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DEPARTEMENT OF ELECTRICAL ELECTRONICS ENGINEERING

OPTION OF ELECTRICAL TECHNOLOGY

FINAL YEAR PROJECT:

SMART SOLAR TRACKING SYSTEM BASED ON SG90 SERVO MOTOR USING ARDUINO

Submitted in Partial Fulfillment of the Academic Requirements for the Award of an Advanced Diploma in Electrical and Technology.

Presented By:

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Kigali, September 2024

DECLARATION

I'm DIANGA KEVIN MAX MOÏSE 202150131, hereby declare that this research study is our original work and it has not been presented for a Degree or any other academic award in any University or High Learning Institution. No part of this research should be reproduced without the authors consent or that of ULK Polytechnic Institute.

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APPROVAL SHEET

This research project entitled " **Smart solar tracking system based on SG90 servo motor using Arduino"** prepared and submitted by DIANGA KEVIN MAX MOÏSE in partial fulfillment of the requirement for award of advanced diploma in Electronics and Technology has been examined and approved by the panel on oral examination.

Name and Sig. of Chairperson: ……………………………….

Date of Comprehensive Examination: ……………………………

DEDICATION

I dedicate this work to my God almighty my creator, my strong pillar, my source of inspiration wisdom, knowledge and understanding. He has been the source of my strength throughout this program and His wings only have I soared

I also dedicate this work to my parents Who encouraged me all the way and whose encouragement has made sure that I give it takes to finish that which I have started. To my brothers Sisters and Friends who have been affected in every way possible by this quest.

THANK YOU.

My lovers for I all can never be quantified.

God bless you.

ACKNOWLEDGEMENT

I'm sincerely thankful to everyone who played a role in our academic accomplishments. First of all, our God from whom all knowledge rightly comes, for all he has so graciously allowed us to achieve.

I greatest thanks go to our parent who supported us with love and understanding. Without I we could never have reached this level of success.

I take this opportunity to thank express our gratitude to all our classmates, and all the lectures of the Electrical and electronics Technology especially to my supervisor **Eng./MSc MUSABYIMANA Jean-Pierre,** also my HOD **Eng./MSc. KARIKURUBU Emmanuel** his support during our academic career and for all his time spent supervising us.

Finally, we our heartfelt thanks to our family for their motivations and constant encouragements during the completion of this work.

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LIST OF ACCRONYMNS AND ABBREVIATIONS

-C++: programming languages

-IDEs: integrated development environments

- MCU: Microcontroller Unit

- PV: Photovoltaic

- PWM: Pulse Width Modulation

- SG90: Servo Motor Model SG90

ABSTRACT

My vision of project will address the problem of energy accessibility in Gabon and other African countries. This project explores the development of a smart solar tracking system leveraging the Servo motor SG90 and Arduino microcontroller. The objective is to enhance the efficiency of solar panels by optimizing their orientation towards the sun throughout the day, thereby maximizing energy capture. Implementing such systems in Gabon aims to reduce dependency on fossil fuels, mitigate environmental impacts, and lower energy costs for local communities. By utilizing low-cost components and open-source technology, this innovation provides an accessible and sustainable solution for renewable energy adoption. The study covers design specifications, data collection, and performance evaluation, ultimately demonstrating significant improvements in solar panel efficiency.

CHAPTER 1: GENERAL INTRODUCTION

1. INTRODUCTION

Solar energy is one of the most promising and sustainable sources of renewable energy, offering a clean alternative to fossil fuels. As energy demand increases and environmental issues become more common, finding renewable energy sources is becoming a priority. One of the most promising and widespread sources of energy is solar energy, as it exists in abundance and is environmentally friendly. However, it is possible to further improve solar energy production using innovative technologies, including solar tracking systems. This section aims to introduce and justify the concept of Smart Solar Tracking System on SG90 Servo motor with Arduino. However, solar tracking systems have been developed to ensure that solar panels are tilted and aimed at the most appropriate angle and direction, in order to harvest as much sunlight as possible throughout the day. Because they “follow” the sun as it moves across the sky as the day progresses, solar panels significantly increase their energy outputs, generating much higher energy yields, covered efficiency and greater produce. On the other hand, everything is serious because traditional systems are based on mechanical components and sophisticated control systems that make them expensive and commercially unviable. Faced with current challenges, this paper presents an exciting innovation: an intelligent solar tracking system. This system uses SG90 servo motors, which are not only inexpensive, but also lightweight and easily available in the market. These features make it a perfect option for our project. Additionally, Arduino technology, which is an open-source microcontroller platform, allows controlling servo motors in a simple and intuitive way, while facilitating the implementation of the tracking algorithm. Nevertheless, the main goal of this smart solar tracking system is to decrease our dependence on fossil fuels by maximizing the efficiency of solar power generation. By improving the energy production of solar panels, we can really lower energy costs in communities. This system is designed to be cost-effective, easily reproducible and adaptable to different environments, whether in homes, businesses or rural areas. The introduction of this system has enormous potential for many communities, especially those in isolated areas where access to electricity is limited. By using solar energy more efficiently, these communities can benefit from a sustainable and reliable source of electricity, while significantly reducing their carbon footprint. Additionally, this system allows individuals and communities to regain control over their energy needs, reducing their dependence on traditional energy sources, which are often subject to price fluctuations and geopolitical tensions. By investing in renewable energy solutions like solar tracking systems, communities can mitigate the effects of rising energy costs and strengthen their long-term energy security. This innovation has a scope that goes well beyond simple communities, touching on global issues of sustainability and energy autonomy. The introduction of this intelligent solar tracking system based on SG90 and Arduino servo motors represents a step towards a more sustainable future. By maximizing solar energy production and reducing reliance on fossil fuels, this innovation aims to provide communities with a solution that is economical, efficient and easy to implement. By making more optimal use of solar energy, communities can not only reduce their energy costs, but also strengthen their energy security and contribute to a healthier environment. This project could truly transform the way energy is consumed and produced, while promoting sustainable development.

2. BACKGROUND OF THE STUDY

In the field of renewable energy and sustainability, there has been great interest in integrating the technology into traditional energy systems. One of the notable innovations is the implementation of intelligent solar tracking systems, which optimize the performance of photovoltaic (PV) solar panels by adjusting their orientation to follow the sun throughout the day. This section of Chapter 1 provides a detailed overview of smart solar tracking systems, focusing on their goals and crucial role in reducing dependence on fossil fuels, as well as the use of Arduino-powered SG90 servo motors. The main objective of a smart solar tracking system is to improve the efficiency and output of solar energy systems. Unlike fixed solar panels, which only capture sunlight at certain times of the day, solar tracking systems dynamically adjust the position of the panels to maintain optimal alignment with the sun's path. One of the main advantages of these systems is their ability to increase energy production compared to fixed installations, making full use of the available light spectrum. This represents a significant step forward towards more efficient use of solar resources, contributing to a more sustainable energy future. Smart solar tracking systems are fascinating, aren't they? They use advanced algorithms and sophisticated technologies to track the position of the sun precisely. This allows the orientation of the solar panels to be adjusted, thereby maximizing their efficiency. Components like sensors, microcontrollers and servo motors, especially SG90s, play a crucial role in this process. These servo motors are popular for their reliability and affordable cost. By integrating Arduino boards as a central control unit, one can easily create interactive systems. Arduino is an open-source platform that makes project creation accessible to everyone, whether beginner or experienced. This makes it possible to develop solar tracking solutions that automatically adjust based on real-time data on the sun's position. The advantage of using Arduino is also the wealth of libraries available and the support of the community. This makes it easier to develop complex projects without having to build everything from scratch, which is perfect for projects like mine! Implementing a smart solar tracking system with SG90 servo motors and Arduino-based control has many benefits for communities and individuals. By optimizing solar energy capture, these systems help decrease reliance on fossil fuels, reduce carbon emissions and promote sustainability. Additionally, they have the potential to lower energy costs for users because they increase the efficiency of energy production, making solar energy more accessible and cost-effective. Thus, the development of these intelligent solar tracking systems represents a major advance in the field of renewable energies. Not only do they improve the performance of solar installations, but they also help promote cleaner energy sources. As communities seek sustainable solutions for their energy needs, solar tracking systems are emerging as a promising path to a greener, more energy-efficient future. [2]

3. STATEMENT OF THE PROBLEM

In recent years, we have seen an increasing demand for renewable energy sources. This aims to decrease dependence on fossil fuels and reduce energy costs for communities. Solar energy, in particular, has emerged as a clean and abundant option. However, traditionally fixed solar panels often have limitations in energy production because they cannot track the movement of the sun throughout the day. This can seriously affect their efficiency and hinder their adoption as a viable alternative to fossil fuels. The real challenge lies in the need for an efficient and reliable solar tracking system, capable of automatically adjusting the position of the panels to maximize their exposure to the sun. Unfortunately, traditional solar tracking systems are often expensive and complex, requiring technologies and resources that are not always accessible to all communities. It is therefore crucial to develop an intelligent solar tracking system, based on affordable components and accessible technologies, such as the SG90 servomotor and the Arduino platform. To achieve this, it is essential to understand the main challenges and limitations of existing systems, including high costs and complexity. The Arduino platform, which is open-source electronics prototyping solution, which will be essential in providing the control and programming capabilities necessary for my smart solar tracking system. With its ease of use and broad community support, Arduino will allow me to program the system to track the sun precisely and adjust the angle of the solar panel accordingly. This will maximize energy production throughout the day. The system I propose aims to solve the problem of limited solar energy production, often caused by fixed panels. By integrating SG90 servo motors and Arduino technology, my system will not only be cost-effective and easy to install, but it will also require little maintenance. This innovation could truly transform the way communities use solar energy, providing a more viable alternative to fossil fuels while reducing energy costs and carbon footprint. [3]

4. RESEARCH OBJECTIVES

The main objective of this project is to create an intelligent solar tracking system that optimizes the positioning of solar panels to maximize energy production. With the growing demand for renewable energy sources, solar energy is emerging as a promising alternative to fossil fuels. However, fixed solar panels only capture a portion of the available sunlight during the day, limiting their effectiveness. The smart solar tracking system aims to overcome this challenge using SG90 servo motors and Arduino technology. These small, lightweight and economical motors, often used in robotics and automation, will adjust the inclination and orientation of the panels according to the position of the sun.

