IJNRD.ORG ISSN : 2456-4184
INTERNATIONAL JOURNAL OF NOVEL RESEARCH AND DEVELOPMENT (IJNRD) | IJNRD.ORG
An International Open Access, Peer-reviewed, Refereed Journal

HELECOTECH: DESIGNING AND DEVELOPING A SOLAR-POWERED CHARGING STATION FOR ELECTRONIC DEVICES WITH AN ARDUINO-BASED SOLAR TRACKER SYSTEM USING SOLAR PHOTOVOLTAIC (PV) ENERGY

[1]Kean Gabriel B. Burlasa, [2]Kieth Adrian L. Cereño, [3]Annavilla L. Clarion, [4]Sage Ryokuh R. Lasconia,
[5]Deborah taborada, [1]Student, [2]Student, [3]Teacher, [4]Student, [5]Student,
[1]Department of Education, [1]Colon National High School, Brgy. Colon, Maasim, Sarangani Province, Philippines

Abstract: The study developed and tested a solar-powered charging station incorporating an Arduino-based solar tracker to maximize renewable energy efficiency for charging electronic devices. The station utilizes a 100W solar panel, Arduino Uno, linear actuators, and sensors to adjust its angle for optimal sunlight capture throughout the day. Performance evaluations across mechanical, electrical, and functional criteria yielded excellent results, with high mean scores of 4.53, 4.60, and 4.85, respectively. The solar tracker enhanced output voltage and current by 6.16% and 36.67% over stationary panels, supported by statistical analysis showing significant improvements in output voltage ($p = 0.00 < 0.05$) and current ($p = 0.048 < 0.05$) with the tracker. The station's time-indicated pop-up outlet provided reliable, convenient power for various devices within specified time frames, highlighting its versatility. The Arduino program's components, including sensors and actuators, functioned effectively, though minor adjustments to the light sensor configuration further improved accuracy. Rated highly for durability, functionality, and safety, the charging station demonstrates considerable potential as a sustainable energy solution, particularly in remote or off-grid areas where renewable power is essential. This project exemplifies the practical impact of green technology, delivering portable, clean energy that reduces fossil fuel dependence and promotes environmental sustainability. The project aims to support the broader adoption of sustainable practices globally by showcasing the viability of renewable energy applications.

INTRODUCTION

Renewable energy is an essential answer for tackling environmental issues and fulfilling increasing energy requirements. Renewable energy, characterized as energy obtained from natural sources such as sunshine, wind, water, and geothermal heat, has several applications, including transportation, industrial use, and electricity generation. Biomass sources, including municipal, agricultural, and industrial waste, exemplify the promise of renewable energy by supplying heat, power, and fuel across several economic sectors. This context establishes the basis for examining the role of renewable energy in environmental sustainability and energy security (Alhijazi, Almasri, & Alloush, 2024).

Prior research highlights the advantages of renewable energy, including its capacity to diminish carbon emissions in contrast to fossil fuels. Attanayake, Wickramage, Samarasinghe, Ranmini, Ehalapitiya, and Jayathilaka (2024) highlight the ecological and financial benefits of renewable energy derived from solar, wind, and hydropower sources. These renewable resources offer a sustainable alternative to fossil fuels, which, while now efficient, are finite in quantity and detrimental to the environment. The necessity to transition to renewable energy sources is broadly acknowledged due to fossil fuel depletion and the imperative of climate change mitigation. Consequently, researchers persist in investigating renewable energy options that reconcile cost, stability, efficiency, and environmental impact.

Moreover, renewable energy technologies, such as solar and wind power, substantially mitigate greenhouse gas emissions and address climate change. Solar panels transform sunlight into electricity, providing a renewable and clean energy source, whereas wind turbines use kinetic energy from the wind to produce power. These renewable technologies increase air quality and bolster energy security by decentralizing power sources, diminishing reliance on fossil fuels, and fostering local energy resilience. Their advancement signifies a transition to a more sustainable energy framework with extensive environmental and social advantages (Maka & Alabid, 2024).

In addition, the implementation of renewable energy infrastructure, including solar-powered charging stations, underscores the societal impact of these technologies. The US Environmental Protection Agency (EPA) states that renewable energy diminishes dependence on fossil fuels and fosters economic growth by generating employment in the clean energy sector. An exemplary instance is the mobile charging station developed by Tran, Ovalle, Molina, Molina, and Lee (2021), which offers a portable, solar-powered method for charging electronics in public areas. This innovation not only fosters the sustainable utilization of solar energy but also meets the growing demand for handy power sources in the digital era, particularly in regions with restricted access to traditional electricity.

Inspired by Tran's work, the researchers developed HELECOTECH, a solar-powered charging station with advanced solar tracking capabilities, using locally sourced materials and an Arduino Uno-based system to maximize daily energy capture. This innovative station enhances functionality with cutting-edge technologies, offering sustainable energy access in sunny tropical areas like Maasim in Sarangani, Philippines. Designed by STEM student-researchers, the project not only supports underserved communities but also contributes to environmental sustainability, paving the way for future advancements in renewable energy applications.

Objectives of the Study

The main objective of the study was to design, develop, and test a solar-powered charging station equipped with advanced solar tracking technology to optimize energy capture and provide a sustainable power source for underserved communities in Maasim, Sarangani Province, Philippines.

In the completion of the study, the researchers performed these subsequent tasks:

1.) Adopt but modify the protocol from Gonzales and Muyot (2022) in designing and developing a Solar-Powered Charging Station for Electronic Devices with an Arduino-Based Solar Tracker System using Solar Photovoltaic (PV) Energy.

2.) Test the designed and developed solar-powered charging station in terms of its:
- 2.1 Mechanical Design;
- 2.2 Electrical Design;
- 2.3 Functionalities;
- 2.4 Solar Harvesting; and
- 2.5 Charging Efficiency.

3.) Compare the solar harvesting ability of the designed and developed solar-powered charging station with or without a solar tracker in terms of its:
- 3.1 Output Voltage
- 3.2 Output Current.

Research Questions

Considering the objectives of the study, the researchers answered the following questions:

1.) How can a Solar-Powered Charging Station for Electronic Devices with an Arduino-Based Solar Tracker System using Solar Photovoltaic (PV) Energy be designed and developed using the adopted but modified protocol from Gonzales and Muyot (2022)?

2.) What are the results of the tests performed in the designed and developed solar-powered charging station in terms of its:
- 2.1 Mechanical Design;
- 2.2 Electrical Design;
- 2.3 Functionalities;
- 2.4 Solar Harvesting; and
- 2.5 Charging Efficiency?

3.) Is there a significant difference in the solar harvesting ability of the designed and developed solar-powered charging station with or without a solar tracker in terms of its output voltage and output current?

Hypothesis of the Study

H_0 There is no significant difference in the solar harvesting ability of the designed and developed solar-powered charging station with or without a solar tracker in terms of its output voltage and output current.

Significance of the Study

This study is hoped to be beneficial to the following:

Robotics. The research works towards the incorporation of automation into renewable energy sources. The system, based on the Arduino Uno, tracks solar panels to change the angle during sunlight availability in order to make them more effective. This, therefore, explains how robotics could be used for optimizing energy generation, and that the knowledge is very useful to be applied later in automation works within the renewable energy sector.

Environment. This research supports environmental sustainability through the reduction of fossil fuel dependency and the decrease in carbon emissions. HELECOTECH, a solar-powered charging station, is an alternative source of clean energy that reduces environmental degradation brought about by traditional power sources. Through the efficient harnessing of solar energy, this research contributes to the long-term efforts in combating climate change and eco-friendly technological solutions.

Maasim Local Community. The local community of Maasim in Sarangani Province may benefit from enhanced energy access, especially in places that lack access to electricity. HELECOTECH offers an alternative, clean, and cheaper source of power for recharging electronic appliances. The project may also create job opportunities for locals and help train them in the use of renewable energy technology.

Colon National High School. The students and the teachers of Colon National High School are upgraders to learning experiences because this study applied the STEM concept practically. The solar-powered charging station is an educational tool for hands-on science, technology, engineering, and math learning. These also encourage students to engage in research and innovation and hence improve the school culture to be sustainable and technologically advanced.

STEM Researchers. The outcomes of this study may be a reference to the further investigation of renewable energy technologies by STEM researchers. Integration of solar tracking systems with locally sourced materials gives some ideas about inexpensive and efficient solutions in energy fields. This research encourages interdisciplinary work in electrical engineering, robotics, and environmental science.

Other Researchers. The research provides a framework for other scholars interested in developing renewable energy solutions. The methodologies and results of this study may serve as a foundation for similar projects, particularly in optimizing solar energy harvesting. Future researchers may build upon this work to improve the efficiency, scalability, and adaptability of solar-powered systems in different environmental conditions.

Future Studies. This might further open up streams of research in the future regarding the improvement of solar tracking technology and its applications. Advanced algorithms such as machine learning integration and hybrid renewable energy systems may be further explored and developed for enhanced energy efficiency. The conclusion of the present study might also inspire the design of more innovative renewable energy projects.

Scope and Delimitation of the Study

This study focused on the design, development, and testing of a solar-powered charging station integrated with an Arduino-based solar tracker system. The innovation employed solar photovoltaic energy to optimize energy efficiency and addressed the growing demand for renewable power solutions, particularly in areas like Maasim, Sarangani Province. The charging station was equipped with a 100W solar panel, Arduino Uno, linear actuators, and sensors, enabling it to adjust its panel angle throughout the day to maximize solar energy capture.

Furthermore, performance testing evaluated the charging station's mechanical, electrical, and functional designs. The study also assessed solar harvesting efficiency, output voltage, and current, comparing the results of stationary panels with those of panels equipped with the solar tracker. The charging station was tailored to support various electronic devices, such as laptops and mobile phones, showcasing its utility for underserved communities and educational institutions. Additionally, it incorporated basic safety mechanisms like alarms and sensors to mitigate risks, though challenges may persist in ensuring complete safety during the retraction of pop-up outlets while devices remain connected.

