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IoT-based Pyranometer Using Photodiode Sensor

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Abstract: Solar irradiance is one of the critical parameters of climatology because it is the driver of most of the dynamic processes in the atmosphere. We need a tool to measure solar irradiance, such as a pyranometer. However, the pyranometer has the disadvantage that it requires cables and electricity to send data to data processing devices, which sometimes causes data loss problems if the connecting cable is damaged unnoticed and a sudden power outage occurs. An IoT-based pyranometer using a photodiode sensor will overcome this problem because the tool will send the measured solar irradiance data directly to the internet. The objective of this research is to minimize the measurement data loss that occurs and to ensure the data quality. This is possible because the device operates with solar cells that constantly recharge the battery. This research is a type of engineering research. The measurement technique used is a direct measurement, comparing solar irradiance data with a standard pyranometer, then indirectly analyzing the accuracy and precision of the design tool. Based on direct testing of the tool, an accuracy and precision rate close to 100% was achieved, which was 98.19% and 98.63%, respectively. Therefore, it can conclude that the tool can work well. Moreover, measurements were also conducted at BMKG Sicincin on July 13, 2022 from 08:56 to 15:10, resulting in a measurement percentage of 4.87% with the highest solar irradiance at 12:15.

Keywords: Solar irradiance, Pyranometer, IoT, Photodiode Sensor.

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1. Introduction

The sun is the primary energy source that affects the weather and temperature in an area, as well as a system of renewable energy sources. The energy is emitted in all directions on earth, where generally, the energy emitted is 1367 W/m^2, in the form of short waves [1]. Solar panels can convert solar energy into renewable energy, that is, turn it into electricity [2]. Solar irradiance plays a significant role in the process of changing the weather in an area. [3]. Solar irradiance that reaches the earth's surface can occur directly and indirectly after being scattered or reflected by aerosols, atmospheric molecules, and clouds [4]. The natural state of solar irradiance has a different intensity in each area. The sun's position and the region's work on the earth's surface influence the radiation potential in an area [5].

The tool used to measure the intensity of solar irradiance is a pyranometer. Pyranometers are widely used by meteorologists, climatologists, atmospheric scientists, and renewable energy scientists [6]. Two types of sensor devices can be used to measure solar irradiance: a temperature sensor using a thermopile and a solid-state sensor using a photovoltaic or photodiode [7]. Pyranometers using photodiodes can generally measure the value of the solar spectrum between 400 nm to 900 nm, with the highest measurement performance ranging from 350 nm to 1100 nm [8]. The measurement results from the pyranometer are influenced by the solar angle-of-incidence (AOI) cosine. Therefore, we can say that all pyranometers are subject to significant measurement error at high AOI due to mechanical misalignment [9].

The photodiode is a light sensor that converts an optical quantity (light) into an electrical amount [10]. The working principle of a photodiode is similar to that of a solar cell. The photodiode can use p-n or p-i-n junction, but both operate under reverse biased conditions. This means that the p side is connected to the anode, and the n side is connected to cathode. Meanwhile, when a photon strikes a diode, a hole and electron pair is created (the photoelectric effect). Suppose absorption occurs within the diffusion length of the depletion region or the depletion region. In that case, these carriers are swept from the intersection through the built-in plane of the depletion region. The electrons move towards the cathode, and the holes move towards the anode, producing a photocurrent [11].

A pyranometer has a disadvantage where it can lose data due to problems such as power outages and damaged connecting cables to data processing devices that go unnoticed. This causes frequent data loss and reduces the quality of the measurement data. To solve this problem in previous studies [12], they built a pyranometer using a microcontroller with a solar cell and a temperature sensor as the primary sensor. In this tool, the data is stored directly in the microcontroller. However, this tool still has a weakness where much measurement data is lost. Then [13] developed research by adding a website-based data monitoring system. The tool for the server is a mini PC, but this tool can activate the server for a long time. We develop a pyranometer with a smartphone display and a cloud-based storage system to solve this problem. In this study, we will replace the temperature sensor from the previous research with a photodiode sensor because the photodiode-based pyranometer has a response time of about 10μs. On the other hand, thermopile-based pyranometers have response times ranging between 1 and 10 seconds, making previous tools less suitable for measuring very rapid changes in solar irradiance [9].

2. Materials and Method

This research is engineering research. Engineering research is a design activity that demands new contributions in each of its activities, both in the form of processes and products/prototypes. In this study, the discussion of design activities involved relatively new things [14]. Meanwhile, stages in engineering research can be viewable in Figure 1.

