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Performance of the Solar PV Module of the Dual Solar Axis Tracker of a Smart Home Monitoring System

Oluwaseyi O. Alabi[1], Oyetunde A. Adeaga[2], Sunday Adeola Ajagbe[3,4]*, Temitope S. Adekunle[5], Matthew O. Adigun[4]

[1] Department of Mechanical Engineering, University of Ibadan, Nigeria

[2] Department of Mechanical and Mechatronics Engineering, First Technical University, Ibadan, Nigeria

[3] Department of Computer Engineering, First Technical University, Ibadan, 200255, Nigeria

[4] Department of Computer Science, University of Zululand, Kwadlangezwa, 3886, South Africa

[5] Department of Computer Science, Colorado State University, USA

* Corresponding author: sunday.ajagbe@tech-u.edu.ng

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Abstract: Nowadays, solar PV power plays a significant role in sustainable electrification. However, because of the positions of PV modules, the electricity generated by the solar system is drastically reduced. This study aims to design, build, and deploy a dual-axis solar PV tracking system. This study describes a module control tracking system based on artificial intelligence for more effective solar energy harvesting. The passive closed-loop system often employs two opposing solar-powered actuators to receive equal solar radiation only when the mirrors point directly toward the sun to provide feedback from its location. Without using feedback to verify the intended result, the controller enters a mathematical equation into the tracking system using only the current state of the system and the algorithm. The solar tracker system rotates the solar panel toward the sun or another light source using an Arduino board, two DC motors, four light dependent resistors, four resistors, and a monocrystalline panel. In conclusion, the project's performance after testing satisfied the design criteria and is likely to boost the efficiency of solar panels.

Keywords: photovoltaic module, Arduino board, smart home monitoring system, solar panel tracking.

智慧家庭監控系統雙太陽軸追蹤器太陽能光電模組的性能

摘要：如今，太陽能光電發電在永續電氣化中發揮著重要作用。然而，由於光伏組件的位置，太陽能係統產生的電力大幅減少。本研究旨在設計、建造和部署雙軸太陽能光電追蹤系統。本研究描述了一種基於人工智慧的模組控制追蹤系統，可更有效地收集太陽能。被動閉環系統通常採用兩個相對的太陽能致動器，僅當鏡子直接指向太陽時才能接收相等的太陽輻射，以提供來自其位置的回饋。在不使用回饋來驗證預期結果的情況下，控制器僅使用系統的當前狀態和演算法將數學方程式輸入追蹤系統。太陽能追蹤器系統使用 Arduino 板、兩個直流馬達、四個光敏電阻器、四個電阻器和一個單晶電池板將太陽能電池板旋轉到太陽或

其他光源。總之，此專案測試後的性能符合設計標準，可望提高太陽能板的效率。

关键词：光伏组件、Arduino 板、智慧家庭監控系統、太陽能板追蹤。

1. Introduction

Due to the demand for clean energy and sustainable electrification, there is a shift from conventional power systems to environmentally friendly, renewable energy sources [1]. Renewable energy is one of the most crucial resources for the growth and development of many countries. According to [2], with the rise in energy consumption and the favorable effects of renewable energy sources on the environment by reducing the carbon footprint, their use has significantly increased over the past 20 years. A home energy management system (HEMS) installed in smart homes in response to dynamic pricing changes the energy consumption pattern of appliances [3]. Large-scale hazardous pollution from the burning of fossil fuels characterizes conventional power systems. Fossil fuels are currently the most prevalent source of electrical energy production; however, they are unsustainable and finite in nature and due to intensive use, their reserves are depleting [4]. Because it relies on varying atmospheric variables such as cloudiness, sun irradiance, humidity, wind speed, and temperature, photovoltaic (PV) power is not intermittent [5]. Owing to its accessibility regardless of the weather, solar PV energy, a renewable energy source, is rising in popularity as a solution to this location issue. By boosting the electrons in semiconductor materials, solar PV modules aid in converting solar radiation into electrical energy. Numerous solar radiation-related variables and the PV panels' orientations influence the amount of PV-generated power. Because of the PV modules' poor conversion rate, these have low efficiency. Solar tracking technology can increase the angle of solar radiation on a PV panel to boost the efficiency of solar power generation. Solar tracking is a method to follow the pathway of sunlight across the sky while keeping the solar PV at a perfect angle perpendicular to the sunlight radiation that can generate an optimal power output [6]. This tracking system can involve single-axis and dual-axis rotational modes [7]. A single-axis tracking system offered adequate tracking ability and followed the pathway of sunlight in the east–west direction but had a limited panel rotation, leading to higher PV-generated power losses. In contrast, dual-axis tracking systems can follow the sun's directions horizontally or vertically and with higher power generation efficiency.

