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DEVELOPMENT OF A MULTI-AXIS CLOSED LOOP SOLAR RADIATION TRACKING SYSTEM BY THE FUZZY LOGIC

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DEVELOPMENT OF A MULTI-AXIS CLOSED-LOOP SOLAR RADIATION TRACKING SYSTEM BY THE FUZZY LOGIC

By Zaid Mawlood Ahmed AL-IBRAHIME

January 2024

We certify that we have read this thesis and that in our opinion it is fully adequate, in scope and in quality, as a thesis for the degree of Master of Science

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ABSTRACT

DEVELOPMENT OF A MULTI-AXIS CLOSED-LOOP SOLAR RADIATION TRACKING SYSTEM BY THE FUZZY LOGIC

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This thesis research aims to optimize the utilization of solar radiation by employing solar cells and addressing any potential barriers that may impede the efficiency of power generation. Hence, it was imperative to consider the planning, design, and implementation of an intelligent system capable of fulfilling this requirement. Consequently, we opted for an external structure that aligns with the concept of a smart tracking system, eliminating the need to determine the azimuth angle. Instead, the focus is on ensuring the system remains perpendicular to the source of solar radiation. The external structure was designed with two interconnected components to enable a 360° horizontal movement and a 180° vertical movement, ensuring optimal tracking and precise outcomes. This design incorporates two motors (DC and servo) and utilizes eight LDR sensors to effectively overcome obstacles, including partial shading, and maintain accurate tracking even if one of the sensors malfunctions. These sensors operate based on a unique mathematical and programming algorithm. An optimal control device for managing these motors and sensors is the Arduino, which utilizes the fuzzy logic algorithm and is known for its precision in handling relative values and components. The fuzzy logic controller will be responsible for controlling and directing all elements of the system and determining the time to move the panels so that they face direct sunlight. The fuzzy logic algorithm, consisting of 524 lines of programming, incorporates comprehensive instructions, inputs, and control mechanisms to achieve precise and optimal outcomes while effectively addressing challenges such as partial shade and the malfunction of an LDR sensor. Data was collected by using a recording unit (SD card) and storing it on a memory card, which may be accessed at any time, to verify the system's efficiency and identify weak points. The practical results showed that the use of 8 LDR sensors enabled us to overcome all the obstacles facing the system, in addition, to accurately aligning the solar radiation source and choosing the best angles to reach the desired target. Moreover, the utilization of both DC and servo motors played a crucial role in surmounting the primary obstacles encountered in this study. Specifically, it facilitated the identification of the optimal angle that is perpendicular to the radiation source, eliminating the necessity for the azimuth angle and the most favorable starting angle. This system can be categorized as a fusion of the advantages of conventional tracking systems and the integration of artificial intelligence into the tracking process in this research.

2024, 68 pages

Keywords: Solar tracking, Fuzzy logic, LDR, DC motor, Servo motor.

ÖZET

BULANIK MANTIĞI KULLANILARAK KAPALI DÖNGÜ ÇOK EKSENLI GÜNEŞ IŞINIMI TAKIP SISTEMININ GELIŞTIRILMESI

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Ocak 2024

Güneş panelleri kullanan enerji üretiminin sistemlerinin verimliliğinin artırılmasını amaçlayan bu çalışmada, ışınları engelleyebilecek potansiyel engelleri dikkate alarak, güneş ışınımının kullanımının maksimizasyonunu sağlamak için, akıllı bir güneş takip sisteminin planlanması, tasarlanması ve uygulanması gerçekleştirilmiştir. Bu amaçla, akıllı güneş takip sistemi konseptiyle uyumlu, azimut açısını belirleme ihtiyacını ortadan kaldıran denetim ve dış iskelet yapısı seçilmiş ve sistemin güneş ışıklarını dik almasını sağlamaya odaklanılmıştır. Dış iskelet, 360° yatay harekete ve 180° dikey harekete imkan verecek şekilde birbirine bağlı iki bileşenle tasarlanmıştır; böylece optimum izleme ve doğru takip başarımı sağlanmıştır. Gerçekleştirilen bu tasarımın hareket tahriki, döner eksen için DC motor, yatay ve dikey eksenler için servo motorlar kullanılarak gerçekleştirilmiştir. Kısmi gölgeler de dahil olmak üzere engellerin etkili bir şekilde üstesinden gelmek ve sensörlerden biri arızalansa bile doğru izlemeyi sürdürmek için sekiz LDR sensörü kullanılmıştır. Bu sensörlerden alınan veriler, geliştirilen bir matematik model ve bulanık tabanlı bir denetim algoritmasına dayalı olarak kontrol edilmektedir. Sensör verilerini işlemek ve eksenel hareketi sağlayan motorları yönetmek için kontrolör seçiminde, bulanık mantık algoritması kullanan ve göreceli değerleri ve bileşenleri işlemedeki doğruluğuyla ve düşük maliyeti ile bilinen Arduino tabanlı bir denetleyici seçilmiştir. Bulanık mantık denetleyici, sistemin tüm elemanlarının kontrol edilmesinden, yönlendirilmesinden ve panellerin doğrudan güneş ışığını optimum şekilde alacak şekilde hareket ettirilmesi için gereken sürenin belirlenmesinden sorumludur. 524 satırlık programlamadan oluşan bulanık mantık algoritması, kısmi gölge ve hatalı LDR sensörü gibi zorlukları etkili bir şekilde ele alırken doğru ve en iyi sonuçları elde etmek için kapsamlı talimatlar, girişler ve kontrol mekanizmaları içerir. Hareket, ışınım, sıcaklık gibi veriler bir kayıt modülü (SD kart) kullanılarak, sistem verimliliğini kontrol etmek ve güvenlik açıklarını belirlemek için istenildiği zaman erişilebilen bir hafıza kartında saklanmaktadır. Dneysel sonuçlar, 8 LDR sensörü kullanmanın, güneş ışınımının kaynağını doğru bir şekilde ayarlamanın ve istenen hedefe ulaşmak için en iyi açıları seçmenin yanı sıra, sistemin karşılaştığı tüm engellerin aşılmasını sağladığını göstermiştir. Bununla birlikte, hem DC hem de servo motorların kullanılması bu çalışmada karşılaşılan temel engellerin aşılmasında önemli bir rol oynamıştır. Spesifik olarak, güneş ışıklarına dik olan optimal açının belirlenmesini kolaylaştırmış, azimut açısı gerekliliğini ve en uygun başlangıç açısının tespiti gibi işlemleri ortadan kaldırmıştır. Gerçekleştirilen bu system ile, geleneksel takip sistemlerinin verim avantajları avantajları ile yapay zekanın takip sürecine entegrasyonunun bir birleşimi olarak kategorize edilebilir.

2024, 68 sayfa

Anahtar kelimeler: Güneş radyasyonu takip sistemi, Bulanik mantik, LDR, DC motor, Servo motors.

PREFACE AND ACKNOWLEDGEMENTS

Praise be to God, with whose praise and grace I completed this valuable work, and I extend my sincere thanks and gratitude to my father and mother for their support and continuous prayers for me, and to my wife and my beloved who had a great influence in supporting me and giving me confidence to complete this thesis.

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Zaid Mawlood Ahmed AL-IBRAHIME

Çankırı-2024

CONTENTS

LIST OF ABBREVIATIONS

A	Ampere
C-H-E	Center horizontal error
C-V-E	Center vertical error
FL	Fuzzy logic
FLC	Fuzzy logic controller
GA	Genetic algorithm
GMPP	Global maximum power point
H-E	Horizontal error
IC	Incremental conductance
ICA	Imperialist competitive algorithm
LDR	Light depending resistor
LMMP	Local maximum power point
MPP	Maximum power point
MPPT	Maximum power point tracking
PCB	Printed circuit board
PLC	Programmable logic controllers
PSC	Partial shading circumstances
PSO	Particle swarm optimization algorithm
PV	Photovoltaic
ST	Sun tracking
STS	Solar tracking systems
V	Voltage
V-E	Vertical error
W	Watt

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1. INTRODUCTION

In recent decades, there has been a focus on developing affordable renewable solar energy technologies (PV) in order to decrease reliance on fossil fuels and mitigate the associated negative impacts. Additionally, there are concerns about the depletion of fossil fuel reserves in the next century, necessitating the exploration of alternative energy sources. With its cost-effectiveness, eco-friendliness, and limitless potential, the success of photovoltaic module technology has prompted consideration for further development and increased production of solar cells and panels. This aims to maximize energy generation and address efficiency issues. Products utilizing these procedures (MPPT) have been fabricated and developed, and they are readily accessible to consumers in the market. Furthermore, solar energy stands out as the most advanced form of renewable energy technology due to its cost-free nature, widespread availability, lack of pollution, cleanliness, and safety (Elzein 2014).

Photovoltaic (PV) cells are solar cells made of silicon or other materials that directly convert sunlight into electricity (Zulkornain *et al.* 2023). The solar energy source is hindered by the constraint that in adverse weather conditions, such as rain or cloudiness, the solar panels (PV) are incapable of effectively capturing solar radiation to generate power. The researchers have developed closed-loop solar tracking systems that utilize diverse sun tracking technologies with varying degrees of complexity and convergence speed (Zakariah *et al.* 2015).

This project will employ a sophisticated approach to ensure that the system is optimized to generate the maximum amount of energy, regardless of the cost, operational scope, and reliability of the sensors. Furthermore, we will ensure the longevity of the solar panels and prevent heat-related harm by implementing precise angle control and minimizing shade.

The utilization of fuzzy logic, along with an optimal algorithm, enhances the efficiency of decision-making in the rotation of solar panels, resulting in a reduction in the mistake rate. Consequently, two stepper motors will be independently controlled, with the sun's position being continuously monitored by eight sensors to detect the highest solar radiation. Throughout the sun's movement from sunrise to sunset, the first power motor will be active while the second power motor remains inactive, responsible for the vertical motion of the solar tracker. Subsequently, the secondary power motor activates following the sun's movement towards the north or south, while the primary power motor ceases operation. Consequently, this system experiences a reduction in energy usage.

Past research, necessitated knowledge of the azimuth and elevation angles as a frame of reference in order to precisely determine the sun's position (Zakariah *et al.* 2015). However, in this study, we successfully and precisely addressed this issue without requiring knowledge of these two angles by rotating the solar panel at the beginning of its operation. Several research studies were conducted to enhance energy generation through solar tracking systems. These studies involved investigating the optimal angle for the movement of solar panels by creating a closed loop in the horizontal direction and a 180-degree angle in the vertical direction. By employing a precise solar tracking system, we successfully ensured that the photovoltaic panels remained perpendicular to the solar radiation, thereby maintaining their alignment. Solar tracking technology is classified as a mechatronic system due to its incorporation of mechanics, electronics, and information technology. The implementation of the solar tracking system is projected to result in an annual energy output growth rate of 35% (Zakariah *et al.* 2015).

The primary aim of this project is to create and formulate a closed-loop, multi-axis tracking system that assesses the intensity of light. By employing eight high-precision light-dependent resistors (LDRs), this system effectively mitigates the impact of partial shading caused by various factors. It also intelligently determines the optimal angle of alignment between the solar panel and the incident solar radiation, thereby preventing excessive temperatures that could potentially harm the photovoltaic cells and compromise their longevity. This has been achieved by adjusting the orientation of the photovoltaic panel to a more optimal angle for capturing solar radiation and using LDR sensors to determine the direction of the radiation. The sensors then communicate with a fuzzy control unit, which in turn commands one of the motors to move in a safe direction. The motor will return to its original position once its temperature decreases to the acceptable limit.

Rezaei *et al*. (2012) offered a comparison between FLC and a traditional control algorithm for attaining the MPP. The results of the MATLAB software simulation are subsequently presented and compared, including variations in temperature and solar irradiation intensity. The utilization of the MPP tracker is necessary to address these challenges, as shown in (Figure 1.1). The FLC consists of three main constituents. The fuzzifier, as the initial component, converts a variable with a binary value into a fuzzy value. The second element comprises an if-then rule-based fuzzy inference engine. The third component is converted into a real value through the process of fuzzyfication, as shown in (Figure 1.2).

The (Figure 1.3) depicts the creation of the P&O algorithm. A maximum power point tracker utilizes the full load current (FLC) and the conventional perturb and observe (P&O) technique to ensure that a photovoltaic (PV) panel operates at its maximum power point, even in different weather situations. This helps minimize oscillations in output power and reduces power loss. The results demonstrate that FLC has the ability to mitigate the disadvantages of the P&O method. Similarly, the FLC has the ability to transition more efficiently and reach the maximum power point (MPP) at a faster rate. (Rezaei *et al.* 2012).

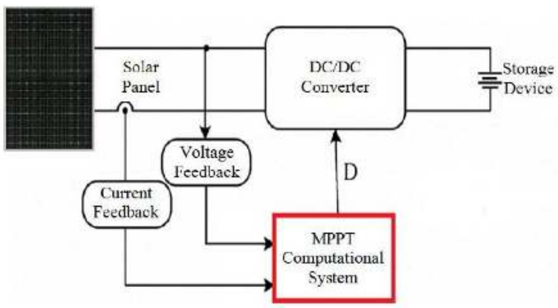


Figure 1.1 Stand-alone photovoltaic system configuration (Rezaei *et al.* 2012)

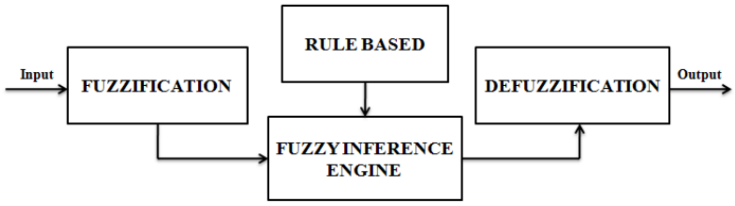


Figure 1.2 Fuzzy system configuration (Rezaei *et al.* 2012)

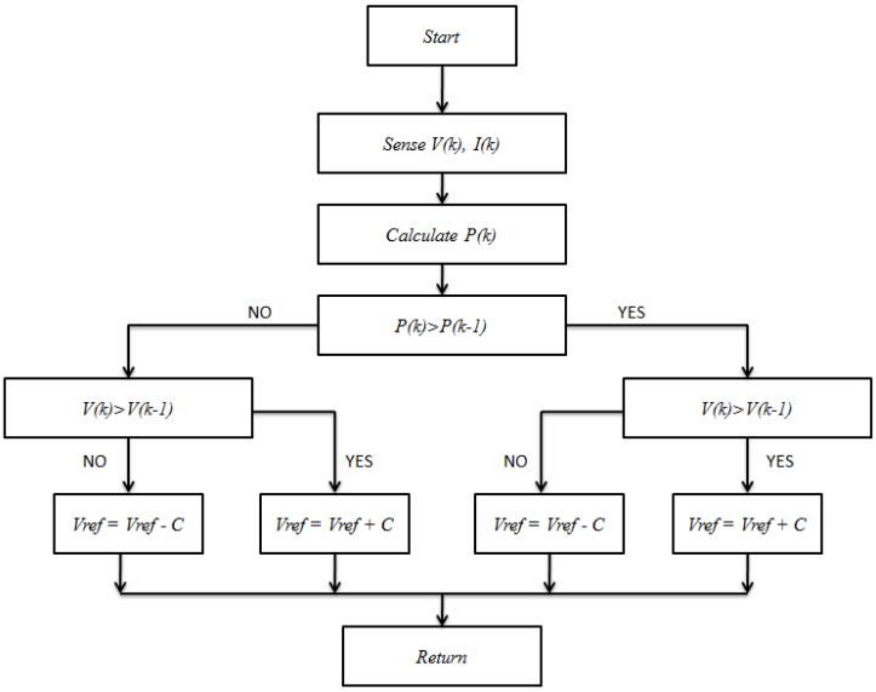


Figure 1.3 P&O algorithm (Rezaei *et al.* 2012)

Abadi *et al.* (2014) Introduced a sun tracking system designed for PV conversion panels, with a specific emphasis on achieving maximum energy conversion efficiency. The technology employs a solitary-axis DC motor regulated by a fuzzy logic controller to achieve an ideal alignment with the sun's location. The experimental results demonstrate a 47% increase in power compared to the fixed system (Abadi *et al.* 2014).

