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Using the Fuzzy Logic Algorithm in the High-Precision Solar Tracking System

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***Abstract* - The fundamental framework of the smart solar tracking system, as described in this study, relied on the development of a mathematical algorithm to regulate the motion of the solar panel. The system is developed using fuzzy logic, which is known for its high accuracy and efficiency. An Arduino device is utilized to define all the necessary components and inputs, such as the DC motor with gear box for horizontal movement, the servo motor for vertical movement, and the temperature sensor, etc.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. The implementation of this empirical approach in the study yielded the maximum solar radiation during the generating phase, as recorded by the SD card readings from the eight LDR sensors.**

Keywords: Solar tracking system, LDR sensors, DC MOTOR, SERVO MOTOR, Fuzzy logic.

I. INTRODUCTION

Solar energy is the best-developed renewable technology due to its accessibility, non-polluting, clean, and safe nature [4]. The direct usage of solar energy faces a major constraint, namely the limited time when the sun emits massive radiation, so its function cannot be continued. For that, the researchers have studied solar tracking systems, which change the direction of solar panels based on their solar radiation position [9]. The purpose of this method is to optimize the electrical power received by solar panels when capturing solar radiation by controlling the position of the solar panel against the position of the solar [6]. A solar tracking system (STS) adjusts a solar panel's position or tilt to face the sun perpendicularly, enhancing its efficiency compared to a fixed system [8].

The solar tracking system can be either single-axis or dual-axis, Single-axis systems allow for the panels to be moved in the east-west direction (Azimuth), Dual-axis systems enable motion in both the horizontal (east-west) and vertical (north-south or zenith) directions [14]. Typically, active sun trackers are in motion as a result of their response to LDR sensors that gauge the magnitude of sunshine. Furthermore, multiple studies have shown that sensor-based trackers exhibit lower tracking errors and higher power output compared to sensorless trackers [3]. Therefore, this study aims to design a dual-axis closed-loop solar tracking system with eight LDR sensors. Solar-tracking systems are classified as mechatronics systems, combining components of mechanics, electronics, and information technology [1]. Increases in the efficiency of energy production of 35% per year have been achieved by solar-tracking systems [15]. Therefore, the efficiency of solar energy can be enhanced by using a tracking system or a maximum power point tracking (MPPT) system for solar photovoltaics (PV)[16].

Many studies have been done on the control methods of solar tracking systems. Some of these studies have focused on fuzzy logic-based control [15]. Furthermore, the utilization of fuzzy logic yields the most precise and practical outcomes in comparison to alternative software. Fuzzy logic, which relies on human decision-making [12], it has the benefit of being able to perform well with erroneous inputs. Thus, a precise mathematical model is not necessary [3]. An inherent benefit of the fuzzy logic controller (FLC) is its applicability in scenarios where the controlled system is excessively intricate or challenging to quantitatively characterize. Thus, the FLC is smart and user-friendly [5].

In addition, the utilization of fuzzy logic control has demonstrated superior performance in Maximum Power Point Tracking (MPPT) when compared to traditional approaches [10]. In this paper, a fuzzy logic control is designed to achieve the required tracking. The fuzzy logic algorithm that gives the best accuracy in positioning is also intensively highlighted. The study depends on a closed-loop system where the apparent position of the sun is utilized as control feedback by employing solar sensors [13]. The solar tracking system should be robustly developed with high-quality materials at a low cost [7].

An eminent challenge confronting this study 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. Partial shadowing and significant temperature increase significantly contribute to the low precision of tracking and can potentially harm solar cells if

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they surpass the allowed temperatures set by the manufacturer. So, the study's objective is to achieve optimal tracking precision and perpendicular alignment of photovoltaic cells with continuous sun radiation in order to maximize renewable energy generation. Partial shading bypass can occur due to factors such as shade trees, foreign objects, and others. It involves managing the high temperature of photovoltaic panels to prevent them from exceeding the maximum limit. Additionally, it involves determining the starting angle for tracking solar radiation without knowing the azimuth angle.

