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Improved Detection of Sunlight Source Determination Using Raspberry Pi 4-Based Fuzzy Logic on Solar Tracking System

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Abstract

Solar panels are the main component of a solar power generation system, converting sunlight into electrical energy. This study develops a solar cell monitoring method to collect output data in a specific text format and uses solar cell modules to maximize the efficiency of solar energy absorption that moves from east to west throughout the day. The solar panel tracking system uses the Raspberry Pi 4 as the central controller to follow the sun's movement. It is supported by LDR sensors to detect light intensity and move the panel according to the direction of light. In addition, the BH1750 and BME280 sensors are used to measure additional factors, such as temperature, wind pressure, humidity, light intensity, and light angle, that also affect the panels' power production. The collected data is processed using fuzzy logic to convert the exact values from the sensor into fuzzy data, allowing for more precise control in panel position optimization. The results showed that the system can improve the efficiency of solar energy absorption, with an optimal intensity level of 53,999.99 lux in very bright conditions and a fuzzy-lux difference of 1.1%, which is lower than previous research, indicating that the system is more efficient and supports accurate real-time monitoring.

Keywords: *BH1750; BME280; Fuzzy Logic; Raspberry pi; Solar Tracking System*

1. Introduction

A solar panel is the primary device of a solar power generation system [1], which generates electrical energy from sunlight. The current solar cell monitoring method is still conventional and only collects output parameter data in a specific text file format. In addition, this data cannot be stored for an extended period. The voltage and current flow towards a load, or lamp, can be regulated with a tool consisting of expensive and inefficient components [2].

Solar cell modules can generate electrical energy [3] using solar panels or concentrators. Therefore, solar panels must always be in a position facing the direction of sunlight to get maximum efficiency from sunlight. Solar cells cannot fully absorb energy from the sun because the sun is constantly in motion, sometimes in the northern hemisphere, in the southern hemisphere, or sometimes at the equator [4].

By detecting the position of the sun, the *solar tracking system* can optimise the orientation of solar panels to follow the sun's movement effectively [5]. This allows users to obtain data such as voltage, current, and position direction generated by the solar panels. In addition, users can obtain data from the approximate light intensity of the panels through the website. With this data, users can plan their load usage so that the power from the load will not be less than the power generated by the solar panels.

Some studies were conducted on detecting sunlight [6] in *solar tracking systems* [7] . The difference in the length of solar irradiation and other factors such as temperature, light intensity, and angle of incidence

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of light also affect the solar panel's power. By implementing a tracking system, solar panels can follow the sun's movements and generate more power than in the usual setup.

Then, the research was conducted by [8]. A solar panel consists of several solar cells that, to achieve the desired output, consist of several solar cells that are combined [9]. This collection of solar cells can convert sunlight into direct current electricity. The battery can be added to the solar panel and stored as a backup of electrical energy to store the power generated from this conversion. In simple terms, solar cells consist of a P- and N-type semiconductor junction semiconductor joint, which generates a flow of electrons called an electric current when exposed to sunlight.

Other research was conducted by [10]. In the study, fuzzy logic has a membership value between 0 and 1. Thus, fuzzy logic can be defined as a logic with an ambiguous value between right and wrong. Fuzzy logic can interpret vague statements into statements that can be expressed in language that humans can understand. It is important to remember that probability and fuzzy logic cannot be applied similarly because probability measures the likelihood of a particular event, whereas fuzzy logic can produce results based on predictions. The fuzzy logic control diagram (FLC) is divided into three main parts: fuzzy logic, inference mechanism, and defuzzification mechanism.

In this situation, most of the installed solar cells are static or stationary, so the process of energy absorption by solar cells becomes less effective. To get the most significant amount of energy, the position of the solar panels must be moved so that they always follow the direction of the sun's movement, known as the solar two-axis tracking method. By using this method, solar trackers can maximize energy absorption. They then use fuzzy logic as a stage to change the sensor input values with crisp properties or definite values into fuzzy form.