The challenge facing researchers in the photovoltaic field is to increase the effectiveness of solar cells. The solar tracking system presents a reliable approach for increasing a solar panel's power output [8]. Recent advances in control and technology have assumed that the foundation of intelligent systems may be the key to finding significant solutions. After discovering a highly effective solar tracking controller to improve the solar energy captured by a photovoltaic cell [9], the maximum amount of solar energy captured by the solar cell related to the accuracy of tracking the direction of solar radiation to the Earth [10]. For positional tracking of solar radiation from the sun in terms of orientation and tilt, numerous strategies have been put forth to improve solar tracking systems [11]. Depending on the amount of movement, there are two primary types of solar tracking systems [12]. The dual-axis solar tracking system [13] tracks the sun in two separate axes using two pivot points, whereas the single-axis solar tracking system tracks the sun from one location to another using a single pivot point. There are two control methods for solar tracking systems: open-loop and closed-loop. [13] used the tracking system in an open-loop control passive tracking system to predict the sun's movement using mathematical formulae without requiring feedback. Without feedback to check the desired output, the active closed-loop system computes the mathematical equation into the tracking system based only on its present state and algorithm [14]. The mechanical layout and the solar tracking system controller have been the subject of numerous investigations. [15] created a two-axe schedule tracking system with a modified algorithm for spreading the sun's rays in the sky. Compared to a fixed sun tracking system, ray dispersion increases the power generated by PV panels. [16] presented an overview of a dual-axis solar tracking system and the most recent advancement in solar tracking system configuration. The review evidences that the authors created a practical model for a successful tracking system. [17] describes a sensor-based tracking system that uses UV radiation to improve its freedom of movement and the power generated by the sensors.

[18] presented a two-axis tracking system with preset positioning, using GPS and an encoder to control the tracking system controller. [19] developed a fuzzy logic system control for a dual-axis PV tracking system. The fuzzy logic controller received the sensors' input data and then adjusted the moveable motors to position the PV panels to face the sun's rays. [20] presented a new offline, non-sensor, dual-axis tracking method for PV and solar concentrator systems. The offline approach uses solar map equations to find the sun's brightest point to capture more energy [12], demonstrating a single- and dual-axes tracking system

that uses the adaptive neural fuzzy inference system (ANFIS) method to anticipate the precise angles needed to track the sun’s exact location and direction throughout the sky. We gain and lose energy at the east and west positions, respectively. The tracker has to collect energy from the sun’s rise until its westward return. The single-axis trackers must follow the sun along this axis, which runs east to west. As a result, the tracker moves with the sun. However, with changing the sun's zenith angle, a single axis cannot track it in both directions. [21] followed the sun in both of these directions - from east to west and south to north using the dual-axis solar tracker.

An intelligent-based control system is necessary in addition to the mechanical design of the solar tracking technology to improve the efficiency of the PV controller and the power produced. Consequently, this study aims to design, build, and deploy a dual-axis solar PV tracking system. LDRs, or light-dependent resistors, track the sun's direction. The tracking device installed on a hydraulic actuator may follow the route of the sun’s radiation based on the raised angles by using the signals from the four LDR sensors as input signals. The tracking system used an internet connection and a GPS module to ensure that the panel was oriented correctly and to enable remote monitoring and system switching.