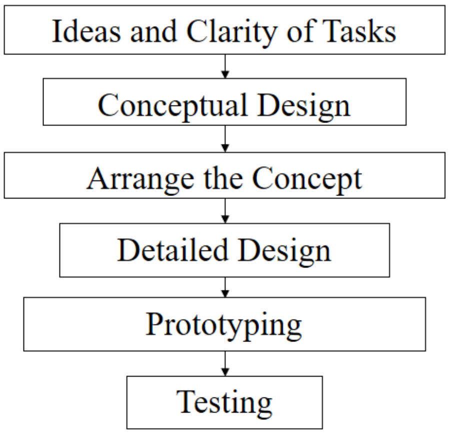

Figure. 1. Engineering research stages

The research begins with the stages of determining ideas and clarity of tasks. This stage is done by looking for literature studies from various sources. Then, the conceptual design stage is the stage of realizing the idea before forming a system of research to be made. Then the next step is to arrange the concepts by making block diagrams. The block diagram can be viewable in Figure 2.

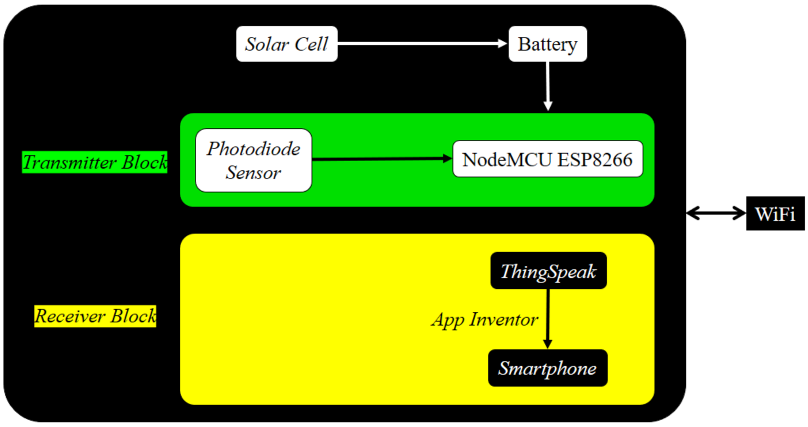

Figure 2. IoT-based pyranometer block diagram

Figure 2 is an IoT-based pyranometer consisting of a solar cell and a battery as a voltage source from the device. A photodiode sensor measures the intensity of solar irradiance, As for the NodeMCU ESP8266 as the microcontroller of the tool made, the microcontroller is an electronic component that can be programmed and can execute programmed steps [15]. WiFi is an internet transmitter to connect the device with a smartphone. Then, ThingSpeak and App Inventor as measurement data display media. In addition, we use smartphones to monitor data to measure the intensity of solar irradiance.

The next stage is to design the IoT-based pyranometer software and hardware in detail. The software consists of a microcontroller program and App Inventor. The programming flowchart is shown in Figure 3.