II. METHODOLOGY AND MATERIALS

As explained in the introduction section, the study problem revolves around the issue of solar panels inaccurately tracking the energy source. Additionally, there is a pressing need to determine the azimuth angle to calculate the east and west angles of the sun. Furthermore, the constant perpendicularity of photovoltaic cells to the sun leads to high temperatures, which can potentially damage these cells. As a result, we created and implemented an intelligent system that precisely addresses these problems and obstacles in order to get the best electricity production while also keeping the cells' efficiency and longevity. To accomplish this, we created an external structure that embodies the idea of this system and stands out for being able to move freely in all necessary axes and directions.

To determine the required angle and direction, eight (LDR) sensors were placed evenly around the solar panel.

In order to improve the accuracy of determining the required movement direction of the solar panel, it is crucial to utilize precise mathematical formulas, as seen below:

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

The term "error" refers to the value of the difference between a sensor and another sensor in a specific direction.

The movement of the solar panel in both directions necessitates the utilization of two motors: a servo motor and a DC motor with a gearbox. Smart devices, specifically Arduino, with a sophisticated programming language, control these motors. Fuzzy logic is employed to enhance the precision of the instructions that govern the system. The solar tracking system employed in this study was designed and implemented using a 3D printer. Figure 1 shows the front and back elevation of the solar tracking system used in the study.

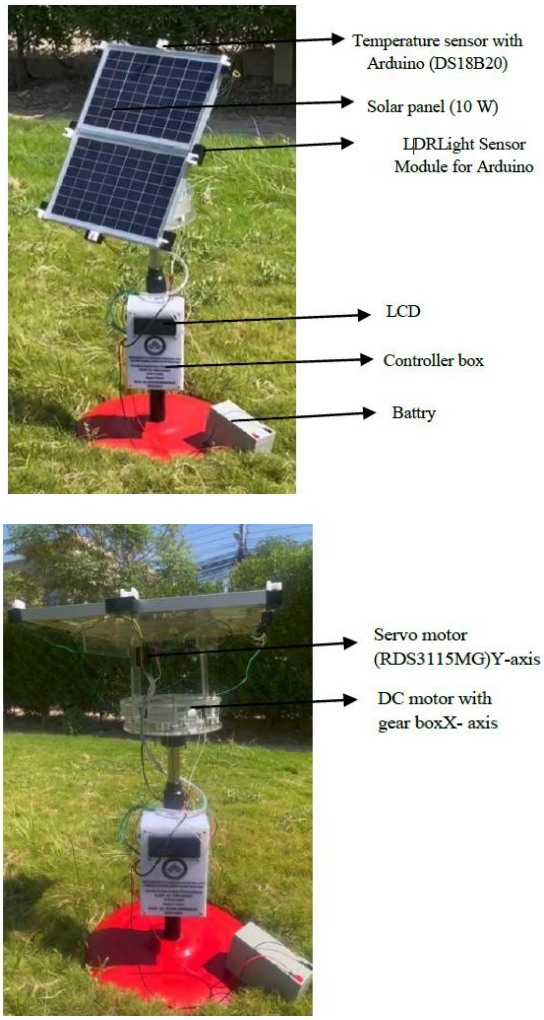

Figure 1: The front and back elevation of the solar tracking system used in the study (Researcher)

2.1 Solar panel (10 W)

For this study, two 10-watt polycrystalline solar panels were utilized because of their low cost and availability in the market as compared to other types of solar panels. The specifications of the 10W solar panel utilized in this study are presented in Table 1.