The study was limited to specific environmental conditions within Maasim, which may restrict the generalizability of results to other climates. The prototype lacks advanced safety features, such as locking mechanisms or sensors to detect connected cables during outlet retraction, which poses risks during unattended use. Furthermore, the charging station was optimized for sunny, tropical regions, limiting its efficiency in areas with low solar irradiance. These delimitations were established to focus the project's scope and ensure feasibility within the available resources and expertise.

After constructing the prototype solar-powered Arduino-based automatic waste compactor and segregator, the researchers evaluated its performance based on mechanical design, electrical design, functionalities, solar harvesting, and charging efficiency. To ensure comprehensive testing, they engaged innovation experts and research advisers, conducted trials on leveled pavement, and meticulously recorded observations. This project was developed at Colon National High School during the academic year 2023–2024, showcasing the institution's commitment to sustainable technology and practical solutions.

Limitations of the Study

During the project development, unexpected challenges emerged, particularly in managing the pop-up outlet's retraction. One significant issue was the lack of a reliable solution to prevent the outlet from retracting with charging cables still attached, as relying solely on an alarm system proved insufficient. Repeated observations indicated a consistent risk of damage when cables remained connected during retraction, as the alarm could not guarantee safety if no one was present to respond. Uncontrolled events, such as unattended charging, further underscored this limitation. This finding suggests the need for an additional safety feature, like an automated sensor or locking mechanism, to detect connected cables and prevent retraction in unattended conditions, thereby ensuring safe system operation.

RESEARCH METHODOLOGY

This study employed the Arduino Integrated Development Environment (IDE) to innovate a Solar-Powered Charging Station for Electronic Devices with an Arduino-based Solar Tracker System using Solar Photovoltaic (PV) Energy. According to Ismailov and Jo'Rayev (2022), the Arduino IDE is crucial in robotics and innovation due to its role as an accessible, open-source platform that simplifies the development and testing of new technologies. By providing a user-friendly environment and extensive library support, the Arduino IDE facilitates rapid prototyping and iteration, allowing researchers and innovators to transform theoretical concepts into practical applications quickly. Its flexibility in supporting various programming languages and hardware platforms further enhances its significance, making it an indispensable tool for advancing the latest projects and experimentation in robotics.

In this study, the researchers adopted but modified the protocol from Gonzales and Muyot (2022), a modified protocol to develop a charging station for electronic devices. Additionally, the researchers used the quantitative method, particularly the true experimental design, that evaluated the performance of the charging station's mechanical design, electrical design, functionalities, solar harvesting, and charging efficiency, and also in determining the significant difference in the solar harvesting ability of the designed and developed solar-powered charging station with or without a solar tracker in terms of its output voltage and output current.

According to Pubrica-Academy (2022), experimental research is a type of scientific examination in which one or more independent variables are changed and then applied to one or more dependent variables to see how they affect the latter. The effect of independent variables on dependent variables is frequently observed and recorded to help researchers reach a plausible conclusion about the link between these two variables. Further, experimental research designs, most associated with laboratory test procedures, entail gathering quantitative data and doing statistical analysis during the study process.

Materials Used

The Helecotech Charging Station comprised the following materials: a 100W Solar Panel, which provides electricity from sunlight to charge electronic devices. The Charge Controller regulates the solar panel's output, preventing overcharging and ensuring efficient charging of batteries in the solar panel system. A 12V Battery stores energy from the solar panel, providing a consistent power source for charging electronic devices. Circuit Breakers safeguard the system by interrupting power flow in case of electrical faults or overloads, enhancing safety in solar panel installations. Types of Cables/Wires used in the panel system included 4mm² DC Cables, 6mm² DC Cables, 10mm² DC Cables, and 2mm² THHN Cu Wire. These wires transmit electricity from solar panels to charge controllers, batteries, and inverters, facilitating power flow. The power inverter converts 12V DC power from the battery into 220V AC power, enabling the operation of charging electronic devices. To enhance the charging station's stability, an AC current sensor was integrated to monitor total wattage consumption. Caster wheels were added for easy transport, and insulation foam was used to resist excessive heat.

Furthermore, the supplies needed for the tracker system to retract and extend are the following materials: Arduino Uno was used as a microcontroller board used in a solar tracker panel system to control the movement of solar panels, ensuring the sun's path for maximum energy generation. Linear actuators are essential for adjusting the angle of solar panels, allowing them to tilt following the sun's movement throughout the day. Breadboard, a prototyping platform was used to connect and test various electronic components in the solar tracker panel system. Jumper wires establish electrical connections between different solar tracker panel system components, facilitating data and power transmission.

Additionally, Light-dependent resistors (LDR) were used as sensors to detect sunlight intensity, providing input to the system to determine the direction the solar panels should move. The IBT-2 motor driver controls the motors responsible for moving the solar panels, enabling precise tracking and positioning. The RTC Module detects the current time and transmits it to sub-components to manage the pop-up outlet’s extension and retraction. The DHT11 Sensor monitors the temperature at the charging station's base, sending data to the DC Fans for ventilation. The DC Fans stabilize the internal temperature to prevent overheating. The Piezo Buzzer activates during rain (when the Water Sensor detects moisture) or 30 seconds before outlet retraction, providing an audible warning. The Water Sensor detects water and alerts other components to ensure quick system responses, maintaining safety and efficiency in the charging station.

Tools Used

The HELECOTECH Charging Station employed the following equipment: The screwdriver, a manually operated tool was used for turning screws with slotted heads. Its purpose was to adjust the screws on the IBT-2 Motor Driver by either tightening or loosening them. The Arduino USB cable was widely used for collecting, transmitting, and storing data between devices. This cable was the conduit through which the code was transferred from the desktop to the Arduino Uno. The cutter plier was used to cut unnecessary wires. The drill created holes of different sizes and depths in various materials. The wire stripper accurately removed insulation or sheathing from wires, facilitating the creation of reliable and safe electrical connections. A metric tape measure was used to evaluate whichever distance needed to be measured.

Equipment Used

The researchers utilized the following instruments for their project: They employed a multimeter, also recognized as a volt-ohm meter or VOM, to gauge the project's voltage, current, and resistance. A soldering iron melted the wires of specific electrical components to form a conductive bond for electricity flow.

Paraphernalia Used

The researchers used specific paraphernalia for their project. Electrically insulated rubber gloves safeguarded users against electrical shocks and burns, while electrical goggles protected the eyes during the experiments.

PROCEDURES

A. Designing and Developing a Solar-Powered Charging Station for Electronic Devices with an Arduino-based Solar Tracker System Using Solar Photovoltaic (PV) Energy

Designing and developing the HELECOTECH Charging Station, a significant contribution to the field of renewable energy, involved integrating three core functionalities: the Photovoltaic (PV) System, the Solar Tracking System, and the deployment of a Pop-up Power Outlet. Each step in this process was crucial. Initially, all necessary materials were gathered for the Solar PV System, including a 100-watt Solar Panel, Wires/Cables, Circuit Breakers, a 20A Charge Controller, a 12-volt Battery, an Inverter, a Digital Check Meter, and a Power Outlet.

Subsequently, based on the wiring diagram for the solar panel setup, connections were established using 4mm² DC Cables to link two wires from the 100-watt Solar Panel to the 10A Circuit Breaker and then to the first two terminals of the 20A Charge Controller. Next, a 10mm² DC Cable was used to connect the third and fourth terminals of the Charge Controller to the 12-volt Battery. A 6mm² DC Cable was extended from the 12-volt Battery through the 20A Circuit Breaker to the Power Inverter. The Power Inverter was then connected to the 20A Circuit Breaker using a 2mm² THHN Cu Wire, which was extended to the Digital Check Meter. Finally, a connection was established between the Digital Check Meter and the power outlets, marking the successful integration of the HELECOTECH Charging Station.

Additionally, the development of the Solar Tracking System required the use of an Arduino Uno, two Light light-dependent resistors (LDRs), a 200mm Linear Actuator, an IBT-2 Motor Driver, Jumper Wires, a Breadboard, two 10k ohm Resistors, and a 12-volt Battery. The researchers initiated the setup by connecting the external power supply to the IBT-2 Motor Driver. The positive terminal was then attached to the B+ input on the IBT-2 Motor Driver, and the ground terminal was connected to the B-. Next, the two wires of the linear actuator were connected to the output terminals on the IBT-2, typically labeled 'M+' and 'M-.' The polarity of these connections determined the direction of movement, allowing for adjustments if the actuator moved contrary to expectations. Also, the LPWM and RPWM pins of the IBT-2 motor driver were attached to DIGITAL PINS 5 and 6 on the Arduino.

Furthermore, it was imperative to establish a voltage divider to ensure precise measurement of light intensity from the two LDRs, designated as LDR1 for the East and LDR2 for the West. To achieve this, the first leg of each LDR was linked to specific analog input pins on the Arduino, specifically ANALOG PINS A0 and A1. Additionally, one leg of a 10k ohm resistor was attached to the same analog input pins (A0 and A1) where the LDRs were connected. The other leg of each resistor was routed to the 5V on the Arduino, while the second leg of the LDRs was grounded (GND) on the Arduino. This configuration ensured accurate light intensity readings, enabling practical functionality of the solar tracking system.

Several components were required to deploy the Pop-up Power Outlet, including an Arduino Uno, 50MM linear actuator, IBT-2 Motor Driver, RTC module, Jumper wires, and a 12-volt Battery. The process began by gathering the specified components. Following this, the linear actuator's positive and negative wires were connected to the M+ and M- terminals of the IBT-2 motor driver. Connections were established between the motor driver's pins (LPWM and RPWM) and Arduino DIGITAL PINS 9 AND 10.