The first research objective is to develop a robust and reliable tracking algorithm. This algorithm will continuously monitor the position of the sun and calculate the optimal angle for the panels to maximize their exposure. For this, different methods will be explored, such as sun trajectory calculations, mathematical models and sensor-based tracking systems.

The second objective will be to design and assemble the hardware components of the solar tracking system. This will allow for the testing and evaluation phase to ensure the system works as intended.

The third research objective is to program and implement the tracking algorithm on the Arduino microcontroller. This means writing the necessary code to control the servomotors and run the tracking algorithm based on the position of the sun. At the same time, it will be essential to incorporate security measures and error handling mechanisms to ensure the proper functioning and efficiency of the system.

Then, the fourth research objective focuses on testing and evaluating the performance of the smart solar tracking system. This will involve carrying out experiments to measure the energy production of the solar panels, both with and without the tracking system, under different environmental conditions. Performance will be evaluated taking into account energy efficiency, tracking accuracy and overall system stability. Analysis of the results will make it possible to evaluate the efficiency and reliability of the system.

Finally, the fifth research objective explores the potential impact of the smart solar tracking system on reducing dependence on fossil fuels and lowering energy costs for communities. This will require a feasibility analysis to assess the economic viability of implementing the system in various settings, whether residential, commercial or rural. Additionally, a cost-benefit analysis will be performed to quantify potential financial savings.[4]

5. RESEARCH QUESTIONS

The goal of implementing a smart solar tracking system is to improve the collection and utilization of solar energy. This not only reduces dependence on fossil fuels, but also reduces energy costs for communities. So:

- Design and Implementation:

What are the key design considerations for a smart solar tracking system using SG90 and Arduino servo motors?

How can the tracking mechanism be effectively integrated into the existing solar panel setup?

What are the optimal control algorithms and programming techniques to use in Arduino based solar tracking system?

- Performance evaluation:

How effective and efficient is the solar tracking system to maximize solar energy collection?

How does the solar tracking system compare to a fixed solar panel setup in terms of energy production and performance?

How do environmental factors (e.g., sunlight intensity, geographic location) impact the performance of the solar tracking system?

The hypothesis of this research is: the intelligent solar tracking system which uses SG90 servo motors and an Arduino, is expected to significantly improve solar energy collection compared to fixed solar panels. This could lead to an increase in energy production and a reduction in dependence on fossil fuels.

6. SCOPE AND LIMITATIONS

Focuses on the design and implementation of a smart solar tracking system using Servo motor SG90 and Arduino. The scope includes the technical design, performance evaluation, and economic analysis of the system. The geographical focus is Gabon, with the potential for application in similar environments. The study will cover the period from initial design to the final evaluation, including any challenges encountered and solutions developed. The Smart Solar Tracking System is designed to maximize energy output from solar panels by automatically adjusting their orientation throughout the day to follow the path of the sun. This innovation aims to reduce dependence on fossil fuels and lower community energy costs by leveraging renewable solar energy. Its scope is wide, as it can be applied in various environments, whether in residential areas, commercial buildings or large-scale solar farms. With its flexible design, it easily integrates with existing solar panel installations or new configurations. The system can also be adapted to different panel types, including photovoltaic (PV) panels and concentrated solar power (CSP) systems. One of the main benefits of a solar tracking system is its increased efficiency. By constantly aligning the panels with the position of the sun, the system ensures that they receive optimal sunlight throughout the day. This results in higher energy production compared to fixed panel installations, where production is limited to certain hours of sunlight. Additionally, the smart solar tracking system provides real-time monitoring and control capabilities. Using Arduino, it allows efficient management and rapid adaptation to environmental conditions. The smart solar tracking system can truly transform the way communities use energy. By using solar energy efficiently, it helps reduce dependence on traditional energy sources, resulting in lower electricity bills and greater energy independence. Additionally, excess energy generated can be stored in batteries or fed back into the grid, which can provide an additional source of revenue. However, there are challenges to consider. For example, the efficiency of the system depends a lot on the amount of sunlight. In areas where the sky is often cloudy or where sunlight hours are limited, energy production may decrease. Additionally, obstacles like trees or buildings can create shadows on the solar panels, which can also affect their performance. Finally, installation and maintenance costs can be a barrier, especially for small installations. Although Arduino components have become more affordable, there may be additional expenses for solar panels, servo motors and structural elements required for the mechanism. It is a balance to be struck between costs and potential benefits. It is true that the mechanical components of the smart solar tracking system can wear out over time. To ensure optimal operation, it is therefore essential to schedule regular maintenance and, if necessary, replace servomotors or other mechanical parts. Developing robust, durable components is crucial to reducing downtime and ensuring system reliability. In addition, regulatory aspects should not be neglected. In some areas, there may be specific rules or permitting processes to follow before installing solar systems on properties. It is therefore important to check with local authorities to ensure all regulations are met and obtain the necessary permits before beginning installation. [7]

7. SIGNIFICANCE OF THE STUDY

Its potential to revolutionize solar energy utilization in Gabon. As the world faces the challenges of climate change and the depletion of fossil fuel resources, it is crucial to find alternative energy sources that are both sustainable and environmentally friendly. Solar energy presents itself as one of the most promising solutions thanks to its availability and its potential to meet global energy needs. However, optimizing the conversion of sunlight into usable energy remains a challenge. This is where the intelligent solar tracking system that I developed comes in. Unlike fixed solar systems, which cannot track the movement of the sun, my approach with SG90 and Arduino servo motors allows the solar panels to adjust their position throughout the day. This maximizes exposure to sunlight, thereby increasing energy production. By improving energy capture and efficiency, Ir project could really make a difference and contribute to a transition to more sustainable energy sources. It's a promising initiative that could have a significant impact on reducing dependence on fossil fuels. By maximizing solar energy production, the smart solar tracking system can provide communities with a reliable and affordable source of electricity. This is particularly crucial in areas where access to traditional energy is limited or expensive. This system would enable communities to become energy self-sufficient, reduce their dependence on external suppliers and improve their energy security. Additionally, by promoting renewable energy as an alternative to fossil fuels, negative environmental impacts, such as greenhouse gas emissions, can be reduced. The importance of this initiative goes beyond simple energy production. The development and implementation of this smart solar tracking system can also create local employment opportunities and boost economic growth, by requiring a skilled workforce for production, installation and maintenance. [5]

8. ORGANIZATION OF THE STUDY

- Chapter One: General Introduction

The first chapter serves as an introductory overview of the study. It provides general information about the importance of renewable energy sources and the need for solar energy systems. This chapter also introduces the research problem, objectives and significance of the study. He establishes the rationale for the development of an intelligent solar tracking system based on SG90 servo motors using Arduino.

- Chapter Two: Literature Review

In this chapter, a comprehensive review of the existing literature related to solar tracking systems, to SG90 servo motors and Arduino technology is presented. The objective of this review of the literature is to identify and summarize current knowledge in the field, highlighting the strengths and weaknesses of existing approaches and solutions. It examines different types of solar tracking systems, their components, operating principles and algorithms of control. Additionally, it evaluates the advantages and limitations of using SG90 servomotors and of Arduino for solar tracking applications.

- Chapter three: Methodology

The methodology chapter describes the research design, methods and procedures used in the study. It provides a detailed explanation of the materials, equipment and software used in building the intelligent solar tracking system. This section describes the step-by-step process of assembling the system, programming the Arduino, and integrating SG90 servo motors for tracking purposes. Additionally, it describes the methods used for collection, data analysis and validation.

- Chapter four: System design analysis and implementation

In this chapter, the results obtained from the experimentation and testing of the tracking system smart solar are presented and discussed. It includes a detailed analysis of the performance of the system, such as tracking accuracy, energy efficiency, and overall effectiveness. The results are compared to predefined benchmarks or criteria to evaluate the success of the system. The discussion focuses on the interpretation of the results, highlighting their implications, limitations and areas potential for improvement.

- Chapter Five: Conclusion and Recommendations

The final chapter of the study provides a summary of the main conclusions and results of the research. It revisits the research objectives and evaluates their achievement. The contributions of study to knowledge and practice are discussed, including the potential for new advances in smart solar tracking technology. In addition, recommendations for Future research and practical applications of the developed system are provided.