Table 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

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Max.system Voltage Vmax (V)	1000
Model	WHC-10M-32

2.2 Temperature sensor with Arduino (DS18B20)

This study used a DS18B20 temperature sensor with an Arduino, as shown in Figure 2, which is used for measuring and monitoring temperature. In addition, the Arduino can be programmed to interface with temperature sensors and process temperature data. The most important features of the DS18B20 temperature sensor used in this study are:

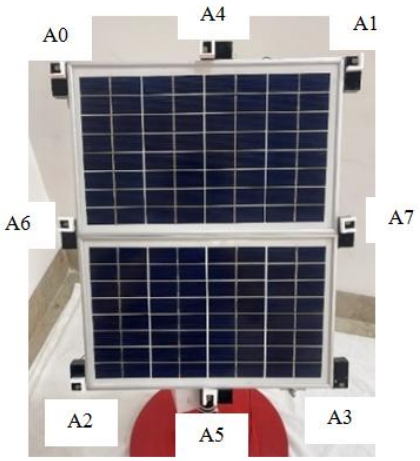
- Power supply range: 3.0V to 5.5V
- Operating temperature range: -55 ^{o}C to +125 ^{o}C
- Accuracy +/-0.5 ^{o}C (between the range -10^{o}C and 85^{o}C)

Figure 2: The temperature sensor used in the solar tracking system of this study

2.3 Light Dependent Resistor (LDR)

This study used 8 LDR Light Sensor Modules for Arduino, brand OEM, which include the LDR as well as additional circuitry to interface the LDR with a microcontroller Arduino. The function of using these 8 LDRs is to detect ambient brightness and light intensity. These 8 LDRs were distributed as follows, as shown in Figure 3:

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



3: Distribution of the 8 LDRs around the solar panel

2.4 Liquid Crystal Display (LCD)

The study employed an I2C LCD in conjunction with an Arduino to generate visual content, such as graphics or text, for the solar tracking system.

2.5 Controller box

The controller box of the solar tracking system in this study includes:

2.5.1 Current sensor with Arduino (ACS712)

This study employed the ACS712 Current Sensor, a device utilized for the measurement of both AC and DC currents within a range of +5A to -5A, +20A to -20A, and +30A to -30A, as shown in Figure 4.

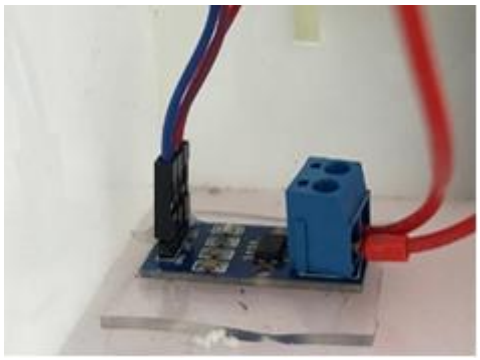


Figure 4: The Current Sensor used in the solar tracking system of this study

2.5.2 SD card with memory 2 GB

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 research, as shown in Figure 5.

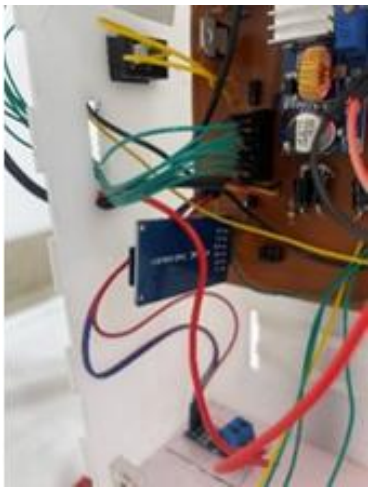


Figure 5: The SD card used in the solar tracking system of this study

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2.5.3 DC to DC converter

This study employed a DC-DC Module to convert voltage from 12V to 5V to operate the Arduino device.

2.5.4 Mega 2560 Rev3 (The 8-bit board with 54 digital pins, 16 analog inputs, and 4 serial port)

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.

2.6 Servo motor and DC motor

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.

The first motor is a DC motor with a gearbox (12V-1 RPM), and it is responsible for the movement of the solar panel in the horizontal direction. And the second motor is a Servo motor (RDS3115MG) 180°, and it is responsible for the movement of the solar panel in the vertical direction, as shown in Figure 6.