2. Methods

The type of research conducted is experimental research [11] on converting everyday energy sources, such as electricity, to solar panels. To achieve a more optimal use of solar panel solar energy output, IoT-based tracking was implemented. The measured parameters include temperature, wind pressure, humidity, and light intensity.

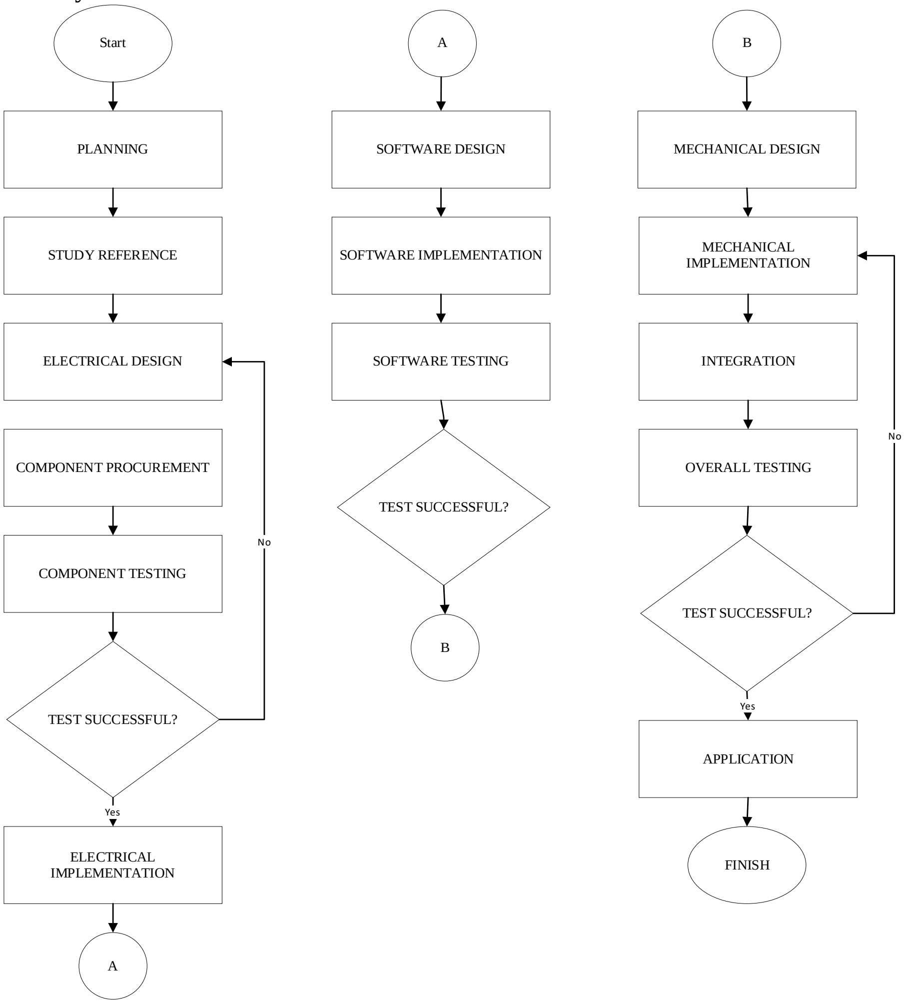

Figure 1. Research Flow Chart

2.1. Planning

In planning a research project, several important factors must be carefully identified and considered to ensure the project's success. Some of the key elements in this planning phase include:

a. Tool Research Analysis
   This step includes an analysis of the tools needed for the project. The goal is to understand the function, specifications, and usefulness of the tool to fit the goals and technical needs of the project.
b. Estimated need for tools and materials
   Estimating the need for tools and materials from the outset is crucial. This step includes listing and assessing all the physical resources needed for the project to run smoothly, ensuring each component is available and aligned with the project's objectives.
c. Budget estimates
   Proper budget planning is essential for a project's success. By conducting cost estimates, teams can effectively allocate funds, covering needs such as material procurement and reserve funds for unforeseen needs. This helps prevent disruptions to the project due to unexpected costs so that the project can run smoothly as planned.
d. Application of hardware to be designed
   The planning stage should also consider the specific application of the hardware. This involves determining how the hardware will be designed, implemented, and integrated into the project. A clear picture of the hardware's role and functionality is needed to ensure smooth integration at the later stages of development.
e. Electrical Design
   In this step, the electrical design is planned to ensure compatibility with the project's objectives and requirements. The process includes creating circuit diagrams, selecting appropriate components, and identifying potential challenges in integrating electrical elements into the system. This step ensures that the electrical system aligns with both functional and technical goals.
f. Component Procurement
   This phase focuses on identifying and acquiring components that match the specifications defined in the electrical design. It involves ensuring the availability of required materials and verifying their quality and compatibility. The process also includes evaluating suppliers, comparing costs, and managing logistical constraints to ensure timely procurement.
g. Component Testing
   Component testing aims to ensure that the procured components meet the specifications defined during the Electrical Design phase. This process involves validating the functionality, compatibility, and performance of each component. If the testing result is unsatisfactory (No), the process returns to the Electrical Design phase. At this stage:
   1. Design Adjustments: The design is reviewed and modified to align with the specifications of the procured components.
   2. Alternative Component Selection: Alternative components are identified and procured if the current components do not meet the design requirements.

   The iteration between Electrical Design and Component Procurement ensures that the system achieves compatibility and functionality before proceeding to the next stages.

2.2. Mechanical Design

The mechanical design in this project used the Fritzing application [12] as a tool to design a mechanical system that fits the project's specific needs while ensuring that the design is efficient and safe. This application helps create a structured system design where each component can be arranged appropriately before physical implementation.

Through Fritzing [13], designers can sketch out details of mechanical circuits, including the placement of components such as sensors, actuators, cables, and microcontrollers. Each component can be connected virtually, and designers can see potential problems or conflicts in the layout. This way, the design can be adjusted before the actual hardware is assembled, reducing the risk of errors and minimizing the cost of repetition or repair.

In Figure 2, using Fritzing, every part of the system is visible, from the layout of the components to the relationships between the parts. This visualization makes it easier for the team to ensure that each part will work well and according to plan when implemented later.

A mature design at the mechanical design stage provides a solid foundation for the entire system. By prioritizing efficiency and safety, teams can ensure that the designed system will run optimally when operated. The design created with Fritzing helps ensure that the system functions properly and meets the required safety and quality standards so that the final result meets the project's expectations.

The choice to use Raspberry Pi 4 instead of Arduino in this project was driven by specific technical requirements of the solar tracking system. Raspberry Pi 4 offers higher processing power, multitasking capabilities, built-in connectivity features, and support for high-level programming languages, making it ideal for handling complex tasks such as fuzzy logic computation, real-time sensor data processing, and IoT integration. Additionally, its scalability and ability to manage large data sets enhance the system's reliability and future expandability. These factors collectively make Raspberry Pi 4 a more suitable choice for achieving the objectives of this project.

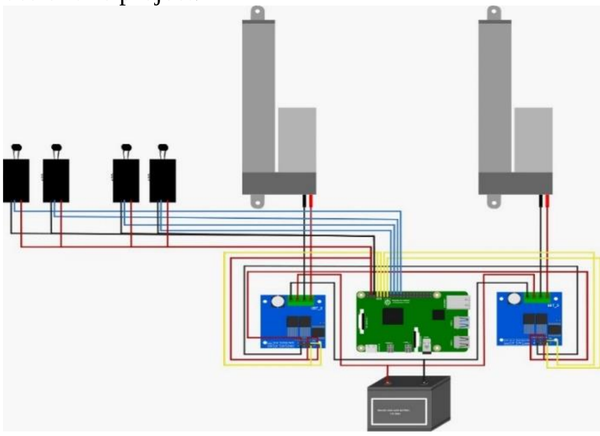

Figure 2 Mechanical Design

2.3. Tool Planning

Mechanical design is an essential aspect of tool design that must be considered to ensure that the system functions as expected. Mechanical design focuses on appearance, efficiency, and practicality of use. Several critical needs must be considered when designing a mechanical design for this system application.