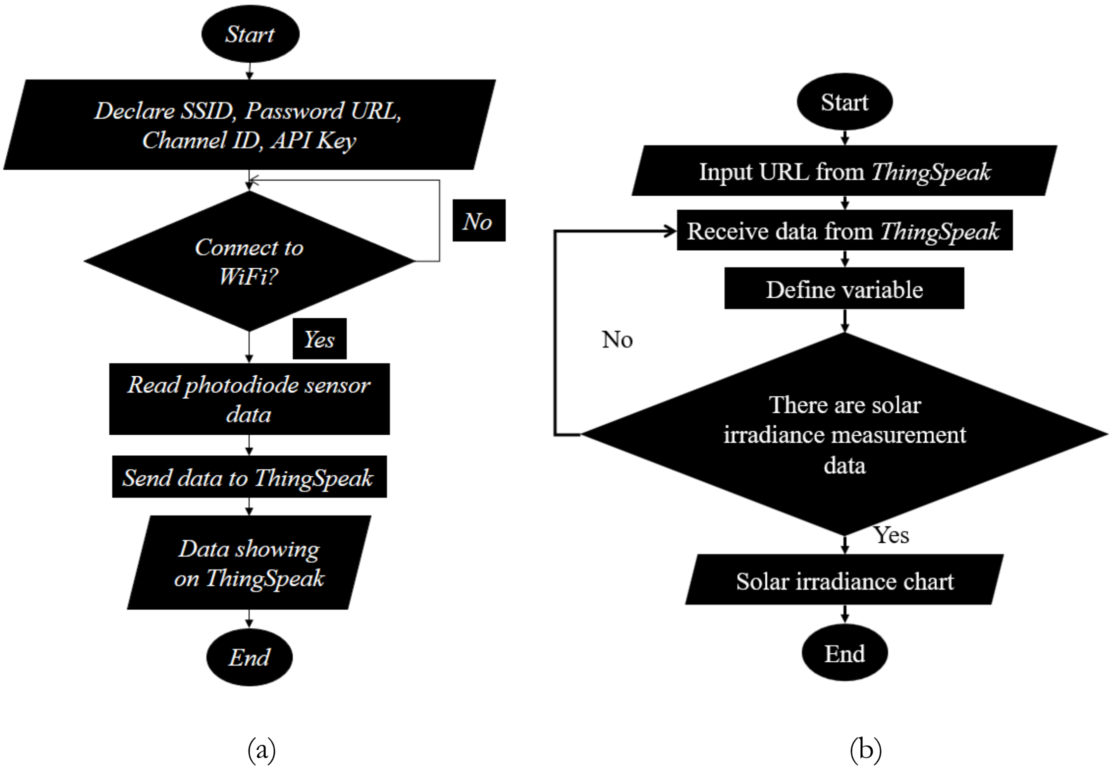

Figure 3. The programming flowchart: (a) the microcontroller and (b) App Inventor

Figure 3 shows the program flowchart of this measuring device. The first part represents the flowchart for the microcontroller program. The first stage is the declaration of WiFi to display the SSID, Password URL, Channel ID, and API Key. Meanwhile, if the system is connected to WiFi, the microcontroller will send the photodiode sensor data to ThingSpeak. However, if the system is not connected to WiFi at the initial stage, the microcontroller will repeat the process back to the beginning. The photodiode sensor measurement data will appear on ThingSpeak. The data stored in the ThingSpeak database will then be displayed to the smartphone through software that has been designed using App Inventor.

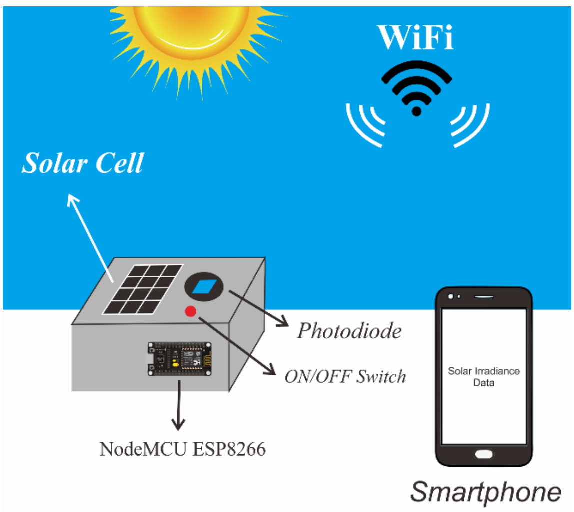

Figure 4. IoT-based pyranometer design

Second part is an application design flow in App Inventor. At this stage, it begins by entering the URL of ThingSpeak. The App Inventor will define the data in it. Meanwhile, the measurement data for the intensity of solar irradiance will continue to be displayed on smartphones in graphic form. The IoT-based pyranometer hardware is in the form of a black box. The IoT-based pyranometer design can be viewable in Figure 4. The next stage is making a prototype according to the design that has been made. The testing process can be carried out when the tool can function correctly. Tool testing was carried out at BMKG Sicincin.

3. Results and Discussion

The results of the study obtained performance specifications and tool design specifications. The performance specifications are obtained by identifying each tool's function and component. Meanwhile, design specifications are obtained from direct testing of the equipment in the field. The performance specifications include a power supply circuit, a photodiode sensor circuit, an IoT-based pyranometer, and a monitoring application display.

The power supply circuit is a circuit that connects the battery as a voltage source for the tool and the solar cell as a component that functions to charge the battery regularly, so it doesn't run out. The solar cell module converts solar energy into DC electric current [16]. Solar cell is connected to the TP4056 module, which is a charging module. The positive pole of the solar cell is connected to the diode first before being connected to the module. Meanwhile, the negative pole of the solar cell is connected to the negative pin on the module. The batteries used are 18650 batteries with voltage of 4V in as many as two pieces. The two batteries are connected in parallel to the TP4056 module via pins B+ (positive) and B- (negative). Then, each battery's positive and negative poles are connected to a 5V step up. Here step up 5V to increase the voltage to provide the voltage needed by the tool, namely 5V [17]. There are two 5V step-ups to provide a voltage source for the sensor and microcontroller circuits. The photodiode sensor circuit consists of an Operational Amplifier (Op-Amp). Op-Amp is a differential amplifier with a very high gain [18].

