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Solar Panel Light Intensity and Voltage Measurement System Using Atmega 328

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Abstract— This research explores the development of a real-time measurement system for light intensity and voltage in solar panels. It utilizes the ATmega328 microcontroller with an INA219 sensor for voltage measurement, a BH1750 sensor for light intensity measurement, and a logger module. The objective of this research is to assist and reduce losses in the use of solar panels. The research method is a simplified version of the 4D model, reduced to 3D: define, design, and develop. This system is designed to accurately collect data directly from solar panels, with a recorded data error rate of 23%. The gathered data is stored via an SD card on the logger module and converted into CSV text format. Test results indicate that this system can measure accurately and store data in a readily accessible and processable format. ATmega328, as the system's core, allows accurate real-time monitoring of solar panel conditions while storing data in CSV format, facilitating further analysis. Therefore, this system can be a valuable tool for monitoring and enhancing the energy efficiency produced by solar panels.

Keywords: solar panel, light intensity, voltage, ATmega328, INA219 sensor, and BH1750 sensor

I. INTRODUCTION

The development of alternative energy technology is growing rapidly today (A. Suryanti et al., 2021). The use of solar energy is one innovation. Another factor driving the development of sustainable energy technology is the increasing need for energy (Afriyanti et al., 2020; Mamahit et al., 2022). The development of alternative energy is one of the efforts to reduce the energy crisis and the impact of global warming caused by burning fossil fuels (Adi Gunawan et al., 2021; Anugraheni et al., 2024; Farghali et al., 2023; Ozili & Ozen, 2023; S. Singh, 2021).

Having information about solar radiation is essential when planning a solar panel installation (Kabir et al., 2018; Kalogirou, 2023; Sengupta et al., 2021). This can be predicted by measuring solar irradiance, which requires estimating the power (measured in watts) available in a given square meter area (Coddington et al., 2019; Kumar et al., 2020; Michael et al., 2020). Measured in watts/m2, irradiance is the power per unit area of electromagnetic radiation incident on a surface (Ali & Windarta, 2020; Vignola et al., 2019; Wald, 2018). Above 1000 watts/m2, good irradiance allows solar cells to produce the optimal amount of electricity (Al-Shahri et al., 2021; Kirchartz & Rau, 2018; Wang et al., 2018).

Specialized monitoring equipment that can measure solar power periodically and in real-time is needed to collect data on solar irradiance at a particular location (Pakradiga & Suryono, 2019; Sari et al., 2024; Taqwin et al., 2023). Solar irradiance information is essential when simulating and evaluating a location or site to see if it is suitable for installing solar panels (Ardianto et al., 2021; Nurdiansyah et al., 2020). In addition, this data is essential to verifying the operational quality of the system, ensuring that the power output is consistent with anticipated levels.

Solar panel reference or pyranometer sensors can calculate the amount of sunlight (Khuriati, 2022). Because of their high accuracy and relative ease of use, pyranometers are usually used in instrumentation to measure sunlight (Levinson et al., 2020; Nugraha & Adriansyah, 2021, 2022). However, pyranometers are very expensive, and the BH1750 sensor may eventually replace them. Meanwhile, the INA219 sensor will be used for voltage measurement (Dwika et al., 2024; El Hadi et al., 2021; Habiburosid et al., 2019). The data logger module will store all the data that needs to be read (T. Singh & Thakur, 2019).

Therefore, accurate solar panel installation is essential, based on visual observation and the analysis of data recorded from several voltage and sunlight insolation measurements. This study aims to design a voltage and irradiance measuring device based on

ATMega328 with a data logger to facilitate data analysis.

II. METHOD

Quantitative research, or more precisely, experimental research, involves testing a system and examining its results to determine its capabilities and performance level. One technique for research and development is the 4D model, which is used in the creation of educational resources. S. Thiagarajan, Dorothy S. Semmel, and Melvyn I. Semmel created the 4D model (Yusuf, 2023).

A. Prototype Method

The prototype method is a method of the system creation process that is structured and has several stages that must be passed in its creation (Nelwan et al., 2023). However, if the final stage states that the system that has been created is not perfect or still has shortcomings, then the system will be re-evaluated and will go through the process from the beginning. The prototype approach is an iterative process that involves a close working relationship between the designer and the user. This prototype model aims to develop the initial software into a final system.