2.4. Tool Testing

At this stage, tests are carried out on the project tools to assess their performance and reliability on each part and the entire system. This test aims to ensure that each component functions as designed and that the entire tool works as intended to meet the project's needs.

The main objective of testing this tool is to obtain accurate and valid data regarding each part's performance and the tool's conformity to the expected specifications. The test result data will provide a clear picture of the system's effectiveness and stability under natural conditions. With thorough testing, teams can identify which parts need adjustment or improvement so that the tool can achieve optimal performance.

In addition, these tests ensure that the appliance meets the set standards regarding safety and efficiency. Thus, the final result of this test will determine whether the tool is ready to use in an actual application or still needs further customization. Well-planned and measurable testing is a crucial step in the development process, as it ensures that the resulting tool is functional and reliable in the long run.

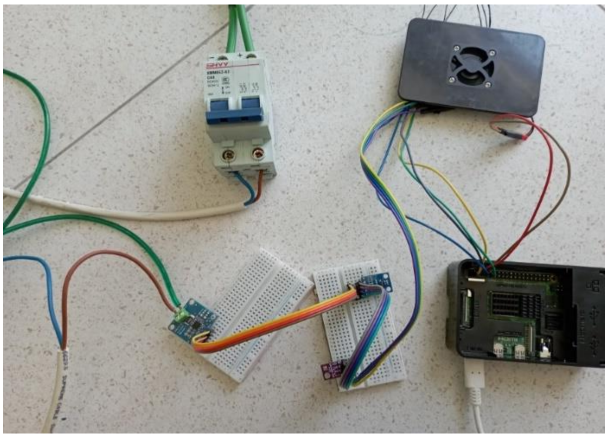

Figure 3. Tool Testing

2.5. Data Collection

The data collection stage occurs after the system successfully operates properly and stably. This process aims to gather the information necessary to achieve the research objectives and evaluate the system's performance thoroughly. The data collected provides an accurate picture of how the system functions under actual conditions so that the results can be used as material for analysis and the basis for further decision-making.

Data collection involves recording the results and monitoring and recording factors affecting system performance. This data includes variables relevant to the study, such as the system's response to certain conditions, speed, efficiency, and stability. Through this data, the team can understand how much the system meets the expectations and specifications set at the planning stage.

A structured and accurate data collection process also helps ensure the research results are highly valid. The information obtained can be used to improve, perfect systems, or even develop innovations based on existing findings. With complete and reliable data, research can significantly contribute to developing knowledge in related fields and support the effective achievement of project objectives.

2.6. Software Design

The software design [14] used in this study uses Fritzing software, Microsoft Office Visio application, Visual Studio Code, and PHPMysql.

2.7. Data Processing

At this stage, the collected raw data is processed to be converted into meaningful and valuable information for users. Raw data in numbers or records that have yet to be interpreted will have a low value if not processed correctly. Therefore, data processing is essential in converting the data into information that can be interpreted and used in decision-making.

The data processing process includes filtering, categorizing, analyzing, and calculating [15], which is needed to produce information by the research objectives. Filtering ensures that only relevant data is used, while categorization makes it easier to understand and analyze data based on specific variables. The analysis is then carried out to find patterns, trends, or relationships among the data that can support the findings or recommendations of the research.

The results of this processing provide deeper insights into the phenomenon being studied and help users understand more complex information. The processed data will be easier to read and interpret, allowing users to draw more accurate conclusions and better understand the research results. This process is critical so that the collected data can contribute to the research objectives and produce valuable information.

