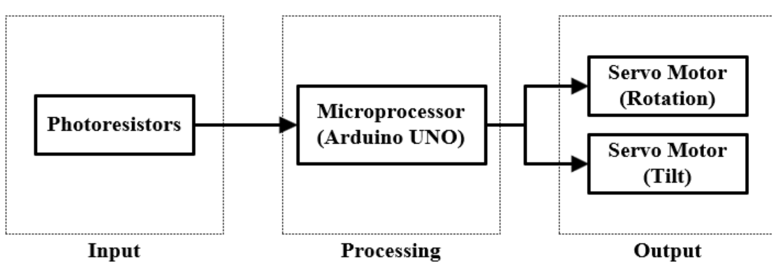


Figure 9. Data flow diagram.

Figure 10 illustrates the developed control algorithm flowchart. The Arduino UNO determines the direction of the PV panel rotation based on luminosity measurements from the photoresistors. The control program compares the sum of the top two photoresistors, LDR1 + LDR2, to the sum of the bottom two photoresistors, LDR3 + LDR4, and rotates the y-axis servo motor towards whichever measures more luminosity. Similarly, the control program compares the sum of the left two photoresistors, LDR1 + LDR3, to the sum of the right two resistors, LDR2 + LDR4, and rotates the x-axis servo motor.