2. Methodology

2.1. Smart Module

A smart module is a device that combines several parts, such as a processor, memory, and communication interfaces, to offer sophisticated functionality and processing capabilities in a small, efficient package. Embedded systems, home automation systems, industrial control systems, and Internet of Things (IoT) devices are just a few examples of the many uses of these modules. Smart modules frequently include pre-installed software and firmware, simplifying the development and deployment of applications without the need for in-depth programming expertise or familiarity with the underlying hardware. They often support multiple communication protocols such as Wi-Fi, Bluetooth, and Zigbee and may be programmed using various programming languages and development environments.

The smart home app is an IoT-based control system developed for remote network management of the power supply to the water pump and the system power output, making it possible to regulate the solar tracking system via internet connectivity [4]. It shows sensor data, stores it, visualizes it, and performs numerous other surprising tasks in addition to remotely managing hardware [22]. You can interact with projects using various widgets using the smart home app. While Smart Home Server facilitates communication between the smartphone and hardware component, its primary objective is to provide an interface between humans and machines, as shown in Fig. 1. Its open-source design and capacity to support thousands of devices even allow for the launch of a Node MCU Libraries for smart homes: the execution of incoming and outgoing commands from your smart home hardware and app is made possible through communication with the server. Your smart home app automatically locates its hardware when you touch a button. As a result, everything proceeds quickly in the other direction.

2.2. Design Methodology

According to [11], the solar tracking system consists of two motorized moving PV panels and a PV module that converts solar radiation into electrical energy. While the second DC motor only allows a straight-line movement, the first DC motor allows angular movement about its axis in both clockwise and counterclockwise directions. These DC motors use a horizontal coordinate system to determine their location and in which direction they are moving. This approach uses a multidimensional spherical surface to assess the appropriate placement of celestial objects. The coordinate system displays an object’s position in the sky using both azimuth angles and altitude. The angle incident on the PV module’s horizontal surface is called the zenith angle. LDRs, an Arduino Uno board, a liquid crystal display (LCD), DC motors, a stepper motor and driver, and a solar panel with a supporting metallic motor bracket comprise the automatic solar tracking system. A stepper motor and a DC motor are the two drivers in this electromechanical system. The first rotates around north and south, and the second around east and west. The microprocessor automatically adjusts the motors to move the solar panel into the proper position after receiving signals from the microcontroller and LDRs that detect system misalignment. The solar panel generates a voltage proportional to the intensity of sunlight.