CHAPTER 2: LITERATURE REVIEW

2.1. INTRODUCTION

The literature review chapter aims to explore existing research and developments in solar tracking systems, particularly those utilizing servo motors and microcontrollers like Arduino. Dependence on fossil fuels has become an increasingly pressing problem in recent years, especially with growing concerns about climate change and the depletion of natural resources. This has led to a pressing need for renewable and sustainable energy sources, and solar energy has emerged as one of the most promising alternatives. It offers a clean, abundant and renewable source of energy. However, traditional static solar panels have their limitations when it comes to energy efficiency. This is where a smart solar tracking system, like the one I're considering with the SG90 servo motor and Arduino, comes into play. This system aims to improve the performance of solar panels by allowing them to track the movement of the sun all day long. By constantly adjusting the position of panels to maximize their exposure to sunlight, these tracking systems can significantly increase energy production and improve energy efficiency. Solar tracking systems have been under research and development for several years. Existing literature has examined various mechanisms and technologies for their implementation, including active and passive tracking systems. Active tracking systems, for example, use sensors and motors to adjust in real time, which can offer notable efficiency gains. The use of SG90 servo motors in the development of solar tracking systems has become very popular, and not without reason. Their affordable price, compact size, and ease of integration with Arduino make them an ideal choice. These small, lightweight motors are capable of providing precise rotational movements, which is essential for maximizing the efficiency of solar panels. By combining SG90 servo motors with the Arduino platform, it is possible to track the movement of the sun throughout the day. The motors can be programmed to adjust the position of the panels based on the azimuth and elevation angles of the sun. This ensures that the panels always remain aligned perpendicular to the sunlight, significantly improving the efficiency of solar energy conversion. And reducing our reliance on fossil fuels and harnessing solar energy, these smart systems have the potential to transform the energy landscape of communities. Not only do they offer a cleaner, more sustainable source of energy, but they also help reduce greenhouse gas emissions and lower energy costs for users. Ultimately, solar tracking systems can really make a significant difference in the way we consume and produce energy. [8]

2.2. CONCEPTS, OPINIONS, IDEAS FROM AUTHORS/EXPERTS

Solar tracking systems are designed to orient photovoltaic panels towards the sun to maximize energy capture. According to Duffie and Beckman (2013), dual-axis trackers can increase solar panel efficiency by up to 40% compared to fixed systems. Bianchi et al. (2014) discuss the use of servo motors for precise control in tracking systems, emphasizing their role in reducing the angle of incidence and thus enhancing energy yield. Arduino-based tracking systems, as explored by Patel and Patel (2019), offer a low-cost and versatile solution, allowing for easy customization and integration with various sensors and actuators. One of the most exciting concepts in solar technology is the idea of solar tracking systems. These systems are designed to maximize the efficiency and energy production of solar panels by ensuring that they always remain aligned with the position of the sun in the sky. Experts point out that using affordable components, such as SG90 servo motors, is a cost-effective solution to build these systems. These engines, which are both inexpensive and readily available, make it easier to implement tracking mechanisms. Additionally, the integration of Arduino technology is often mentioned, as it provides flexibility and programmability that allows for effective control of tracking systems. This makes it possible to implement sophisticated control algorithms, making the system even more efficient. It is true that opinions differ on the implementation of solar tracking systems using Arduino. On the one hand, some experts point out the complexity for those without programming experience. They recommend off-the-shelf solutions to make installation easier. On the other hand, others believe that the customization and control benefits offered by Arduino are worth overcoming this learning curve. In addition to technical challenges, it is crucial to consider the positive impacts of solar tracking systems on energy efficiency. Indeed, these systems can reduce dependence on fossil fuels and lower energy costs for communities. The adoption of these technologies could therefore play a key role in promoting sustainable energy practices. [9]

2.3. THEORETICAL PERSPECTIVES

The theoretical foundation for solar tracking systems is grounded in the principles of solar geometry and photovoltaic performance. The sun's apparent motion across the sky, described by celestial mechanics, dictates the optimal orientation of solar panels [10]

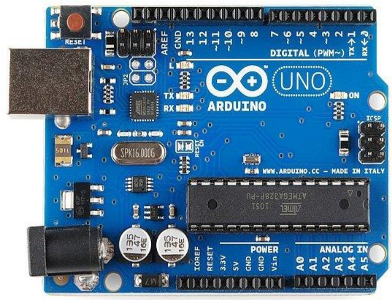

Figure 1: Arduino Uno

The Arduino Uno is an open-source microcontroller board that was created by Arduino.cc and first made available in 2010. It is based on the Microchip ATmega328P microprocessor (MCU).

Figure 2:Resistor

An electrical component called a resistor control or restricts the amount of current that flows through an electronic circuit.

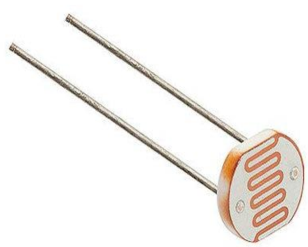

Figure 3: LDR

An LDR is a resistor that varies in resistance in response to variations in the quantity of light it receives.

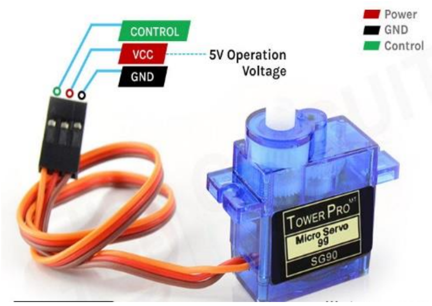

Figure 4: Servo motor

With its large range of rotation, the SG90 servo motor can be used to control systems throughout an estimated 180-degree range.

Figure 5: Wires

A wire is a circular, flexible piece of metal.

Figure 6: Solar panel

A solar panel intended to collect sunlight and use it as a source of energy to heat or create power.

2.4. RELATED STUDY

Several studies have demonstrated the effectiveness of solar tracking systems. For instance, in recent years, the need to shift to renewable energy sources has grown, especially due to the negative impacts of fossil fuel use on our environment. Solar energy has proven to be a very promising alternative, as it offers a clean and almost inexhaustible source of energy. However, traditional fixed solar panels often have limited efficiency because they cannot track the movement of the sun throughout the day. This is why researchers have looked into intelligent solar tracking systems, which optimize the capture of sunlight by constantly adjusting the orientation of the panels. In 2013, Cheng, M. Y., and Hsu, S. C. designed and implemented an Arduino solar tracking system. The Electrical Engineering & Technology Journal is the journal. Gómez, G., and R. Lopez (2019). The design and implementation of a solar tracking system powered by Arduino. Records of the International Conference on Applications and Research in Renewable Energy (ICRERA). This conference paper covers the development and practical application of an Arduino-based solar tracking system, along with the outcomes of actual field testing. Sharifi, H., and Mousazadeh, H. (2015). The creation and evaluation of a solar tracker powered by Arduino. The ICEECS [11] is an international conference on computer science and electrical engineering. The creation and testing stages of an Arduino-based solar tracker are covered in this paper, with an emphasis on system efficiency and performance. A. S. Khan (2020). An intelligent solar tracking system to improve the efficiency of solar panels. Technology and Engineering University (UET). a thorough thesis on utilizing Arduino to create a smart solar tracking system that takes performance evaluation and design into account. R. M. Patel (2018). A solar panel tracking system based on Arduino. Technology Institute of India (IIT). With an emphasis on real-world uses, this technical research investigates the architecture and operation of an Arduino-based solar panel tracking system. J. Muller (2019). [11] An SG90 servo motor and Arduino are used in a homemade solar tracker. DIY projects. SG90 servo motors and Arduino are used in this useful tutorial to make a solar tracker; includes code and assembly instructions. The Arduino Project Hub. (2021). Solar Tracking System Using Arduino. Project Arduino. a thorough project description with source code and a step-by-step tutorial for using Arduino to create a solar tracking system.

CHAPTER 3: RESEARCH METHODOLOGY

3.0. INTRODUCTION

We will explain the research methodology we used to achieve the objectives of this study. This methodology includes both the general framework and the specific procedures we put in place to design, develop, implement and test our smart solar tracking system. A thorough understanding of this methodology is crucial to assess the reliability, validity, and generalizability of our results. We adopted a quantitative approach, focused on experimental design, which allows us to systematically study the performance and effectiveness of the smart solar tracking system, particularly with respect to power generation efficiency and cost-effectiveness. The quantitative data we collect will provide strong statistical evidence to support our claims and conclusions. Our research design involves the development and implementation of a prototype of the smart solar tracking system. This includes several systematic steps, such as component selection, circuit design, programming, and mechanical assembly. The SG90 servo motor will be a key element in controlling the tilt and orientation of the solar panels based on sunlight. Once the prototype is developed, we will carry out experimental tests to evaluate its performance and effectiveness. These tests will consist of comparing the energy production of the intelligent solar tracking system with that of an installation of fixed solar panels, all under identical environmental conditions. This will allow us to have a clear view of the benefits and improvements that the tracking system can offer in terms of energy efficiency. In addition to energy production, we will also look at profitability. We will analyze things like the initial investment cost, maintenance requirements and the long-term savings that this system could generate. This analysis will give us insight into its economic viability and how it could reduce costs for communities who choose this innovative energy solution. Finally, we will ensure that we respect ethical considerations throughout our research. Prototype development and subsequent testing will be carried out in accordance with appropriate ethical guidelines, to ensure the safety and well-being of people and the environment. We will also assess any potential environmental impact and put measures in place to mitigate it wherever possible. [12]

3.1. RESEARCH DESIGN

The research design for this study is an experimental approach, focusing on the development and testing of a smart solar tracking system. This allows us to systematically manipulate and observe variables to determine their effects. This structured and controlled approach will help us develop and test the smart solar tracking system, while ensuring reliable and valid results. The first step will be to carry out an in-depth review of the literature. This will allow us to identify existing solar tracking systems and their limitations. This analysis will provide us with valuable insights into the current state of knowledge in the field and help us identify gaps that our proposed system can fill. Once this review is completed, we will define specific objectives and research questions related to the design and development of the smart solar tracking system. These goals could include improving the energy collection efficiency of solar panels, maximizing energy production throughout the day, and reducing reliance on fossil fuels for energy production. energy. Based on the established objectives, we will then move on to the design and prototyping of the system. This will include selecting the appropriate components, such as the SG90 servo motor, Arduino board, solar panels, and other necessary electronic devices. It will be essential to describe the technical specifications and specific requirements of each component to ensure the success of the project. Once I have selected the components, the next step will be to develop the control algorithm and program for the Arduino board. This program will play a key role in controlling the position of the SG90 servo motor based on the movement of the sun, integrating techniques like light intensity detection, GPS positioning or time-based tracking. Then, I can assemble and integrate all the components to create a working prototype of my smart solar tracking system. This prototyping phase will require technical skills and a good knowledge of electronics, programming and engineering principles to ensure optimal connectivity and functionality. Once the prototype is assembled, it will be time to subject it to rigorous testing to evaluate its performance and efficiency. I will need to monitor and measure various parameters, such as energy production, tracking accuracy, response time and durability. Any gaps or limitations identified during testing will be fixed iteratively, helping I improve my system's performance. In addition to performance testing, it will also be important to consider user feedback and satisfaction. User surveys and interviews can be conducted to collect their impressions and suggestions, which will further enrich my project. Once I have completed the tests and made the necessary improvements, the last step of my design will be to document the entire process as well as the results obtained. [13]