Moving forward, the researchers established the connections for the RTC module. The SDA pin of the RTC module was connected to A4 on the Arduino, and the SCL pin was linked to A5 on the Arduino. Finally, the VCC and GND of the RTC module were secured to the corresponding 5V and GND pins on the Arduino.

In addition, the next feature, automatic ventilation, was designed at the base of the solar charging station to house all electronic and electrical wiring. This feature stabilizes room temperature, preventing materials from overheating under direct sunlight. The LPWM and RPWM of the IBT-2 motor driver should be connected to DIGITAL PINS 11 and 3, respectively. This connection is essential as the functionality relies on readings from the DHT11, commonly called the humidity or temperature sensor. The positive, negative, and output pins of the DHT11 should be linked to the 5V, GND, and DIGITAL PIN 7 of the Arduino, respectively.

The positive wires of the two DC fans were connected to the M+ terminal and the negative wires to the M- terminal on the IBT-2 motor driver. It was crucial to ensure that the L_EN and R_EN pins of each IBT-2 motor driver utilized were connected to the 5V of the Arduino Uno.

In addition to the safety of the Charging Station, it is also monitored by a Hall Current Sensor, which detects the devices attached to the pop-up outlet. In case of a sudden shift in retraction during non-class hours, which is manipulated by the water sensor, the Arduino will override the system of not retracting it if any devices are charging in the pop-up outlet to prevent any damage to the retracted cables.

The HELECOTECH Charging Station integrates a buzzer to enhance safety. Connected to DIGITAL PIN 4 of the Arduino, the buzzer activates for 15 seconds before retracting the pop-up outlet, warning users to prevent potential hazards associated with charger damage. The process concluded by uploading the developed code into the Arduino IDE, designed to command each component effectively. Finally, the fully integrated HELECOTECH Charging Station functionalities were assessed and validated.

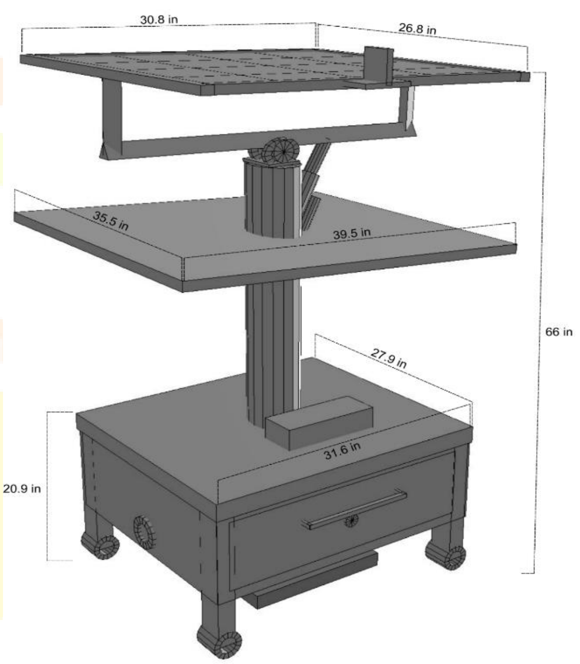


Figure 1. Blueprint of the HELECOTECH Charging Station

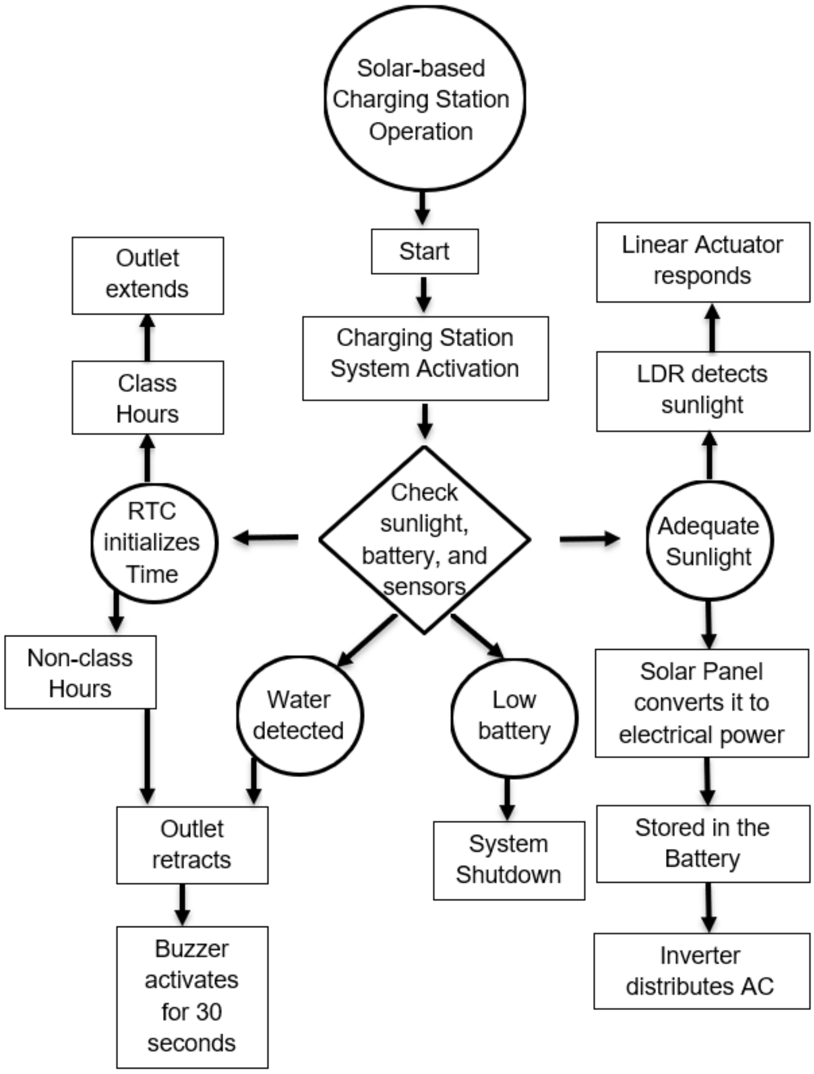
B. Hardware Implementation

This charging station comprises various device types. Its primary elements are the solar tracking system, time-indicated pop-up outlet, and automatic ventilation, which control all aspects of the HELECOTECH Charging Station. The system utilized a motor driver to initiate movement in the two linear actuators and DC fans, an LDR for detecting sunlight, and solar panels for converting sunlight into DC electricity.

1. Arduino Uno: Microcontroller board featuring digital and analog input/output pins, ideal for prototyping and DIY projects, were programmed using the Arduino IDE.
2. DC Fan: This fan provides ventilation in the project, assisting in regulating temperature by expelling hot air and drawing in cooler air for optimal conditions.
3. DH11 Sensor: The humidity and temperature sensor measures air temperature and humidity within the project's base, activating DC fans to expel hot air accordingly.
4. IBT-2 Motor Driver: This device is commonly used as a motor driver in various electronic applications, particularly in robotics and motor control projects.
5. Light Dependent Resistor: A photoresistor is a type of passive electronic component that exhibits a change in electrical resistance in response to variations in light intensity.

6. Linear Actuator: A device that converts rotational motion into linear motion, often used in various applications for precise positioning or pushing/pulling tasks.
7. RTC Module: The real-time clock module facilitates time detection for the retracting and extending phases of the time-indicated pop-up outlet, ensuring synchronized operation.
8. Solar Panels: Photovoltaic (PV) Panels or Modules consist of multiple solar cells that work together to generate electrical power when exposed to sunlight.
9. Water Sensor: The water sensor detects water presence and triggers the retracting mechanism for the pop-up outlet during rainfall, preventing damage or electrical hazards.
10. Piezzo Buzzer: This output is an alarm for the charging station, activating 30 seconds before the pop-up outlet's scheduled retraction.

Figure 2. Schematic Design



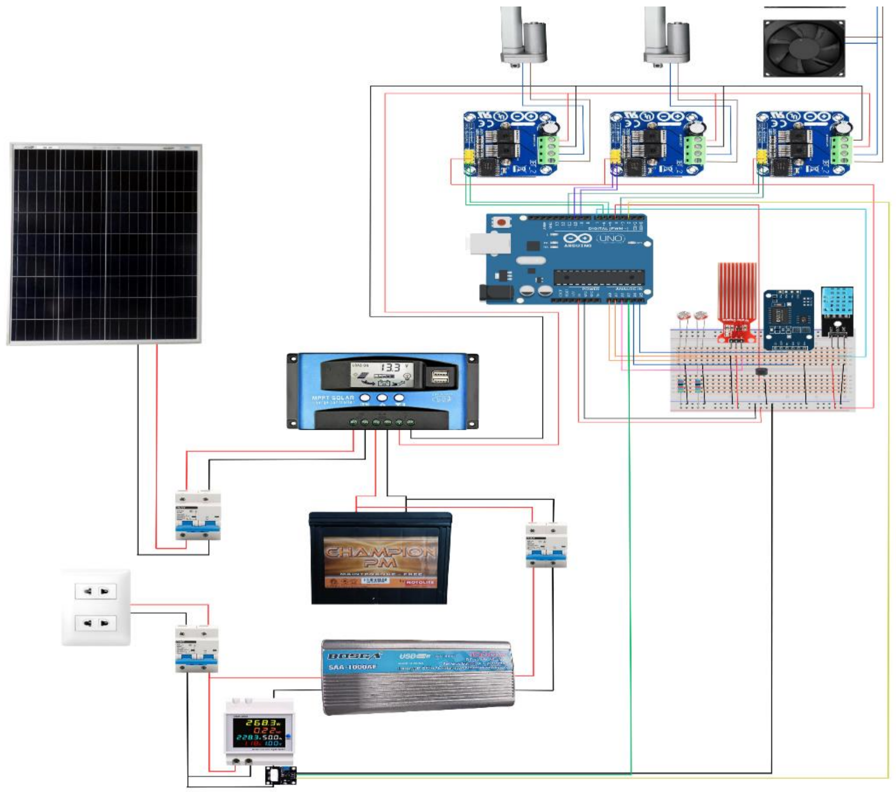


Figure 4. Wiring Diagram

C. Testing the Functionality of the Designed and Developed Project in Terms of its Mechanical Design

In testing the mechanical design, the researchers administered a checklist in the surveys, which were observed and evaluated by respondents from the EIM (Electrical Installation and Maintenance) and SMAW (Shielded Metal Arc Welding) strands.