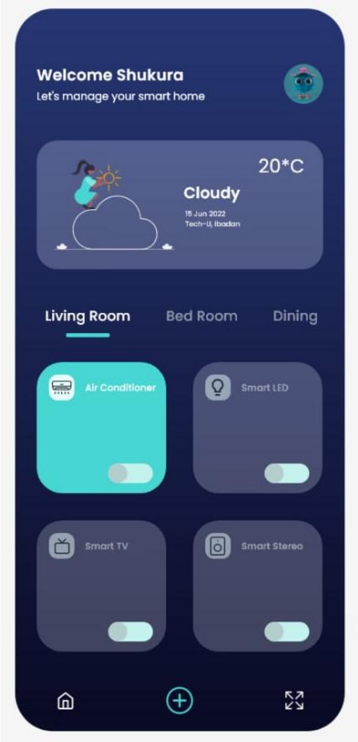


Fig. 1 Smart home module

The automatic solar tracking system uses active and chronological algorithms. The active algorithm is a closed-loop tracking system built on the feedback control principle. Sun brightness is detected using a light sensor that is an input to the system controller. The microcontroller uses the data gathered to analyze how to direct the motor to point the solar panel toward the sun. In the case of cloudy weather or the covered light sensor, the performance of the active solar tracker may suffer even though it produces great tracking accuracy on clear, sunny days. The microcontroller determines the sun's position and commands motors to move the solar panel toward the sun at predetermined intervals using defined azimuth and elevation angles. The azimuth angle is the angle in the horizontal plane measured from true north to the horizontal projection of the sun ray, and the elevation angle is the angle in the vertical plane measured from true north to the vertical projection of the sun ray as given in equation (1), where φ is the latitude of the location, δ is the solar declination angle, and θ denotes the hour angle [7].

$$\text{Azimuth angle} = \tan^{-1}\left[\frac{\sin\theta}{(\cos\theta\sin\varphi)-(\tan\delta\cos\varphi)}\right] \quad (1)$$

The elevation angle, on the other hand, is the sun's height seen from the object's horizon. According to [23], the elevation angle varies throughout the day based on the day of the year and the latitude of that specific area in equation (2). The chronological solar track may not precisely reflect the sun's position because of the complexities of sun movement.

$$\text{Elevation angle} = \sin^{-1}[(\sin\delta\sin\varphi)+(\cos\delta\cos\varphi\cos\theta)] \quad (2)$$

The pseudo-azimuthal mounting system technique provides the foundation for the tracking system structure. The movement of the solar panel is divided into two axes of rotation, as shown in Fig. 2. The panels can revolve around a north–south axis, although they can alternatively move in an east–west orientation after the adjustment. You can easily adjust both azimuth and altitude angles by turning both axes.

2.3. Products Systems and Components

Fig. 3 is an overview of the solar tracking system. To reach the objective of this project, which is to preserve the panel's autonomous operation, the hardware and software systems, and their various options were studied scientifically and practically.

Four LDRs are next to a solar panel on a shared plate. Because all LDRs have the inherent trait of photoconductivity, which causes their resistance to decrease as the incident light intensity rises, light from the source strikes the panel, but the resistance values of each LDR are not always equal [24, 25]. Each LDR transmits an equivalent signal representing the value of its corresponding resistance to the microcontroller using the necessary programming logic. The values are contrasted using a particular LDR value as a benchmark. The driving axle of one of the two DC motors is mechanically connected to the other so that it can travel in tandem with the latter's axle rotation. The former DC motor's axle drives a solar panel. The configuration of these two DC motors allows the solar panel to move along both the X- and Y-axes. Based on the input signals obtained from the LDRs, the microcontroller transmits the proper impulses to the DC motors. Two DC motors track along the x-axis and the y-axis. As seen in the algorithm flowchart in Fig. 4, these programming languages assist in coding.