1. Collection of requirements

The system worked on in this study is divided into several parts. The input system uses the INA219 sensor as a voltage reader and the BH1750 as a light-intensity reader. The control system uses the ATmega328 microcontroller. The LCD and data logger modules are also outputs.

2. Building a prototype

Build a prototype by creating a temporary design that focuses on presenting to customers (for example, by creating input and output formats). After analyzing the device requirements, it is necessary to design the arrangement of components based on the features needed by the system so that the device can be used according to the desired function. The initial step before designing the system is creating a block diagram of the system circuit, as seen in Figure 2. The block diagram of the system circuit is a basic description before designing the device.

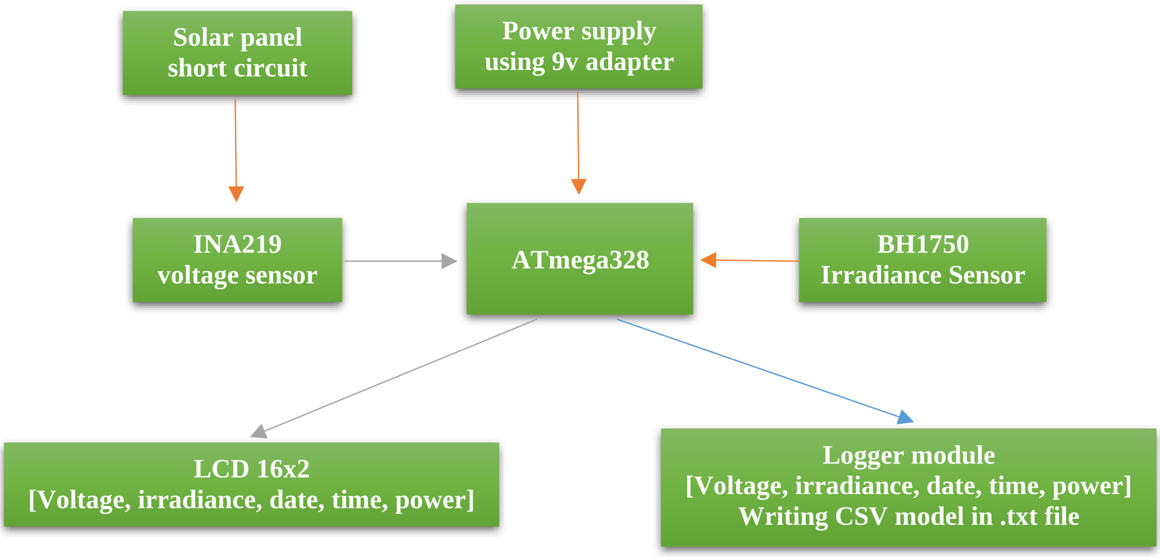


Figure 1. Block diagram of the system circuit

a. System diagram design

The system worked on in this study is divided into several parts. The input system uses the INA219 Sensor as a voltage reader and the BH1750 as a light-intensity reader. The ATmega328 microcontroller is used as a control system. The LCD and data logger modules are used as output. The system worked on in this study is explained in the Block Diagram Scheme in Figure 1.

The components used are:

1) INA219 and BH1750 function as inputs for voltage and light intensity, and then the data that has been read will be processed by the ATmega328 microcontroller.
2) The ATmega328 microcontroller functions as the brain to issue commands (Mamahit et al., 2024).
3) The LCD will display the received data and also the current, voltage, and light intensity data.

4) The logger module functions when all the data the microcontroller has received will be stored in the logger module with storage memory.

b. Software Design

This circuit design uses the fritzing application. The designed circuit system can be seen in Figure 2.