The photodiode sensor has two legs, the cathode, and anode. The anode is connected to the ground, and the cathode is connected to the inverting input on the Integrated Circuit (IC) LM358. LM358 itself is a dual op-amp IC consisting of two inverting inputs, non-inverting input, and output. On the inverting input, the pin is connected to one leg of a 100nF capacitor and a 2kΩ resistor. Meanwhile, the other leg is connected to the output leg. Meanwhile, for the non-inverting input, one leg is connected to a 100nF capacitor and a 1kΩ resistor. Meanwhile, the other leg is connected to the ground. To make the Op-Amp amplifier function run, the LM358 IC must be given a +5 V voltage. The VCC leg of the LM358 IC will be connected to the 5V step-up positive pole, and the LM358 IC GND leg will be connected to the 5V step-up negative pole. Meanwhile, the output leg of the LM358 IC is connected to pin A0 of the NodeMCU ESP8266.

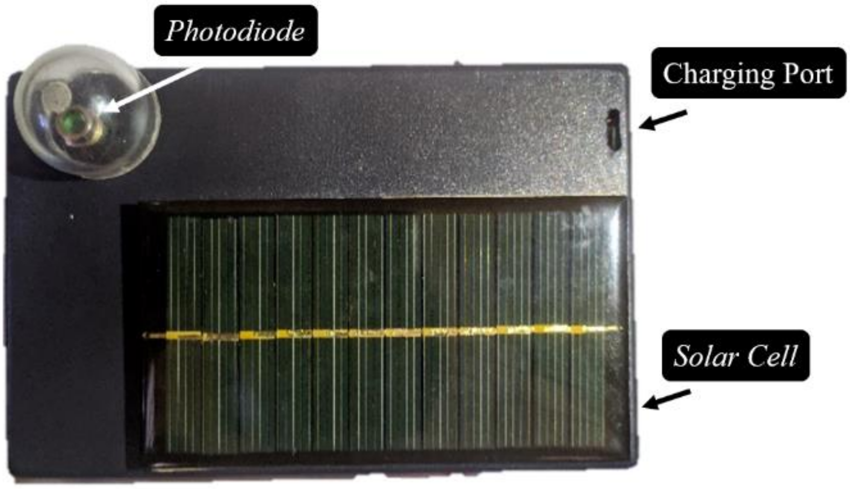

Figure 5. The physical form of an IoT-based pyranometer

The physical form of the IoT-based pyranometer has dimensions of 14.5 cm long, 9.5 cm wide, and 5 cm high. At the top, you can see the photodiode sensor and solar cell because the two components face directly into the sun. In addition, there is also a charging port to charge if the power obtained from the solar cell is still lacking. On the tool's side is an on/off switch to activate/deactivate the device. On the front, you can see the reset button and programming port. The programming port serves to upload programs into the microcontroller so that it is able to carry out the measurement process properly. The physical form of an IoT-based pyranometer can be viewable in Figure 5. The appearance of IoT-based pyranometer monitoring application is designed using App Inventor and the ThingSpeak database as a data repository for solar irradiance measurements. App Inventor is a program that produces applications that we can use on the Android system [19]. ThingSpeak is a facility or place that is open to use in developing IoT applications [20]. The display of the IoT-based pyranometer monitoring application can be viewable in Figure 6.

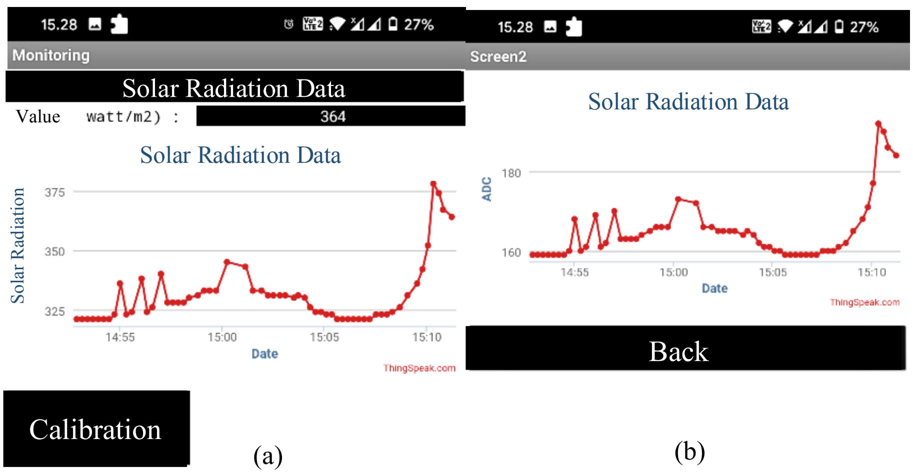

Figure 6. The display of the IoT-based pyranometer monitoring application: (a) main page and (b) second page