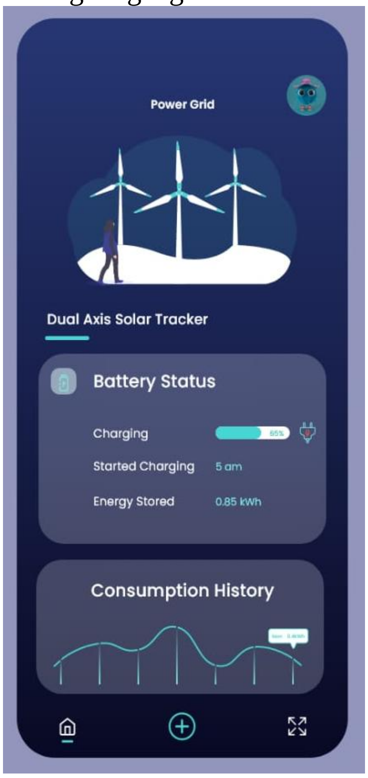


Fig. 2 Dual axis solar tracker

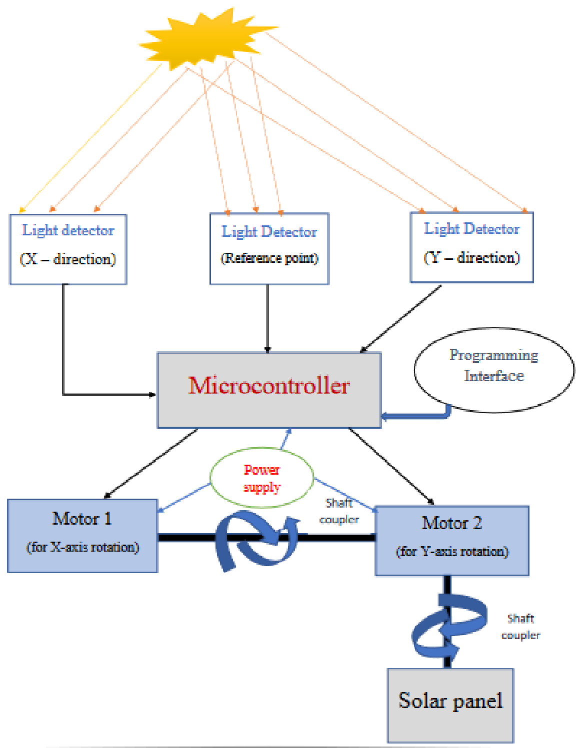


Fig. 3 Solar tracking system [24]

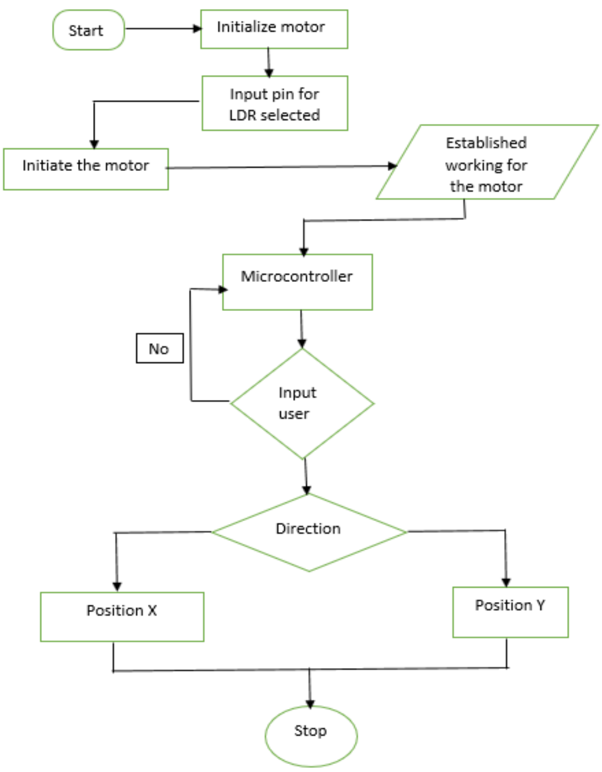


Fig. 4 Algorithm flowchart of the microcontroller system

2.3.1. Description of the Program

The variables positions X and Y store the reference motor locations. One for the reference ADC input pins for LDRs, and two axes of movement are selected. A tolerance or constant value determines how the motors will operate. Digital pins connect the motor object to the motors. The latters return to their original or mid-position after a delay of 1000 ms or 1 second to keep up with the user. With the help of the pin mode, the required analog pins serve as inputs. Four variables read the analog values and convert them to integer values between 0 and 1023. If the difference between the two variables is less than the tolerance value, it will remain there; if not, it will move by changing the values of positions X and Y in the lightest direction. The loop runs after the position writing to the motor until it notices any input value changes more than the minimum tolerance. Since the lower and upper limit angles are 30 and 150, respectively, the motor position will only be 150 if it exceeds 150 and remains at 30 if it falls below 30.