D. Testing the Functionality of the Designed and Developed Project in Terms of its Electrical Design

In testing the electrical design, the researchers subjected the HELECOTECH Charging Station to trials using a checklist in the surveys to determine the functionality of its electrical design.

E. Testing the Functionality of the Designed and Developed Project in Terms of its Functionalities

In testing the functionalities, the researchers conducted trials of the Helecotech Charging Station, utilizing a survey checklist to evaluate the electronics' functionality.

F. Testing the Functionality of the Designed and Developed Project in Terms of its Solar Harvesting

In testing the solar harvesting, a comparative analysis was performed by assessing the voltage and current distributions within the charging station. This analysis involved 18 trials conducted with and without the automatic tilting mechanism.

G. Testing the Functionality of the Designed and Developed Project in Terms of its Charging Efficiency

In testing the charging efficiency, the researchers assessed the charging station's power consumption to determine its capacity for handling the maximum number of devices. Four devices were utilized in the experiment.

Variables of the Study

The independent variable of the study is the functional HELECOTECH Charging Station, a solar-powered grid. In contrast, the dependent variables of the study are the mechanical design, electrical design, functionalities, solar harvesting, and charging efficiency.

Data Gathering Techniques

In gathering the data during the testing of the mechanical design, electrical design, and functionalities of Helecotech, these subsequent tables of interpretation were used:

MECHANICAL DESIGN: Solar Panel Mounting

REMARKS	INTERPRETATION
Excellent (4.50-5.00)	The solar panels are optimally mounted with a well-designed system that maximizes sunlight absorption.
Very Good (3.50-4.49)	The solar panels are mounted using an effective system that enhances sunlight exposure.
Good (2.50-3.49)	The solar panels are mounted adequately, receiving a reasonable amount of sunlight.
Fair (1.50- 2.49)	The solar panels are mounted but have suboptimal positioning, limiting sunlight absorption.
Poor (1.00-1.49)	The solar panels are mounted inefficiently, with minimal consideration for sunlight exposure.

MECHANICAL DESIGN: Appropriate Sizing for Mechanical Components

REMARKS	INTERPRETATION
Excellent (4.50-5.00)	All mechanical components have been precisely sized for the intended application, achieving optimal performance and efficiency.
Very Good (3.50-4.49)	Nearly all mechanical components are correctly sized for the intended application, ensuring reliable performance with only slight deviations from the ideal.
Good (2.50-3.49)	Most mechanical components are appropriately sized for the intended application, providing satisfactory performance with minor room for improvement.
Fair (1.50- 2.49)	Some mechanical components are sized adequately, but several show noticeable mismatches that could hinder optimal performance.
Poor (1.00-1.49)	Many mechanical components are mis-sized—either overly large or too small for the intended application—resulting in poor functionality and inefficiencies.

MECHANICAL DESIGN: Durability and Outdoor Suitability

REMARKS	INTERPRETATION
Excellent (4.50-5.00)	The materials selected are exceptionally durable and ideally suited for outdoor use, ensuring superior performance and long-term reliability in all weather conditions.
Very Good (3.50-4.49)	The materials are highly durable and well-suited for outdoor use, offering robust performance with only minor concerns in extreme environments.
Good (2.50-3.49)	The materials selected are generally durable and acceptable for outdoor use, though they may require occasional maintenance under harsh conditions.
Fair (1.50- 2.49)	The materials provide minimal durability and have limited resistance to outdoor conditions, leading to potential issues with longevity and reliability.
Poor (1.00-1.49)	The materials selected for the mechanical components show inadequate durability and are unsuitable for outdoor use, resulting in rapid degradation under environmental exposure.

MECHANICAL DESIGN: Mechanical Layout

REMARKS	INTERPRETATION
Excellent (4.50-5.00)	The mechanical layout is expertly designed to endure a wide range of environmental conditions, ensuring superior resistance to wind, rain, and temperature variations for long-term, reliable performance.
Very Good (3.50-4.49)	The mechanical layout is robustly engineered to withstand environmental factors, effectively coping with wind, rain, and temperature variations with only minor vulnerabilities in extreme cases.
Good (2.50-3.49)	The layout is adequately designed to handle common environmental conditions, offering reasonable resistance to wind, rain, and temperature variations, though it may struggle under extreme circumstances.
Fair (1.50- 2.49)	The layout provides minimal protection against environmental influences; while some basic measures are in place, significant exposure to wind, rain, and temperature variations may compromise performance.
Poor (1.00-1.49)	The mechanical layout shows little to no consideration for environmental factors, making it highly vulnerable to damage from wind, rain, and temperature variations.

ELECTRICAL DESIGN: Electrical Component Sizing

REMARKS	INTERPRETATION
Excellent (4.50-5.00)	All electrical components are precisely sized for the expected power loads, guaranteeing optimal safety, efficiency, and reliable system performance.
Very Good (3.50-4.49)	Nearly all electrical components are correctly sized, ensuring safe and efficient operation with only minor deviations that have little overall impact.
Good (2.50-3.49)	Most electrical components are appropriately sized for the expected power loads, providing acceptable safety and efficiency, though there is room for improvement.
Fair (1.50- 2.49)	Some electrical components are sized correctly, but several are inadequately matched to the expected power loads, resulting in occasional safety and efficiency issues.
Poor (1.00-1.49)	The electrical components are significantly mis-sized for the expected power loads, leading to serious safety risks and inefficient system performance.

ELECTRICAL DESIGN: Electrical Connections

REMARKS	INTERPRETATION
Excellent (4.50-5.00)	All electrical connections are meticulously secured and fully insulated, providing comprehensive protection against short circuits and hazards, and ensuring optimal system integrity and safety.
Very Good (3.50-4.49)	The majority of electrical connections are well-secured and insulated, effectively minimizing risks of short circuits or hazards, thereby ensuring robust system integrity and safety.
Good (2.50-3.49)	Most electrical connections are generally secure and adequately insulated, offering acceptable protection against short circuits and hazards, though minor improvements are still needed.
Fair (1.50- 2.49)	Basic security and insulation measures are in place, but some connections remain vulnerable, potentially resulting in intermittent short circuits or safety concerns.

Poor
(1.00-1.49) Electrical connections are insecure and poorly insulated, leading to a high risk of short circuits and hazards that severely compromise system integrity and safety.

ELECTRICAL DESIGN: Electrical Fault Protection

REMARKS	INTERPRETATION
Excellent (4.50-5.00)	Comprehensive and highly reliable protection mechanisms are implemented, fully safeguarding the system and its components against overcurrent, overvoltage, and all identified electrical faults, thereby ensuring optimal safety and performance.
Very Good (3.50-4.49)	Robust protection systems effectively mitigate the risks associated with overcurrent, overvoltage, and other electrical faults, ensuring most components are well-protected under a wide range of conditions.
Good (2.50-3.49)	Adequate protection measures are in place to handle typical overcurrent, overvoltage, and electrical faults, offering reasonable safeguarding of the system and its components, though extreme events might still pose risks.
Fair (1.50- 2.49)	Basic protective measures are implemented, but they are insufficient against severe overcurrent, overvoltage, and other faults, which could still lead to potential damage or malfunctions under certain conditions.
Poor (1.00-1.49)	The system provides minimal to no protection against overcurrent, overvoltage, and other electrical faults, leaving components highly vulnerable to damage or malfunction.

ELECTRICAL DESIGN: Arduino Wiring

REMARKS	INTERPRETATION
Excellent (4.50-5.00)	The Arduino wiring has been meticulously inspected, with all connections verified as secure and correctly configured, ensuring optimal and reliable system performance.
Very Good (3.50-4.49)	A thorough inspection of the Arduino wiring confirmed that nearly all connections are secure and correctly implemented, resulting in reliable performance.
Good (2.50-3.49)	The Arduino wiring has been inspected, with most connections verified, ensuring generally proper functioning, though minor issues may persist.
Fair (1.50- 2.49)	The wiring was inspected, but several errors and loose connections were overlooked, leading to intermittent functionality problems.
Poor (1.00-1.49)	The Arduino wiring shows significant issues; inspection was either incomplete or ineffective, resulting in numerous wiring faults and unreliable performance.

FUNCTIONALITIES: Solar Tracker Actuator

REMARKS	INTERPRETATION
Excellent (4.50-5.00)	The Solar Tracker Actuator extends or retracts based on the light reading of less than 1 second.
Very Good (3.50-4.49)	The Solar Tracker Actuator extends or retracts based on the light reading of more than 2 seconds.
Good (2.50-3.49)	The Solar Tracker Actuator extends or retracts based on the light reading of more than 3 seconds.
Fair (1.50- 2.49)	The Solar Tracker Actuator extends or retracts based on the light reading of less than 4 seconds.
Poor (1.00-1.49)	The Solar Tracker Actuator extends or retracts based on the light reading of less than 5 seconds.