2.8. Data Analysis

The data analysis stage transforms the obtained data into meaningful and usable information. At this stage, the processed data is interpreted in depth to obtain specific insights according to the research objectives. This analysis simplifies results and provides a solid basis for decision-making or conclusions.

In this study, the research design was implemented using a combination of quantitative and qualitative analysis. Quantitative analysis involved collecting data from sensors, such as light intensity, temperature, voltage, and power output, which was then analysed using statistical and computational tools. This process aimed to identify trends and correlations to optimise the solar panel positioning and energy efficiency. For instance, data from LDR sensors was used to determine the position of the sun, while fuzzy logic algorithms were applied to adjust the orientation of the panels for optimal performance. Qualitative analysis, on the other hand, focused on observing patterns and relationships not directly visible from numerical data. Environmental factors, such as humidity and wind pressure, were considered to evaluate their impact on system efficiency.

The data analysis stage transforms the obtained data into meaningful and usable information. At this stage, the processed data is interpreted in depth to obtain more specific insights according to the research objectives. This analysis aims to make the necessary results more straightforward and can be used as a basis for decision-making or conclusions.

During the analysis process, the data will be studied to find patterns, trends, or relationships that may not be visible in the raw data. Various analysis methods, both qualitative and quantitative, can be applied depending on the type of data and the goal to be achieved. The results of this analysis will provide a clearer picture of the results achieved and lead to relevant findings for the study.

Data analysis makes the information produced easier to understand and can support recommendations or strategies designed based on research results. This process is critical to ensuring that each piece of data collected makes a tangible contribution to understanding the research topic and achieving project objectives effectively and efficiently.

3. Result and Discussion

Fuzzy logic has a membership value between 0 and 1. Thus, fuzzy logic can be defined as a logic with an ambiguous value between right and wrong. Fuzzy logic can interpret vague statements into statements that can be expressed in language that humans can understand. It is important to remember that probability and fuzzy logic cannot be applied similarly because probability measures the likelihood of a particular event, whereas fuzzy logic can produce results based on predictions. The fuzzy logic control diagram (FLC) is divided into three main parts: fuzzy logic, inference mechanism, and defuzzification mechanism [10]. The logical sequence of the fuzzy logic can be shown in Figure 4.

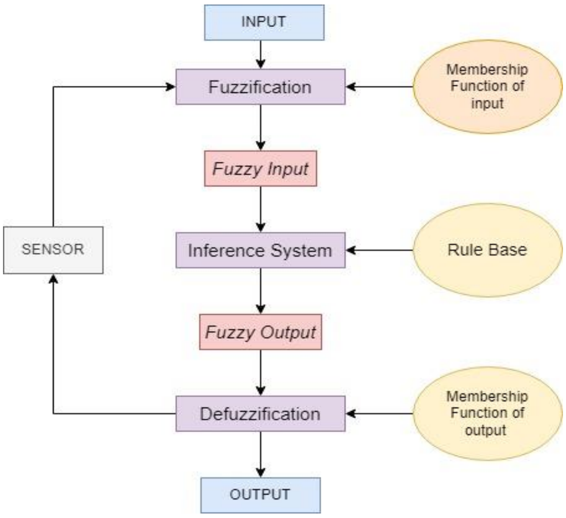

Figure 4. Fuzzy Logic Controller

3.1. Fuzzification

In this study, stages were made to change the values of sensor inputs that have crisp properties, better known as definite values, into fuzzy forms. Each sensor's input value will have the same fuzzy set in the design with five members: very dark, dark, normal, light, and very light.

Table 1. Variable Value

No	Variabel	Variable Value (%)
1	Sangat Terang (Very Light)	81 - 100%
2	Terang (Light)	61 - 80%
3	Normal	41 - 60%
4	Gelap (Dark)	21 - 40%
5	Sangat Gelap (Very Dark)	0 - 20%

3.2. Inference

In this step, the author chooses to use fuzzy logic with the Sugeno model, which is a variant of the Mamdani model; the reason for choosing the Sugeno model is because using the Sugeno model has a more straightforward membership function, where the membership function is a single member. By determining the rules, it is shown in 2 sets of tools used to make decisions.