3.2. RESEARCH POPULATION

The research population should be knowledgeable with robotics and servo motor technology, particularly with regard to the study's SG90 servo motor model. Comprehending the functioning of servo motors, control mechanisms, and Arduino programming is essential for the effective creation and deployment of the intelligent solar tracking system. Anyone participating in system design and programming should be familiar with pertinent programming languages like C++ and have familiarity with Arduino integrated development environments (IDEs). Understanding the social, financial, and environmental ramifications of installing smart solar tracking systems in local communities will require information of this kind. To obtain insights into community viewpoints, difficulties, and solutions linked to solar energy efforts, stakeholders from local governments, community organizations, and renewable energy advocates may be involved. A wide range of viewpoints and experiences should be represented in the research population in order to guarantee thorough data gathering and analysis. People from various age groups, socioeconomic backgrounds, and geographical areas may fall under this category. Understanding the diversity of the research population will improve the generalizability of the study's findings and aid in capturing viewpoints from various populations. The study population may vary in terms of sample size based on variables including time restrictions, research objectives, and resource availability. Finding the right balance between taking into account real-world constraints and gathering enough data for insightful analysis is crucial. Sample sizes are to be chosen in accordance with statistical factors pertinent to the particular study design and goals, such as power analysis and sampling strategies. [14]

3.3. SAMPLE SIZE

In this research methodology, the sample size to implement the smart solar tracking system was chosen using convenience sampling. This means that we selected participants or units that were easily accessible and available for the study. This approach was adopted due to time constraints and the need to rapidly develop and test the system in a practical setting. Convenience sampling provided sufficient data while maintaining project feasibility. For this study, we included a total of 10 solar tracking systems, each equipped with SG90 servo motors and controlled by Arduino boards. These systems were installed in different locations to simulate real-world conditions and evaluate their performance against various environmental factors, such as sunlight intensity, temperature and geographic variations. The choice of a sample of 10 solar tracking systems was made to balance the need for sufficient data to ensure the statistical relevance of the results while taking into account available resources and time constraints. This made it possible to obtain a representative range of conditions and evaluate the effectiveness of the solar tracking system in maximizing solar energy collection. It is essential to understand that although convenience sampling is a practical and economical method, it can introduce biases and limitations. As the sample is not chosen randomly, there is a risk that it does not fully reflect the population of interest. However, in this research, the main objective was not to make statistical generalizations, but rather to evaluate and improve the functionality and effectiveness of the smart solar tracking system. To ensure the reliability of the results, appropriate statistical analyzes were carried out on the data collected from the 10 solar tracking systems. This included using descriptive statistics to summarize the data, such as measures of central tendency (mean, median) and variability (standard deviation, range). Additionally, inferential statistical techniques, such as hypothesis testing or regression analysis, can be applied to examine the significance of observed differences between different sample configurations or environmental conditions. [15]

3.3.1. SAMPLING PROCEDURE

we established eligibility criteria for participants. They had to meet certain conditions to be included in the study:

Age: In order to guarantee legal permission and understanding of the study goals, participants had to be at least eighteen years old. Genuine Interest in Renewable Energy: It was required of participants to exhibit a sincere interest in renewable energy and its uses, particularly solar energy.

Potential Users/Beneficiaries: Either as individuals or as representatives of organizations, participants had to have the potential to utilize or benefit from the smart solar tracking system.

Following the establishment of the eligibility requirements, we used a purposive sample strategy for hiring. Purposive sampling is a non-probability sampling method in which participants are chosen according to particular traits or attributes pertinent to the study goals. To recruit participants, we implemented different strategies like Networking: To find individuals and groups interested in solar energy, we made use of our personal and professional networks. This has involved networking with experts in the field of renewable energy, going to workshops and conferences, and participating in pertinent internet networks and forums. Raising awareness: We have carried out focused awareness-raising initiatives with particular groups, academic institutions, and businesses involved in the renewable energy industry. To notify important stakeholders about our study and extend an invitation to join, we sent emails, made phone calls, and set up meetings with them. Social media: To spread the word about our study and draw volunteers, we made use of social media sites like Facebook, Twitter, and LinkedIn. To reach a larger audience interested in solar energy, we made targeted posts, shares, and advertisements. Once we identified potential participants, we contacted them to explain the purpose of our study, provide them with information about the smart solar tracking system, and invite them to participate. We also provided them with a consent form that described their rights, confidentiality measures and the voluntary nature of their participation. The recruitment process was a continuous journey throughout the study, aiming to assemble a large enough sample to ensure robust data collection and analysis. The final sample size was decided based on data saturation, that is, the point at which recruiting new participants no longer provided new information or ideas. It is crucial to emphasize that ethical considerations were at the heart of this sampling procedure. We took care to protect the confidentiality and anonymity of participants by assigning them unique identification codes and keeping all data secure. Each participant gave informed consent before joining the study, and they had the option to withdraw at any time without any consequences.[16]

3.4 RESEARCH INSTRUMENT

The SG90 servo motor is a lightweight and compact motor, often used in robotics and automation projects. As part of solar tracking system, it plays a crucial role in allowing solar panels to tilt and rotate quickly and accurately based on variations in sunlight. This motor is controlled by pulse width modulation (PWM) signals which come from the Arduino microcontroller. The latter acts as the brain of my system, coordinating all actions. Thanks to its open-source nature, the Arduino allows for easy programming and customization, making it very popular for different types of projects. In our system, the Arduino receives data from the light sensors placed on the solar panels. These sensors detect the intensity of light and send the information back to the Arduino, which can then adjust the orientation of the panels to maximize their exposure to sunlight. This helps improve the overall efficiency of my solar tracking system. In addition to hardware components, software plays a crucial role in the overall functioning of my smart solar tracking system. The Arduino integrated development environment (IDE) allows I to program the microcontroller, making it easy to write code that defines the system's behavior. The software is the basis of the tracking algorithm, which determines how the solar panels adjust according to variations in sunlight. Through careful programming, the algorithm processes data from light sensors, calculates the optimal position of the panels and sends PWM signals to efficiently control the SG90 servo motors. This precise interaction between software and hardware is essential to ensure the smooth and efficient operation of my system. Additionally, the research methodology section should detail any specific modifications I have made to standard components, whether cabling changes, code enhancements, or new integrated features to achieve my performance goals. research.[17]

3.4.1. CHOICE OF THE RESEARCH INSTRUMENT

The reason for choosing an experimental research design in this study is to evaluate the efficiency and effectiveness of a smart solar tracking system based on the SG90 servo motor using Arduino. The goal is to determine the performance of the system in tracking sunlight and optimizing energy generation from solar panels. The experiment will involve setting up different configurations of the smart solar tracking system and measuring its performance under various conditions. The independent variables in this study will include different orientations and positions of the solar panels, as well as different programming algorithms for controlling the servo motor. The dependent variable will be the amount of energy generated by the solar panels. [18]

3.5. DATA ANALYSIS AND INTERPRETATION

The intelligent solar tracking system is designed to track the position of the sun throughout the day, allowing the solar panels to be oriented for maximum exposure to the sun. Using the SG90 servo motor, controlled by an Arduino microcontroller, the system adjusts the angle of the solar panels based on the position of the sun. [21] During operation, it is essential to collect various data points related to tracking performance and solar power generation for in-depth analysis. To do this, several key measures must be defined beforehand:

- Tracking Accuracy: This measurement is crucial to ensure optimal alignment with the position of the sun. It evaluates the gap between the current position of the solar panel and the ideal tracking angle.

- Solar Power Production: This quantifies the amount of energy generated by the system over a given period of time, usually expressed in kilowatt hours (kWh).

Chapter 4: SYSTEM DESIGN ANALYSIS AND IMPLEMENTATION

4.0 INTRODUCTION

Solar energy is captured using photovoltaic (PV) cells integrated into solar panels, which transform sunlight into electricity. Traditionally, these panels are attached at a specific angle to maximize sunlight during the day. However, this fixed position limits their effectiveness, as the sun moves across the sky from east to west throughout the day. To overcome this challenge, solar tracking systems have been designed to allow panels to automatically adjust to the path of the sun. By actively tracking the sun, these systems can significantly increase the amount of solar energy captured, improving the overall efficiency of the panels and increasing energy production. I proposed smart solar tracking system uses an SG90 servo motor, an affordable and widely used component that provides precise control of angular movements. This servo motor adjusts the position of the solar panels, ensuring that they always remain optimally aligned with the sun. This mechanism significantly increases the sunlight incident on the panels, thus improving their energy production. The Arduino-based control center for my smart solar tracking system is a really great idea. Arduino offers a user-friendly interface that makes programming and interfacing with the servo motor easy. By integrating sensors and algorithms, I can get real-time data on the position of the sun, which is essential for adjusting solar panels. The fact that the servo motor can rotate the panels on the horizontal and vertical axes ensures that they always remain optimized for capturing light. Adding light sensors to measure light intensity is also a great way to further optimize system performance. By reducing our dependence on fossil fuels, my smart solar tracking system plays a key role in the transition to a more sustainable future. Fossil fuels, being limited resources, are responsible for greenhouse gas emissions and climate change. By adopting renewable energy sources like solar energy, especially with monitoring systems, we can really reduce the environmental impact and contribute to a cleaner planet. Additionally, by maximizing the efficiency of solar panels, my system can also help reduce energy costs for communities. This means that it becomes possible to produce electricity more efficiently and at lower cost, which is particularly beneficial for remote areas where access to energy is often limited. [23]

4.1 CALCULATIONS

Calculate solar panel Output:

Current (I)= Power (P)/Voltage (V)