FUNCTIONALITIES: Time-Indicated Pop-Up Outlet Actuator

REMARKS	INTERPRETATION
Excellent (4.50-5.00)	The Time-Indicated Pop-up Outlet Actuator functions flawlessly, extending or retracting precisely as per the indicated time in the class and non-class hours schedule with consistent reliability.
Very Good (3.50-4.49)	The Time-Indicated Pop-up Actuator performs well, with only minor issues such as fluctuations in the extension and retraction based on time that do not affect overall functionalities.
Good (2.50-3.49)	The Time-Indicated Pop-up Outlet Actuator generally operates as intended, though there are occasional inconsistencies such as fluctuations and its extension and retraction and does not meet the exact time schedule.
Fair (1.50- 2.49)	The Time-Indicated Pop-up Outlet Actuator meets the basic functionality of extending or retracting but does not meet the exact time schedule. Frequently encounter errors or delays.

Poor
(1.00-1.49) The Time-Indicated Pop-up Outlet Actuator fails to consistently extend or retract as per the indicated time, significantly affecting its reliability and usefulness.

FUNCTIONALITIES: Time-Indicated Pop-Up Outlet Actuator (When detecting water)
REMARKS INTERPRETATION

Excellent
(4.50-5.00) The Time-Indicated Outlet retracts without delay when detecting water. The response is highly accurate, consistent, and reliable under all tested conditions, ensuring maximum safety and efficiency.
Very Good
(3.50-4.49) The Time-Indicated Outlet reliably retracts upon detecting water, with only slight delays or occasional minor inconsistencies, such as fluctuations in the extension and retraction based on time that do not compromise overall safety.
Good
(2.50-3.49) The Time-Indicated Outlet generally retracts when water is detected, but there are noticeable delays or occasional false triggers. While functional, improvements in response time and sensitivity are necessary to enhance reliability.
Fair
(1.50- 2.49) The Time-Indicated Outlet struggles with consistent water detection, often retracting late or requiring repeated exposure to water to activate. It may pose a safety risk in environments where timely response is critical.
Poor
(1.00-1.49) The Time-Indicated Outlet fails to retract upon detecting water in most cases. It exhibits significant functional issues, such as delayed or non-existent responses, making it unsuitable for use in safety-critical environments.

FUNCTIONALITIES: DC/Exhaust Fan
REMARKS INTERPRETATION
Excellent
(4.50-5.00) The DC / Exhaust Fans work when detecting beyond 36 degrees Celsius.
Very Good
(3.50-4.49) The DC / Exhaust Fans activate consistently when temperatures exceed 36°C, with only minor delays in schedule or slight inconsistencies in activation speed.
Good
(2.50-3.49) The DC / Exhaust Fans operate when temperatures go beyond 36°C. However, there are occasional delays, false activations, or inefficiencies in maintaining consistent airflow, requiring adjustments to enhance reliability.
Fair
(1.50- 2.49) The DC / Exhaust Fans function intermittently, with noticeable delays or failures to activate when the temperature surpasses 36°C.
Poor
(1.00-1.49) The DC / Exhaust Fans fail to activate in most instances when the temperature exceeds 36°C. The system shows critical flaws in temperature detection or fan operation, rendering it ineffective for its intended purpose.

Statistical Analysis

The acceptance or rejection of the null hypothesis in this study was determined through a time series t-test, used to identify significant differences in voltage and current outputs between systems with and without a solar tracker.

All statistical tests were conducted at a 0.05 significance level.

IV. RESULTS AND DISCUSSION

Innovation of the Solar-Powered Charging Station for Mobile Devices with an Arduino-based Solar Tracker System (Helecotech)

The functional prototype of the solar charging station was not just developed but also meticulously crafted. It involved the acquisition of requisite components, comprising a *100*-watt Solar Panel, *12*V Battery, Charge Controller, Arduino Uno, Breadboard, Power Inverter, Circuit Breakers, DC Fan, DH*11* Sensor, IBT-*2* Motor Driver, Jumper Wires, Light Dependent Resistor (LDR), Linear Actuator, RTC Module, and Wires/Cable. The researchers then uploaded the pre-established programming codes that utilized the Arduino Integrated Development Environment (IDE), interfacing with a desktop/laptop system via an Arduino cable to ensure seamless transmission of commands to the innovation. Expert guidance from an electrician was sought to facilitate the correct configuration of the solar panel system, followed by its integration with the Arduino program to realize functional aspects such as the solar tracking mechanism, time-indicated pop-up outlets, and automated ventilation, each of the electrical and electronic components housed within the structure's base.

Upon completing the assembly process, the researchers refined the innovation by applying a coat of paint in their preferred color scheme. The testing phase was then undertaken to ascertain the functional integrity of the charging station. The mechanical design underwent a comprehensive scale-testing checklist assessing the efficacy of their respective mechanisms. In contrast, electrical designs were scrutinized for adherence to safety standards in electrical configuration. Functional assessments were conducted, culminating in the invention of the program by a scale-testing checklist. The evaluation process was observed by Grade *12* students and faculty from the Electrical Installation and Maintenance (EIM) and Shielded Metal Arc Welding (SMAW) departments, serving as impartial observers. These evaluative objectives were devised to ascertain the efficacy and functionality of the innovation. Furthermore, the researchers conducted empirical investigations into solar harvesting by comparing the output voltage and current of the solar panel under conditions of solar tilting and static orientation. Charging efficiency was meticulously observed and quantified to delineate the maximum wattage output attainable from the charging station.

The automatic solar tracker employed by a Light Dependent Resistor (LDR) was the response to the pressing challenges posed by the energy crisis and the environmental repercussions of conventional energy sources. Renewable alternatives have gained significant attention. Solar energy is a pivotal solution among these alternatives due to its cleanliness and reliability. However, realizing its full potential necessitates optimizing solar panel efficiency by amalgamating sensor technology; this system accurately determines the sun's position, thus enhancing solar energy capture across various weather conditions. Integrating such innovative technologies underscores the critical role of solar tracking in advancing sustainable energy utilization. This innovation mitigates environmental impacts and reduces dependence on traditional energy sources by facilitating more efficient solar energy collection, marking a significant stride toward a more sustainable future (Román-Raya et al., 2020).

The Arduino ATMEGA-*328* microcontroller, a cornerstone in contemporary technological applications, plays a pivotal role in the solar charging station. Its inherent programmability and adaptability make it a versatile platform conducive to diverse applications. In practice, initializing the microcontroller involves establishing a connection to a computer via a power jack cable, thereby enabling program execution. The focal point of this paper lies in the comprehensive examination of the Arduino UNO ATMEGA-*328* microcontroller, delving into its multifaceted utility within computer applications. Central to its functionality is the Arduino software, which serves as a conduit for program editing and uploading, predominantly leveraging the C and C++ programming languages. Distinguished by its array of *14* analog and digital input/output pins, including six Pulse Width Modulation (PWM) pins, the microcontroller offers a versatile platform conducive to diverse applications ranging from motor control to valve management. The industrial realm accentuates its efficacy, particularly in actuator and sensor control, thereby underscoring its pivotal role in automation frameworks. The paper elucidates the architectural intricacies and technical specifications characterizing the ATMEGA-*328* microcontroller, highlighting its analog and digital input capabilities, pulse width modulation functionalities, and requisite power parameters. Furthermore, the microcontroller's versatility extends to various engineering ventures, facilitated by its seamless compatibility with various processors. Harnessing the potential of Arduino microcontrollers empowers engineers to exert precise control over processes and systems, leveraging their innate programmability and adaptability to tailor solutions that align with the exigencies of specific applications (Halder et al., 2021).

Testing of the Innovative Solar-Powered Charging Station for Mobile Devices with an Arduino-based Solar Tracker System

The study aimed to evaluate the performance of the innovative solar-powered charging station, incorporating an Arduino-based solar tracker system, across various domains, including mechanical design, electrical design, functionalities, solar harvest, charging efficiency, and statistical analysis. A systematic set of trials was conducted to ascertain the outcomes of these assessments, guided by a predefined checklist. The respondents of this capstone project were from the EIM (Electrical Installation and Maintenance) and SMAW (Shielded Metal Arc Welding) strands at Colon National High School. Detailed outcomes of these evaluations are presented in Tables *1-7.*

Table 1. *Average Score of the Mechanical Design Testing Results*

Mechanical Designs	Mean		Interpretation	
	EIM	**SMAW**	**EIM**	**SMAW**
The solar panels are mounted using a suitable mounting system to optimize sunlight exposure.	4.79	5	Excellent	Excellent
All mechanical components have been appropriately sized for the intended application.	4.86	4.31	Excellent	Very Good
The materials selected for the mechanical components are durable and suitable for outdoor use.	3.86	4.81	Very Good	Excellent
The mechanical layout is designed to withstand environmental factors such as wind, rain, and temperature variations.	3.97	4.63	Very Good	Excellent
AVERAGE	**4.53**		**Excellent**	

The table presents the average score of the mechanical design testing results, evaluating different aspects of the mechanical design based on two criteria by EIM (Electromechanical Installation and Maintenance) and SMAW (Shielded Metal Arc Welding). The results are assessed using a rating scale with corresponding interpretations for each criterion.

The highest rating was given to the mounting system for solar panels, with EIM scoring *4.79* and SMAW scoring *5.00*, both interpreted as Excellent. This indicates that the mounting system effectively optimizes sunlight exposure, ensuring efficient energy absorption. Additionally, the appropriate sizing of mechanical components received high ratings, with EIM at *4.86* (Excellent) and SMAW at *4.31* (Very Good). This suggests that the components were well-matched to their intended application, ensuring functional reliability. Also, the material selection for mechanical components received *3.86* (Very Good) from EIM and *4.81* (Excellent) from SMAW, highlighting that the materials used are durable and suitable for outdoor conditions. Lastly, the mechanical layout's ability to withstand environmental factors such as wind, rain, and temperature variations scored *3.97* (Very Good) in EIM and *4.63* (Excellent) in SMAW, suggesting that the design is well-prepared for external environmental challenges.

On average, the overall mechanical design received a score of *4.53*, interpreted as Excellent. This indicates a well-engineered system that meets high standards in terms of durability, efficiency, and environmental resilience. The slightly lower ratings in material selection and environmental resistance suggest areas for minor improvements, particularly in ensuring consistent performance under varying conditions.