Table 2. Rule Base

INA219		SG	SG	N	G	N
		SG	G	N	N	T
		G	G	T	T	ST
		T	T	N	T	ST
		T	T	T	ST	ST

Note:
ST : Sangat Terang
T : Terang
N : Normal
G : Gelap

SG : Sangat Gelap

3.3. Defuzzification

In the last process, fuzzy logic is Defuzzification, where the process allows the system to change the value that appears after being processed by fuzzy step by step, which was previously an unambiguous value by the member function that has been defined in the previous rule. The selection process of the membership function of the Sugeno model has a singleton rule; the reason for choosing the singleton rule is for a simple choice, namely with a predetermined value, although the process results are always accurate.

3.4. Sensor

In system evaluation, functional, structural, and validation tests and trials are carried out to determine how the system works and whether the results processed by the microcontroller remain fixed or change. After the installation and design of the device are completed, the data will be entered into a graph to show the test results.

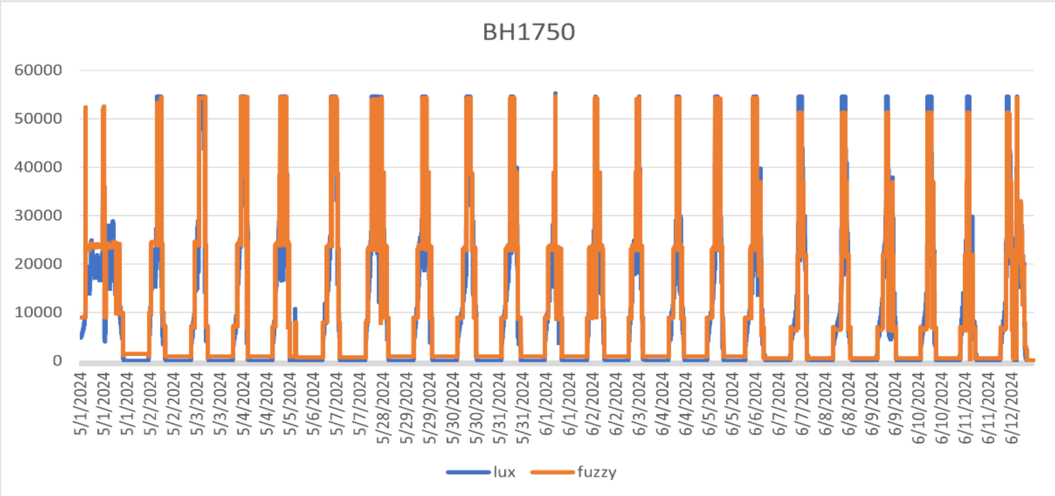

Figure 5. Testing the Results of the BH1750 Sensor Reading

Figure 5 shows that the reading of the BH1750 sensor and fuzzy logic have a slight error value because the following solar panel is blue, and the lux value and the fuzzy logic are orange. Thus, it can be concluded that the BH1750 is very good, but at night, the fuzz value stays at 500 because the calibration is different at 500 when it is night, while the lux value is below 1, which means that 0 is no longer catching sunlight.