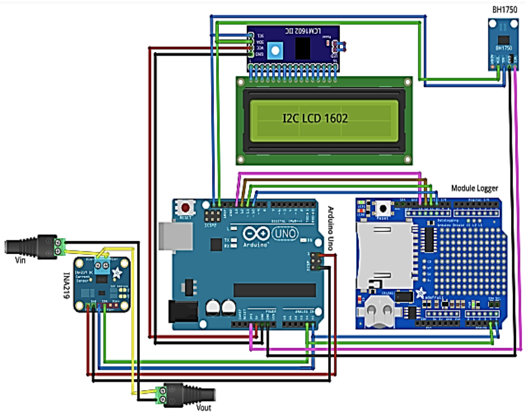


Figure 2. Circuit Design

3. Prototype Evaluation

The customer evaluates whether the prototype that has been built is in accordance with the customer's wishes. If it is, step 4 will be taken. If not, the prototype is revised by repeating steps 1, 2, and 3.

4. System Testing

After the system becomes ready-to-use software, it must be tested before use. This testing is done with Black Box. We are conducting several trial tests on the tools developed.

5. System Evaluation

Evaluate whether the finished system is by expectations. If yes, step 6 is carried out; if not, repeat steps 4 and 5.

6. Using the system

The software that has been tested and meets the needs is ready to use.

The design diagram can be seen in Figure 3.

Figure 3. Design diagram

B. Data Analysis Techniques

In this research, data analysis for data analysis techniques is done by measuring research factors that may affect the continuity of a product's feasibility. The calculations carried out are error, accuracy, and precision.

1. Error

An error or mistake is a deviation of the value of a measurement from the actual value, which can be stated (Cohen, 2013).

$$Error = |Yn - Xn| \qquad (1)$$

Where:

Error = Error Absolute
Yn = True Value
Xn = Measurement Value

If you want to express the error in percent, you can see it in equation 2.

$$Percent\ Error\ (\%) = \frac{Yn - Xn}{Yn} \times 100\% \quad (2)$$

2. Accuracy

Accuracy is defined as the closeness of the measurement results of a measuring instrument to an agreed-upon standard value or a valid value. To obtain the relative accuracy value, equation 3 is used (Cohen, 2013).

$$A = 1 - \left|\frac{Yn - Xn}{Yn}\right| \quad (3)$$

Where:

Xn = Measurement Result Value
Yn = True Value
A = Relative Accuracy

Accuracy can also be expressed as a percentage of accuracy, as follows:

$$Accuracy\ percentage = 100\% - Error\ Percentage \quad (4)$$

The accuracy value of testing this tool is expressed in percent using equation 4.

3. Precision

Precision is the closeness of the results of repeated measurements to the average measurement. The equation for the precision value is as in equation 5 (Cohen, 2013).

$$Percentage\ Precision = 100\% - \left|\frac{Xn - \overline{Xn}}{\overline{Xn}}\right| \times 100\% \quad (5)$$

Where:

Xn = Measurement Result Value
$\overline{Xn}$ = Average Value of Measurement Results

III. RESULTS AND DISCUSSIONS

A. *Research Design Results*

This circuit design uses the Fritzing application. System design consists of hardware and software design. The system used in this study is divided into several parts. The input system uses solar panels via jack ports and an INA219 sensor to measure voltage and power. The BH1750 sensor measures irradiance. A logger module stores data in real time, and the LCD displays all data, including the day and date. Here, we can see Figure 4.

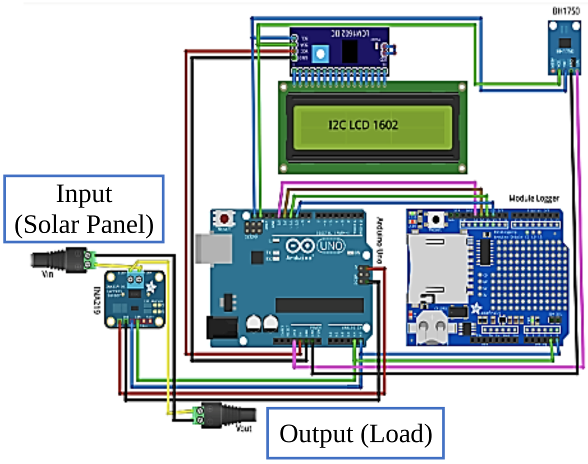


Figure 4. Solar panel intensity and voltage measurement circuit

B. *Solar Panel Voltage and Irradiance Measurement*

The entire device configuration, as depicted in Figure 4, is complete. A 9-volt input voltage adapter is used to supply power through the adapter cable. The INA219 voltage sensor receives input from the solar cell. The timer of the data logger module is used to record data into the SD Card module: a 16 x 2 alphanumeric LCD, with the measurement data as text. The device's physical form is similar to the image shown in Figure 5.