Faramarzi *et al.* (2015) Proposed a technique for incorporating a fuzzy logic controller into a solar tracking system of moderate size in order to achieve the most efficient and accurate real-time positioning of a solar PV panel towards the sun. The system employs intelligent fuzzy logic to track the movement of the sun in two dimensions. The primary controller of the system is an Arduino UNO microprocessor, while light-dependent resistors (LDRs) are utilized to measure the sun's maximum irradiance.

Two power window motors, one for the horizontal axis and the other for the vertical axis, work together and rotate in opposite directions to track the position of the sun. The LDR sensors can determine the sun's position every five minutes by measuring the intensity of incident solar irradiance. The fuzzy logic controller aids the microcontroller in reaching the most precise determinations regarding the direction and stationary position of the solar PV panel.

The experiment's results revealed that the solar tracking system, when employing the intelligent technique, consistently outperformed a stationary panel running without tracking by collecting a significantly higher amount of input electricity. The weekly input power collected fluctuates according to the weather, with the highest quantity recorded on May 4, 2015, exhibiting approximately 90% efficiency due to the sunny and mild weather conditions. The overall power efficiency collected on May 6, 2015, was approximately 75%, slightly lower than in previous days.

Once in operation, the solar tracking system requires minimal energy while achieving great efficiency in electricity generation. In order to expedite the identification of the greatest power point, the system utilizes a fuzzy logic controller to ensure precise and reliable determination of the solar PV panel's rotation direction and position (Faramarzi *et al.* 2015).

Huang *et al.* (2016) Suggest the implementation of fuzzy control theory in a fully autonomous solar tracking system that can adapt to a dynamic environment and consider weather variations and external disturbances caused by malfunctions. In order to reduce inefficient energy dissipation, this approach avoids situations with gloomy sky, cloud cover, and adverse weather conditions. In order to maximize the charging efficiency of the system, the database containing information on the elevation and horizontal angle of the solar cells is utilized.

The fuzzy logic controller (FLC) is an intelligent and practical approach for controlling complex or challenging-to-model systems. The system functions by utilizing four components: fuzzification, decision-making logic, fuzzy knowledge bases, and defuzzification. Fuzzification is the process of transforming numerical values into membership grades, while decision-making logic assesses the efficacy of each rule. A fuzzy inference engine is utilized to implement the FLC system on the output voltage and current measurements obtained from solar sensors.

The matlab Fuzzy Logic Toolbox is utilized to determine the output value of the fuzzy controller and to analyze the behavior of the solar panel. The flowchart depicted in (Figure 1.4) outlines the control algorithm that is derived from fuzzy logic. In order to track the sun's rays, solar panels must have a minimum output value of 0.5. Rotating solar panels are superfluous when the value is below 0.5. The determination of the sun's angle is achieved through the application of database theory in the context of revolving solar panels. A stepper motor is employed as the power source to rotate the solar panel in the direction of the sun during axial tracking.

A fuzzy algorithm, utilizing the voltage and current measurements of solar cells as inputs and the stepper motor as an output, is employed to ascertain the precise position of the sun. An analog-to-digital converter is utilized to convert the voltage from the sensor and the current from the cell into a digital format. This digital data is subsequently transmitted to the FLC for alignment. The output of the FLC is linked to the stepper motor's driver via a gearbox, enabling the panel to rotate on a single axis until it aligns with the sun (Huang *et al.* 2016).

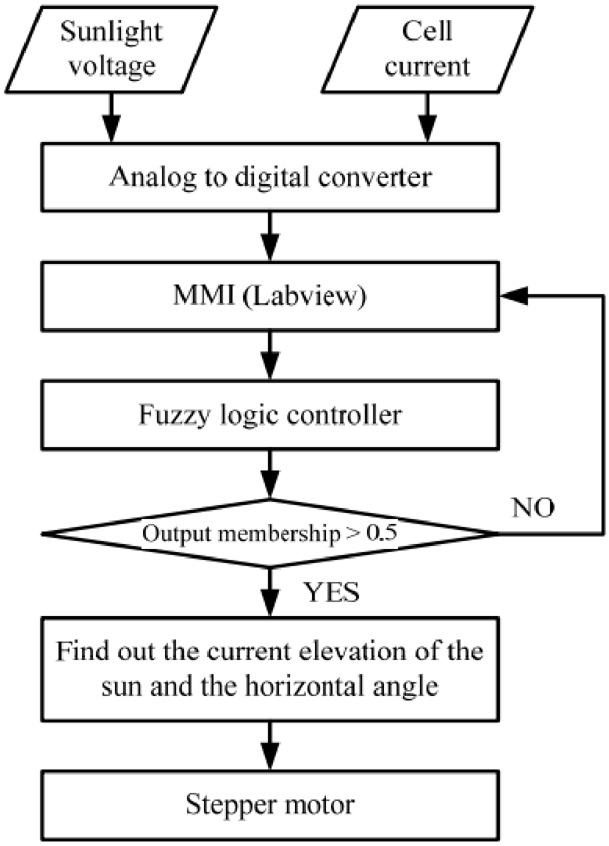


Figure 1.4 Flowchart of solar tracking system (Huang *et al.* 2016)

Yilmaza *et al.* (2018) Propose the implementation of the Fuzzy Logic MPPT (Maximum Power Point Tracking) technique on a boost converter powered by a solar panel, considering varying temperature (25–60 °C) and irradiance (700–1000 W/m2). Subsequently, the proportional-integral (PI) control algorithm was implemented on the boost converter in order to regulate its behavior as a charge controller. The voltage and current characteristics of PV panels are non-linear and are influenced by external factors such as temperature and irradiation. The system was implemented and evaluated using MATLAB and Simulink (Yilmaza *et al.* 2018).

The proposed system has undergone examination in four distinct situations, assessing its response to variations in temperature and radiation. The accuracy of the Maximum Power Point Tracking (MPPT) algorithm's detection of the Maximum Power Point (MPP) ranged from 94.8% to 99.4%. Throughout the duration of the system, the load current and voltage of the buck converter remained consistent at 2.39 A and 15.03 V, respectively, as shown in (Table 1.1). A significant proportion of the necessary efficiency has been achieved. The objective of this system is to maximize the output from the PV panel to reduce expenses. Additionally, the battery is charged with a constant current and appropriate voltage to minimize losses, expedite charging, and prolong the battery's lifespan. The approach will be put into practice in reality if there is substantial backing for the material (Yilmaza *et al.* 2018).

Table 1.1 The power of MPP, accuracy of MPPT, power of PV and current, voltage of buck converter (Yilmaza *et al.* 2018)

States	P_{MPP}	$P(pv)$	Accuracy %	I_{buck}	V_{buck}
State 1 (1000 W/m2 and 25 °C)	84 W	79.7 W	94.8%	2.934 A	15.01 V
State 2 (700 W/m2 and 25 °C)	64.7 W	63.3 W	97.8%	2.932 A	15.03 V
State 3 (1000 W/m2 and 60 °C)	71.2 W	65.8 W	92.4%	2.933 A	15.015 V
State 4 (700 W/m2 and 60 °C)	51.6 W	51.3 W	99.4%	2.932 A	15.03 V

Imron *et al.* (2020) compared two studies for solar tracking systems in 2010 The first study focused on designing a single-axis solar tracking system that utilized an Arduino Mega 2560 and PID control. The system aimed to achieve specific performance metrics, including a maximum overshoot of 3.85%, a settling time of 58 seconds, a rising time of 37 seconds, and a steady-state inaccuracy of 1.1%.

The second study of the sun tracking system was developed during the second semester, utilizing PID control on the azimuth axis. The experiment conducted using the two-panel locations resulted in settling and rising times of 59.5 and 33.799 seconds, respectively. The answer, meanwhile, fluctuated incessantly until it reached a steady condition. The research presents fuzzy logic control techniques that integrate three membership functions for input and output, utilizing two forms of fuzzy logic-owned input membership functions: triangles and trapezoids. An active two-axis solar tracking control system consists of several components. Components such as sensors, controllers, actuators, and plans are involved. The system utilizes four LDR sensors to measure pitch and yaw, with an ATMEGA16 microcontroller implementing fuzzy logic as the controller. Two DC motors serve as the actuators, while solar panels provide the power supply. The active two-axis solar tracking system can be controlled by adjusting the pitch angle and yaw angle.

The results indicate that implementing a fuzzy control logic-based active two-axis solar tracking system can increase power output by over 30%, with a power difference of 7.49 W between the tracking panel and the fixed panel. The active two-axis solar tracking system achieves an average power efficiency of 36.63% after every three days of testing (Imron *et al.* 2020).

Aprillia *et al*. (2021) Created a sensorless tracking system with two degrees of freedom for solar panels that operates in a closed-loop configuration. The fuzzy logic controller (FLC) technique serves as the basis for the tracking controller employed in this study. Based on this study, a dual-axis photovoltaic (PV) system has the potential to increase power generation by 20.2% compared to a fixed PV system with a zero-degree axis orientation. A dual-axis photovoltaic (PV) system, in contrast to a fixed PV system, adjusts the orientation of the solar panel so that it is perpendicular to the sun's rays, optimizing the conversion of sunlight into power (Aprillia *et al.* 2021).

Asyadi and Muliadi (2023) Explain the process of acquiring the solar module's output power. Fuzzy logic control (FLC) is implemented using a boost converter. Several studies have been conducted to optimize the power output of solar modules, utilizing techniques such as perturb and observe (P&O), incremental conductance (IC), and other standard methods. Nevertheless, these strategies are effective solely in constant environmental conditions but are inadequate when confronted with fluctuations in radiation and temperature. The objective of this work is to determine the optimal power output of a solar module by employing the MPPT-FLC approach while considering variations in radiation and temperature. In addition, the MPPT-FLC approach was evaluated on solar modules across various radiation and temperature conditions. The MPPT-FLC approach is designed through the utilization of Matlab and Simulink simulations in order to determine the maximum power point of the solar module. Consequently, the duration required to reach the maximum power point of each solar module is 0.05 seconds. The MPPT-FLC approach demonstrates superior performance compared to the MPPT-P&O method, both in standard settings and in the presence of variations in radiation and temperature (Asyadi and Muliadi, 2023).

1.1 Research Problems

An eminent challenge confronting this thesis is the imprecision of solar tracking in attaining optimal photovoltaic energy, thus leading to a potential decline in the productivity and efficiency of solar cells.

Furthermore, the servo motor not only causes an imbalance in the horizontal movement of the system, but it also cannot support loads that surpass 5 kilos.

1.2 Research Aims

- Obtaining the best tracking accuracy and perpendicularity of the photovoltaic cells with the sun radiation continually in order to obtain the greatest sustainable generation of energy.
- Bypassing partial shadowing that may occur for numerous causes, like shading trees, the presence of a foreign body, and others.
- Knowing the starting angle for tracking solar energy without having to know the azimuth angle

1.3 Research Importance

- The accuracy of tracking and alignment with solar radiation is enhanced by employing 8 Light Dependent Resistors (LDR) sensors and two stepper motors, as opposed to using only 4 sensors and one motor.
- Employing fuzzy logic to yield the most precise and practical outcomes in comparison to other software.

1.4 Construction of the Thesis

This thesis has been divided into five chapters, which are:

- Chapter One: This chapter includes an introductory overview of the thesis issue, highlighting the distinctions between this current research and previous studies. It also addresses the challenges faced by the thesis, emphasizes the significance of this study, and outlines its objectives.

- Chapter two: This chapter includes an explanation of the main topics of the thesis: solar tracking systems (STS), maximum power point tracking (MPPT), comparison between fuzzy logic and evolutionary algorithms, adaptive fuzzy logic controller (FLC)-based MPPT, classification of solar tracking algorithms, and azimuth and tilt angle determination.

- Chapter Three: This chapter presents the design and construction of the solar tracking system, specifications of the system components, and a detailed presentation and comprehensive explanation of the practical materials used in this study.

- Chapter Four: This chapter provides a comprehensive analysis of the practical materials used in this study, the results that were achieved, and the interpretations of these results within the thesis.

- Chapter Five: This chapter includes an explanation of the most important conclusions of the study, in addition to the recommendations for solving the study problem.

2. SOLAR TRACKING SYSTEM

2.1 Introduction

The utilization of alternative energy sources to meet the growing energy demand has witnessed a significant rise. Nevertheless, the conversion efficiency of conventional photovoltaic technology remains relatively low, ranging from 15 to 20%. In contrast, concentration technology achieves a higher conversion efficiency, ranging from 40 to 45% (Palomino-Resendiz *et al*. 2023).

Solar radiation, with its infinite abundance and unwavering reliability, stands as a fundamental renewable energy source (Rashid *et al.* 2024).

Solar tracking systems are utilized as applications to enhance the efficiency of solar energy systems, which are experiencing significant expansion. Several factors influence the efficacy of solar energy systems. Furthermore, photovoltaic cells achieve optimal performance when exposed to direct sunlight. Hence, optimizing the efficiency of the stationary panels is a difficult task. Implementing solar tracking systems, which enhance efficiency by around 30%, is thus considered one of the most effective approaches to mitigate productivity decline. The solar tracking system (STS) optimizes the performance of the photovoltaic panel by aligning it with the sun's different locations. As a result of increasing energy demands, diminishing fossil fuel supplies, the release of greenhouse gases, and the instability of conventional energy systems, there has been a global shift towards renewable energy. The sun is the sole renewable energy source that remains continually accessible for a fixed duration (Awan *et al.* 2023).

This chapter includes an explanation of Solar tracking systems (STS), Maximum power point tracking (MPPT) Comparison between Fuzzy logic and evolutionary algorithms, Adaptive Fuzzy logic controller (FLC)-based MPPT, Classification of solar tracking algorithms, and Azimuth and tilt Angle Determination.

2.2 Solar Tracking System Methods, Strategies and Applied

A solar tracking system (STS) is a mechanism that automatically adjusts the position or inclination of a solar panel to ensure that it is always facing the sun directly and following its course accurately. When contrasted with a stationary approach, this tactic has been proven to enhance the efficiency of a solar panel. A solar tracker optimizes efficiency by continuously adjusting the position of the panel to ensure it is constantly exposed to the highest light intensity throughout the day (Kumar and John 2020).

Solar tracking systems (STS) can be categorized into single-axis and multi-axis systems based on their degrees of freedom (Nsengiyumva *et al.* 2018). Utilizing these technologies can significantly enhance energy production, with single-axis sun tracking (ST) yielding an increase in the range of 12% to 25%, while multi-axis sun tracking can achieve a higher range of 30% to 40% (Singh *et al.* 2018).

Nevertheless, STS is subject to some limits that can only be overcome through meticulous optimization and administration. The primary focus for improving tracker control should be on configuring the tracking axes, optimizing mobile technology, and ensuring proper design of the control systems (Skouri *et al.* 2016).

Recent advancements in computer technologies and reliable control systems have facilitated the enhancement of design and operation algorithms for solar tracking systems (STS). This development is expected to significantly increase the efficiency of photovoltaic systems (Lazaroiu *et al.* 2015).

2.2.1 Solar tracking system methods

Solar technologies that track the movement of the sun can enhance the efficiency and productivity of solar applications.

Sun tracking systems can be categorized based on their degree of freedom (Babiker and Abdulwahabg 2023):

- Single-axis
- Dual-axis

In order to optimize energy generation from the solar panel, it is essential to utilize a dual-axis solar tracker that can rotate the panel along both its horizontal and vertical axes (Muthukumar *et al.* 2023).