Implications

The results of the mechanical design testing indicate that the system is highly efficient and well-engineered, with an overall "Excellent" rating. The high scores in solar panel mounting and component sizing suggest that the design effectively maximizes energy absorption and ensures proper functionality. This implies that the system can operate at optimal performance levels, reducing energy losses and increasing long-term reliability. Additionally, the durability and environmental resistance scores suggest that the materials and layout are well-suited for outdoor conditions, though some improvements may be necessary. Enhancing these aspects could further strengthen the system's resilience against extreme weather, ensuring consistent operation in various climates.

From a practical standpoint, these findings suggest that the mechanical design is highly suitable for real-world applications, particularly in renewable energy projects. The excellent mounting system ensures optimal sunlight exposure, which could lead to higher energy efficiency and better return on investment. However, the slightly lower scores in material durability and environmental resistance indicate the need for additional testing or material enhancements. Future improvements, such as using weather-resistant coatings or stronger materials, could extend the lifespan of the system. Overall, these results support the feasibility of implementing this design in sustainable energy solutions while highlighting areas for potential optimization.

According to Ríos et al. (2016), a well-designed charging station utilizing durable materials showcases its mechanical functionality through rigorous testing. An angle bar is essential for the station's structural integrity, offering significant support and stability. This design choice contributes to a robust mounting framework and enhances the station's resilience against environmental challenges such as wind and weather variations. Furthermore, the careful placement and secure fitting of the solar panel optimize energy capture and operational efficiency, which is vital for maintaining overall performance in fluctuating environmental conditions.

Additionally, hardwood was utilized to construct a robust and resilient enclosure for the station's electronics and electrical systems. These veneers provide a durable, protective barrier that protects internal components from external damage, including harsh weather conditions. Renowned for their exceptional strength and longevity, hardwood veneers are particularly well-suited for safeguarding sensitive electronics in demanding outdoor environments. Moreover, using these veneers enhances the enclosure's structural integrity and contributes to the overall aesthetic appeal of the station. This thoughtful design choice underscores the importance of functionality and appearance in constructing durable outdoor electronic systems (Ríos et al., 2016).

Table 2. *Average Score of the Electrical Design Testing Results*

Electrical Designs	Mean		Interpretation	
	EIM	SMAW	EIM	SMAW
Properly sizing all electrical components for expected power loads is essential for safe and efficient system operation.	4.21	4.25	Very Good	Very Good
Ensuring all electrical connections are secure and insulated to prevent short circuits or hazards is imperative for system integrity and safety.	4.21	4.94	Very Good	Excellent
Providing adequate protection against overcurrent, overvoltage, and other electrical faults safeguards the system and its components from damage or malfunction.	4.57	4.94	Excellent	Excellent
The Arduino wiring has been thoroughly inspected to ensure proper functioning.	4.77	4.94	Excellent	Excellent
AVERAGE	**4.60**		**Excellent**	

The table presents the average score of the electrical design testing results, assessing different aspects of the electrical system based on the evaluation criteria of both EIM (Electromechanical Installation and Maintenance) and SMAW (Shielded Metal Arc Welding). The overall average score for the electrical design is *4.60*, which falls under the "Excellent" category, indicating a well-structured and efficiently designed system. The highest rating was given to Arduino wiring inspection, with EIM scoring *4.77* and SMAW scoring *4.94*, both interpreted as "Excellent", suggesting that the wiring was thoroughly checked to ensure proper functionality. Similarly, protection against electrical faults such as overcurrent and overvoltage received high ratings, with EIM at *4.57* and SMAW at *4.94*, highlighting the system's strong safeguard mechanisms against potential electrical damage.

Other components of the electrical design, such as proper sizing of electrical components and secure electrical connections, received slightly lower scores, with EIM at *4.21* and SMAW at *4.25–4.94*, interpreted as "Very Good" to "Excellent." These scores indicate that while the system is generally well-designed, there may still be room for minor improvements in ensuring secure connections and properly sizing components for power load distribution. The secure insulation of electrical connections was particularly rated *4.21* (Very Good) by EIM and *4.94* (Excellent) by SMAW, emphasizing that while the system is well-protected against short circuits and hazards, additional refinements in installation techniques could further improve reliability. Overall, the high ratings across all categories suggest that the electrical design is safe, reliable, and efficient, making it well-suited for practical applications while still leaving opportunities for minor optimizations in component sizing and connection security.

Implications

The results of the electrical design testing suggest that the system is highly efficient, safe, and well-structured, as reflected in its overall "Excellent" rating. The high scores for Arduino wiring inspection and electrical fault protection indicate that the system is properly safeguarded against malfunctions, ensuring reliability in real-world applications. This implies that the design minimizes risks associated with electrical failures, reducing maintenance costs and improving operational longevity. However, the slightly lower ratings in component sizing and secure connections suggest that minor refinements may still be necessary to enhance performance. Addressing these areas could further optimize energy distribution and prevent potential issues related to improper load balancing or loose wiring.

From a practical perspective, these findings reinforce the suitability of the electrical design for long-term use in various applications, including renewable energy systems and automation projects. The strong ratings in fault protection and wiring inspection suggest that the system can withstand electrical fluctuations, making it ideal for environments where stability is crucial. However, improving component sizing and insulation methods could lead to even greater efficiency and durability, ensuring that the system operates at peak performance under different conditions. Implementing additional quality control measures and refining installation techniques could further enhance safety and reliability. Overall, these results highlight a well-engineered electrical system that is ready for deployment while offering opportunities for continuous improvement.

Also, the positive feedback from respondents indicates that the design effectively addresses common challenges associated with electricity distribution, such as minimizing voltage drops and reducing power losses. This suggests that the design has been meticulously developed to prioritize operational efficiency and safety. Such a high rating provides confidence in the station's ability to perform reliably over the long term (Gonzales & Muyot, 2022).

The components used, including PV wires, charge controllers, and DC/AC circuit breakers, were selected with great precision to ensure their compatibility and optimal functionality within the system. The high score indicates that these components have been successfully integrated to enhance the overall operation of the charging station. Furthermore, this design aligns with industry standards, mirroring the rigorous guidelines set forth by Gonzales and Muyot (2022). Their work emphasizes the importance of precise component selection and placement for superior electrical system performance. This alignment with established standards reinforces the design's credibility and suggests it may surpass typical performance expectations.

Table 3. *Average Score of the Functionalities Testing Results*

Functionalities	Mean		Interpretation	
	EIM	SMAW	EIM	SMAW
The Solar Tracker Actuator extends or retracts based on the light reading.	4.71	5	Excellent	Excellent
The Time-Indicated Pop-up Outlet Actuator extends or retracts based on the time.	4.64	4.88	Excellent	Excellent
The Time-Indicated Outlet retracts when detecting water.	4.71	5	Excellent	Excellent
The DC / Exhaust Fans work when detecting beyond 36 degrees Celsius.	4.86	5	Excellent	Excellent
AVERAGE	**4.85**		**Excellent**	

The table presents the average score of the functionalities testing results, evaluating different automated functions based on the ratings from EIM (Electromechanical Installation and Maintenance) and SMAW (Shielded Metal Arc Welding). The overall functionality of the system received an average score of *4.85*, interpreted as "Excellent," indicating that the automated features performed effectively and reliably. Among the tested functions, the DC/Exhaust Fans, which activate when the temperature exceeds 36°C, received the highest rating of *4.86* (EIM) and *5.00* (SMAW), both classified as "Excellent." This suggests that the thermal regulation system is highly responsive and dependable in maintaining optimal conditions. Similarly, the Solar Tracker Actuator, which adjusts based on light readings, and the Time-Indicated Outlet, which retracts upon detecting water, both received scores of *4.71* (EIM) and *5.00* (SMAW), highlighting their effectiveness in adapting to environmental conditions.

Additionally, the Time-Indicated Pop-up Outlet Actuator, which extends or retracts based on time, received slightly lower scores of *4.64* (EIM) and *4.88* (SMAW), still interpreted as "Excellent." This implies that while the function operates effectively, minor refinements in precision or responsiveness may further enhance its performance. The consistently high ratings across all functionalities indicate that the system's automation features are well-implemented, ensuring reliable operation in different scenarios. The Excellent ratings suggest that these functions contribute to increased efficiency, safety, and automation, making the system highly suitable for real-world applications. While the results affirm the strong functionality of the design, continuous optimization and refinement could further improve responsiveness and long-term performance.

Implications

The Arduino program received a notable score of *4.85*, reflecting its high effectiveness and the superior quality of its functional components. This score highlights the program's excellent performance, particularly in operating output devices such as linear actuators and DC fans. The robust design and quality materials improve the program's reliability in these critical applications.

The high rating signifies that the program is well-optimized for managing various system functions efficiently. Overall, the program demonstrates outstanding functionality and effectiveness.

However, a minor issue has been identified in the light reading configuration and the Real-Time Clock (RTC) Module's ability to detect precise dates and times. While this minor error does not significantly compromise the overall functionality, it requires attention to enhance the program's accuracy and reliability. Correcting this issue will improve the precision of time-dependent operations, which is crucial for applications requiring accurate environmental monitoring. Addressing this concern will ensure that the program functions with the highest level of reliability. This adjustment is essential for maintaining the program's overall performance (Raj, Srivasan, Vijay, & Pranav, 2023).

The time gap set within the program is a crucial factor influencing the performance of the linear actuators. This time gap determines how frequently the program evaluates sensor data and actuates the actuators. An incorrect time gap can lead to delays or inaccuracies in the actuators' responses to environmental changes. Optimizing the time gap settings is vital for ensuring prompt and accurate actuator adjustments. Proper configuration will enhance the system's efficiency and responsiveness.