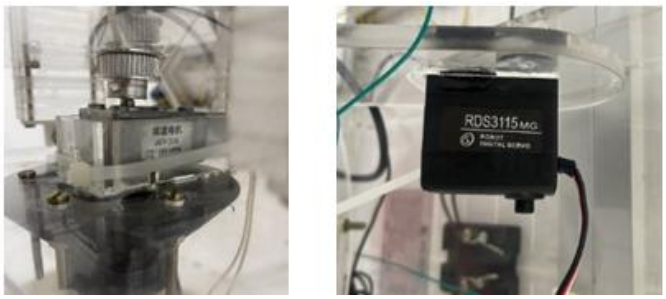

Figure 6: The Servo motor and DC motor used in the solar tracking system of this study

2.7 Fuzzy logic system programming and design

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
- Observe and exceed high temperatures

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. The figures below show the algorithm programming of fuzzy logic in this study.

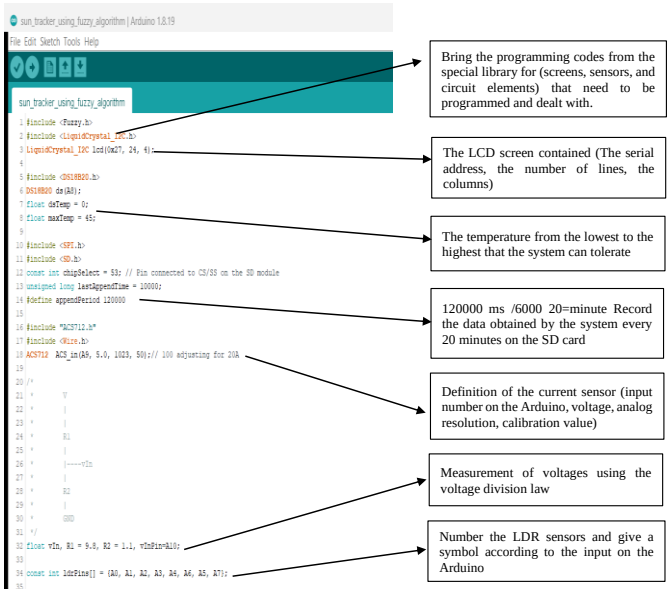

Figure 7: Bring the programming codes from the library and definition of the system elements