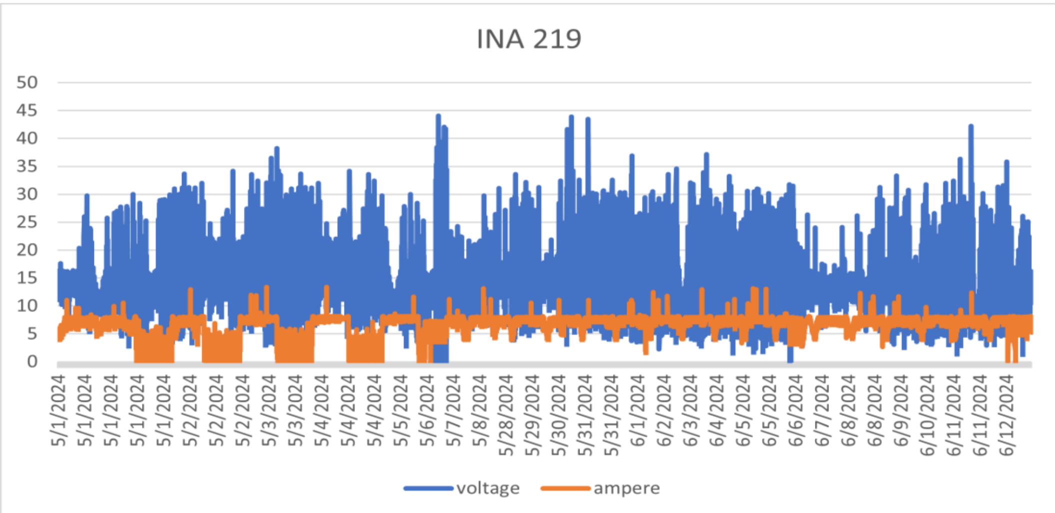

Figure 6. INA219 Sensor Reading Testing

The INA219 sensor in Figure 6 is suitable. However, the resistance used on the sensor should be reconfigured to obtain better voltage and current readings.

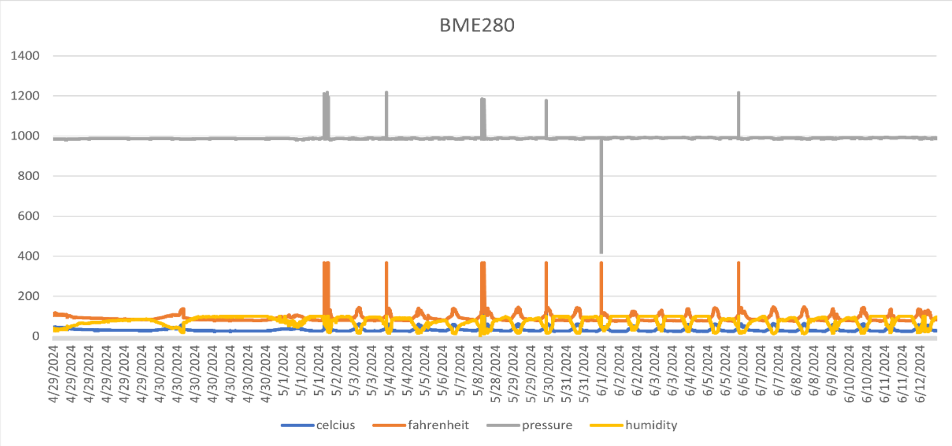

Figure 7. INA219 Sensor Reading Testing

Furthermore, in Figure 7, the bme280 sensor from the reading graph has a better reading and a small error value when the temperature exceeds 50 degrees because it is constantly exposed to sunlight and kept dry.

Table 3. LDR Sensor Reading Test Results

Time	Sensor				Information
	North LDR	East LDR	West LDR	South LDR	
7.00	84.00	94.00	90.00	92.00	Moving East
8.00	69.00	73.00	70.00	71.00	Moving East
9.00	73.00	77.00	75.00	74.00	Moving East
10.00	68.00	70.00	72.00	67.00	Moving West
11.00	81.00	78.00	84.00	78.00	Moving West
12.00	91.00	92.00	92.00	91.00	Immobility
13.00	91.00	92.00	92.00	91.00	Immobility
14.00	90.00	89.00	92.00	90.00	Moving West
15.00	94.00	90.00	95.00	91.00	Moving West
16.00	76.00	74.00	80.00	74.00	Moving West
17.00	75.00	73.00	79.00	74.00	Moving West

Table 3 can be seen. From 07.00 to 09.00, the solar panels move eastward following the highest light intensity detected by the Eastern LDR sensor. From 10:00 to 11:00, the panels move west as the Western LDR sensor shows a higher light intensity. At 12:00 and 1:00 p.m., the solar panels are stationary because the light intensity in all directions is almost the same, indicating the sun's position at its peak. Afterwards, from 2:00 p.m. to 5:00 p.m., the panel again moved west as the Western LDR sensor continued to record the highest value, following the westward movement of the sun.