Addressing the RTC Module's accuracy and optimizing the time gap settings in the Arduino program will resolve the identified issues and enhance the program's overall performance. Improvements in these areas will ensure that the program operates more precisely and effectively. This will contribute significantly to the program's reliability in managing and controlling output devices. Such enhancements are essential for effectively meeting the system's operational demands. The program will reach its full potential and sustain its high performance by resolving these issues, including those related to the Arduino setup (Alam, Kader, Hossain, Noushin, Alam, & Farid, 2021).

Table 4. *Comparative Results of the Solar Harvest Testing*

Trials	Time	Output Voltage (V)		Output Current (A)	
		Without Solar Tracker	With Solar Tracker	Without Solar Tracker	With Solar Tracker
1	8:00 AM	13.54	14.40	1.8	2.9
2	9:00 AM	14.40	14.80	2.5	2.1
3	10:00 AM	14.70	15.20	3.2	3.7
4	11:00 AM	14.90	15.70	3.4	4.5
5	12:00 PM	15.00	14.80	3.3	3.5
6	1:00 PM	14.90	15.60	3.1	3.8
7	2:00 PM	14.10	15.30	2.1	3.5
8	3:00 PM	14.00	15.30	1.9	3.2
9	4:00 PM	13.04	15.40	0.3	2.3
AVERAGE		**14.29V**	**15.17V**	**2.4A**	**3.28A**

Table *4* presents the experimental findings regarding solar harvest conducted without incorporating a linear actuator for tilting within the Arduino program, designed to function as a solar tracking system. Throughout the experimental trials, the solar panel remained fixed at a *180*-degree angle relative to the horizon. This setup resulted in varied readings across multiple trials, suggesting that solar rays were inconsistent with the sun's position. Notably, the output voltage and current reached their nadir during the final trial as the sun approached the horizon's edge, deviating from the solar panel's orientation. Conversely, the most significant increase in solar harvest occurred between trials *4* and *5*, transpiring from *11:00* AM to *12:00* PM, coinciding with the solar panel's optimal alignment with the sun during midday.

The table also presents a supplementary set of experiments incorporating an automated solar tracking system designed to follow the trajectory of solar rays. Across the testing period, the output voltage and current exhibited marginal deviations, albeit with minimal fluctuations. The integration of the solar tracker notably influenced the distribution of harvested energy, contrasting with the results obtained without its implementation. A substantial disparity in solar yield is evident between scenarios employing and omitting the solar tracking system.

Nine trials were undertaken to maintain methodological consistency and enhance the reliability of the measurements. The average output voltage and current for these trials are presented as follows:

$V_{avg.nt} = 14.29$ Volts
$I_{avg.nt} = 2.4$ Amperes
$V_{avg.t} = 15.17$ Volts
$I_{avg.t} = 3.28$ Amperes

Here, $V_{avg.nt}$ represents the average output voltage of the solar harvest without the solar tracker, and $I_{avg.nt}$ denotes the average output current. Conversely, $V_{avg.t}$ represents the average output voltage of the solar harvest with the solar tracker, and $I_{avg.t}$ denotes the average output current.

The mathematical concept of the percentage increase in voltage and current between the solar harvest with and without the solar tracker can be elucidated. By applying the formula for percentage increase in voltage:

Percentage Increase in Voltage = $[(V_{avg.t} - V_{avg.nt}) / V_{avg.nt}] \times 100$
Percentage Increase in Voltage = $[(15.17 - 14.29) / 14.29] \times 100$
Percentage Increase in Voltage = $(0.88 / 14.29) \times 100$
Percentage Increase in Voltage = $(0.06158) \times 100 \approx 6.158\%$
The percentage increase in voltage is *6.16*%

By applying the formula for percentage increase in current:

Percentage Increase in Current = $[(I_{avg.t} - I_{avg.nt}) / I_{avg.nt}] \times 100$
Percentage Increase in Current = $[(3.28 - 2.4) / 2.4)] \times 100$

Percentage Increase in Current = (*0.88* / *2.4*) × *100*
Percentage Increase in Current = (*0.36667*) × *100* ≈ *36.67*%
The percentage increase in current is *36.67*%

The analysis delineates the percentage of amplification in both voltage and current consequent to integrating the solar tracking mechanism. Notably, this charging station's solar harvesting potential is *100*% functional, evidenced by the cohesive cooperation of its constituent components, leading to discernible enhancements in voltage and current parameters.

Implications

The experimental results highlight the significant impact of integrating solar tracking systems on the efficiency of solar energy harvest. By comparing scenarios with and without tracking mechanisms, it became evident that fixed solar panels produce inconsistent energy outputs due to the sun's changing angle and intensity throughout the day. Using a solar tracker enhanced the stability of energy capture and maximized output during peak sunlight hours, demonstrating a clear advantage in optimizing solar panel performance. This finding is crucial for the advancement of solar technology. Moreover, the improved efficiency of solar tracking systems can lead to lower energy costs and a higher return on investment for solar energy users. These results support the development of more adaptive and intelligent renewable energy solutions that respond dynamically to environmental conditions.

The implications of these findings extend to practical applications across various sectors, indicating that the adoption of solar tracking technology can enhance the economic viability of solar installations. According to Muyot and Gonzales (2022), increased energy output effectively meets residential and commercial energy demands while advancing broader sustainability objectives. Stakeholders can reduce reliance on conventional energy sources by investing in tracking systems and fostering environmental protection and energy security. As renewable energy sources gain prominence worldwide, integrating solar tracking technology represents a significant advancement towards optimizing solar power potential, facilitating the transition to sustainable energy systems. In addition to this, deploying solar trackers could also help generate more clean energy worldwide, supporting global efforts at carbon emission reductions. Governments and industries should begin to incentivize the adoption of this technology to accelerate the pace of a greener and cleaner future.

Table 5. *Charging Efficiency Testing Results*

Set	Quantity	Devices	Watts	Watt-hour	Hours Used
1	2	Smartphones	**30**	**144**	**2.4**
	2	Laptops	**45**	**216**	
2	1	Standard Stand Fan	**70**	**193.85**	**2.77**
	1	32-inch Smart TV	**60**	**166.15**	

The table presents the charging efficiency testing results, detailing the power consumption of various electronic devices under different sets. Set *1* consists of two smartphones and two laptops, and each of these devices has different wattage and energy consumption. The two smartphones that used *30* watts resulted in *144* watt-hours after *2.4* hours. The laptops with *45* watts consumed *216* watt-hours after the same amount of time. For Set *2*, the standard stand fan, at *70* watts, had a consumption of *193.85* watt-hours while running for *2.77* hours. Further, the consumption of *60* watts was made by a *32*-inch Smart TV, thus consuming *166.15* watts-hours, with the same time for running, which is *2.77* hours.

These results highlight the variability in power consumption across different devices, with laptops demonstrating the highest energy usage among the tested items due to their prolonged operation and higher wattage. The findings suggest that charging and running multiple devices simultaneously requires careful energy management to optimize efficiency and prolong battery life in off-grid systems. The data also underscores the importance of using energy-efficient devices to reduce power consumption, particularly in renewable energy setups or battery-dependent applications. The recorded watt-hour values provide insights into the overall energy demands of each device, which can be useful for designing solar energy systems or backup power solutions. Overall, these results emphasize the significance of power consumption monitoring and energy optimization in ensuring sustainable and efficient electricity use across various electronic devices.

Implications

Based on the data presented, the total energy consumption of two smartphones and two laptops amounted to *360* watt-hours (Wh), with smartphones consuming *144* Wh and laptops consuming *216* Wh over *2.4* hours of combined usage. Another set of devices, a standard stand fan and a *32*-inch Smart TV, consumes *193.85* Wh and *166.15* Wh, respectively, with a combined usage time of *2.77* hours. This energy demand is directly correlated with the capacity of a *30* amp-hour (Ah) battery operating at *12* volts, which provides *360* Wh of energy.

This calculation implied that a fully charged *30*Ah battery could power the listed devices for their respective usage durations without requiring an additional power source. The battery capacity precisely matched the total watt-hour consumption of the smartphones and laptops combined, indicating its potential adequacy for this specific use case. However, real-world inefficiencies must be considered, such as energy losses during charging or power conversion. These factors could have reduced the battery's effective output, potentially necessitating a larger capacity to account for energy loss and ensure uninterrupted use. Furthermore, adding other devices or longer usage times would have exceeded the battery's capacity, highlighting the need for careful consideration of total energy consumption when selecting an appropriate battery size (Tran et al., 2021).

Table 6. *Significant Difference in Output Voltage (V) With or Without Solar Tracker*

	Test	N	Mean (M)	Standard Deviation (SD)	t-value	df	p-value	Remarks (2-tailed)
Output Voltage	Without Solar Tracker	9	14.29	0.68	-3.30	8	0.000	Significant
	With Solar Tracker	9	15.17	0.42				

The table presents a statistical comparison of output voltage (V) between the Helecotech with and without a solar tracker. The findings indicate that the mean output voltage for the system with a solar tracker is *15.17*V, whereas the system without a tracker has a lower mean voltage of *14.29*V. Besides, the standard deviation for the system with the tracker is *0.42* compared to *0.68* without the tracker. This indicates that the output of the voltage was stable in case a solar tracker was employed. The t-value of *-3.30* and p-value of *0.000* are below the significance threshold of *0.05*. This is proof that the observed difference is statistically significant. This would mean that with a solar tracker, the collection of solar energy is more efficient and reliable.

These results align with other research studies that proved the advantages of solar tracking systems. A study by Abdallah and Nijmeh (2004) found that single-axis solar tracking systems can increase solar panel efficiency by *25-30*%, while Koussa (2011) reported even greater efficiency gains with dual-axis tracking systems, especially in regions with varying solar angles. Similarly, Roth (2005) observed that solar trackers enhance power output, particularly during peak sunlight hours, which aligns with the lower standard deviation seen in the table. Moreover, Patil and Ramkrishna (2017) mentioned that solar tracking systems minimize power generation fluctuations to allow for a more consistent and reliable supply of energy. Since solar trackers entail a high initial cost, Mousazadeh (2009) found that increased energy yield results in payback shorter than the time of investment.