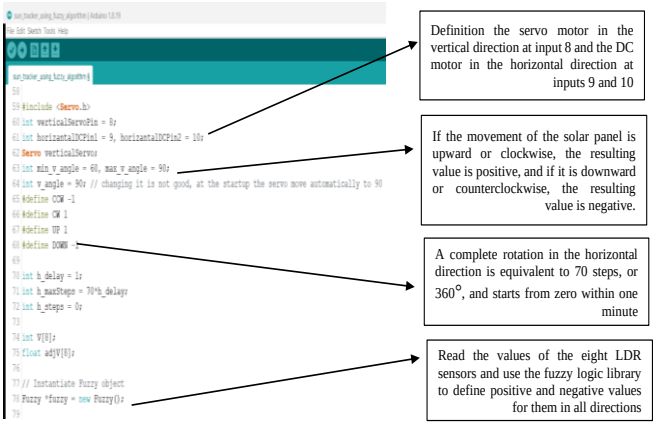

Figure 8: Definition of the motors (DC and Servo) movement

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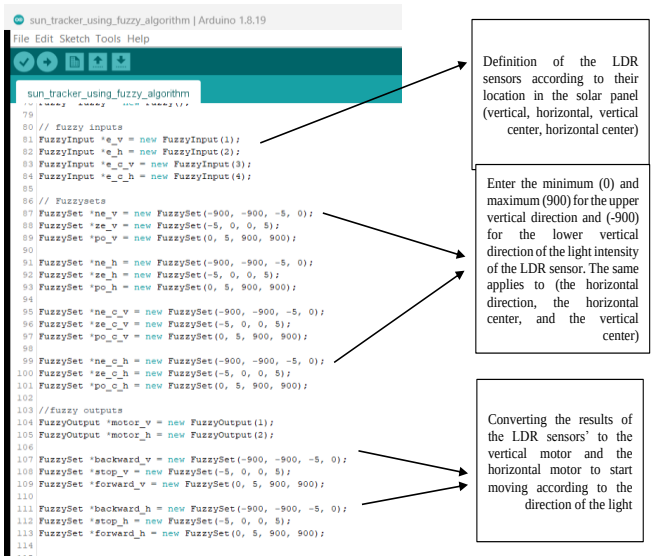

Figure 9: Definition of the LDRs sensor locations and values

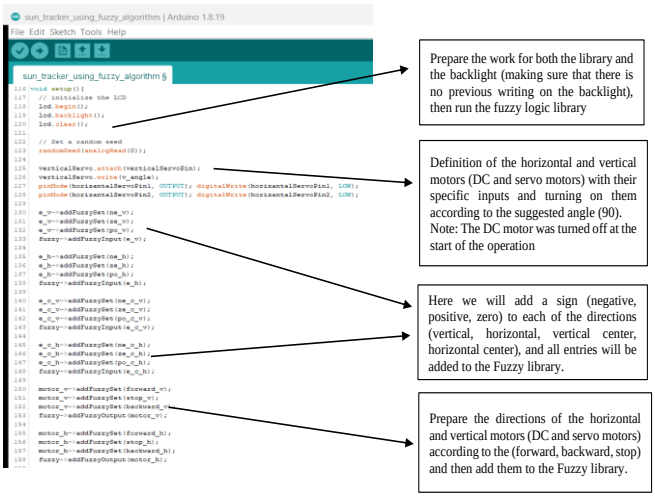

Figure 10: Adding mathematical signs to determine directions

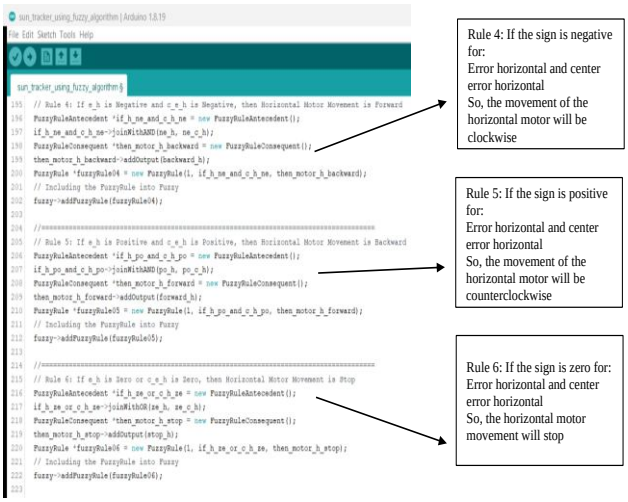

Figure 11: Preparing special rules to determine the horizontal and vertical motor (DC and Servo) movement

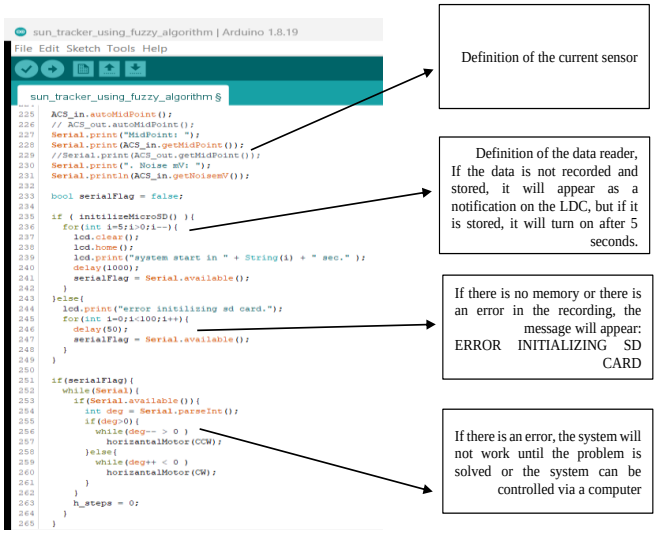

Figure 12: Definition of the SD card and gave the warning messages in case there is an error in the reading or definition