2.4. Implementation

This solar tracker system rotates the solar panel toward the sun or another light source using an Arduino board, two DC motors, four LDRs, four resistors, and a monocrystalline panel. This project considered numerous possibilities, including stepper motors and various types of solar panels. Alternative photoresistor sensors include photodiodes and phototransistors. Different communication systems, including rubber sweep, microcontrollers, and PLCs (programmable logic controllers), have been carefully investigated.

This project uses LDR because it has no polarity, is simple to connect to the circuit, is affordable and reliable, and has high spectral sensitivity, i.e., it quickly transmits a change in the radiation intensity by changing the resistance value. Because of its high efficiency, low cost, and excellent resistance to the environment, this project uses the mono-panel type. The main reason for the DC motor's choice for this project is that they are programmable to switch out in the event of failure. The Arduino Uno choice was due to its low price and ease of use. LDRs gauge solar light intensity when building a solar tracking system. The board's pins have connections to four LDRs. It is possible to solder the resistors and LDR together to prevent losing their connection for the constant mounting of the solar tracker. A breadboard is ideal if you are trying this project out for fun. A DC motor implements rotation, and a backup DC motor is employed [26, 6]. Usually, a pin on the board must connect the yellow wire to the DC motor that controls the cycle. The Arduino will probably not supply a DC motor with enough power to accomplish its full torque capability if it weighs more than 9 grams; in that case, a separate 5V power source drives the DC motor directly. The resistance of the LDR varies when light strikes it, and a potential divider circuit calculates the corresponding voltage value from the resistance of the LDR. The microcontroller is supplied with a voltage signal.

On the basis of the voltage signal, a corresponding PWM signal is sent to the DC motor, starting it to rotate until it reaches the point where the light intensity striking the solar panel is at its highest. Which LDR is in shadow determines the angles created in this project. For instance, if the high source shines so that the left LDR is in the shadow and the right LDR receives the lightest, make sure also to connect the Arduino's GND to the ground of the external power source, otherwise, the PWM control signal for the DC motor will not function. Now, it is possible to upload your sketch to your Arduino board. Even when both sensors receive the same quantity of light, their signals will differ due to variations in the LDRs, resistors, and the used wire resistance by including a calibration offset in the calculation. Depending on your system, your code will need to change this value. If this calibration factor is in the code, adjust it. The best way to estimate this factor is to illuminate both sensors evenly and to read the values that the east and west sensors emit using your computer's serial monitor. The calibration offset is the difference between these two numbers. Due to the LDRs' high sensitivity, the tracker only moves when the difference between them in the code is more than 15. Otherwise, it would constantly track forward and backward, wasting power.

Here is a brief description of the design and some important recommendations, although this instruction mainly focuses on Arduino control and is not intended to explain the creation of a tracking platform due to the widely diverse variety and size of panels available. When finished, your stand should resemble the one in the attachment. The stands can be wood, plywood, or PVC pipe; however, angle aluminum is the best material because it is sturdy, long-lasting, and suited for outdoor use. The base and panel support are the two main components of the stand. A pivot on which the panel support rotates connects them. The arm activates the panel support while the DC motor stands on the base. To reduce the unbalanced load on the DC motors, the panel should stick out from the panel support as little as possible. Although it is not always realistic, the pivot point should be at the center of gravity of the panel, and its support for the DC motor equal load regardless of which way the panel faces.

3. Results and Discussion

3.1. Smart Home Monitoring System

Smart home monitoring systems can also integrate artificial intelligence (AI) and machine learning algorithms to learn and adjust to the homeowner's behaviors and tastes. The above enables the system to optimize energy usage and boost security by automatically adjusting settings and offering tailored recommendations. In addition to providing convenience and security, smart home monitoring systems can improve well-being and health. For instance, smart lighting can adjust to the homeowner's circadian rhythm to promote better sleep, while sensors can monitor the air quality and humidity levels to improve indoor air quality. A smart home monitoring system can, in general, give homeowners more control, comfort, and peace of mind while also promoting wellness, health, and energy efficiency [27]. A smart home monitoring system created after testing has a quick mobile interface response time. This study aims to agree on the necessity and significance of a smart home monitoring system, as reported in [28].