Based on the tracking mechanism, the system is further divided into categories (Kumar and John 2020):

- Manual Tracking
- Sensor Tracking
- Azimuth or Zenith Angles Tracking
- FLC, Fuzzy Logic Controller Tracking Algorithms

The power is generated via a single-axis solar tracking system that uses horizontal tracking based on computed solar geometry and monthly radiation. The system has a minimum efficiency of 10–24% and a maximum efficiency of 47% when a fuzzy logic controller is used. The utilization of a sensor-based dual-axis tracking algorithm in solar tracking systems is limited to a minimum gain of 14%. However, incorporating an air-cooling system can enable the system to attain a maximum gain of 49.83% (Kumar and John 2020).

2.2.2 Solar tracking system strategies and applied

The active trackers can be operated by either a microcontroller or a programmable logic controller (PLC), which use an electric motor as the driving mechanism, depending on the sun's position. This controller is employed in a system that periodically, or in real time, monitors the movement of the sun. The position of the sun can be established by inputting the azimuth angle, the solar elevation angle, and directly measuring it using sensors (Pulungan and Son 2018). To attain technical maturity in this system and significantly enhance its effectiveness, it is crucial to maintain the software development process and the implementation of solar monitoring techniques. Minimizing expenses associated with design, building, implementation, and maintenance is essential, and the progress of technology will greatly contribute to the expansion of solar tracking systems. Consequently, the production of solar tracking devices with higher precision and accuracy will increase (Tarazona-Romero *et al.* 2022).

2.2 Maximum Power Point Tracking (MPPT)

In the process of building a photovoltaic (PV) system, it is imperative to employ an algorithm that enables the tracking of the maximum power point (MPPT) to attain the highest level of efficiency from the solar module. This will enable the solar module to efficiently transmit maximum power to the load under these conditions. The solar battery's susceptibility to partial shading, its reliance on solar radiation and temperature for power generation, and the non-linear relationship between the generated current and output voltage of the solar module contribute to the complexity of this task (Bakhriddinovich and Obidovich 2020).

The (Figure 2.1) demonstrates the impact of temperature and irradiation on the estimation of the Maximum Power Point (MPP) point (Arpaci 2019).

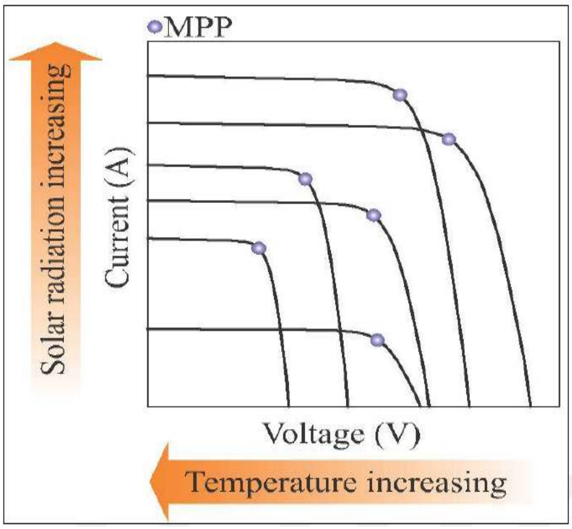


Figure 2.1 Mpp across the I-V plan with variable solar irradiation and temperature (Arpaci 2019)

Maintaining the maximum power point (MPP) of a photovoltaic (PV) system is difficult under different weather conditions. Several approaches for Maximum Power Point Tracking (MPPT) have been presented, which can be categorized into two groups (Awan 2022):

- Traditional algorithms are advantageous because of their straightforward architecture, minimal computational requirements, low memory utilization, and cost-effective implementation. Nevertheless, there are other drawbacks that come with it, such as dependence on the system, consistent oscillations, and the possibility of becoming trapped under partial shading circumstances (PSC).
- Soft computing approaches are independent of specific systems and perform efficiently in any weather condition without any steady-state oscillations.

Maximum power point tracking can optimize its power output by continuously monitoring and adjusting its operation to align with the maximum power point of the PV (Abuhashish *et al*. 2022).

Solar tracking allows for the efficient capture of the highest possible amount of power from the sun by aligning with the sun's trajectory. These strategies can enhance the energy generation of photovoltaic (PV) systems to varying degrees of effectiveness. Solar tracking offers a significant benefit in improving the efficiency of the photovoltaic (PV) system compared to a stationary solar system (Kanwal *et al*. 2023).

There is no single MPPT technique that can be universally applied in all weather conditions. PSC prohibits the utilization of straightforward methodologies, and those that are feasible may encounter intricacies and extensive computations. In order to assess an algorithm, it needs to have the capability to differentiate between LMPP (local maximum power point) and GMPP (global maximum power point), efficiently and accurately track MPP (maximum power point) in consistent weather circumstances and when there is partial shading, be unaffected by the electrical characteristics of PV (photovoltaic) panels, and not display any sustained oscillations.

This example utilizes the incremental conductivity methodology to track the maximum power control point (MPPT). To optimize performance and optimum efficiency, the conductivity increment should be adjusted based on the distance between the MPPT and the actual operating point. The increment should be larger for longer distances to enable quicker response times. The increment ought to be smaller at closer distances to reduce stationary inaccuracy. This notion dictates that the expression should be used to determine whether to increase or reduce the reference current (Saitov and Akhmedov 2023).

$$\Delta\ Iref = \pm\beta = \left(\frac{\Delta V}{\Delta I} + \frac{V}{I}\right) \qquad (2.1)$$

$\Delta\ I_{ref}$ - is the adjustment of the reference current

β - is the scaling factor

The selection of the sign change for the reference current depends on whether the present operating point is located on the left or right side of the maximum power point tracking (MPPT). The relationship between solar radiation power and short-circuit current in photovoltaic panels is inversely proportional. The x-coordinate of the peak point shifts slightly towards decreasing voltage as solar radiation power decreases. The y-coordinate of the maximum power point is essentially inversely proportional to the solar radiation power. The maximum power point, which is crucial for the battery's longevity, is found along the voltage line that allows the lowest permitted voltage, exhibiting minimal variation. At low solar radiation power, there is a discrepancy between the maximum point and the value of the lowest allowable charge voltage. The evaluated panel exhibits a decrease in performance, delivering only two-thirds of its output when exposed to approximately 100 W/m2 of solar light. The efficiency of the panels diminishes as solar radiation intensity increases. When the battery is directly connected to the solar panel, the output power significantly diminishes to zero in low light conditions. Under peak solar radiation, the photovoltaic panel generates an output equivalent to 10 to 12.5 percent of its designated power capacity. However, the output voltage must also be lower than the battery's minimum allowable voltage. If the photovoltaic power plant is comprehensive rather than consisting of a single solar panel, the energy that is currently being squandered could have significant value (Saitov and Akhmedov 2023).

2.3 Comparison Between Fuzzy Logic and Evolutionary Algorithms

Fathi and Parian 2021, in their study, designed and tested maximum power point tracking MPPT by using four intelligent methods: fuzzy logic, evolutionary algorithms like GA, PSO, and ICA. The next section will explain the comparison of this study and the most important results (Fathi and Parian 2021).

The genetic algorithm (GA) is a commonly utilized clever optimization technique. To discover the best weights, it uses natural selection, mutation, and crossover operators (Kramer 2017). The particle swarm optimization algorithm (PSO) employs swarm intelligence to identify ideal weights and is based on the behavior of fish and birds (Wang *et al*. 2018). The Imperialist Competitive Algorithm (ICA) is an developing algorithm inspired by imperialism, focusing on assimilation and imperialist competition (Aleardi and Pierini 2018).

Furthermore, the empirical findings of the empirical investigation conducted by Fathi and Parian demonstrated the fuzzy logic developed for MPPT has outperformed alternative methods such as evolutionary algorithms like GA, PSO, and ICA in every aspect. It exhibits superior speed, enhanced precision, heightened user-friendliness, and increased resilience to environmental fluctuations. The proposed fuzzy logic approach in this study is deemed as an effective solution for Maximum Power Point Tracking (MPPT) in solar panels due to its accurate implementation of the fuzzy logic system and the advantage of not necessitating the involvement of an expert for designing the fuzzy system (Fathi and Parian 2021).

2.3.1 Fuzzy logic (FL)

Fuzzy logic is a form of logic. Logic is the examination of the principles and methods employed in human cognition. Classical logic adheres to the convention of dealing with propositions that are binary in nature, meaning they can only be either true or false, such as conclusions or judgments. Each assertion is accompanied with a counterargument. Hence, classical logic pertains to collections of variables that represent propositions. Every combination of the variables ultimately assumes a truth value, either true or false, without any possibility of being both simultaneously, since each variable represents a hypothetical proposition. The majority of classical logic is dedicated to the examination of concepts that facilitate the creation of new logical variables through the use of specific pre-existing (Chen *et al*. 2000).

Fuzzy logic relies on human cognitive processes, allowing it to provide conclusions that are acceptable or useful even in situations where inputs are ambiguous or uncertain, without requiring a precise mathematical framework (Shanthi *et al.* 2018).

There are three fundamental parts to a typical FLC.

- The inference engine
- Defuzzification module
- Fuzzification module

The (Figure 2.2) shows the basic structure of a fuzzy logic controller (FLC). There is one output signal (yg) and two input signals (xk1, xk2), each with a unique value. The current signal's precise numerical value is converted into suitable linguistic values, such as small and large associate membership functions, using the process of fuzzification, which is based on the concept of fuzzy sets. The inference engine of the FLC makes decisions based on fuzzy rules. The engine utilizes the data obtained from the fuzzification process to generate control actions expressed in fuzzy terms. The fuzzy rule applies IF-THEN logic using linguistically variable fuzzy words. The defuzzification module is responsible for converting the output of the fuzzy controller, which is in fuzzy form, into a precise value that can be used to control the physical plant (Subiyanto *et al.* 2012).

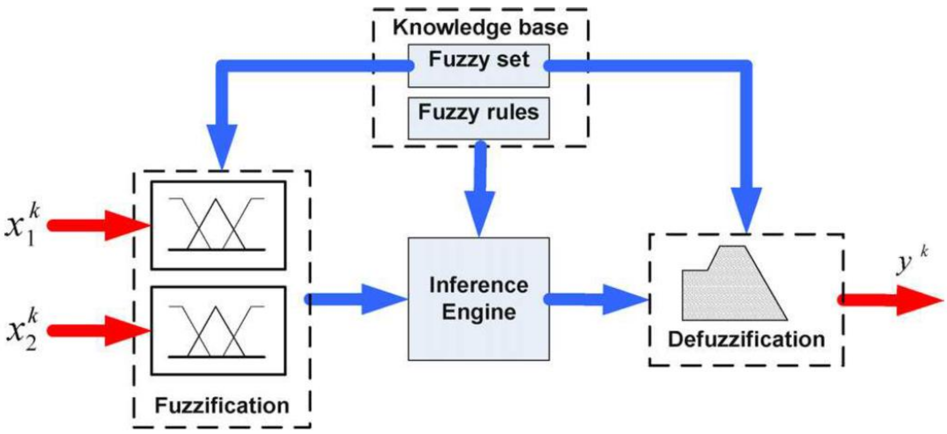


Figure 2.2 Structure of fuzzy logic controller (Subiyanto *et al.* 2012)

2.4 Adaptive Fuzzy Logic Controller (FLC) Based MPPT

The Fuzzy logic controller is one of the most common artificial intelligence technologies. To get the maximum energy possible out of solar generators, it may be utilized as a controller for seeking the MPP. It has the benefit of being able to perform well with erroneous inputs. Thus, a precise mathematical model is not necessary. Dealing with nonlinear situations utilizing it is also quite successful (Babaie and Al-Haddad 2020).

The study Fapi *et al* 2021 describe the Adaptive Fuzzy logic controller (FLC) based MPPT. The application of fuzzy set theory allows for the direct conversion of linguistic values into an automated control strategy in an asymmetrical FLC-based MPPT system. This integrates human knowledge and experience into the process of designing controls.

The equations (2.2) and (2.3) explain the input variables of FLC, which are error (E) and error change (CE) at time samples n, respectively. The PWM signal it generates is utilized to operate the DC-DC boost converter (Fapi *et al* 2021).

$$E\,(n) = \frac{P\,pv\,(n) - P\,pv\,(n-1)}{V\,pv\,(n) - V\,pv\,(n-1)} \tag{2.2}$$

$$CE\,(n) = E\,(n) - E\,(n-1) \tag{2.3}$$

Where P pv(n) and V pv(n) are the power and voltage of the PV panel, respectively.

The scaling factors ke and kce are used to normalize the inputs associated with the mistake and to account for its variance. Number inputs are fuzzyfied into linguistic variables to varying degrees, depending on the membership functions.

The membership functions applied in the case of a fuzzy controller are shown in (Figure 2.3). For both the inputs and outputs, asymmetrical triangular and trapezoidal forms are employed (Fapi *et al* 2021).

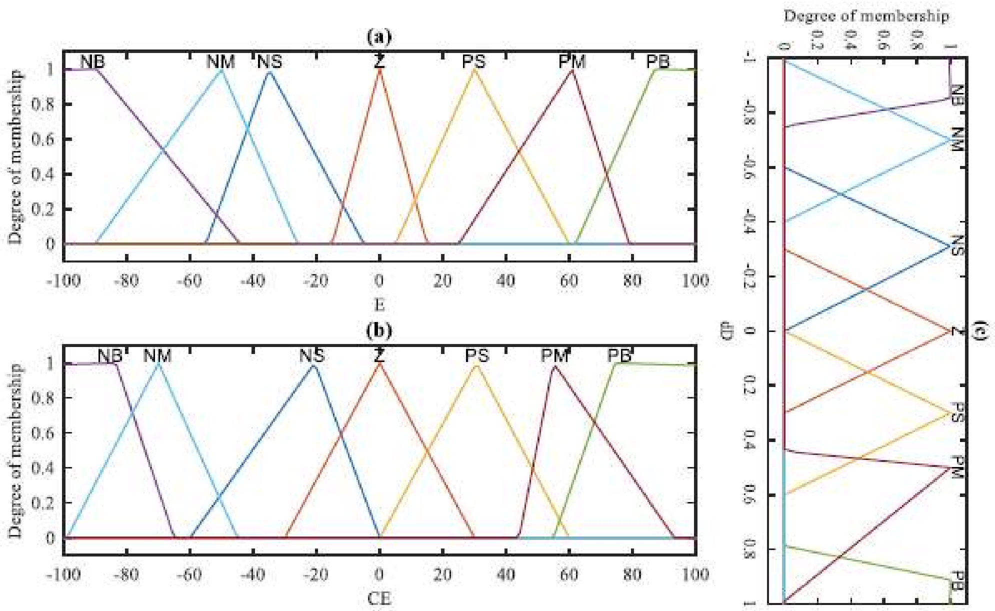


Figure 2.3 Membership functions, (a) for E(k), (b) for CE(K), and (c) for dD (Fapi *et al* 2021)

The (Table 2.1) provides the fuzzy controller's inference rule. The matrix elements in this table represent the error E (n), the variation of the error CE (n), and the duty cycle dD of the DC-DC boost converter.

For the input and output variables, the discourse universe is divided into seven classes: NB, NM, NS, Z, PS, PM, and PB. NB stands for "negative big," NM for "negative medium," NS for "negative small," Z for "zero," PS for "positive small," PM for "positive medium," and PB for "positive big," among others (Fapi *et al.* 2021).