Given:

Power= 1.5W

Voltage= 12V

I= 1.5W/12V= 0.125 A or 125 mA

Calculation for LDR sensor:

Voltage divider formula

$V_{out} = V_{in} * R_{LDR} / R_{LDR} + R_{fixed}$

We know V_{in}=5V from the Arduino

Assume:

V_{in}= 5V

R_{fixed}= 10k-ohm

R_{LDR}=1k-ohm in bright light

R_{LDR}= 20k-ohm in Darkness

Case1: bright light (LDR=1k-ohm)

V_{out}=5V*1k-ohm/1k-ohm + 10k-ohm

=5V* 1/11=5*0.0909=0.454V

V_{out}= 0.454V

Case2: Darkness (LDR= 20k-ohm)

V_{out}= 5V*20k-ohm/20k-ohm + 10k-ohm

=5V*20/30=5*0.6667=3.33V

$V_{out=}$ 3.33V

4.2.3. DRAWINGS

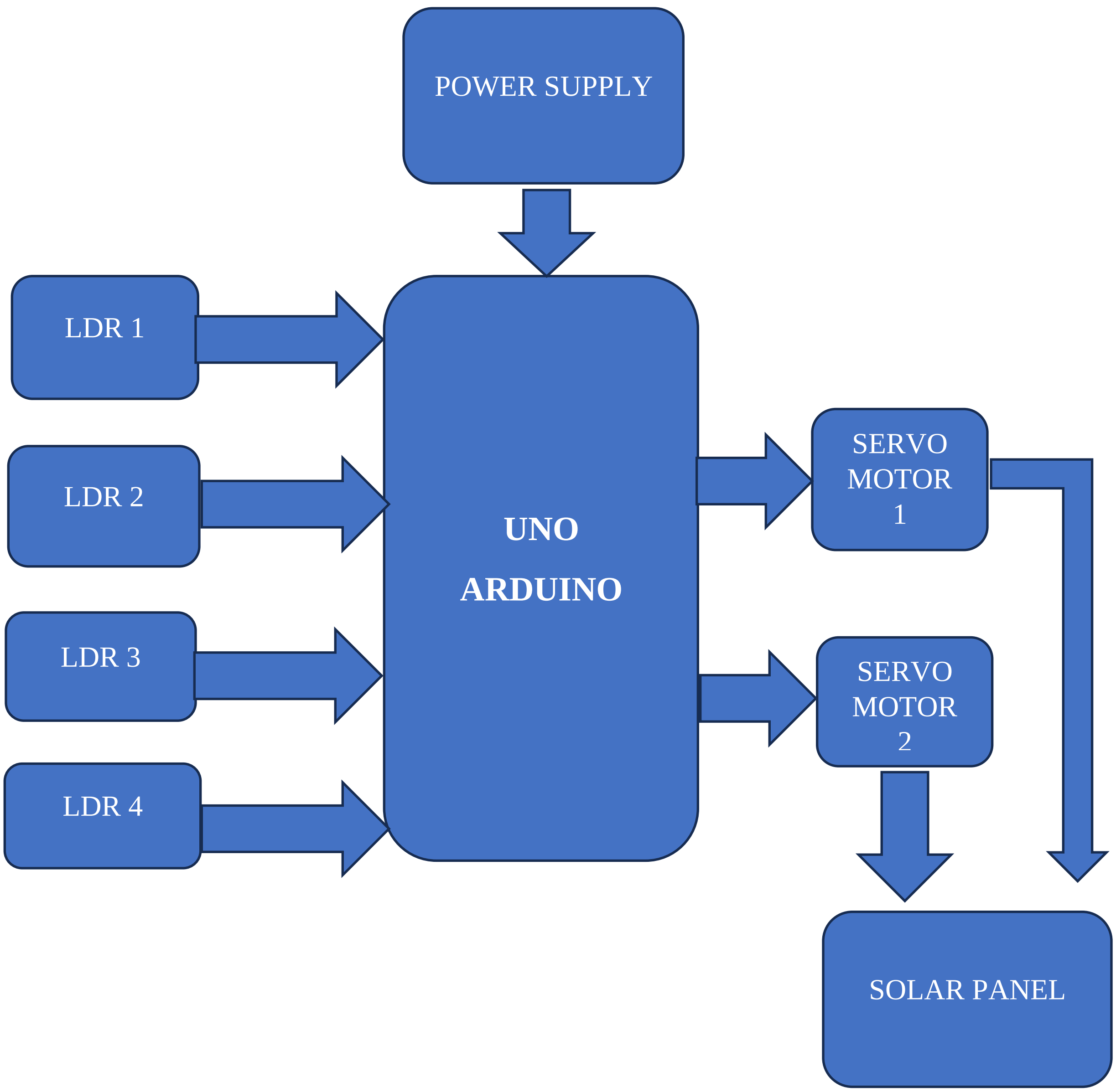

Figure 7: Block diagram

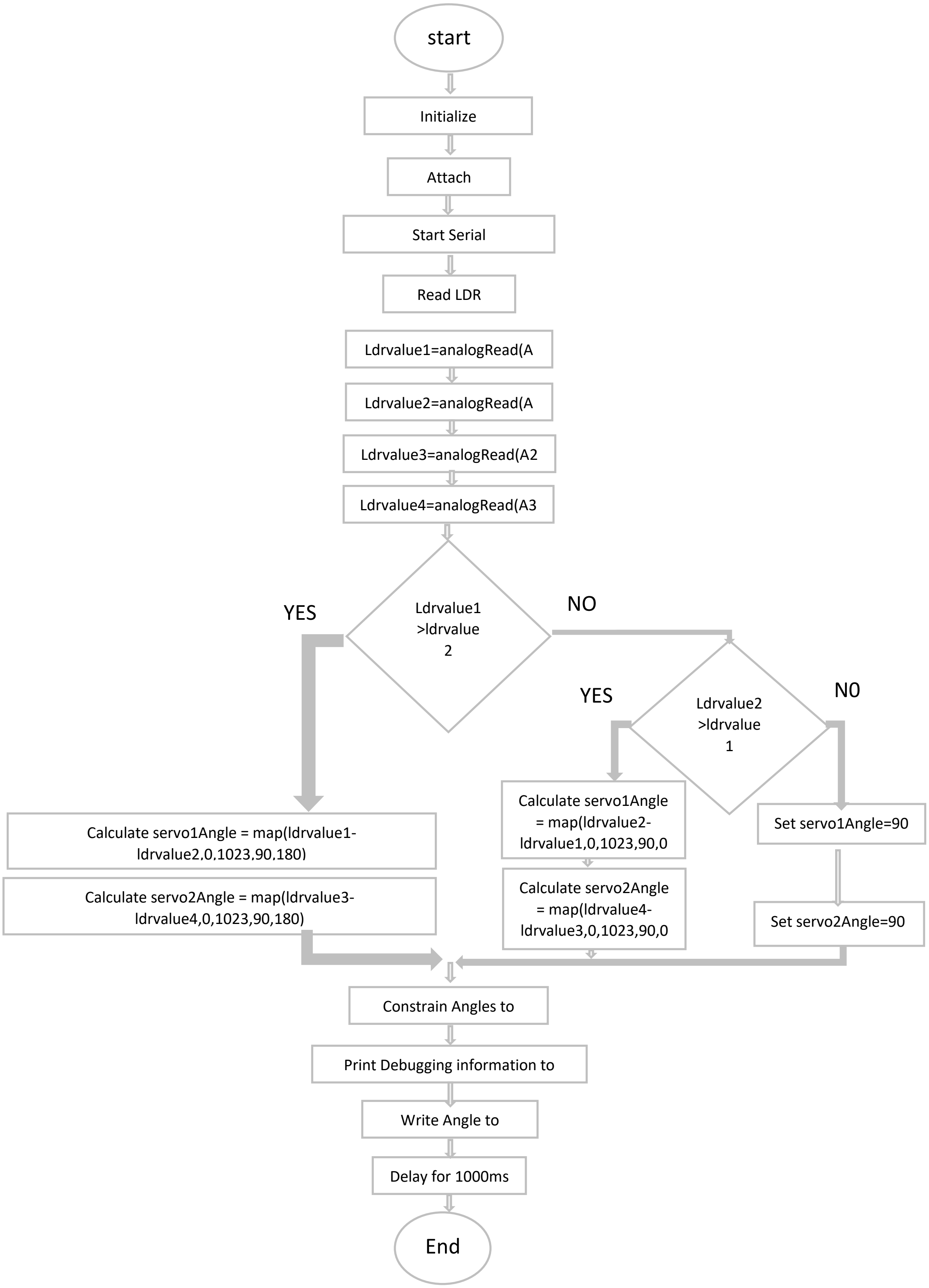

Figure 8: Flowchart

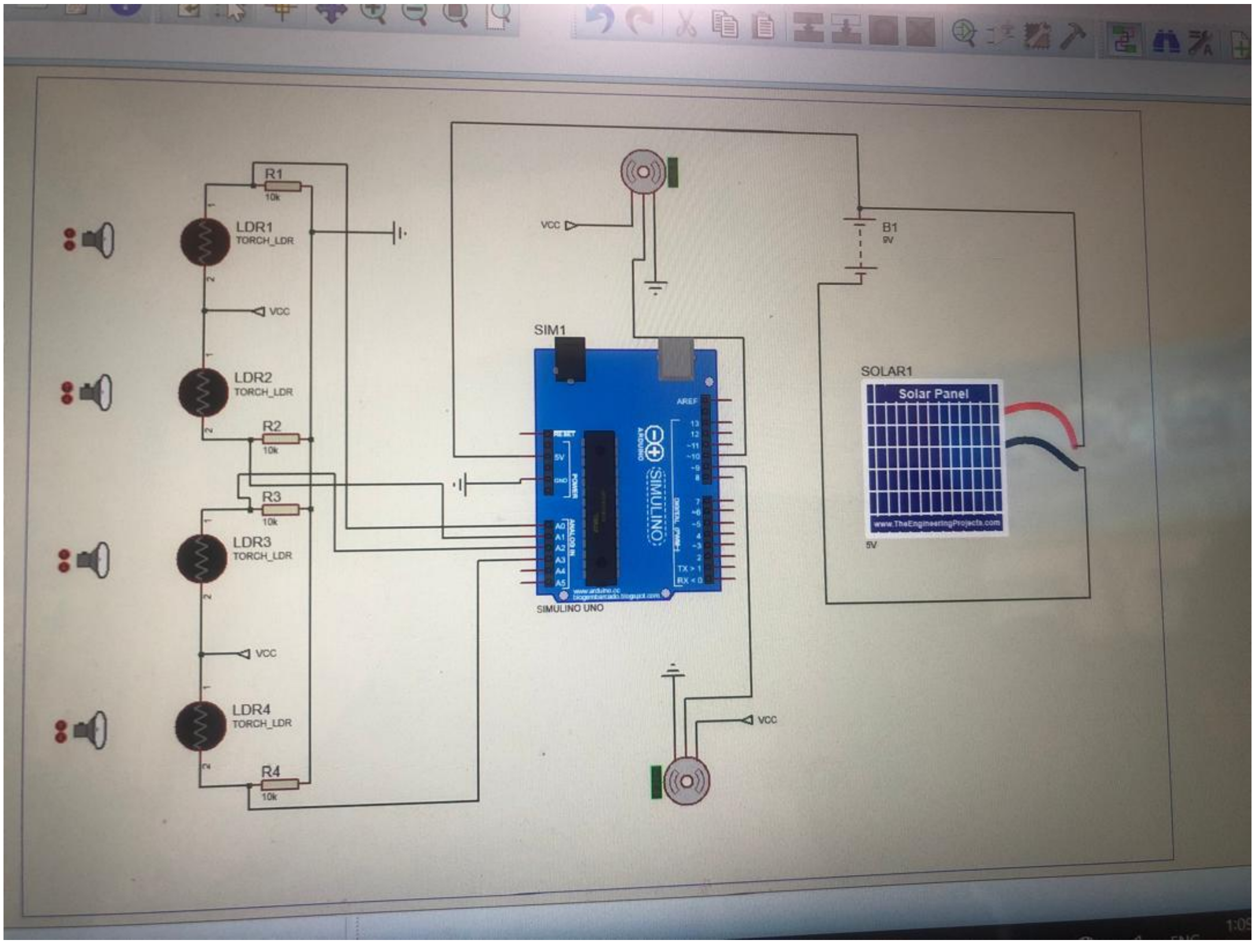

Figure 9: Circuit diagram

4.3. SPECIFICATION

The smart solar tracking system is truly fascinating because it consists of multiple hardware components that work together to maximize solar energy capture. [24] Here are the main elements:

Arduino microcontroller: At the heart of the system, we find an Arduino UNO card or similar. This microcontroller acts as the brain of the system, controlling the motors, processing sensor data, and running the algorithms needed to optimize sun tracking.

SG90 Servo Motor: For the movement mechanism, SG90 servo motor is essential. It is a small, lightweight motor that allows precise and smooth movement. Two of these servo motors are used: one for horizontal rotation (panning) and another for vertical tilting of the solar panel.

Table 1: Specification of servo motor

Pulse width	500µs - 2400µs
Rotation/Support	Bushing
Shaft diameter	4.5 mm
Speed	0.32 oz (9.0 kg)
Torque	4.8V: 25.0 oz-in (1.80 kg-cm)
Gear type	Plastic
Modulation	Analog
Motor type	3 Pole Servo Motor
Range	180^{o}
Phase voltage	5V

Light sensors: These sensors play a crucial role in determining the direction of sunlight. They can be simple photoresistors or more advanced sensors like photodiodes. Strategically positioned on the panel, they measure the amount of light reaching different areas, allowing the orientation of the panel to be adjusted to capture maximum light.

Power: Of course, all of this needs a power source to operate, ensuring that each component can operate efficiently.

Mounting Structure: For the solar tracking system to work effectively, it is essential to have a sturdy mounting structure. This structure must be able to hold both the solar panel and the moving components. I can use materials like metal or wood, as long as they are suitable for outdoor conditions and can securely support all the equipment.

Software Components: The smooth functioning of the smart solar tracking system also relies on well-designed software components. Here are the main ones:

Arduino IDE: This is the integrated development environment that allows I to program the Arduino microcontroller. It offers a user-friendly interface to write, compile and upload my code to the microcontroller.

Control Algorithm: This algorithm is crucial because it determines how the system reacts to data from the light sensors and manages the movement of the servo motors. Basically, it compares the light intensity readings from the sensors, calculates the necessary adjustments to the pan and tilt angles, and sends the appropriate signals to the servo motors.

Calibration Code: This code is used during initial setup to calibrate the light sensors and fine-tune the system behavior. Proper calibration is essential to ensure the system operates optimally and tracks the movement of the sun accurately.

Enclosure/Design Considerations: When designing my smart solar tracking system, it is crucial to consider several elements regarding housing and design to ensure both the functionality and durability of the system.

Protection against environmental factors: The enclosure must provide adequate protection to the components against harsh weather conditions, such as rain, wind, humidity, dust and high temperatures. It is advisable to use weatherproof enclosures or protective enclosures to prevent damage and ensure longevity of the system.

Light Sensor Location: The location of light sensors is critical for accurate solar tracking. They should be positioned to cover a wide field of view, which will allow them to effectively detect the intensity and direction of sunlight. Proper calibration is also necessary to avoid false readings and ensure optimal monitoring.

Wiring and Connections: It is important that the wiring and connections between different components are secure and properly insulated to prevent short circuits and electrical failures. Careful and organized cabling management not only improves system reliability, but also facilitates maintenance and troubleshooting.

Maintenance Considerations: Finally, it is essential to think about ease of maintenance when designing the enclosure. Easy access to components will allow repairs or replacements to be carried out without much difficulty.

Cost Effectiveness: When designing and implementing my smart solar tracking system, it is important to keep cost effectiveness in mind. This doesn't mean I have to sacrifice performance or reliability. By choosing materials carefully, optimizing components and using my resources efficiently, I can reduce costs while ensuring that the quality of my system remains high.