3.2. Construction

The project was executed and tested to guarantee its viability along with the paper design and analysis. This project's construction had three phases. The project implementation used a solderless experiment board, often known as a breadboard, and the software code writing and debugging used the Arduino IDE program. The circuits are soldered onto printed circuit boards.

3.3. Coding

This project's programming used the free Arduino IDE software. It makes writing and uploading code to the microcontroller (Arduino Nano) incredibly simple. The installation file for the Servo.h library was downloaded from the official website, www.arduino.cc, using this offline IDE. This file controlled the angle and direction of the horizontal and vertical servos. The "void setup ()" and the "void loop ()" are the two default routines that the Arduino software uses to operate. At the first switch-on of the microcontroller, the void setup () executes once, and the void loop () continues indefinitely as long as the microcontroller is powered. Hardware components were soon necessary to test the program code.

3.4. Implementation

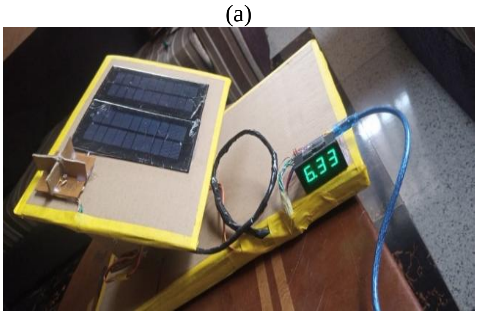
Soon after delivering the hardware, this project implementing used a breadboard to test the software code. The hardware components were linked by the circuit schematic provided for this report on an earlier breadboard to verify the functionality of the circuits before soldering on a PC board. The project implementation used a breadboard successfully, and each stage worked as intended and achieved the design goals. To ensure the intended project functioning, it included different hardware components soldering onto a PCB board. Before completing the digital display, the two servos, and the solar panel, the IC socket had to be soldered. As depicted in Fig. 5, soldering used a Vero board with parallel connections.

Fig. 5 Project at the beginning of the soldering state

3.5. Design Fabrication and Testing

As depicted in Fig. 6 from different perspectives, project packaging is the final stage of project construction. The moving portion of this project construction used a hard carton, similar to a safety box used in a hospital, while the project’s base was wooden. In Fig. 6 (a), two circular-shaped cartons were on the wood foundations, with a horizontal servo motor sandwiched between the circular carton discs. A handle attached to the top of the horizontal servo holds the vertical servomotor in place. A handle supports a flat container with the LDR and solar panels. A 90-degree angle of 90 degrees is possible only between the left and right movements of the horizontal and vertical servos. Figs 6 (b) and 6 (c) illustrate the setup and testing of the motor drivers. A multimeter measured the four output pins of the motor driving module from Fig. 6 (b) to ensure that the switching procedure functioned duly. Measurements of parameters such as component voltage, continuity, current, and resistance values, as well as frequency measurements, were necessary for the design on the board. The LDR and motor driver are connected correctly due to Arduino. Therefore, the measured voltage on each pin will increase as Arduino’s power output increases. The mechanical actuators need to be driven by the high voltage. In addition, the output of the voltage divider circuit examination using the LDR used a digital multimeter.

(a)



(b)

(c)

Fig. 6 Different views of the project

4. Conclusion

This study involves creating a dual-axis solar tracking system using a microcontroller to control the rotation of the solar PV module by the direction of the sun or a flashing light using LDR sensors. We used four LDR sensors in the tracking system to improve the angle of the sun's irradiance on the PV module, while a pseudo-azimuthal mounting technique ensured rigid mechanical construction. The design process considered the efficiency, adaptability, portability, durability, and the solar tracking system's economic application. The project’s performance after testing met the design criteria and is likely to boost the efficiency of solar panels.

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