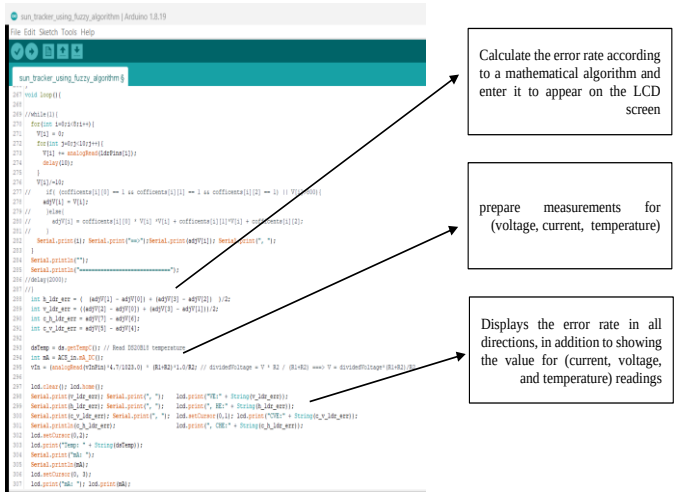

Figure 13: Calculate the error rate according to a mathematical algorithm

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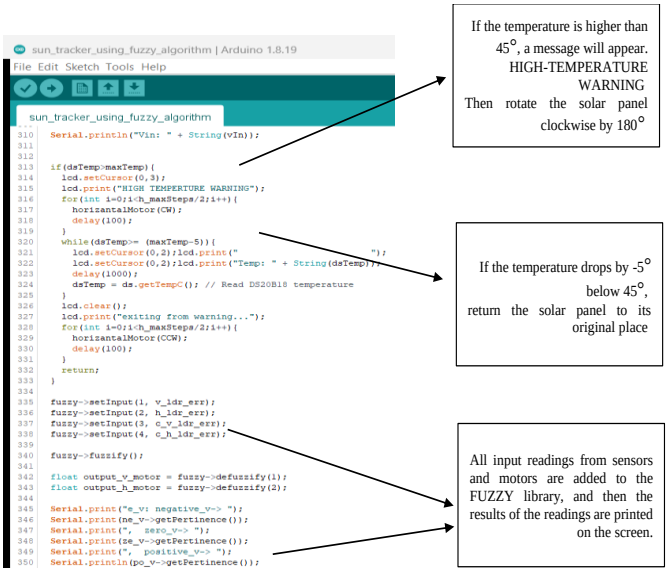

Figure 14: Determine the lower and upper limits of the temperature allowed for the system