4.5. IMPLEMENTATION (THE PROJECT)

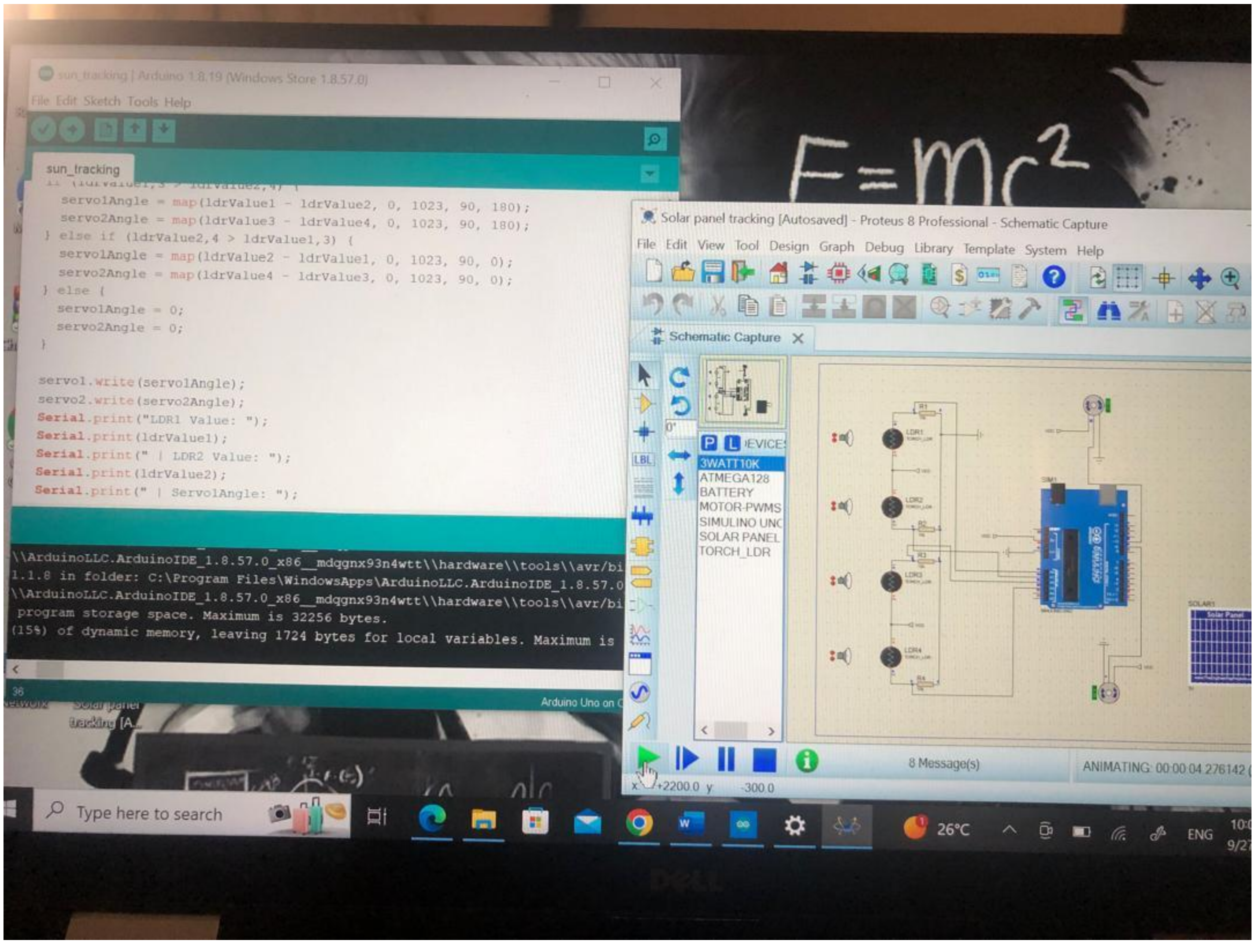

Figure 10: Project

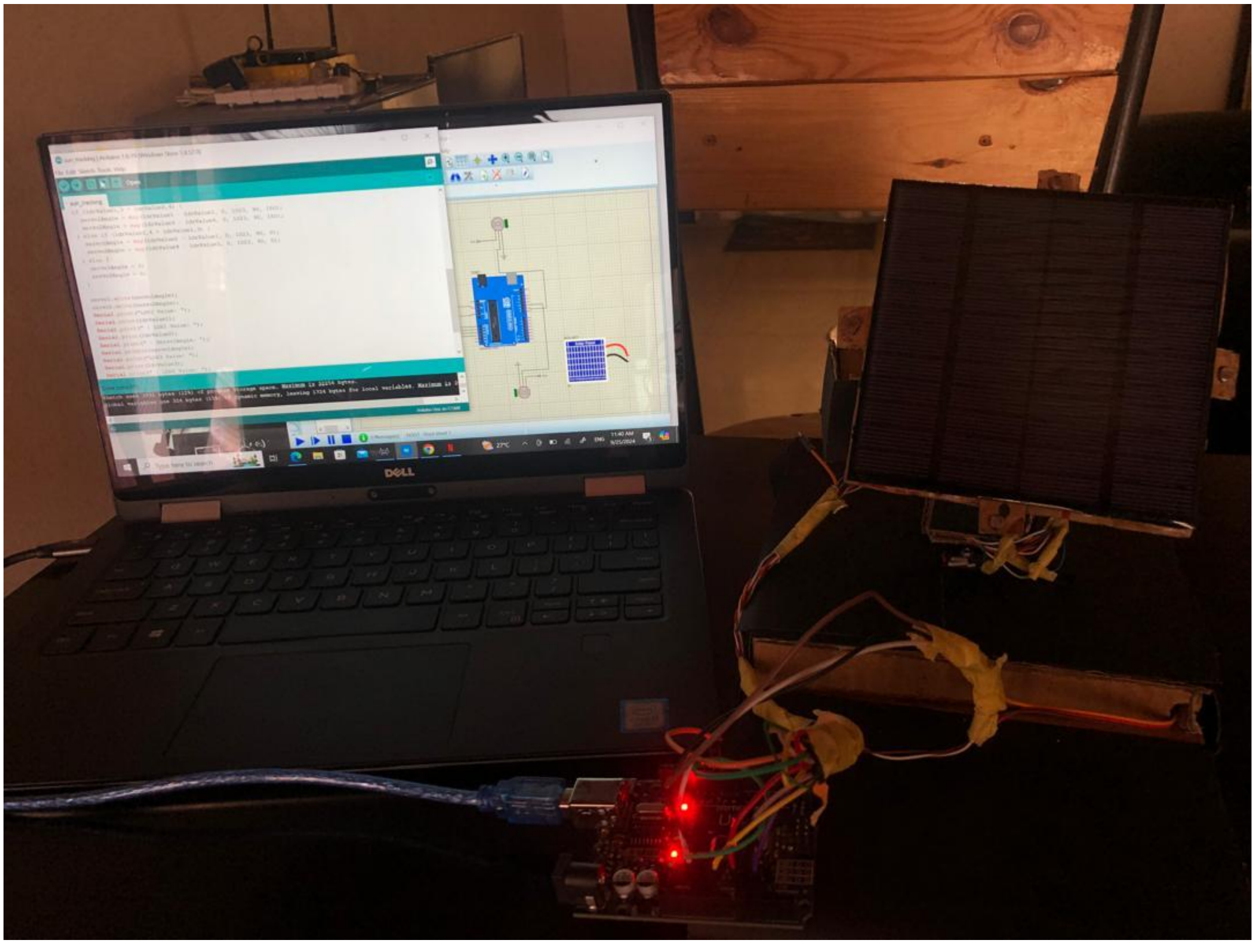

Figure 11: project

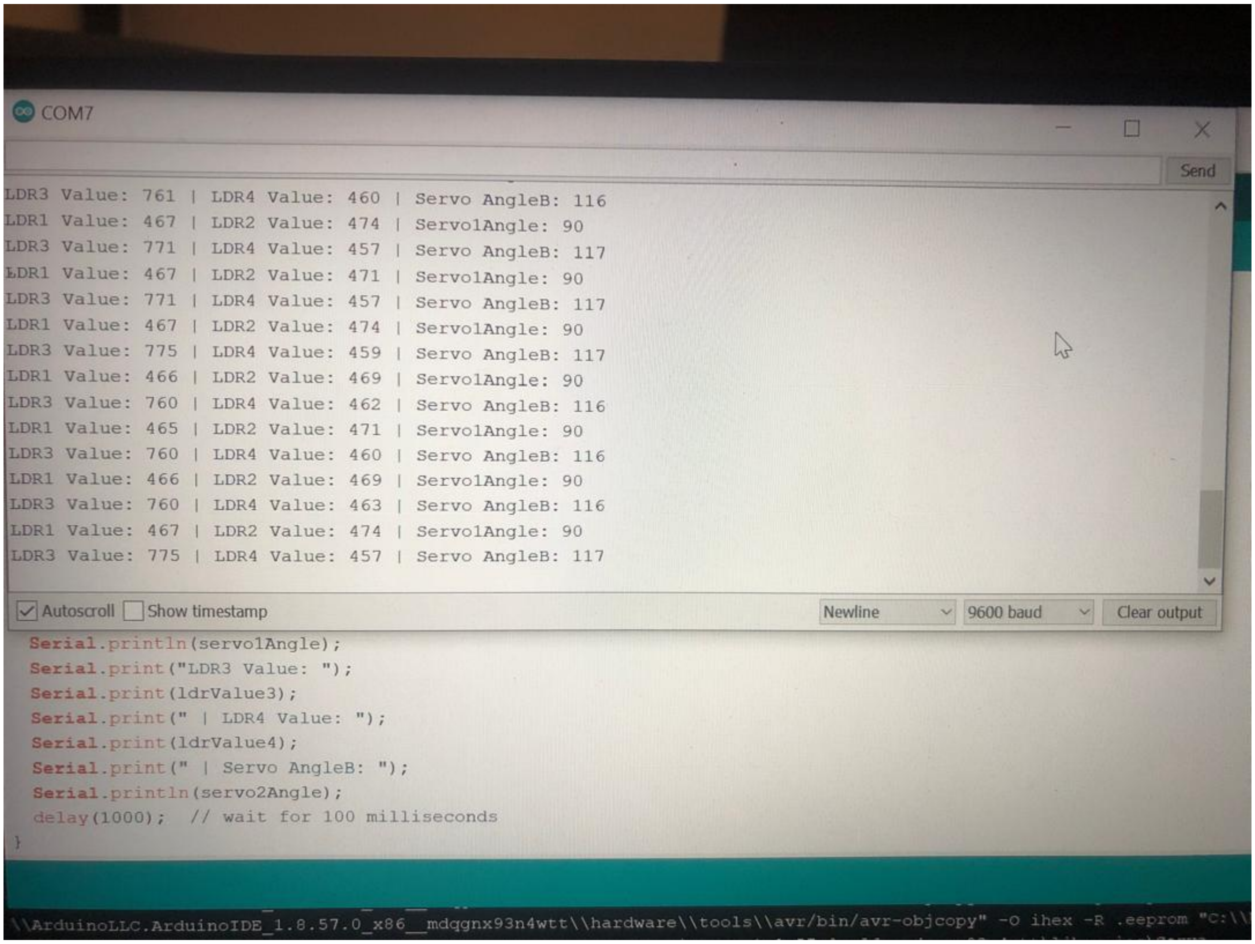

Figure 12: Output

CHAPTER 5: CONCLUSION AND RECOMMENDATIONS

5.0. INTRODUCTION

The rising global demand for energy, along with the urgent need to tackle climate change, has led to a growing interest in alternative and sustainable energy sources. Solar energy stands out as a renewable resource that is abundant and accessible in many regions. However, traditional static solar panels often miss out on capturing the maximum amount of sunlight throughout the day, which can result in lower energy output. To address this issue, researchers and engineers have created solar tracking systems that allow solar panels to follow the sun's path. This adjustment optimizes their exposure to sunlight, significantly boosting energy production. This document specifically highlights a smart solar tracking system that utilizes SG90 servo motors and Arduino, which is a well-known open-source electronics platform. The benefits of implementing such a system are numerous. By incorporating solar tracking technology, communities can greatly improve their ability to capture solar energy, maximizing the efficiency of their solar panels. This enhancement leads to increased energy production and a potential decrease in reliance on fossil fuels, contributing to environmental sustainability and helping to mitigate climate change. Additionally, the economic advantages of adopting a smart solar tracking system are substantial. By maximizing solar energy capture, communities can lower their energy costs, reduce dependence on external energy sources, and promote energy independence. This is particularly advantageous for remote or off-grid areas where access to traditional energy infrastructure may be limited or expensive. Incorporating SG90 servo motors into the tracking system provides a budget-friendly and efficient way to achieve precise sun tracking. These servo motors enable accurate angular movement for the solar panels, allowing them to follow the sun's path while using minimal energy. When combined with the flexibility and programmability of the Arduino platform, various control algorithms can be implemented to ensure the best tracking performance throughout the day. This document outlines the design and implementation details of the smart solar tracking system that utilizes SG90 servo motors with Arduino. It covers the technical specifications of the components, the coding structure for programming the Arduino, and the installation and calibration processes for the tracking system. We’ve also looked into the potential applications of this technology across different contexts, including residential, commercial, and agricultural settings. The introduction of a smart solar tracking system offers communities a great opportunity to enhance their solar energy generation while reducing their dependence on fossil fuels. By integrating innovative technologies like SG90 servo motors and Arduino, communities can effectively harness solar power in a cost-efficient way, resulting in significant environmental and economic advantages.