Table 2.1 Rules of the fuzzy system (Fapi *et al*. 2021)

		CE						
		NB	*NM*	*NS*	*Z*	*PS*	*PM*	*PB*
E	*NB*	*NB*	*NB*	*NB*	*NM*	*NM*	*NS*	*Z*
	NM	*NB*	*NB*	*NM*	*NM*	*NS*	*Z*	*PS*
	NS	*NS*	*NM*	*NM*	*NS*	*Z*	*PS*	*PS*
	Z	*NS*	*NM*	*NS*	*Z*	*PS*	*PM*	*PM*
	PS	*NM*	*NS*	*Z*	*PS*	*PM*	*PM*	*PB*
	PM	*NS*	*Z*	*PS*	*PM*	*PM*	*PB*	*PB*
	PB	*Z*	*PS*	*PM*	*PM*	*PB*	*PB*	*PB*

The output language variable is converted into a numerical variable during defuzzification. As shown in Equations (2.4), the center of gravity serves as the defuzzification interface, and the output of the FLC, which represents the duty cycle, is identified using this method.

Following defuzzification and before being presented to the DC-DC converter, the DC-DC boost converter is scaled by the Equations (2.5) (Fapi *et al* 2021).

$$dD(j)= [\ \sum_{j=1}^{n} \mu \ (Dj) - Dj\ ] \,/\, [\ \sum_{j=1}^{n} \mu \ (Dj)] \qquad (2.4\ )$$

$$D(t)= D(t\text{-}1) + K_s dD(j) \qquad (2.5)$$

Where ks is the gain for scaling the duty cycle.

2.5 Classification of Solar Tracking Algorithms

In this section three category open-loop algorithm, closed-loop algorithm, and hybrid algorithm will be covered.

2.5.1 Open loop algorithm

The sun tracking methodology that relies on solar sensors and lacks control feedback is referred to as an "open-loop" method. (Figure 2.4) is a block diagram illustrating the open-loop solar tracker technique (Tarazona-Romero *et al.* 2022).

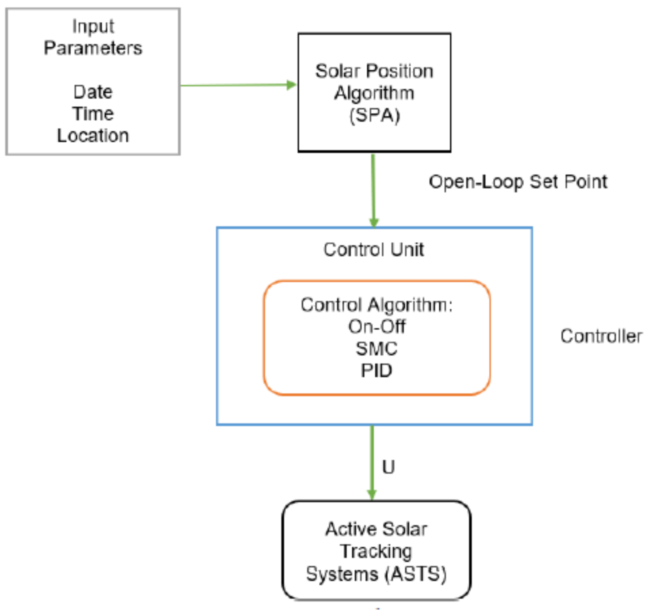


Figure 2.4 Block schematic of an open-loop solar tracker method (Romero *et al.* 2022)

Open-loop solar tracking systems commonly employ Solar Positioning Algorithms (SPA) to forecast the apparent sun position relative to the system's geographical coordinates on Earth for either one-axis or two-axis solar trackers. Electrical control units are commonly programmed with these algorithms utilizing open-source software and easily accessible hardware, including the Arduino, microcontrollers, programmable logic controllers (PLC), smart relays, and Raspberry Pi, among other options. Once the algorithm programming has been created in the software and linked to the hardware, it calculates the solar zenith and azimuth angles. These angles help predict the position of the sun using a control signal (U), which then aligns the solar panel photovoltaic or thermal system with the solar vector. (Tarazona-Romero *et al.* 2022). They are heavily utilized in small-scale solar systems, which is crucial to note (Fuentes *et al.* 2022).

2.5.2 Closed loop algorithm

The solar tracking approach, which can be done on one or two axes, is known as closed-loop because it uses the apparent position of the sun as control feedback by utilizing solar sensors. (Figure 2.5) is a block diagram illustrating a closed-loop solar tracker technique (Romero *et al.* 2022).

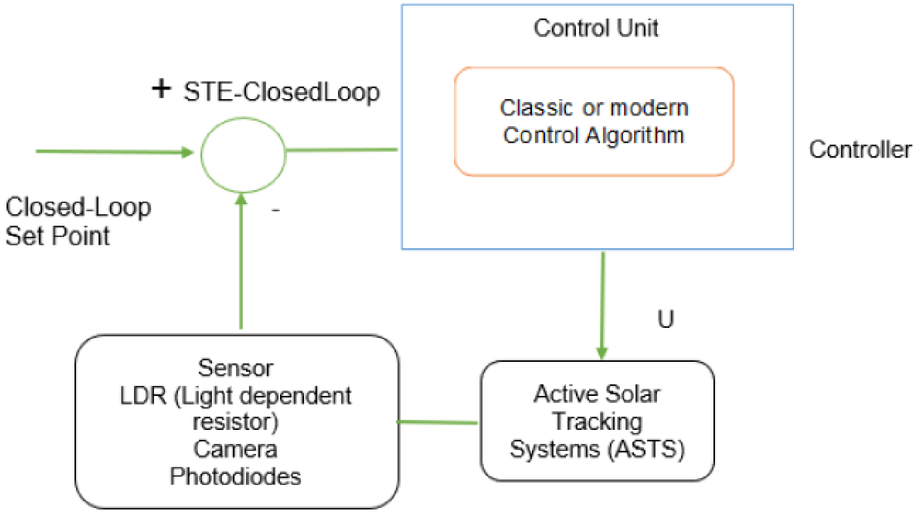


Figure 2.5 Block schematic of a closed-loop solar tracker method (Romero *et al.* 2022)

A solar sensor is commonly employed in closed-loop solar tracking systems, which also need the establishment of a set point. This set point is typically determined by arrays of photosensors or the focal point of an image (0, 0) in a solar imaging sensor. This algorithm is typically implemented in electronic control devices using open-source software and hardware that are widely accessible locally. This includes platforms such as Raspberry Pi, Arduino, microcontrollers, and programmable logic controllers (PLC), among others. Additionally, modern control techniques are employed for specific scenarios. The closed-loop technique, incorporating feedback control and the integration of a solar sensor, offers a notable advantage of greater precision compared to open-loop systems. In addition, they are not limited by location or geography and do not necessitate an algorithm for monitoring the sun or predicting its apparent position. The utilization of this technology in photovoltaic and concentrated solar power systems has been highly regarded. However, its operation relies on climatic variations as it requires a solar sensor that may be affected by diffuse irradiance and weather disruptions. Due to the non-linear response of the sensors to temperature and radiation variations, the sun position is constrained by the field of view of the sensors used in this method (Romero *et al.* 2022).

In a closed-loop control system, the actuating error signal, which can be either the output signal or a function of the output signal and its derivatives and/or integrals, is transmitted to the controller. The purpose of this is to minimize the error and increase the system's output to reach a desired value. The term "closed-loop control" commonly denotes the utilization of feedback control techniques to reduce system error (Ogata 2010).

2.5.3 Hybrid algorithm

This solar tracking system is referred to as a hybrid loop due to its combination of closed loop and open loop approaches. While it is utilized in photovoltaic systems with one or two axes, its development was prompted by the requirements of solar concentration systems. The block design of a hybrid-loop solar tracker technology is illustrated in (Figure 2.6). This method commonly employs two control loops: an open loop with robust control and a closed loop with precise control (Romero *et al.* 2022).

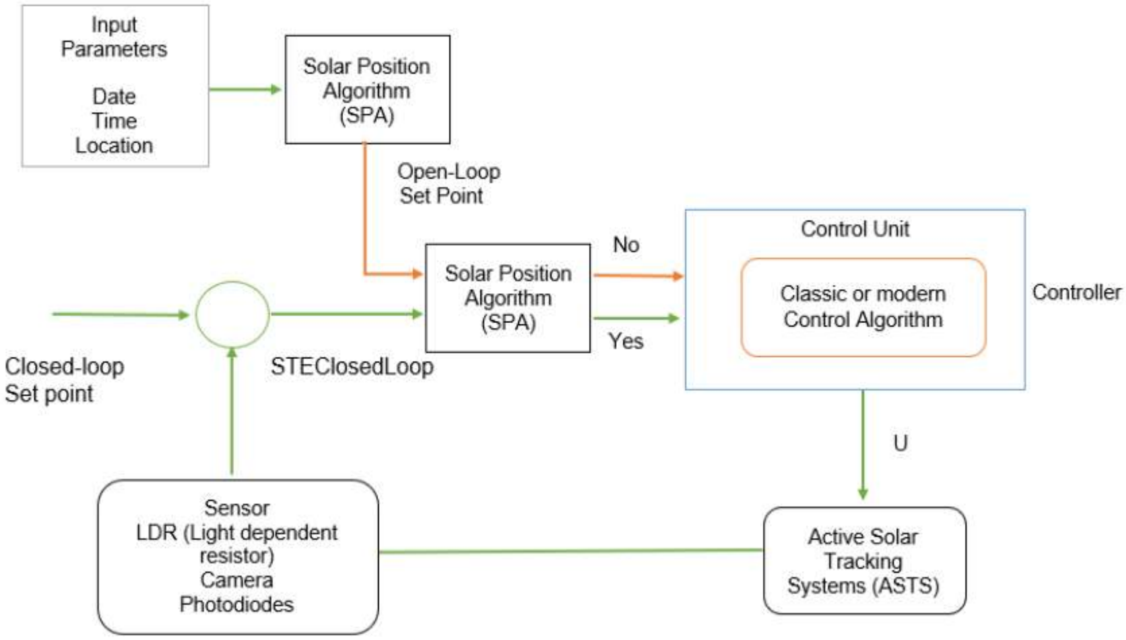


Figure 2.6 Block schematic of a Hybrid -loop solar tracker method (Romero *et al.* 2022)

The integration of the two tools is achieved through the utilization of both open and closed access software. The algorithm is often programmed in robust and conventional electronic control units. Locally, there are several hardware components, such as Arduinos, microcontrollers, and programmable logic controllers (PLCs), that can be used. Hybrid loop algorithms are more dependable and exact than open or closed loop systems because they are not influenced by factors such as tracker installation variance, mistakes in calculating the sun's location, and weather conditions. Nevertheless, its execution incurs high costs and requires both a sensor and a sun tracking algorithmd (Romero *et al.* 2022).

2.6 Azimuth and Tilt Angle

The azimuth angle and tilt angle have distinct interpretations as per the literature.

The tilt angle refers to the deviation from the horizontal plane of the photovoltaic modules in a fixed (non-tracking) setup. It is generally advised to construct solar systems with a tilt angle that matches the latitude of the site. The azimuth angle is the angle formed between the current position of the sun and the point on the horizon where the arc of a vertical plane passing through the zenith intersects. (Figure 2.7) displays the definitions of the tilt angle and the sun azimuth angle (Božiková *et al.* 2021).

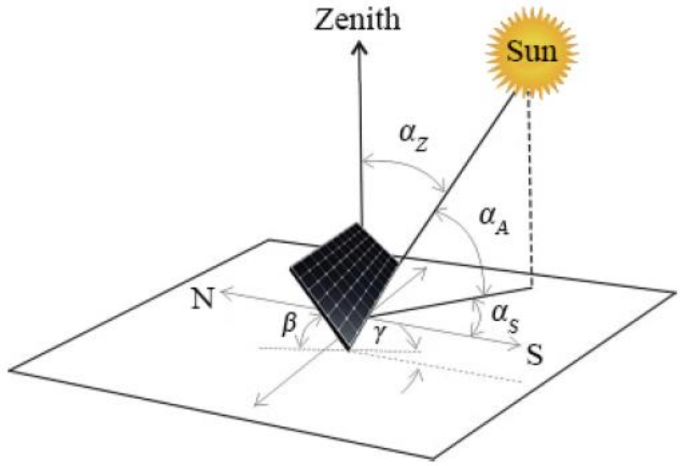


Figure 2.7 The definition of the tilt angle and the solar azimuth angle (Božiková *et al.* 2021)

The location of a region geographically is necessary for optimizing azimuth direction and tilt angle for solar panels. Consequently, the azimuth direction and tilt angle parameters vary depending on the location. Initially, the maximum tilt angle is ascertained by measuring the amount of solar radiation that impacts an inclined surface. The sum of direct, diffused, and reflected radiation, known as albedo, is commonly combined to determine the overall average radiation on the surface of the inclined plane (Lukman *et al.* 2020).

The study conducted by Aprilia *et al.* (2021) elucidates the process of determining azimuth and tilt angles.

3. SOLAR TRACKING SYSTEM DESIGN

Wind systems are a crucial renewable energy source for maintaining low noise levels. They are particularly effective and feasible on the outskirts of cities and require large-scale construction to be economically viable. However, solar energy is another promising source of renewable energy, as the quantity of solar energy that reaches the Earth in a span of 40 minutes is equal to the energy requirements of an individual for an entire year (Huang et.al 2016).

This chapter provides a detailed description of the solar path tracking system utilized in this study, as well as the solar energy materials employed in the system. The incorporation of these materials has been shown to greatly enhance system performance.

The tracking device adjusts the solar panel's position in an axial rotation to follow the sun's movement, so maximizing the production of electrical energy. It achieves this by aligning itself with the direction of sunlight, we will be able to significantly increase productivity in this study by approximately 50% (Huang *et.al* 2016).

This study utilizes a high-precision multi-axis closed-loop solar tracking device. This system will require the utilization of dual sets of motors to regulate the orientations of the solar panels. The system will require eight optical sensors (LDR) and employ fuzzy control theory to develop a completely automated solar tracking system that can adapt to environmental variations, including cloudy conditions, gloomy skies, and unpredictable weather, in order to minimize energy waste. Taking into account the database, determine the height and horizontal angles of the solar panels to achieve the best quality of the system’s charging effect.

3.1 Methodology

In the section on problem definition in this study, we examined the issue we are dealing with, namely the accuracy of solar panels tracking the energy source, with a varying error rate from one system to another. Additionally, it is crucial to determine the azimuth angle to calculate the east and west angles of the sun. Moreover, the constant perpendicularity of photovoltaic cells to the sun leads to high temperatures, which can potentially cause damage to these cells. As a result, we created and implemented an intelligent system that precisely addresses these problems and obstacles in order to achieve the best electricity production while maintaining the efficiency and durability of these cells. To do this, we have created an external framework that embodies the concept of this system and offers unrestricted mobility in all necessary axes and directions.

The movement of the solar panel in both directions necessitates the utilization of two motors, provided that these motors are governed by smart devices (Arduino) coded in a sophisticated language utilizing fuzzy logic to enhance the precision of the instructions governing the system. In addition, we equipped the solar system with a temperature sensor to prevent excessive heat that may potentially harm the photovoltaic cells. Furthermore, a rechargeable battery was installed to power the entire system. In order to determine the necessary angle and direction, 8 (LDR) sensors were evenly positioned around the solar panel. These 8 LDRs were distributed as follows:

- 4 LDRs sensors around the corners of the solar panel
- 4 LDRs sensors in the middle of the outer ribs of the panel and between the first four sensors.

Furthermore, the utilization of specific plastic pieces to manipulate the angle of light that enters the (LDR) serves to enhance the sensitivity of the device in the intended direction, as shown in (Figure 3.1). To enhance the precision of identifying the necessary movement direction of the solar panel, it is vital to employ specific mathematical equations, as shown below:

- Horizontal LDR ERROR ((A1-A0) + (A3-A2)) / 2
- Vertical LDR ERROR ((A2-A0) + (A3-A1)) / 2
- Center-Horizontal LDR Error (A7) - (A6)
- Center: Vertical LDR ERROR (A5) - (A4)

The term "error" is used to denote the value of the difference between the sensor and the other sensor in a certain direction.