Table 4. Comparison Table of Monitoring Sensor Values

No	Lux	Current (mA)	Voltage (V)	Watt	Fuzzy Value	Fuzzy and Lux Difference (%)	Temp (Celcius)	Temp (Fahrenheit)	Pressure (hPa)	Humidity
1	13.200,83	2,6	13,2	34,32	14.097,82	6,3%	35	96.74	985.59	48.34
2	13.318,33	2,6	13,3	34,58	14.107,42	5,5%	35	97.19	985.77	47.38
3	13.897,5	2,7	13,8	37,26	14.139,19	1,7%	36	98.12	985.58	46.23
4	14.900,83	2,8	14,8	41,44	14.166,50	5,6%	36	96.98	985.69	47.64
5	15.740,83	2,3	14,3	32,89	14.591,55	7,8%	38	97.65	985.47	43.39
6	4.664,35	2	9	18	4.488,16	3,9%	29	84.57	991.43	72.57
7	4.555	2,5	8,3	20,75	4.307,57	5,6%	29	84.28	991.45	72.61
8	4.975	2,1	10,7	22,47	4.987,03	2%	29	85.14	991.49	73.57
9	54000	2,2	20,6	44,57	54612.5	1,1%	46	133.72	981.12	18.04
10	34117.5	2,4	17,3	41,52	38711.2	11,8%	44	130.72	983.81	20.41
Average Score	18.637,52	2,42	13,79	32,38	18.820,7	5,13%	35,6°C	100,81°F	986,64	49,82

In Table 4, the data collected shows the results of measurements from ten different time points, including light intensity (lux), current, voltage, power, fuzzy value, and the percentage difference between fuzzy and lux values. The average measured light intensity is 18,637.52 lux with an average current of 2.42 mA and an average voltage of 13.79 V, resulting in an average power of 32.38 W. The calculated average fuzzy value is 18,820.7, with an average difference of 5.13% from the actual lux value, indicating the accuracy of the fuzzy calculation in approaching the measured light intensity. The average ambient temperature was recorded at 35.6°C (100.81°F), with an average atmospheric pressure of 986.64 hPa and an average humidity of 49.82%. These results provide an overview of the system's performance under various environmental conditions.

4. Conclusion

This research has succeeded in developing a solar energy absorption optimization tool for solar panels that can be monitored in real-time and visualize data directly during the research process. The tool's development aimed to increase the efficiency of solar energy absorption, which helps convert more sunlight into electrical energy so that the power generated by solar panels is optimal. This tool can generate measurable data based on the planned stages, ensuring the research results meet the expected targets.

This research process includes several critical stages, such as data collection, data analysis, design, and implementation of the analysis results. Each stage is developed with the main components consisting of a microcontroller, sensors, and a website for monitoring. The use of microcontrollers helps control and process the data received from the sensors, while the sensors used, such as LDR and light intensity sensors, support light detection for automatic panel positioning. The monitoring website developed provides convenience in accessing and monitoring data remotely so that measurement results can be accessed anytime in real-time.

The data shows this device can achieve an optimization level in very bright lighting conditions of up to 53,999.99 lux. This optimisation level has a difference of only 1.1% between the fuzzy result and the lux value, demonstrating the tool's accuracy and effectiveness in converting raw data into reliable information. This low difference is better than the results of the previous study, indicating that the tools produced in this study have a better level of optimization. This increase in efficiency makes solar energy absorption optimization tools a more effective solution to produce electrical power from solar energy optimally and consistently.

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