Overall, the conclusions drawn from the table results are based on the universal acceptance that a solar tracking system improves PV performance. Allowing the orientation of the panel concerning the sun increases the output voltage, promotes stability, and maximizes the efficiency of the energy. In this regard, solar trackers play a very beneficial role in developing the effectiveness of solar power systems.

Table 7. *Significant Difference in Output Current (A) With or Without Solar Tracker*

	Test	N	Mean (M)	Standard Deviation (SD)	t-value	df	p-value	Remarks (2-tailed)
Output Current	Without Solar Tracker	9	2.40	1.00	-2.10	8	0.048	Significant
	With Solar Tracker	9	3.28	0.75				

The table presents a statistical analysis of the significant difference in output current (A) between systems with and without a solar tracker. The sample size for both conditions is *N=9*. The mean output current without a solar tracker is *2.40* A with a standard deviation of *1.00*, while the mean output current with a solar tracker is higher at *3.28* with a lower standard deviation of *0.75*. A paired t-test was conducted to determine whether the difference between these means is statistically significant. The calculated t-value is *-2.10*, with *8* degrees of freedom (df), and the corresponding p-value is *0.048*. Since this p-value is less than the conventional significance level of *0.05*, the difference is considered statistically significant. This suggests that using a solar tracker significantly increases the output current, improving the system's performance.

Implications

The results indicate that implementing a solar tracker significantly increases the output current, suggesting improved efficiency in solar energy harvesting. With a mean output current of *3.28* compared to *2.40* without a tracker, the system with tracking technology generates more electricity. This implies that solar trackers optimize panel orientation to capture maximum sunlight, reducing losses due to improper alignment. The lower standard deviation in the tracker system further suggests greater consistency in energy production, making it a more reliable option. Therefore, adopting solar trackers in photovoltaic systems can enhance overall power generation, making them ideal for regions with fluctuating sunlight angles.

Furthermore, the statistical significance of the difference (p = *0.048*) reinforces the practical benefits of solar tracking systems in real-world applications. Since the increase in output current is not due to random chance, investing in solar trackers can yield measurable improvements in energy output. This has implications for both residential and commercial solar installations, where efficiency maximization is crucial for cost-effectiveness. Additionally, the enhanced performance of solar trackers can contribute to greater sustainability by reducing dependence on non-renewable energy sources.

Overall, these findings support the integration of solar tracking technology as a viable solution for improving the efficiency and reliability of solar power systems. According to Bakirci (2012), the use of time-series analyses to compare PV systems with and without trackers confirmed that systems with trackers consistently outperformed their stationary counterparts in terms of both voltage and current generation.

I. Acknowledgment

The researchers would like to sincerely thank everyone who contributed to the success of their project. Their crucial support for their capstone research project made this accomplishment possible.

They express their heartfelt gratitude to God/Allah for providing guidance and blessings throughout their journey. This achievement is a testament to His kindness and assistance.

To Imelda T. Dujeñas, P-1, the school principal, and Gemma E. Roldan, the Assistant School Principal 1, for granting permission to carry out this research project;

To Ellin T. Vicera, P-1, the former principal of Colon National High School, for her significant support of the researchers' efforts;

To Tito B. Cagang, Jr., MT-1, MAEd, their STEM head and class adviser, for his unwavering support and direction in their research endeavors, which have been essential to the progress of this undertaking. His dedication is deeply appreciated, and his continued assistance is hoped to foster further success.

To Annavilla L. Clarion, T-2, MST, their research adviser, for her outstanding guidance and leadership in their research. Her commitment to their growth is valued, and her mentorship is anticipated to lead to future success and innovation;

To the study's consultants and panelists—Sir Mariel G. Villanueva, MT-1, MST; Ma'am Jenelyn A. Mangging, T-2, MST; Sir Orly Q. Gantala, T-1; Sir Rolex D. De Jose, Jr., T-1, MAEd; Ma'am Leah D. Padojinog, T-2; Ma'am Maria Cristina S. Gajusta, SST-1; Ma'am Maria Amormia S. Villano, MT-1; and Ma'am Annelyn H. Eribal, T-3, MPA—for their invaluable insights and expertise;

To Jamaico H. Taborada, T-3, MST, for his expertise in statistical analysis, proficiency in handling newly acquired data, and ability to conduct time series t-tests to assess the significance of the solar tracker's performance.

To Rev. Ralph A. Trivilegio, their project developer and technician, for transforming the researchers' vision into reality. His effort and kindness are highly valued.

To Alfloro J. Arcala, designated supervisor, for his consistent guidance, dedication, and commitment to overseeing this project and ensuring its completion.

To Electrical Engineer John T. Turno and Mechanical Engineer Re-gie G. Castillon, the qualified scientists who greatly enriched this research's quality and rigor with their technical expertise, thoughtful insights, and meticulous attention to detail.

To their families for their unwavering support and inspiration. Their love and encouragement have provided a constant strength throughout this journey.

To their friends and classmates for their support and camaraderie. Their encouragement and shared experiences have made this journey both memorable and meaningful.

The researchers are beyond grateful for your support.

References

[1] Abro, A. A., Bano, S., Tariq, U., & Shah, I. A. (2022). Sun tracking and control design for pv solar energy system. In *International Journal of Innovations in Science and Technology* (Vol. 4, Issue 5, pp. 77–93). 50Sea. https://doi.org/10.33411/ijist/2022040507

[2] Alam, Md. E., Kader, M. A., Hossain, M., Noushin, F., Alam, M. S., & Farid, S. (2021). IoT-based smart and secured mobile charging station in public places. *In 2021 3rd International Conference on Sustainable Technologies for Industry 4.0* (STI). 2021 3rd International Conference on Sustainable Technologies for Industry 4.0 (STI). IEEE. https://doi.org/10.1109/sti53101.2021.9732560

[3] Alhijazi, A.A.K., Almasri, R.A., Alloush, A.F. (2023). *A hybrid renewable energy (solar/wind/biomass) and multi-use system principles, types, and applications: a review*. Sustainability 2023, 15, 16803. https://doi.org/ 10.3390/su152416803

[4] Ao, X., He, R., Zhang, C., & Wan, L. (2019). A new outdoor energy-sharing mobile phone charging station. *In 2019 34rd Youth Academic Annual Conference of Chinese Association of Automation* (YAC). 2019 34rd Youth Academic Annual Conference of Chinese Association of Automation (YAC). IEEE. https://doi.org/10.1109/yac.2019.8787589

[5] Attanayake K, Wickramage I, Samarasinghe U, Ranmini Y, Ehalapitiya S, Jayathilaka R, et al. (2024). *Renewable energy as a solution to climate change: Insights from a comprehensive study across nations.* PLoS ONE 19(6): e0299807. https://doi.org/10.1371/journal.pone.0299807

[6] Gonzales, A. N., & Muyot, N. B. (2022). Portable solar-powered outdoor charging station with the application of a servo motor in a sunlight tracking system with light detection relay sensor. *International Journal of Science, Technology & Management*, 3(4), 950–958. doi: https://doi.org/10.46729/ijstm.v3i4.563

[7] Hassan, Q., Algburi, S., Sameen, A. Z., Salman, H. M., & Jaszczur, M. (2023). *A review of hybrid renewable energy systems: solar and wind-powered solutions: challenges, opportunities, and policy implications.* In Results in Engineering (Vol. 20, p. 101621). Elsevier BV. https://doi.org/10.1016/j.rineng.2023.101621

[8] Maka, A. O. M., & Alabid, J. M. (2022). *Solar energy technology and its roles in sustainable development*. In Clean Energy (Vol. 6, Issue 3, pp. 476–483). Oxford University Press (OUP). https://doi.org/10.1093/ce/zkac023

[9] Mohamed, A. A. S., Shaier, A. A., Metwally, H., & Selem, S. I. (2023). *Wireless charging technologies for electric vehicles: Inductive, capacitive, and magnetic gear.* In IET Power Electronics. Institution of Engineering and Technology (IET). https://doi.org/10.1049/pel2.12624

[10] Panwar, N. L., Kaushik, S. C., & Kothari, S. (2011). *Role of renewable energy sources in environmental protection: A review.* In Renewable and Sustainable Energy Reviews (Vol. 15, Issue 3, pp. 1513–1524). Elsevier BV. https://doi.org/10.1016/j.rser.2010.11.037

[11] Raj, S. V., Srivasan, K., Vijay, R., & Pranav, B. S. (2023). *Real-time-clock using Arduino*. UGC Care Gr. I J, 13(5), 356-363.
[12] Ren, K., Li, M., Cen, X., & Huang, H. (2024). *The electric vehicle routing problem of a new mobile charging service.* In Transportation Safety and Environment. Oxford University Press (OUP). https://doi.org/10.1093/tse/tdae012
[13] Ríos, Guamán, Vargas, & García. (2016). Design, dimensioning, and installation of isolated photovoltaic solar charging station in Tungurahua, Ecuador. *International Journal of Renewable Energy Research*, 7(1). https://doi.org/10.20508/ijrer.v7i1.5340.g7005
[16] Tran, B., Ovalle, J., Molina, K., Molina, R., & Le, H. T. (2021). *Solar-powered convenient charging station for mobile devices with wireless charging capability*. In WSEAS TRANSACTIONS ON SYSTEMS (Vol. 20, pp. 260–271). World Scientific and Engineering Academy and Society (WSEAS). https://doi.org/10.37394/23202.2021.20.29
[17] U.S. Department of Energy. (n.d.). How does solar work? Energy.gov. Retrieved from https://www.energy.gov/eere/solar/how-does-solar-work.