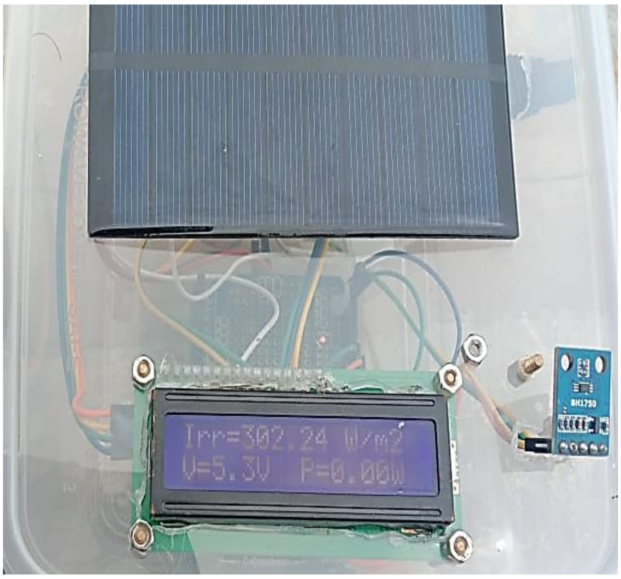


Figure 5. Physical form of the device

There must be several stages of testing to ensure that the device functions as expected and that the data recording procedure is accurate. The voltage sensor, a vital part of the entire system, is the primary target of testing. Figure 6 shows the test circuit for the current sensor.

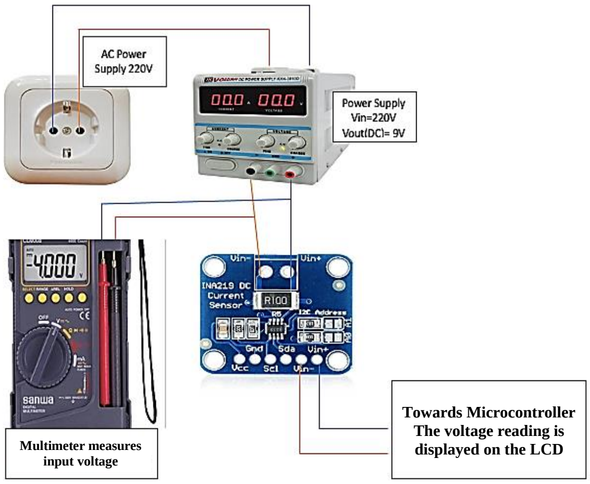


Figure 6. Sensor Testing

After the tool testing was completed, data was recorded on-site on the fourth floor of the Tarbiyah B Building. The developed tool will be used to record data, and as shown in Figure 7, the results obtained will be compared with the readings from the SM-206 photodiode-based solar power meter.

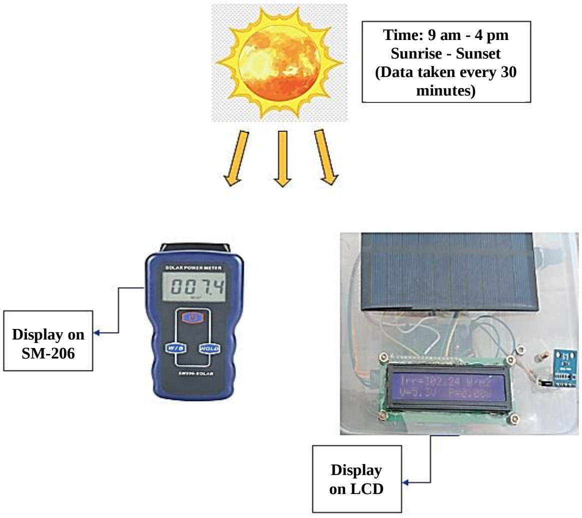


Figure 7. Illustration of irradiance data recording

The tool was used to record irradiation data for one whole day on the terrace of the 4th floor of the Tarbiyah B Building to obtain the most optimal insolation data from sunrise to sunset, namely from 9:30 a.m. to 4:00 p.m. Cloud conditions were ignored and considered bright for each data collection.