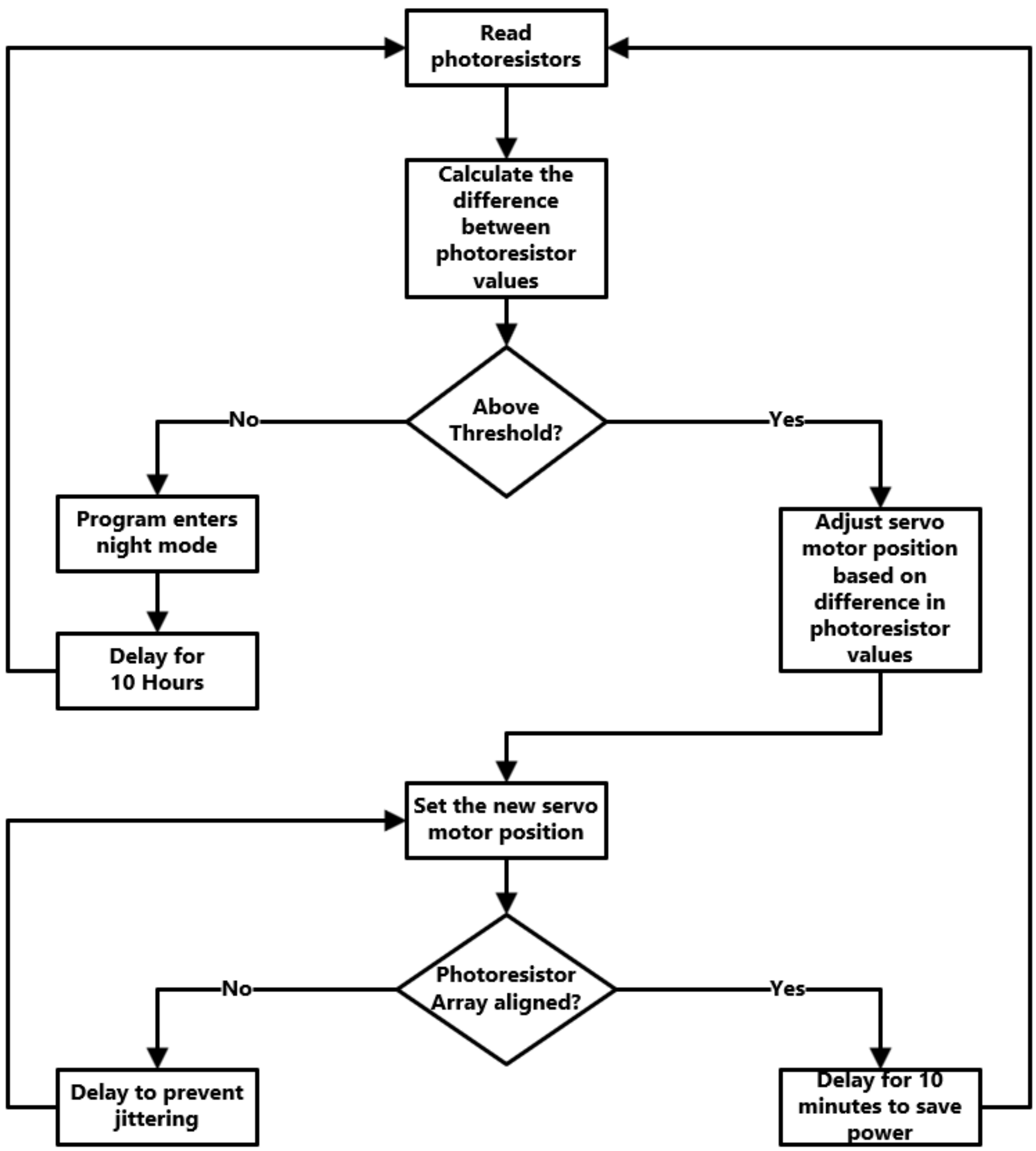


Figure 10. Developed control algorithm flowchart.

Each photoresistor has a theoretical minimum value of 0 (dark) and a theoretical maximum value of 1000 (bright) read by the Arduino UNO. In our outdoor testing, each photoresistor reached a maximum value of about 650 in direct sunlight. Thus, the maximum cumulative testing value of all the four photoresistors is $4 \times 650 = 2600$. This value is chosen to determine when the panel is aligned well with the sunlight direction. Once the photoresistors reach this threshold, a 10-minute power saving delay is induced. If the cumulative testing value of all the four photoresistors goes under a threshold of 400, then the program enters the night mode, which resets the positions of the motors for the next day. The night mode also induces a 10-hour delay to save power and to prevent the generator system from accidentally tracking the moon.

Conclusion

In this project, a sun-tracking solar generator is designed and developed, which is portable to be used in emergency situations by providing two AC outlets and two DC USB ports. The sun-tracking mechanism is achieved by using photoresistors that feed their luminosity measurements into an Arduino UNO. The control algorithm in the Arduino UNO drives two servo motors to control the rotation and tilt angles of the PV panel in the x- and y-axes, respectively. The Arduino UNO monitors the luminosity measurement values from the photoresistors until the combined values of all the photoresistors reach a luminosity threshold. Once this threshold level is reached, the Arduino UNO starts a 10-minute delay, after which the Arduino UNO starts reading the photoresistor measurement values and powering the servo motors over again. This process continues until the Arduino UNO detects a lower threshold, which is only achievable once the sun sets, and resets the PV panel's position and starts a 10-hour delay to ensure that power is not wasted overnight. The entire system and all its components are powered by a stand-alone PV system. In the future, the thresholds within the code will be fine-tuned and the delays will be changed to allow for a more accurate tracking of the sun and to ensure that the tracking system uses as minimum power as possible.

Educational Impact and Contribution

In this project, five undergraduate students from the ECET program at NJIT were involved. The students practiced teamwork and conducted and learned about the different phases of the project including system requirements identification, design specifications, project development, testing, and troubleshooting. The project was showcased to and gained significant attention from the students of different engineering disciplines at NJIT. Moreover, it has been used as a case study in the Solar PV Installation and Troubleshooting course and provided the students with a real-life engineering application of solar PV systems and the installation and troubleshooting skills, which are in-demand in industry.

The contribution of this project as compared to the similar projects in the literature is that it provides a compact, portable, and efficient (sun-tracking) power generation system that offers power outlets and USB ports. This paper provides a guideline and roadmap to develop a similar product with less than $2K budget. The parts and components were chosen to minimize the total project cost without sacrificing the performance.

Acknowledgement

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