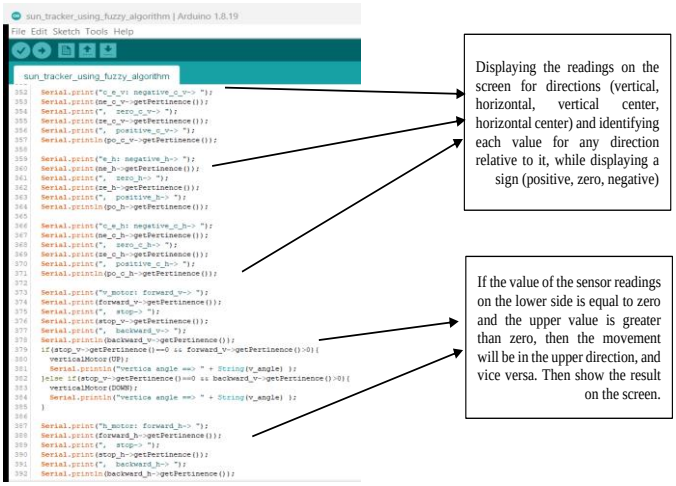

Figure 15: Displaying the motors (DC and Servo) values on the screen

Figure 16: Record and store all input data in the system on the SD card

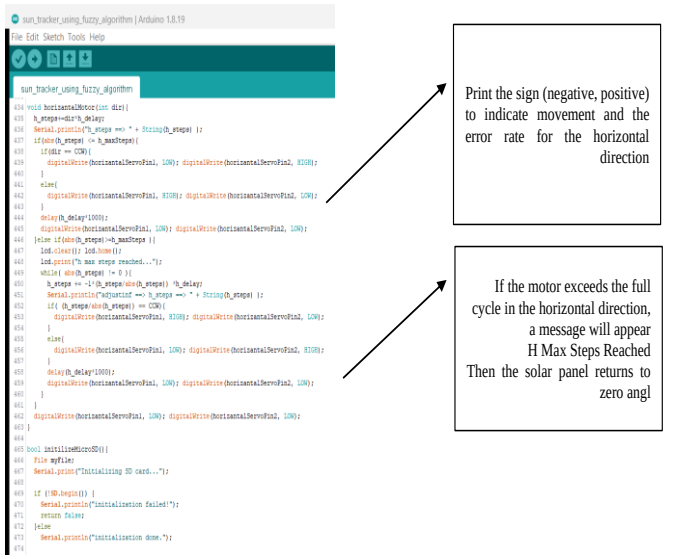

Figure 17: Displaying the signal for each direction of the two motors, and determining if the horizontal motor exceeds the full cycle

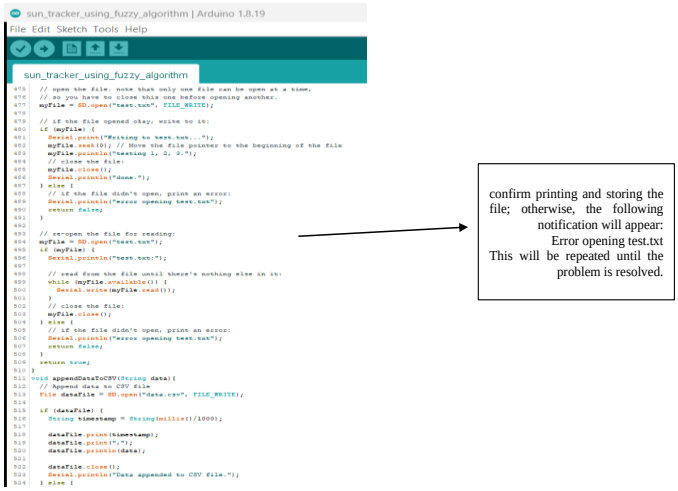

Figure 18: Confirmed the SD card store and turn it on, otherwise a warning message will appear

III. RESULTS AND DISCUSSIONS

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. also This study focused on the average temperature increase in Iraq, which can reach up to 65°C during the summer season. To ensure the preservation of the solar cell's lifespan and minimize production decline to acceptable levels, we used an average temperature of 45°C.

The temperature sensor was linked to the vicinity of the solar panel and subsequently connected to the Arduino device. Subsequently, the LCD screen displayed the obtained data and temperature readings. As a result of using a DS18B20 temperature sensor in the solar tracking system of this study, when the temperature of the solar panel reaches 45°C, it will rotate 180° in the opposite direction. The solar panel will

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remain in this new position until the temperature decreases by 5°C, at which point it will return to its original position, as shown in Figure 19.