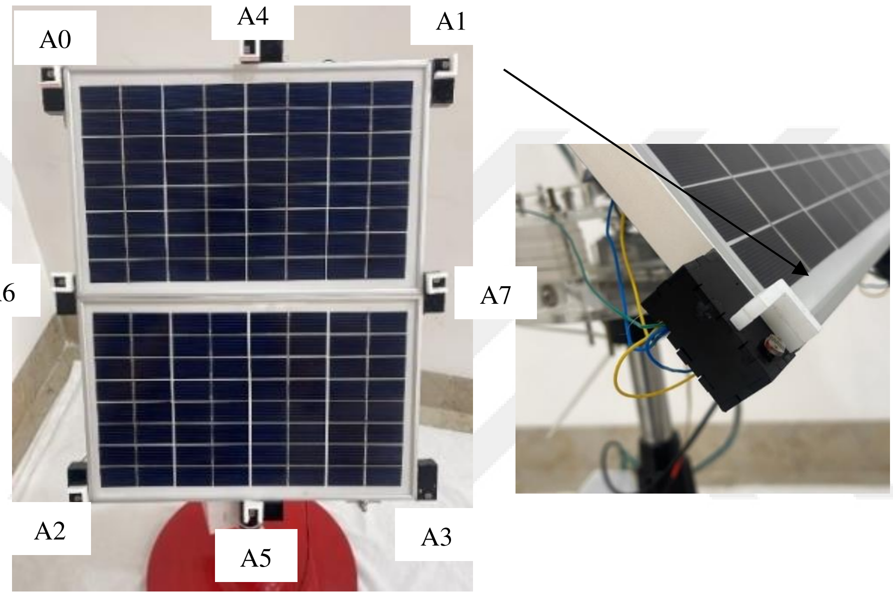


Figure 3.1 Distribution of the LDRs with the specific plastic pieces in this study

The distribution of 8 LDR and utilization of the mathematical algorithm above can be attributed to several fundamental reasons, with the most significant ones being:

First: the variation in values arises from differences in the manufacturing and production processes of LDR sensors by the company. This discrepancy is primarily caused by variations in the internal resistance, resulting in different sensing and reading values for sensors under the same conditions. Consequently, this discrepancy leads to inaccuracies in the instructions sent to the horizontal and vertical motors through an Arduino device, as it becomes challenging to select the optimal angle perpendicular to the source of solar radiation as shown in (Figure 3.2).

Figure 3.2 The difference in the value of the internal resistance for each LDR sensor, and for the same LDR sensor values used in this study

Second: in the event of partial shading, the system can effectively address this issue by increasing the number of LDR sensors using the technique outlined before.

Third: in the event of damage or malfunction in one of the LDR sensors, the system will remain unaffected due to the presence of other LDR sensors and an algorithm that can establish the necessary angle using the functioning sensors.

Fourth: oscillation and delayed reaction in practice can be mitigated by implementing the mathematical technique, which effectively minimizes the fluctuations caused by many and varying readings.

3.2 Geographical Location of Iraq

The location at which a system is installed on the grid is crucial in determining how well it will produce electricity (Shakir et.al 2022). In this study, one location in Iraq, Mosul (36.3765 degrees north, 43.1440 degrees east), has been chosen.

3.3 Solar Tracking Device

The solar tracking device utilized in this study was devised and executed employing a 3D printer. (Figures 3.3) and (Figures 3.4) depict the components of the system as seen from the front and back elevations. (Figure 3.5) specifically shows the components of the controller box.

Furthermore, the study elaborates on the key specifications of the components of the solar tracking system employed in this study in Section 3.4.

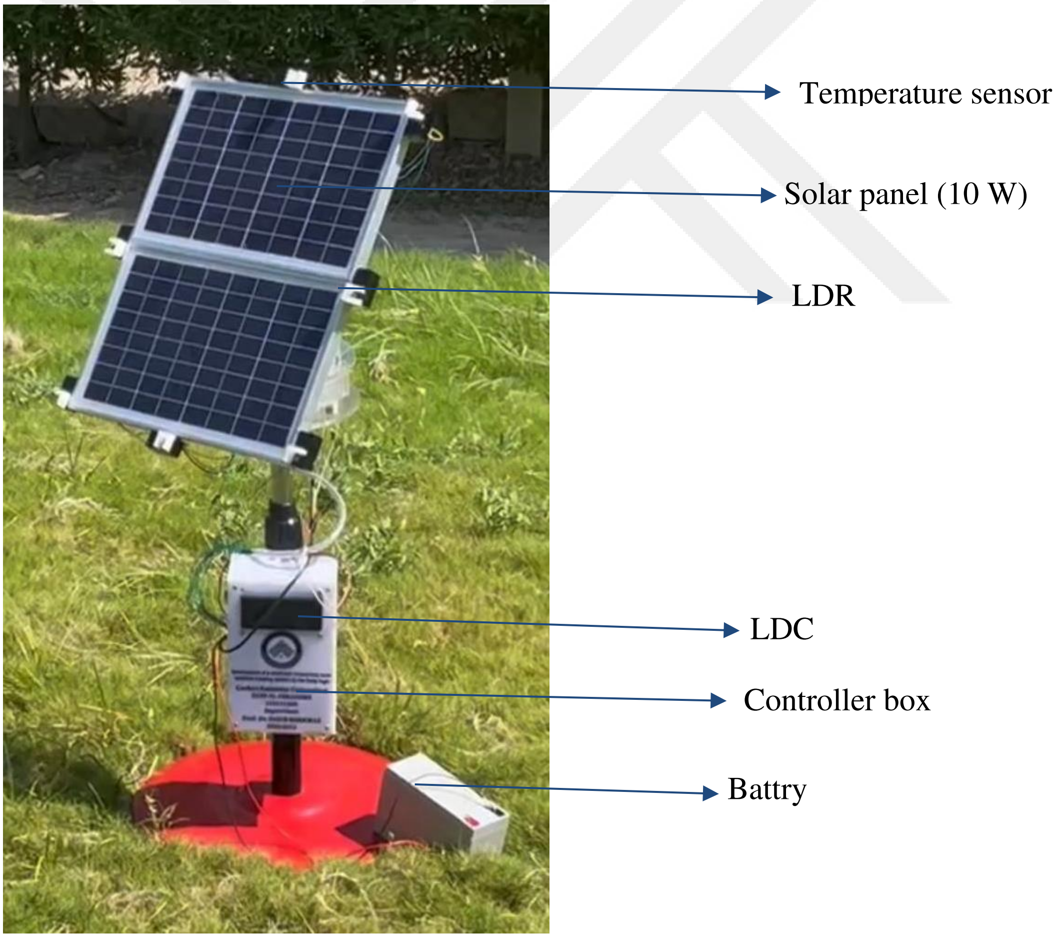


Figure 3.3 The front elevation of the solar tracking device used in the study

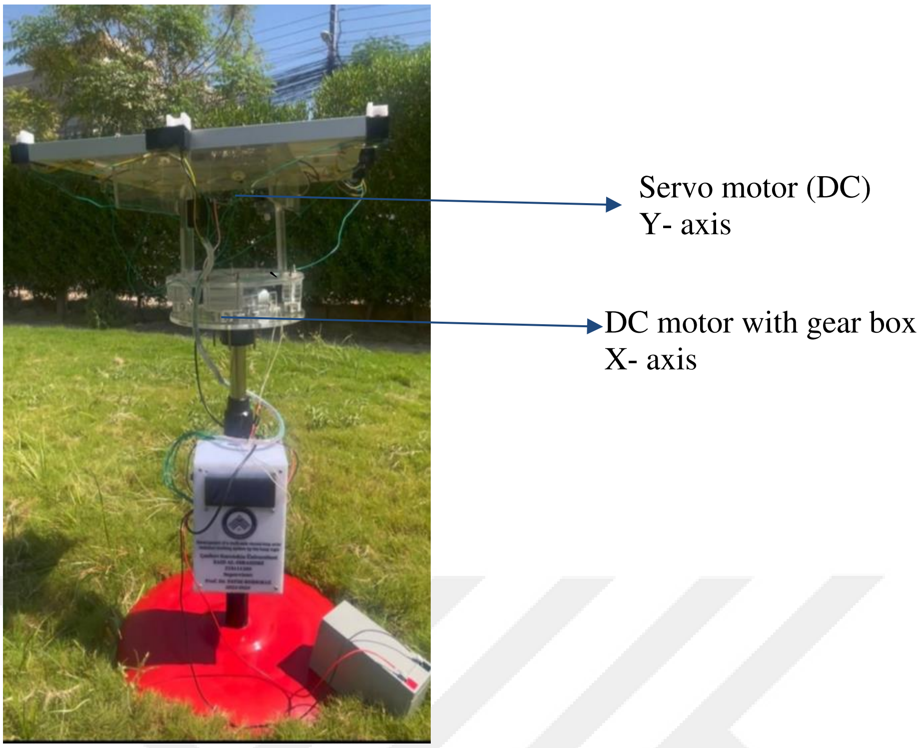


Figure 3.4 The back elevation of the solar tracking device used in the study

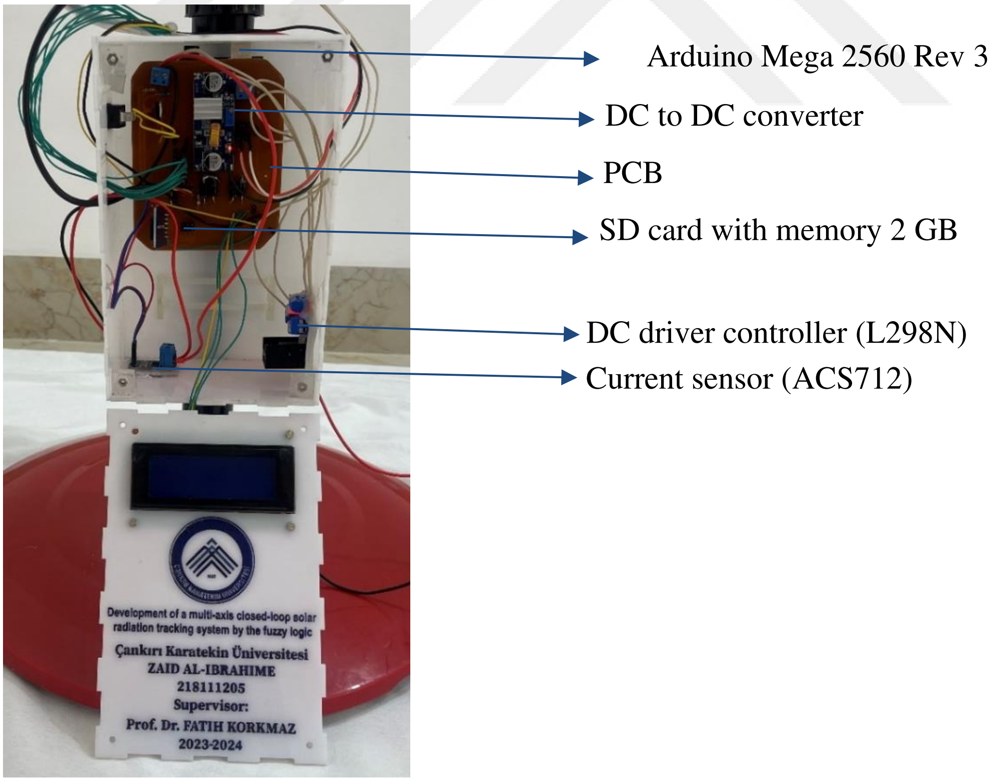


Figure 3.5 The controller box components of the solar tracking device used in the study

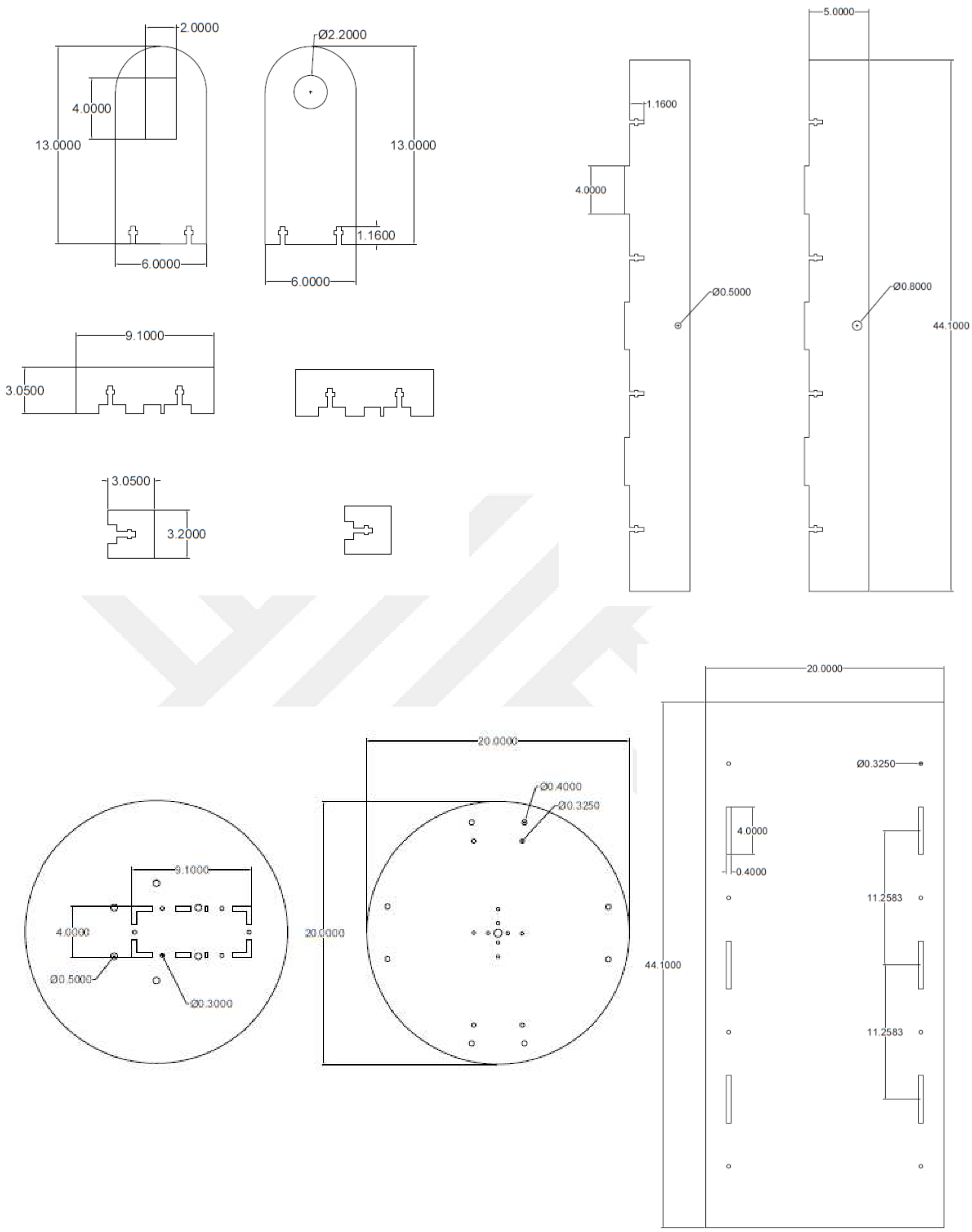


Figure 3.6 The plans of the solar tracking device used in the study

3.4 Solar Tracking Device Component Specifications

The solar tracking device adopted in this study consists of the following components: solar panel, LDR, LDC, temperature sensor, current sensor, servo motor, dc motor with gear box, interfacing microSD card with Arduino, Arduino Mega 2560 Rev3, interface L298N DC Motor Driver Module with Arduino, DC-DC, battrey, and PCB. These components will be explained in detail in the following paragraphs.