The results of data recording after one full day can be seen in Table 1, which has a reasonably large percentage of error data.

Table 1. Testing Tools and Data Error%

No	**Time**	**BH1750 (W/m^2)**	***Solar Power Meter (W/m^2)***	***% Error***
1	9:46	300.15	370.6	19%
2	10:21	335.95	420.2	20%
3	11:01	431.44	645.7	33%
4	11.30	431.44	729.3	-
5	11.52	431.44	1008.4	-
6	0:17	340.35	415.8	18%
7	2:05	431.44	619.3	29%
8	2:28	358.41	437.8	18%
9	3:04	352.10	475.9	26%
10	3:33	431.44	678.0	-
11	4:02	130.33	165.4	21%
Rata-rata				23%

The irradiance (W/m2) test results and measurement on the BH1750 sensor with a comparison of solar power meters were carried out on December 1, 2023, at the Tarbiyah B building floor with an average error of 23%. Some data are marked with a strip (-). The maximum data limit the BH1750 sensor can read is only up to 431.44 W/m2, which is not included in the percentage error calculation. The results in the comparison of tools can be seen in Figure 8.

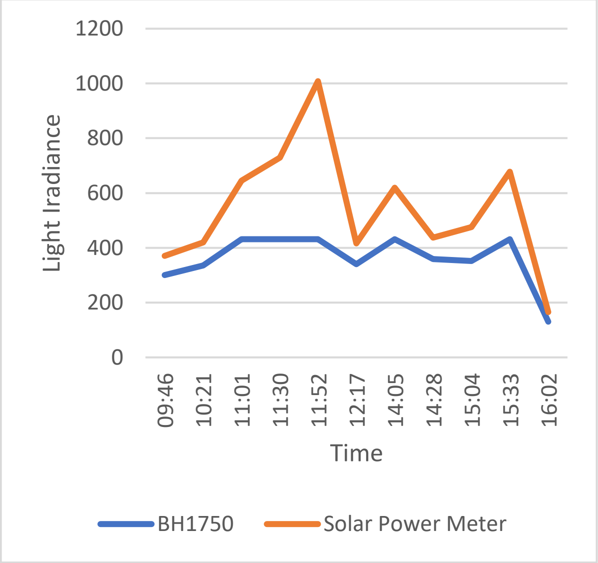


Figure 8. Comparison Data Results of Tools

As seen in Figure 9 below, the LCD screen test results show that the characters displayed by the LCD are following the LCD screen design. The LCD screen can display all displayed data, including output power, voltage, and solar radiation, without any characters being hidden or not displayed.

Figure 9. LCD view

Table 2 shows the details of the total data recorded, including the amount of data recorded on the SD Card. Each distance limiter will be marked with a (,) for data reading, as shown in Figure 10.