5.1. CONCLUSION

The research focused on creating a smart solar tracking system designed to maximize solar energy absorption by optimizing the angle of solar panels. It aimed to be cost-effective, using an SG90 servo motor for precise movements and an Arduino microcontroller to control the system's operations. The main goal was to help reduce reliance on fossil fuels and lower energy costs for communities by harnessing solar power more effectively. The study's results showed that the smart solar tracking system was quite effective. It successfully tracked the sun's movement and adjusted the solar panels' angles accordingly, leading to a significant increase in energy captured throughout the day compared to fixed solar panels. This tracking mechanism allowed for better alignment with the sun's rays, maximizing energy absorption and improving overall panel efficiency. Moreover, the system's cost-effectiveness was clear in its design and implementation. The use of the SG90 servo motor, which is affordable and widely available, made it accessible for many communities. The Arduino microcontroller, known for its simplicity and low cost, allowed for easy programming and customization to fit specific needs. This combination resulted in a practical and budget-friendly solution for solar tracking. The research's significance lies in its potential to impact energy consumption and the environment positively. By enhancing solar energy absorption through this smart tracking system, communities can use renewable energy sources more effectively, reducing dependence on fossil fuels. Ultimately, this can lead to lower energy costs, increased energy independence, and a smaller carbon footprint.

5.2. RECOMMENDATION

Practical Implementation and Prototype Development:

A key recommendation is to focus on practical implementation and prototype development for the smart solar tracking system. It would be beneficial for researchers and engineers to partner with communities, organizations, and government bodies to build and test prototype systems in different environments. This hands-on approach will yield valuable insights into how the system performs in real-world conditions and help identify any challenges that may come up during implementation.

Optimization of Solar Tracking Algorithms:

To enhance energy capture and boost the overall efficiency of the solar tracking system, it's important to further research and optimize the solar tracking algorithms that work with SG90 servo motors and Arduino. Exploring various algorithms and techniques, such as predictive modeling, machine learning, and real-time data analysis, can significantly improve the tracking accuracy and responsiveness of the system.

Integration with Renewable Energy Sources:

To further decrease reliance on fossil fuels and promote sustainable energy solutions, integrating the smart solar tracking system with other renewable energy sources is crucial. Researchers should investigate how well the system can work alongside wind energy, hydroelectric power, or energy storage solutions like batteries. This integration can lead to a more reliable and stable energy supply for communities.

Community-Based Training and Education:

For the successful adoption and use of the smart solar tracking system, community-based training and education programs are vital. These programs should aim to equip community members with the knowledge and skills needed to operate, maintain, and troubleshoot the system effectively. Organizing workshops, seminars, and hands-on training sessions in collaboration with local educational institutions, NGOs, and government agencies can greatly enhance community engagement and understanding.

Cost-Effective Manufacturing and Scalability:

It's crucial to look into cost-effective manufacturing methods for the components of the smart solar tracking system, such as the SG90 servo motor and Arduino. Research and development should aim to find alternatives that keep performance high while lowering production costs. By achieving this, the system can become more accessible to communities, particularly those in low-income or remote areas.

Policy and Regulatory Support:

Governments and policymakers have a vital role in promoting sustainable energy solutions. Therefore, it’s important to seek policy and regulatory support that encourages the adoption of the smart solar tracking system. This could involve offering incentives, grants, and subsidies for individuals and communities that invest in renewable energy technologies. Additionally, developing policies that streamline the permitting process and create favorable regulations for the installation and operation of these systems is essential.

Collaboration with Industry Partners:

To ensure the practical implementation and deployment of the smart solar tracking system, collaborating with industry partners is essential. Researchers should connect with technology companies, renewable energy organizations, and manufacturers to share knowledge, resources, and expertise. These partnerships can lead to joint ventures, sponsorships, and funding opportunities, facilitating a quicker transition from research and development to real-world applications.

Continuous Monitoring and Data Collection:

To evaluate the long-term performance and effectiveness of the smart solar tracking system, continuous monitoring and data collection are necessary. This approach allows for ongoing assessment and adjustments based on real-world energy generation data. Researchers can use advanced monitoring tools and technologies, such as remote sensors and data analytics software, to gather detailed information on energy output, efficiency, and system stability. [28]

5.3. SUGGESTIONS FOR FURTHER STUDY

Exploring Advanced Tracking Algorithms:

While the basic tracking algorithm in the proposed system does improve energy capture, there's definitely potential for further optimization. Future research could delve into advanced tracking algorithms, like predictive and adaptive algorithms that leverage machine learning or AI techniques. These smarter algorithms could adjust to changing environmental factors, such as shading from nearby objects, cloud cover, and seasonal changes, leading to even better energy capture and overall system performance.

Incorporating Weather Forecasting Capabilities:

Adding weather forecasting capabilities to the smart solar tracking system could greatly boost its efficiency and output. By utilizing real-time weather data and forecasts, the system can prepare for adverse weather conditions—like heavy rain, storms, or extended cloud cover—and adjust its tracking angle accordingly. Future studies might explore integrating reliable weather forecasting models that predict temperature, humidity, wind speed, and cloud cover, optimizing the solar tracking system's performance in various weather scenarios.

Investigating Optimal Energy Storage Solutions:

To enhance energy efficiency and lessen dependence on the grid, it's essential to integrate effective energy storage systems with the smart solar tracking setup. Future research could investigate different energy storage technologies, such as lithium-ion batteries, flywheels, or supercapacitors, to find the best fit for integration. Key factors to consider would include energy capacity, discharge efficiency, cost, and scalability, ensuring the optimal energy storage solution for various applications and locations.

Evaluating the Economic Viability:

Conducting economic analyses is crucial for determining the feasibility and viability of deploying smart solar tracking systems on a larger scale. Future studies could focus on cost-benefit analyses, life-cycle assessments, and financial modeling to evaluate the economic impacts of these systems. This would provide valuable quantitative data to support decision-making, considering factors like installation costs, maintenance needs, energy savings, and return on investment.

Investigating Alternative Tracking Mechanisms:

While using SG90 servo motors is a solid choice for tracking solar panels, it’s worth exploring other alternatives that might enhance performance or offer different configurations. Future studies could look into the effectiveness of stepper motors, linear actuators, or even hydraulic systems. By comparing the pros and cons of these various tracking mechanisms, we can identify the best options tailored for different applications and operational needs.

Enhancing System Durability and Reliability:

To ensure that the smart solar tracking system lasts and performs reliably, future research should focus on boosting its durability against environmental challenges like extreme temperatures, humidity, wind, and mechanical stress. Investigating material selection, design tweaks, and protective measures can significantly enhance the robustness of system components, reducing the risk of failures and ensuring consistent performance over time.

Exploring Hybrid Renewable Energy Systems:

Integrating the smart solar tracking system with other renewable sources, such as wind turbines or small-scale hydroelectric generators, could improve energy independence and reliability. Future studies can delve into hybrid renewable energy systems that combine multiple sources to deliver a steady and uninterrupted power supply. Thorough investigation into energy management, load balancing, and system integration will be key to maximizing the benefits of these hybrid systems.

Testing in Real-Life Scenarios:

Putting the smart solar tracking system to the test in real-world situations is crucial for validating its performance and efficiency. Future studies should include extensive field trials and pilot projects to assess the system under various geographical and environmental conditions. These practical tests will yield valuable data about energy capture efficiency, maintenance needs, and overall usability, helping refine and optimize the system based on hands-on experience.

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Chapter Five: Conclusion and Recommendations

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Table 2: Cost Estimation

Components Name	Description	Quantity	Costs
Arduino	ARDUINO UNO R3	1	15000
Servo Motor	Micro Servo-SG90	2	8000
LDR	LDR(Photoresistor) Sensor	4	800
Resistors	10k-ohm resistors	4	1600
PCB	Mini PCB	1	1000
Solar panel	Mini Solar panel	1	8000

APPENDICES

```
#include <Servo.h>


Servo servo1;

Servo servo2;

int ldrPin1 = A0;

int ldrPin2 = A1;

int ldrPin3 = A2;

int ldrPin4 = A3;


void setup() {

  servo1.attach(10);

  servo2.attach(9);

  Serial.begin(9600);

}


void loop() {

  int ldrValue1 = analogRead(ldrPin1);

  int ldrValue2 = analogRead(ldrPin2);

  int ldrValue3 = analogRead(ldrPin3);

  int ldrValue4 = analogRead(ldrPin4);

  int servo1Angle;
```

```
int servo2Angle;


if (ldrValue1,3 > ldrValue2,4) {
  servo1Angle = map(ldrValue1 - ldrValue2, 0, 1023, 90, 180);
  servo2Angle = map(ldrValue3 - ldrValue4, 0, 1023, 90, 180);
} else if (ldrValue2,4 > ldrValue1,3) {
  servo1Angle = map(ldrValue2 - ldrValue1, 0, 1023, 90, 0);
  servo2Angle = map(ldrValue4 - ldrValue3, 0, 1023, 90, 0);
} else {
  servo1Angle = 0;
  servo2Angle = 0;
}


servo1.write(servo1Angle);
servo2.write(servo2Angle);
Serial.print("LDR1 Value: ");
Serial.print(ldrValue1);
Serial.print(" | LDR2 Value: ");
Serial.print(ldrValue2);
Serial.print(" | Servo1Angle: ");
Serial.println(servo1Angle);
Serial.print("LDR3 Value: ");
Serial.print(ldrValue3);
```

```
  Serial.print(" | LDR4 Value: ");
  Serial.print(ldrValue4);
  Serial.print(" | Servo AngleB: ");
  Serial.println(servo2Angle);
  delay(1000);  // wait for 100 milliseconds
}
```