3.4.1 Solar panel 10 W

The classification of solar panels can be divided into three main categories: thin-film, polycrystalline, and monocrystalline (Ghazi, 2021). This study employed a pair of 10-watt polycrystalline solar panels, chosen for their affordability and widespread availability in the market, as shows in (Figure 3.7). The specifications of the 10W solar panel employed in this study are presented in (Table 3.1). The solar panel utilized in this study has a power output of 10 watts. The description of the solar panel (10W) used in this study:

- no diode; but these can be installed in addition
- surface of hardened ESG solar glass with weatherproof coating
- frame in anodized aluminum
- performance guarantee to 10 years with 90% and up to 25 years with 80

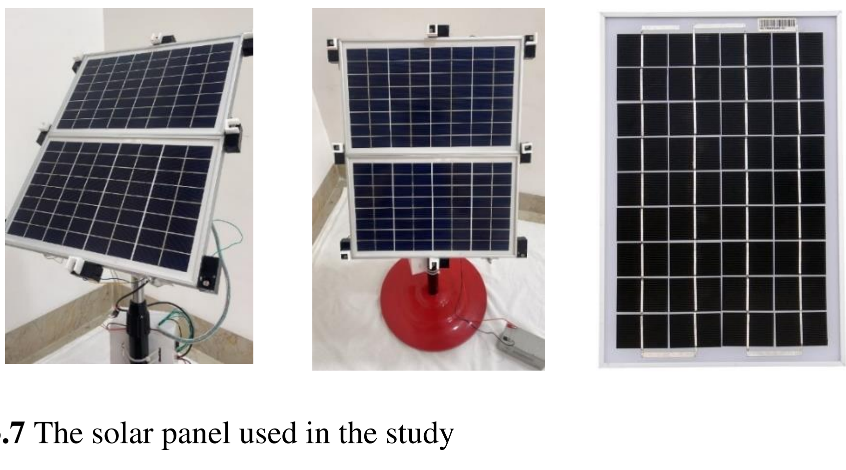


Figure 3.7 The solar panel used in the study

Table 3.1 The specifications of the solar panel used in this study

WHC SOLAR PANEL	
Dimensions	304x270x18 mm
Weight	0,8 Kg
Max.Power Pm (W)	10
Rated Voltage Vpm (V)	16
Rated Circuit Ipm (A)	0.63
Open Circuit Voltage Voc (V)	19.2
Short Circuit Current Isc (A)	0.68
Max.system Voltage Vmax (V)	1000
Model	WHC-10M-32

3.4.2 LDR (Light Depending Resistor)

This study employed an OEM brand LDR Light Sensor Module for Arduino, which encompasses the LDR along with supplementary circuitry for facilitating the connection between the LDR and the Arduino microcontroller. These modules frequently incorporate elements such as voltage dividers and output pins, facilitating their connection and utilization with Arduino boards, as shown in (Figure 3.8) and (Figure 3.9). The most important features of the LDR used in this study are:

- Can detect ambient brightness and light intensity
- Adjustable sensitivity (via potentiometer)
- Operating voltage 3.3V-5V
- With fixed bolt hole, easy installation
- Uses LM393 comparator chip
- PIN assignment
    - VCC = 3.3V - 5V
    - GND = 0V
    - DO = digital output from module

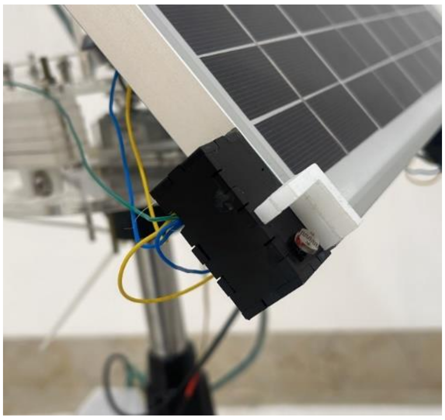


Figure 3.8 The LDR used in this study

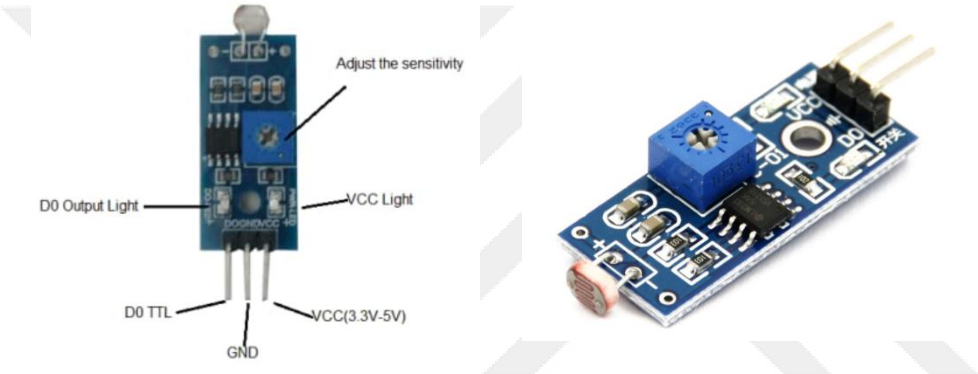


Figure 3.9 The LDR component used in this study

3.4.3 LCD (Liquid Crystal Display)

This study used an I2C LCD with an Arduino, which was used to produce images or text. A typical I2C LCD display consists of an HD44780-based character LCD display and an I2C LCD adapter. (Figure 3.10) shows the LDC used in this study.

An 8-bit I/O expander chip (PCF8574) is the brains of the adaptor. The I2C data from an Arduino is transformed into the parallel data needed for an LCD display by this chip. In addition, the board has a tiny trim pot for fine-tuning the contrast of the display, as shown in (Figure 3.11).

Figure 3.10 The LCD used in this study

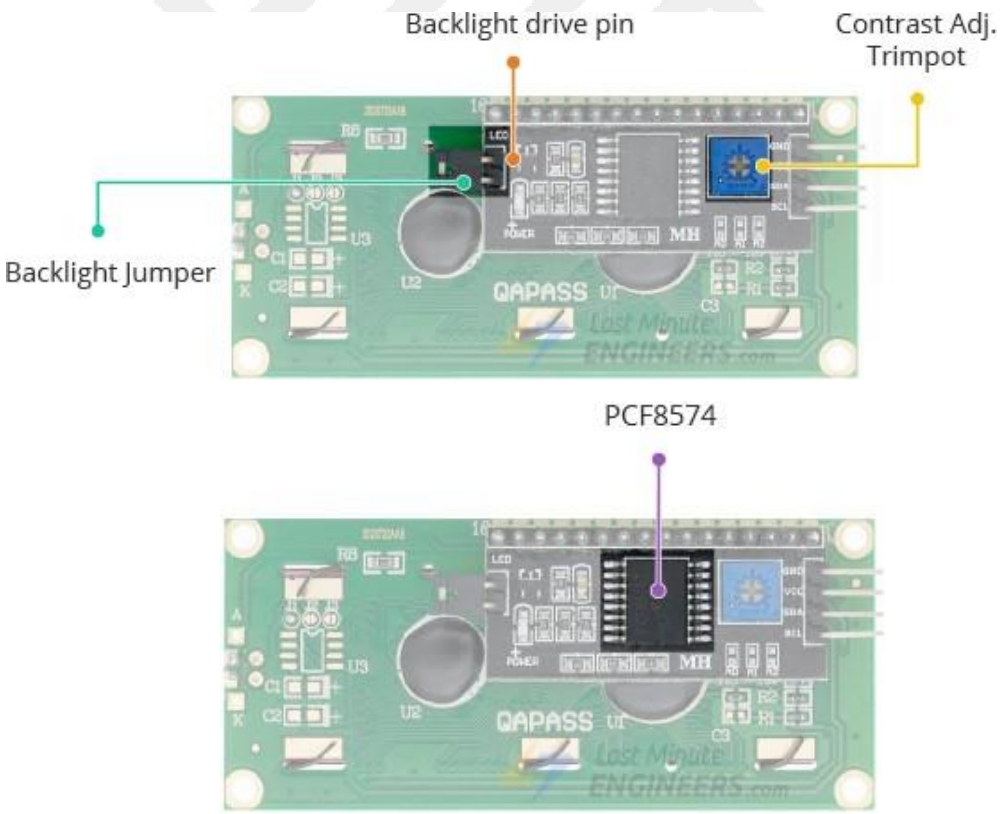


Figure 3.11 The LCD component used in this study

3.4.4 Temperature sensor with Arduino (DS18B20)

This study used a DS18B20 temperature sensor with an Arduino, which is used for measuring and monitoring temperature. In addition, the Arduino can be programmed to interface with temperature sensors and process temperature data.

A one-wire digital temperature sensor, the DS18B20 measures temperature. This indicates that communication with the Arduino only needs one data line (together with GND). As shown in (Figure 3.12), it can be supplied by an external power supply or it can draw power from the data line (known as "parasite mode"), which does not require an external power supply. The most important features of the DS18B20 vtemperature sensor used in this study are:

- Communicates over one-wire bus communication
- Power supply range: 3.0V to 5.5V
- Operating temperature range: -55ºC to +125ºC
- Accuracy +/-0.5 ºC (between the range -10ºC to 85ºC)

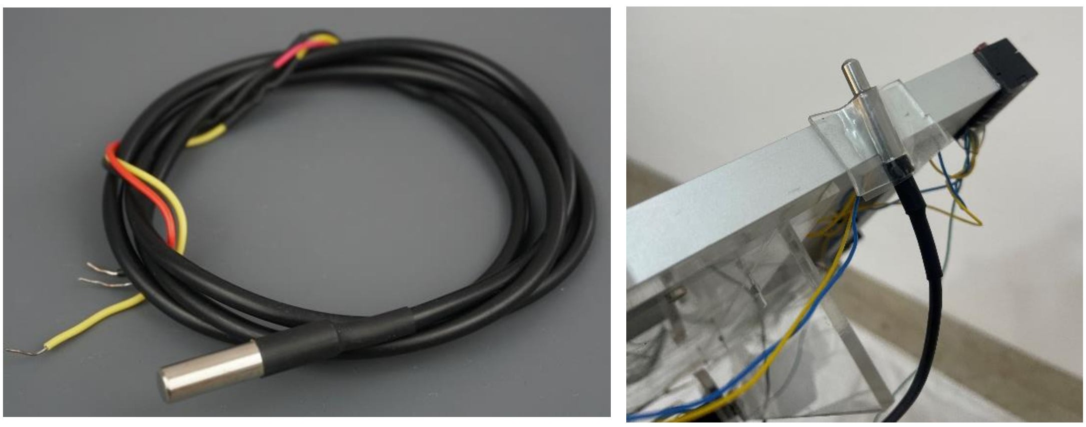


Figure 3.12 The temperature sensorused in this study

3.4.5 Current senser with Arduino (ACS712)

The ACS712 Current Sensor was utilized in this investigation to measure both AC and DC currents within the range of +5A to -5A, +20A to -20A, and +30A to -30A. Because this module produces an analog signal ranging from 0 to 5 volts, it is straightforward to connect it to any microcontroller.

The ACS712 module is equipped with two phoenix terminal connectors, identifiable by its green color, and are accompanied by mounting screws, as depicted in (Figure 3.13). and the most important features of ACS712 Current Senso that were used in this study:

- Measures both AC and DC current
- Available as 5A, 20A and 30A module
- Provides isolation from the load
- Easy to integrate with MCU, since it outputs analog voltage
- Scale Factor

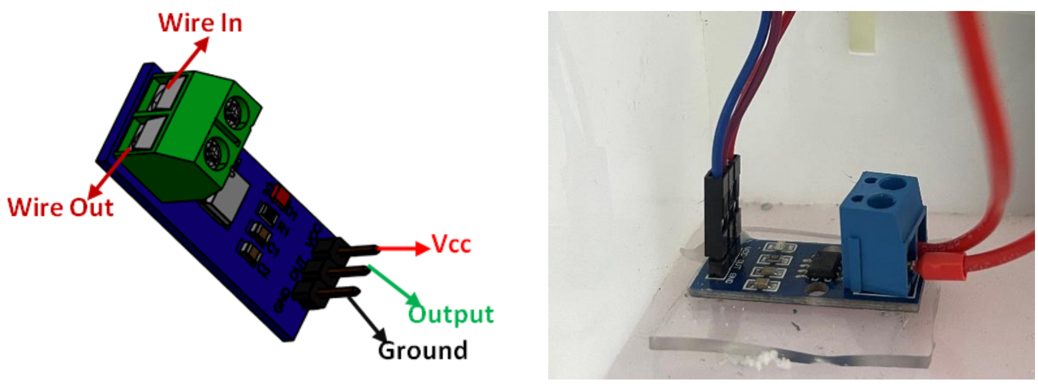


Figure 3.13 The Current Sensor used in this study

3.4.6 Servo motor (RDS3115MG) 180◦ degree

This study used a servo motor type RDS3115MG 15KG LARGE TORQUE 180◦ DEGREE SERVO WITH BRACKETS, and it is responsible for the movement of the solar panel in the vertical direction. This servo motor may be controlled using an Arduino that is connected by jumper wires and powered by a battery. and the most important features of the RDS3115MG servo motor at 180◦ degrees that were used in this study:

- High-performance standard digital servo
- Used for RC robot Low operating noise, good linearity
- Servo control with MCU

(Figure 3.14) shows the servo motor used in the study, and (Table 3.2) shows the specifications of the servo motor (RDS3115MG) used in the study.

Table 3.2 The specifications of the servo motor (RDS3115MG) used in this study .

The specifications of the servo motor (RDS3115MG)	
Model	RDS3115
Operating Voltage	DC 4.8V~7.2V
Operating speed	0.16Sec/60 ° (4.8V) And 0.14Sec/60 ° (7.2V)
Stall torque	13.5kg/cm (4.8V) And 15kg/cm (6V) And 17kg/cm (7.2V)
Operating angel	180 degrees
Size	40mm x 20mm x 40.5mm

Figure 3.14 The servo motor (RDS3115MG) used in this study

3.4.7 Dc motor with gear box (12V-1RPM)

This study used a 12V-1RPM DC motor with a gearbox, which is responsible for the movement of the solar panel in the horizontal direction. As shown in (Figure 3.15), At 12V, it will take approximately 1 rotation every minute (1 RPM). The motor can be reversed but cannot be rotated by moving the shaft due to the worm gear assembly. meaning that even under tension, there will not be any movement unless the motor itself is rotated. The metal construction makes this quite tough and suitable for high-torque applications. (Table 3.3) shows the specifications of the 12V-1RPM DC motor with a gearbox used in this study.

Table 3.3 The specifications of the DC motor with a gearbox (12V-1RPM) used in this study

The specifications of the DC motor with a gearbox (12V-1RPM)	
Overall D, L, H	25mm, 32.1mm, 24.8mm
Rated Voltage	12VDC
Mounting Holes	M3
Shaft Diameter	6mm
Shaft Length	14mm
No Load Shaft RPM	~1 RPM @ 12VDC
No Load Current	~40mA
Flatted Shaft	

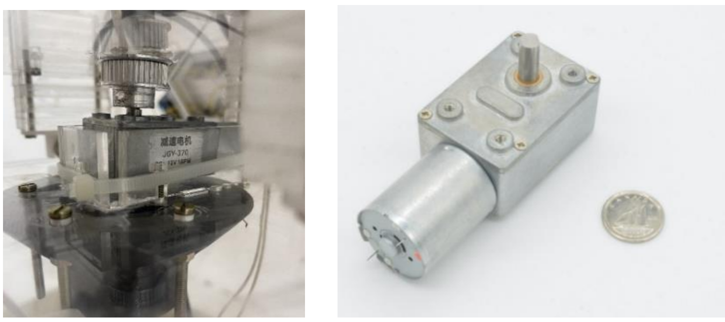


Figure 3.15 The DC motor with a gearbox (12V-1RPM) used in this study

3.4.8 Interfacing micro-SD card with Arduino

This study employed an interface micro-SD card with Arduino to efficiently store a substantial amount of log data and other pertinent information obtained from the solar tracking system utilized in this study, as shown in (Figure 3.16). The two primary parts of the microSD card module employed in this study are as follows:

- The operating voltage for a typical microSD card is 3.3 V. Because of this, we are unable to directly link it to circuits that require 5V logic; in fact, any voltages higher than 3.6V run the risk of irreversibly damaging the microSD card. For this reason, the module has an internal ultra-low dropout voltage regulator that can control voltage up to 3.3V.
- A 74LVC125A logic level shifter chip is also included in the module, enabling simple and secure connection with your preferred 3.3V or 5V microcontroller without endangering the SD card.