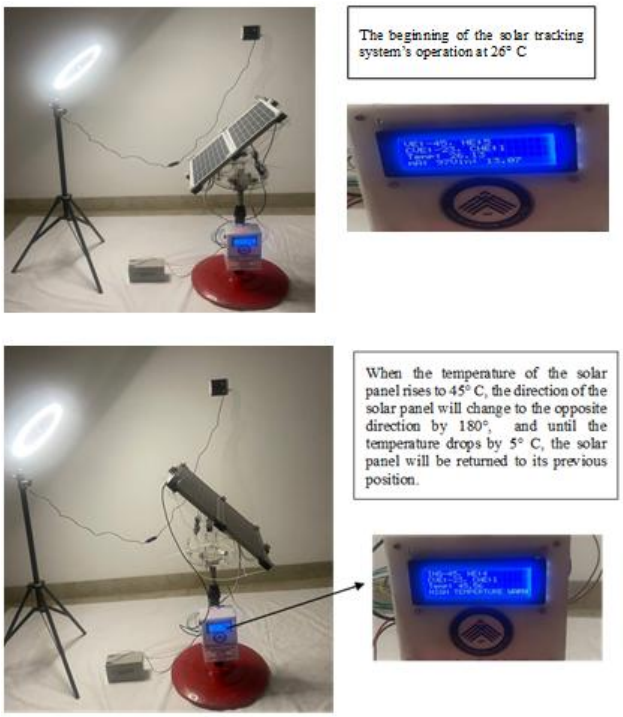

Figure 19: Using the temperature sensor (DS18B20) in the solar tracking system of this study

The study relies 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 20. 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.

Figure 20: The beginning of the solar tracking system's operation

Figure 21 shows the measurements obtained from the eight Light Dependent Resistor (LDR) sensors in the intelligent system during the experimental trial, captured at different time intervals. The LDR sensors were programmed using fuzzy logic, where a value of 0 corresponds to complete darkness and a value of 1024 corresponds to the maximum intensity of light exposure. The system effectively monitored a group. The maximum recorded value was measured at sensor A4, reaching a peak of 978 between 10:00 and 11:00. The minimum sensitivity value was observed between sensors A4 and A7 at 18:00.

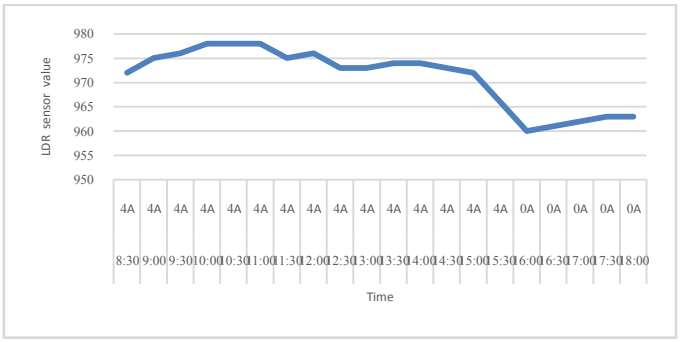

Figure 21: The highest reading for LDR sensor value in relation to time

IV. CONCLUSION

This study presents the development and execution of a sophisticated solar tracking system capable of moving in multiple axes (360° horizontally and 180° vertically). The system utilizes fuzzy logic as the primary controller for determining the timing of solar tracking and aligning it with the perpendicular position to direct sunlight.

When compared to standard 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.

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. In addition, we equipped the system with a temperature sensor to safeguard the cell's longevity by preventing damage caused by elevated temperatures. The selection was made based on practical considerations, and the system effectively achieved conversion. When the temperature exceeds the permissible limit, the movement of the solar panel reverses by 180°, and it reverts to its original direction once the temperature falls below the permissible limit.

Based on the information provided, this method can be regarded as more efficient and secure, as it serves as a dependable model for calculating the orientation of a substantial quantity of solar panels.

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Fatih Korkmaz was born in Kırıkkale, Turkey in 1977. He received the B.T., M.S., and Doctorate degrees in electrical education, from University of Gazi, Turkey, respectively in 2000, 2004 and 2011. His current research field includes Electric Machines Drives and Control Systems.

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