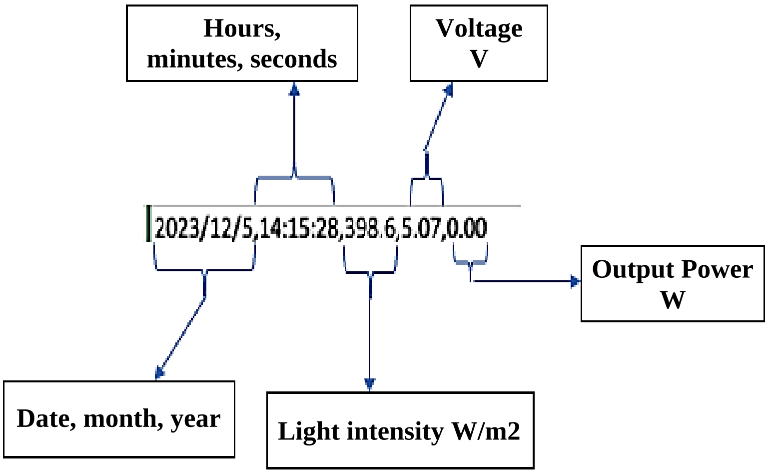
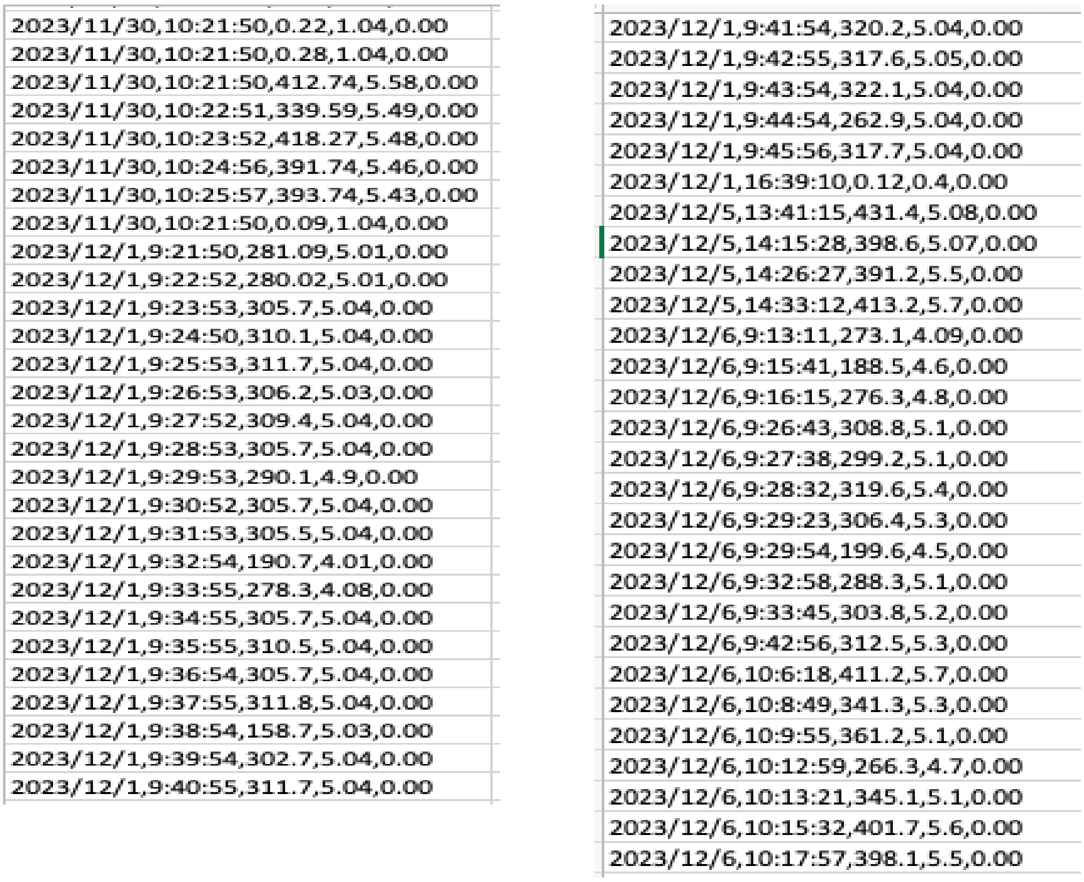