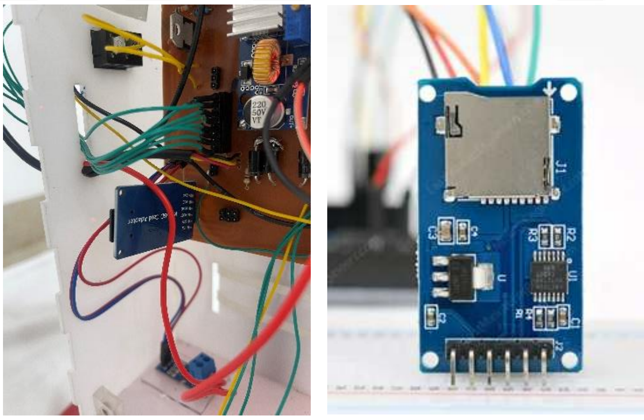


Figure 3.16 The Interfacing Micro SD card with Arduino used in this study

3.4.9 Arduino mega 2560 Rev3 (The 8-bit board with 54 digital pins, 16 analogs)

This study employed The Arduino Mega 2560 is a microcontroller board based on the ATmega2560, which is used to control the operation of the entire system by programming it, As shown in (Figure 3.17), and the (Table 3.4) shows the technical specifications of the Arduino Mega 2560 Rev3 used in the study.

Table 3.4 The technical specifications of the Arduino Mega 2560 Rev3 used in this study

The technical specifications for the Arduino Mega 2560 Rev3		
Microcontroller	ATmega2560	
Power	I/O Voltage	5V
	Input voltage (nominal)	7-12V
	DC Current per I/O Pin	20 mA
	Supported battery	9V battery
	Power Supply Connector	Barrel Plug
Clock speed	Main Processor	ATmega2560 16 MHz
	USB-Serial Processor	ATmega16U2 16 MHz
Memory	ATmega2560	8KB SRAM, 256KB FLASH, 4KB EEPROM
Dimensions	Weight, Width, Length	37 g, 53.3 mm, 101.5 mm

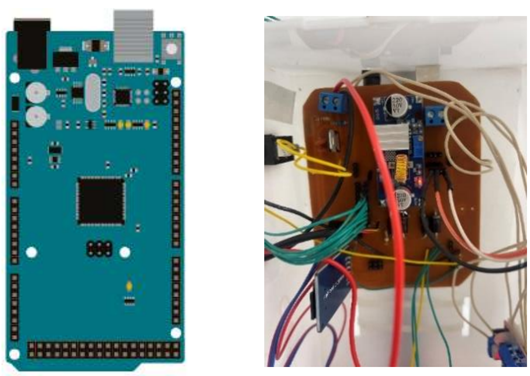


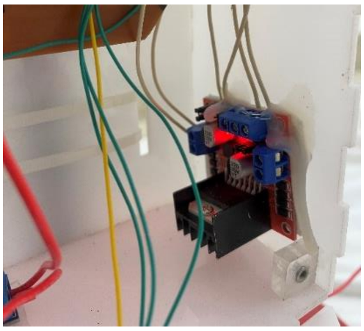
Figure 3.17 The Arduino Mega 2560 Rev3 used in this study

3.4.10 Interface L298N DC motor driver module with Arduino

This This study used the Interface L298N DC Motor Driver Module with Arduino to control motors, as it allows us to connect up to four motors simultaneously, but only two motors can be linked if we also wish to control the speed and direction. as shown in (Figure 3.18), and (Table 3.5) shows the specifications of the Interface L298N DC Motor Driver Module with Arduino used in the study.

Table 3.5 The specifications Interface L298N DC Motor Driver Module with Arduino used in this study

The specifications Interface L298N DC Motor Driver Module with Arduino	
Driver Model	L298N
Driver Chip	Double H-bridge L298N
Maximum Power	25W
Maximum Motor Supply Voltage	46V
Maximum Motor Supply Current	2A
Driver Voltage	5-35V
Driver Current	2A
Size	43x43x26mm



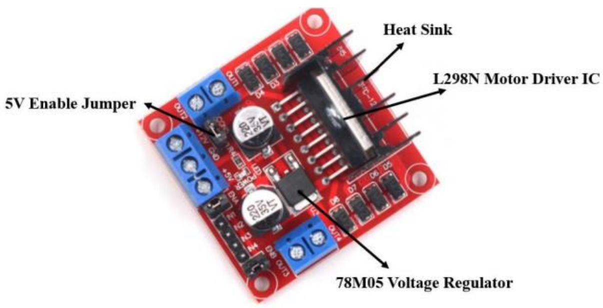


Figure 3.18 The Interface L298N DC Motor Driver Module with Arduino used in this study

3.4.11 DZS Elec DC-DC step-down constant current regulator module 4-38v input to 1.25-36v output adjustable large power 5A 75W converter for charging or LED driver module

This study used the DZS Elec DC-DC Step-Down Constant Current Regulator, as shown in (Figure 3.19), which is used for converting voltage from 12V to 5V to operate the Arduino device. (Table 3.6) shows the specifications of the DC-to-DC converter used in the study.

Table 3.6 The specifications DZS Elec DC-DC Step-Down Constant Current Regulator used in this study

The specifications DC to DC converter	
Input Voltage	4V-38V (38V is max)
Output Voltage	1.25V-36V (Used as a step-down module, the input voltage muse be higher than output voltage more than 2V.)
Output Current	5A (MAX), the output voltage can only be adjusted when the voltage is above 2V.
Output Power	75W (MAX, please strengthen the cooling when the output is above 3A 35W.
Work Temperature	-45 to +85 degree centigrade
Switching Frequency	180KHz
Transfer Efficiency	less than or equal to 96%
Connection Mode	Terminals or solder terminals. V-IN for input, V-OUT for output
Length, Width, Height, Weight	61mm, 26mm,15mm, 25g

Figure 3.19 The DZS Elec DC-DC step-down constant current regulator used in this study

3.4.12 Battery BT-12M9-0AC 12v9.0Ah/20HR

This study used Battery BT-12M9-0AC 12v9.0Ah/20HR to operate the entire system, as shown in (Figure 3.20), and (Table 3.7) shows the specifications of the battery used in the study.

Table 3.7 The specifications Battery used in this study

The specifications battery	
Battery Size	12V 200ah
Charging Ratio	high
Nominal voltage	12 V
Internal resistance	8.3 mΩ
Dimension(L/W/H)	151x98x95mm

Figure 3.20 The Battery used in this study

3.4.13 PCB (printed circuit board)

This study used PCB (printed circuit board) to connect various electronic components and conduct signals between them, as shown in (Figure 3.21).

Figure 3.21 The PCB used in this study

3.5 Programming and Design Fuzzy Logic System

The smart tracking system primarily relies on programming the elements to exert control over them. This programming is accomplished using the Arduino microcontroller (Mega 2560 Rev3), which serves as the central controller for the system components.

The optimal software algorithm for addressing this system is fuzzy logic, which effectively handles the relative mistake by considering values within the range of (0,1). The study aims to yield four specific outcomes:

- Orthogonality and accuracy with the source of solar radiation
- Bypass partial shading.
- No need for azimuth angle

In order to accomplish this, it was imperative to develop a precise and highly effective software algorithm for managing the many components of the system. This algorithm starts by bringing the programming codes from the special library for screens, sensors, and circuit elements that need to be programmed and dealt with.

The LCD screen contains the serial address, the number of lines, and the columns, and records the data obtained by the system every 20 minutes on the SD card. then the definition of the current sensor (input number on the Arduino, voltage, analog resolution, calibration value) and measurement of voltages using the voltage division law, number the LDR sensors, and give a symbol according to the input on the Arduino. after that definition of the motors (DC and Servo) movement.

Then define the LDR sensors according to their location in the solar panel (vertical, horizontal, vertical center, horizontal center) by entering the minimum (0) and maximum (900) for the upper vertical direction and (-900) for the lower vertical direction of the light intensity of the LDR sensor. The same applies to the horizontal direction, the horizontal center, and the vertical center, and converting the results of the LDR sensors to the vertical motor and the horizontal motor to start moving according to the direction of the light.

Adding mathematical signs to determine directions is done by preparing the work for both the library and the backlight (making sure that there is no previous writing on the backlight), then running the fuzzy logic library, then defining the horizontal and vertical motors (DC and servo motors) with their specific inputs and turning on them according to the suggested angle (90).

Then add a sign of (negative, positive, zero) to each of the directions (vertical, horizontal, vertical center, horizontal center), and all entries will be added to the fuzzy library. and prepare the directions of the horizontal and vertical motors (DC and servo motors) according to the directions (forward, backward, stop), and then add them to the fuzzy library. After that, prepare special rules to determine the horizontal and vertical motor (DC and servo) movements, which include:

- Rule 1: If the sign is negative for: Error vertical and center error vertical, So, the movement of the vertical motor will be upward.
- Rule 2: If the sign is positive for: Error vertical and center error vertical, So, the movement of the vertical motor will be downward.
- Rule 3: If the sign is zero for: Error vertical and center error vertical, So, the vertical motor movement will stop.
- Rule 4: If the sign is negative for: Error horizontal and center error horizontal, So, the movement of the horizontal motor will be clockwise.
- Rule 5: If the sign is positive for: Error horizontal and center error horizontal, So, the movement of the horizontal motor will be counterclockwise.
- Rule 6: If the sign is zero for: Error horizontal and center error horizontal, So, the horizontal motor movement will stop.

Definition of the SD card and the warning messages in case there is an error in the reading or definition, which includes rules:

- Rule 1: If the data is not recorded and stored, it will appear as a notification on the LDC, but if it is stored, it will turn on after 5 seconds.
- Rule 2: If there is no memory or there is an error in the recording, the message will appear: error initializing sd card.
- Rule 3: If there is an error, the system will not work until the problem is solved or the system can be controlled via a computer.

After 5 seconds of turning on the solar tracking system, it starts by calculating the error rate according to a mathematical algorithm and entering it to appear on the LCD screen, preparing measurements for voltage, current, and temperature, then displaying the error rate in all directions, in addition to showing the value for current, voltage, and temperature readings. also displaying the readings on the screen for directions (vertical, horizontal, vertical center, horizontal center) and identifying each value for any direction relative to it, while displaying a sign (positive, zero, negative). If the value of the sensor readings on the lower side is equal to zero and the upper value is greater than zero, then the movement will be in the upper direction, and vice versa. Then the result will show on the screen.

The input data in the system will be recorded and stored on the SD card via an Excel file for later use by printing the sign (negative or positive), which includes:

The sign (negative or positive) indicates movement and the error rate for the horizontal direction. Also, if the motor exceeds the full cycle in the horizontal direction, a message will appear.

H Max Steps Reached

Then the solar panel returns to zero angel. Finally, confirm printing and storing the file otherwise, the following notification will appear (Error opening test). (Figure 3.22) and (Figure 3.23) Show the flowchart diagram that explains the software algorithm for managing the many components of the solar tracking system used in this study.