Figure 10. How to Read Data



```
2023/11/30,10:21:50,0.22,1.04,0.00
2023/11/30,10:21:50,0.28,1.04,0.00
2023/11/30,10:21:50,412.74,5.58,0.00
2023/11/30,10:22:51,339.59,5.49,0.00
2023/11/30,10:23:52,418.27,5.48,0.00
2023/11/30,10:24:56,391.74,5.46,0.00
2023/11/30,10:25:57,393.74,5.43,0.00
2023/11/30,10:21:50,0.09,1.04,0.00
2023/12/1,9:21:50,281.09,5.01,0.00
2023/12/1,9:22:52,280.02,5.01,0.00
2023/12/1,9:23:53,305.7,5.04,0.00
2023/12/1,9:24:50,310.1,5.04,0.00
2023/12/1,9:25:53,311.7,5.04,0.00
2023/12/1,9:26:53,306.2,5.03,0.00
2023/12/1,9:27:52,309.4,5.04,0.00
2023/12/1,9:28:53,305.7,5.04,0.00
2023/12/1,9:29:53,290.1,4.9,0.00
2023/12/1,9:30:52,305.7,5.04,0.00
2023/12/1,9:31:53,305.5,5.04,0.00
2023/12/1,9:32:54,190.7,4.01,0.00
2023/12/1,9:33:55,278.3,4.08,0.00
2023/12/1,9:34:55,305.7,5.04,0.00
2023/12/1,9:35:55,310.5,5.04,0.00
2023/12/1,9:36:54,305.7,5.04,0.00
2023/12/1,9:37:55,311.8,5.04,0.00
2023/12/1,9:38:54,158.7,5.03,0.00
2023/12/1,9:39:54,302.7,5.04,0.00
2023/12/1,9:40:55,311.7,5.04,0.00
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2023/12/1,9:41:54,320.2,5.04,0.00
2023/12/1,9:42:55,317.6,5.05,0.00
2023/12/1,9:43:54,322.1,5.04,0.00
2023/12/1,9:44:54,262.9,5.04,0.00
2023/12/1,9:45:56,317.7,5.04,0.00
2023/12/1,16:39:10,0.12,0.4,0.00
2023/12/5,13:41:15,431.4,5.08,0.00
2023/12/5,14:15:28,398.6,5.07,0.00
2023/12/5,14:26:27,391.2,5.5,0.00
2023/12/5,14:33:12,413.2,5.7,0.00
2023/12/6,9:13:11,273.1,4.09,0.00
2023/12/6,9:15:41,188.5,4.6,0.00
2023/12/6,9:16:15,276.3,4.8,0.00
2023/12/6,9:26:43,308.8,5.1,0.00
2023/12/6,9:27:38,299.2,5.1,0.00
2023/12/6,9:28:32,319.6,5.4,0.00
2023/12/6,9:29:23,306.4,5.3,0.00
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2023/12/6,9:32:58,288.3,5.1,0.00
2023/12/6,9:33:45,303.8,5.2,0.00
2023/12/6,9:42:56,312.5,5.3,0.00
2023/12/6,10:6:18,411.2,5.7,0.00
2023/12/6,10:8:49,341.3,5.3,0.00
2023/12/6,10:9:55,361.2,5.1,0.00
2023/12/6,10:12:59,266.3,4.7,0.00
2023/12/6,10:13:21,345.1,5.1,0.00
2023/12/6,10:15:32,401.7,5.6,0.00
2023/12/6,10:17:57,398.1,5.5,0.00
```

Figure 11. Data entered and saved in Excel

The input data recorded using the logger will be transferred to the SD card and formatted into Excel. The data written in the TXT file will follow the Comma Separated Value (CSV) method, where the data is separated by a semicolon (;) or comma (,). The CSV format is used for writing data to make it easier to enter large amounts of data into a table that the Microsoft Excel application can read.

The measurement results, which can be seen in Table 2, suggest that the system works well.

Table 2. Results of the tool test data sheet

No	Date	Time	Irradiance (W/m^2)	Voltage (V)	Power On Load (W)
1	30/11/2023	10:1:50	412.74.	5.5	0
2	30/11/2023	10:22:51	339.59	5.4	0
3	1/12/2023	9:21:50	281.09	5.01	0
4	1/12/2023	9:22:52	280.02	5.01	0
5	5/12/2023	1:15:28	431.44	5.8	0
6	5/12/2023	2:26:27	391.2	5.5	0
7	6/12/2023	10:6:18	411.2	5.7	0
8	6/12/2023	10:8:49	341.3	5.3	0

IV. CONCLUSION

The performance of the system tool with the presence of data marked with a strip (-) indicates the possibility of interference or conditions that affect the accuracy of the sensor measurement at that time. It is essential to record and investigate these data to determine the cause, such as environmental conditions, interference with the sensor, or other technical factors that may affect the measurement results.

In conclusion, the BH1750 sensor provides irradiance measurement results with an average error of 23% and has a maximum measurement limit of 431.44 W/m2. However, further analysis of invalid data or data outside the sensor's measurement range is needed to ensure its accuracy in practical applications.

The results of measuring solar panel voltage and irradiance are important in evaluating solar panel performance and efficiency and can provide valuable insights for improving or increasing their efficiency in the future.

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