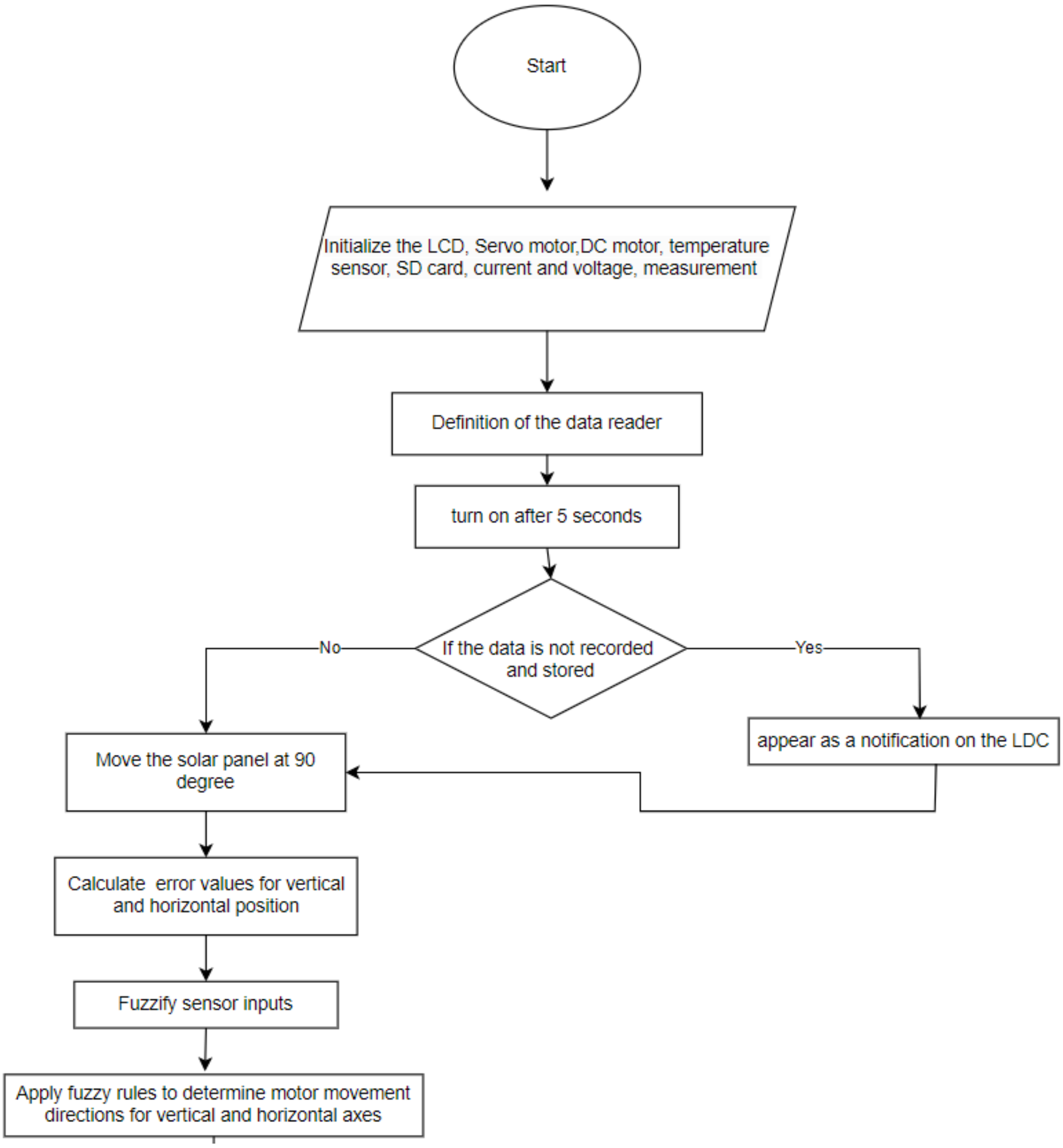


Figure 3.22 The flowchart diagram of solar tracking system part 1

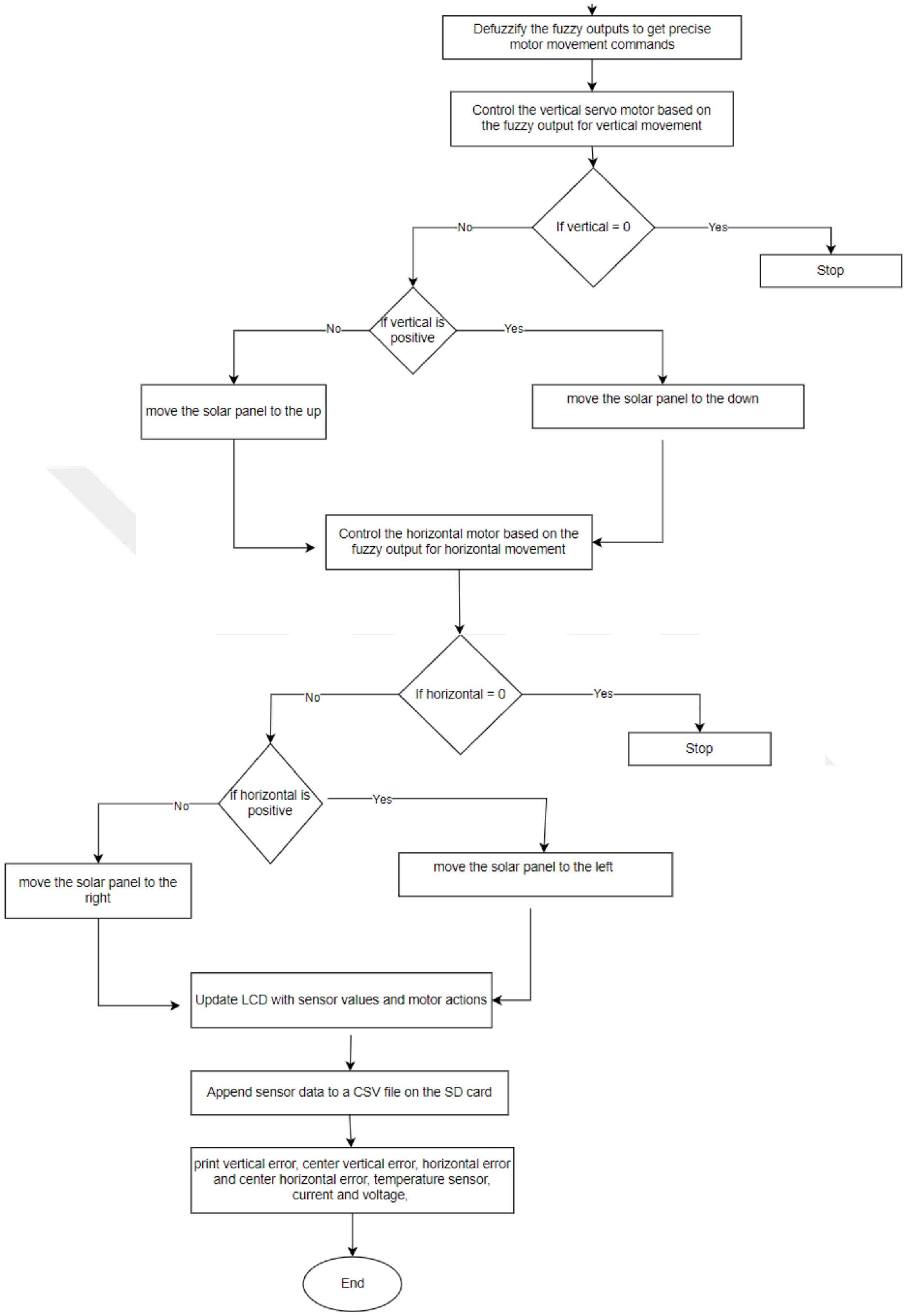


Figure 3.23 The flowchart diagram of solar tracking system part 2

4. RESULTS AND DISCUSSION

The results of the study that was conducted in Iraq, Mosul (36.405255, 43.150255), on November 5, 2023, from 8:30 a.m. to 18:00 p.m. through reading the system's LDR sensors.

4.1 Analysis and Results of Using 8 LDRs to Track the Greatest Radiation Point Controlled by a Special Mathematical Algorithm

(Table 4.1) shows the system data obtained from the SD card. It includes the recorded values of the eight LDR sensors and the temperatures experienced by the system during the practical test period. Additionally, it presents the

- Vertical error (V-E)
- Horizontal error (H-E)
- Center vertical error (C-V-E)
- Center horizontal error (C-H-E)

which indicate the panel's movement directions relative to solar radiation. These directions were determined using specialized mathematical equations based on fuzzy logic to enhance tracking precision.

Table 4.1. Solar tracking system data utilized in this study

Time	Temperature	A0	A1	A2	A3	A4	A5	A6	A7	V-E	H-E	C-V-E	C-H-E	mA in	V- in
8:30	23.19	959	966	955	948	972	958	954	919	-11	0	-14	-35	97	13.38
9:00	27.56	960	968	958	951	975	961	958	934	-9	0	-14	-24	97	13.29
9:30	28.19	962	969	959	953	976	962	959	945	-9	0	-14	-14	97	13.25
10:00	26.88	963	970	960	955	978	963	960	953	-9	1	-15	-7	97	13.2
10:30	27.94	963	970	960	955	978	963	959	957	-9	1	-15	-2	97	13.11
11:00	28.75	961	965	959	954	978	958	951	958	-6	0	-20	7	97	13.07
11:30	31.56	942	946	958	955	975	952	920	958	12	0	-23	38	97	13.07
12:00	31.06	943	948	958	954	976	953	922	958	10	0	-23	36	97	12.97
12:30	30.69	923	934	956	954	973	947	911	957	26	4	-26	46	97	12.93
13:00	30.94	925	934	956	954	973	948	908	957	25	3	-25	49	97	12.7
13:30	30.94	926	934	957	954	974	949	906	957	25	2	-25	51	97	12.88
14:00	32	931	936	957	954	974	949	907	952	22	1	-25	45	97	12.84
14:30	31.19	938	939	956	952	973	949	915	944	15	-1	-24	29	97	12.84
15:00	29.94	944	945	954	950	972	950	925	929	7	-1	-22	4	97	12.79
15:30	29	925	926	949	944	966	941	895	908	21	-2	-25	13	97	12.84
16:00	26.75	892	892	926	928	948	920	869	865	35	1	-28	-4	97	12.57
16:30	23.5	769	781	781	777	783	785	727	723	4	4	2	-4	97	12.79
17:00	22.13	489	544	557	525	496	551	434	425	24	11	55	-9	97	11.93
17:30	21.5	35	57	61	47	35	48	35	33	8	4	13	-2	97	11.61
18:00	20.31	27	36	36	29	26	30	27	26	1	1	4	-1	97	11.2

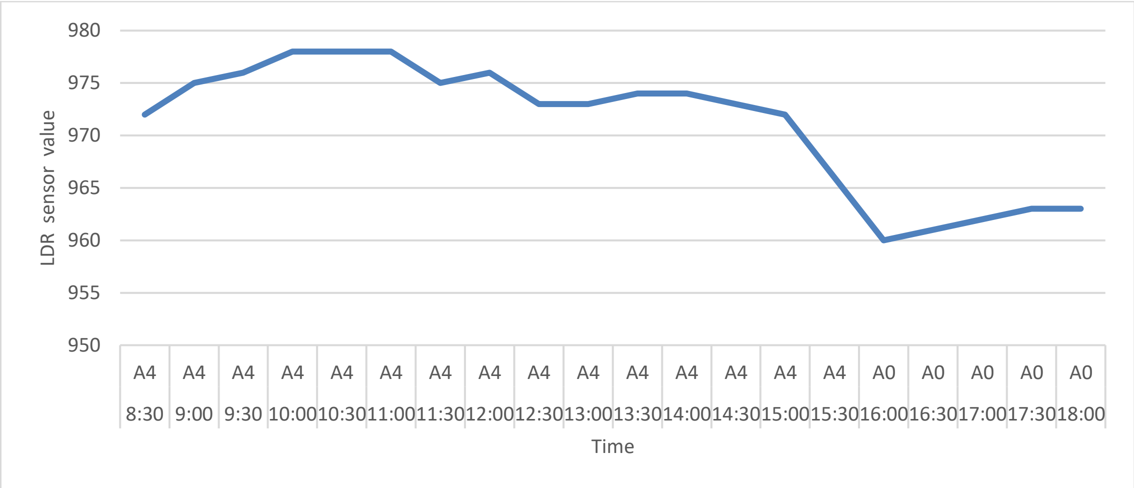


Figure 4.1. The highest reading for LDR sensor value in relation to time

(Figure 4.1) shows the readings from the eight LDR sensors in the smart system during the practical test, taken at various time intervals. The LDR sensors were programmed via fuzzy logic, with the value of 0 representing total darkness and the value of 1024 representing the highest level of light exposure. The system successfully monitored a collective. The highest recorded value was observed at sensor A4, reaching a peak of 978 during the time interval of 10:00 to 11:00. The lowest sensitivity value, on the other hand, was found between sensors A4 and A7, occurring at 18:00. The following conclusions can be elucidated by conducting tests on the smart system:

1. The greatest reading LDR sensor value was obtained during the system's operating period, reaching (978 unit) out of (1024 unit), which is the ideal value for the intensity of light radiation.
2. The system was able to track the source of solar radiation without the need to know the azimuth angle.
3. Generating the greatest electrical energy for the longest possible period of time from the beginning of the system's operation at 8:30 a.m. until 17:00 p.m., then the production capacity decreased to its lowest at 18:00 p.m. as shown in (Figure 4.2).

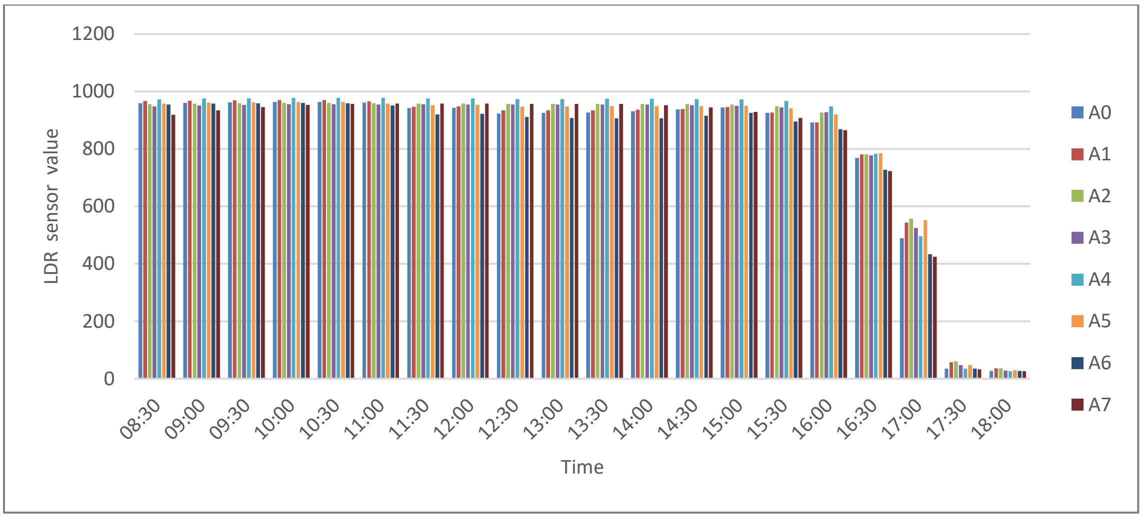


Figure 4.2. Reading of 8 LDR sensor values in relation to time

4. If the V-E value is positive, it means that the solar panel will move toward the north, and if it is negative, it will move toward the south.
5. If the H-E value is positive, it means that the solar panel will move toward the east, and if it is negative, it will move toward the west.
6. If the C-V-E value is positive, it means that the solar radiation value directed toward the bottom of the panel is higher than the solar radiation value directed towards the top.
7. If the C-H-E value is positive, it means that the solar radiation value directed toward the west of the panel is higher than the solar radiation value directed toward its east.

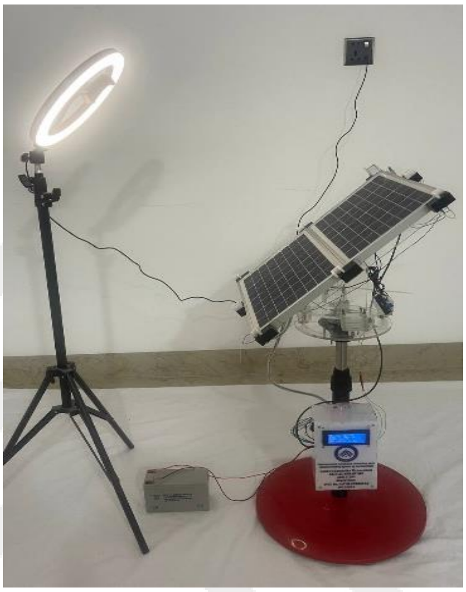
4.2 Analysis and Results of Using Two Motors (Servo and DC) and Determining the Starting Angle of the Movement

The previous chapter provided explanations for both DC motors with gearboxes and servo motors. The study employed a DC motor with a gearbox that has a 360° rotation angle for horizontal movement. This choice was made because the DC motor with the gearbox has the capacity to support a weight of up to 15 kilograms and the weight of the system, in addition to the balance of its movement. In the vertical movement, the study used a servo motor, which is light in weight, precise in its movement, and has a movement angle of 180°. The Arduino device connects to both motors, and special programming determines the direction and speed of these motors.

The study chose on an initial angle of 90° to ensure that the solar panel is in a flat position at the beginning of the operation. This facilitates the determination of the necessary angle without the need for a complete rotation of the board. Consequently, energy consumption is minimized. Further details are provided in (Figure 4.4). This demonstrates the initial phase of the system's functioning, where it instructs the solar panel to move to a horizontal position at the start and subsequently guides it to the highest point of illumination.

The real purpose of using two motors instead of one is to rotate the solar panel in all directions and not in one direction, and with this method, we achieved the best perpendicularity with the power source.

The movement Direction of the solar panel at a 90°angle horizontally.



The movement Direction of the solar panel to the highest lighting point

Figure 4.3 The beginning of the solar tracking system’s operation

5. CONCLUSIONS AND RECOMMENDATION

After employing the intelligent solar tracking system on the ground, we can assert that it surpasses traditional tracking systems in terms of its superior ability to locate the sun's position and its heightened precision, this result was detected by analyzing the data collected during the practical experiment. The alignment of the system with the radiation source was achieved through a sophisticated mathematical algorithm controlled by fuzzy logic. This algorithm considered various factors, such as partial shadowing or sensor damage, to ensure accurate alignment. Furthermore, the study suggests including 8 LDR sensors, using a fuzzy logic system, constructing an exterior structure capable of rotating 360° horizontally and 180° vertically, and utilizing two motors (specifically, a DC motor with a gearbox and a servo motor).

The solar tracking device utilized in this study securely stores all data accumulated throughout the day on a dedicated storage unit known as an SD card.

Based on the results of this study, the proposed system offers numerous benefits in an intelligent framework that allows tracking to commence without requiring knowledge of the azimuth angle. Furthermore, it provides accurate results for the maximum point of electrical power generation over an extended period. In addition, the system can be used to effectively manage a substantial quantity of solar panels to maximize the generation of photovoltaic energy. When compared to traditional tracking systems, this system is the most sophisticated and precise in estimating the perpendicular angle to the sun's beams. It does not require knowledge of the azimuth angle to initiate tracking. The device successfully mitigated instances of abrupt partial shadowing of the solar panels by adjusting its trajectory to maximize power generation.

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