Figure 6 shows the interface of the IoT-based pyranometer monitoring application. The first part is the application's main page, which contains the measurement value of the IoT-based pyranometer solar irradiance in units of W/m^2. Then, when you press the button that says calibrate, it will be redirected to the second page. The second page is a page that contains the analog measurement values of the photodiode sensor, and this page serves to obtain data for calibration purposes. Design specifications include characteristics, accuracy, precision, and solar irradiance measurements. Characteristic data was obtained from the effect of changes in the value of solar irradiance on the output voltage value of the BPW21 photodiode sensor. Sensor output voltage data is needed to determine how sensitive the sensor is. The data graph of the BPW21 photodiode sensor characteristics can be viewable in Figure 7.

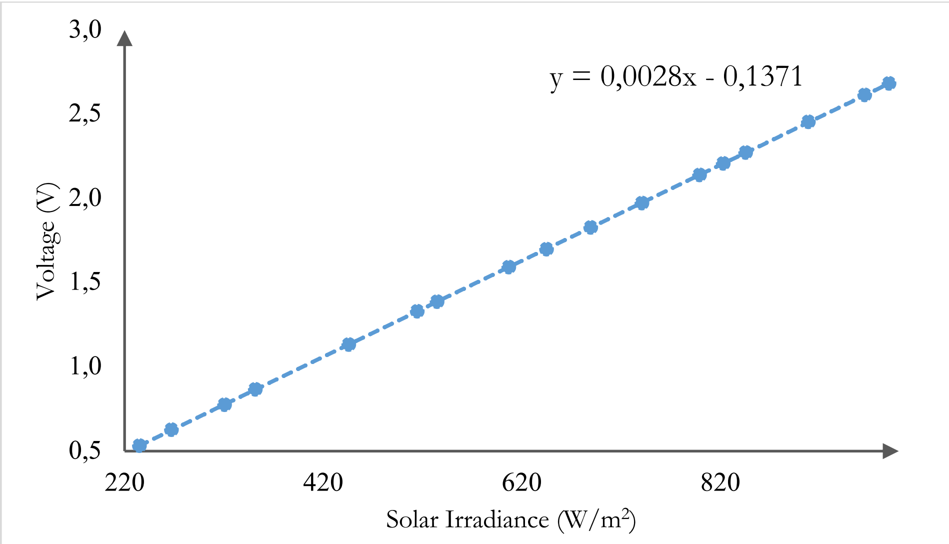

Figure 7. The data graph of the BPW21 photodiode sensor characteristics

Figure 7 shows that the greater the measured solar irradiance value, the greater the output voltage value of the BPW21 photodiode sensor. From the graph above, the sensitivity of the photodiode sensor can be determined by equation (1).

$$V = 0{,}0028CO - 0{,}1371 \tag{1}$$

Data on the accuracy of the IoT-based pyranometer is obtained by comparing the value of solar irradiance from the standard pyranometer and the IoT-based pyranometer. A good accuracy value is that the measurement value is close to the actual value [14]. IoT-based pyranometer accuracy data can be viewable in Table 1.

Table 1. IoT-based pyranometer accuracy data

Standard Tool (W/m^2)	Measuring Tool (W/m^2)	% Accuracy	% Error
288,70	279,77	96,81	3,19
368,00	372,43	98,81	1,19
382,80	387,87	98,69	1,31
456,70	442,78	96,86	3,14
542,40	547,44	99,08	0,92
630,10	638,38	98,70	1,30
706,90	713,88	99,02	0,98
874,40	871,74	99,69	0,31
912,80	900,91	98,68	1,32
1107,90	1060,48	95,53	4,47
Average		98,19	1,81

Table 1 shows that the value of solar irradiance measured by a standard pyranometer and an IoT-based pyranometer has some less significant differences. In the following result, IoT-based pyranometer precision data is obtained by repeatedly measuring solar irradiance at similar conditions and times ten times. The expected precision is the measurement value repeatedly doesn't change and remains the same. IoT-based pyranometer precision data can be viewable in Table 2.

Table 2. IoT-based pyranometer precision data

Solar Irradiance (W/m^2)	%Precision
310,66	96,57
310,66	96,57
307,22	100,00
307,22	100,00
307,22	100,00
307,22	100,00
305,51	98,28
305,51	98,28
305,51	98,28
305,51	98,28
Average	98,63

The IoT-based pyranometer data was obtained by measuring solar irradiance from 08:56 to 15:10 on July 13, 2022, at BMKG Sicincin. Measurements are made by taking into account several circumstances, such as the height between the standard tool and the measuring instrument made must be close to the same. Then the measurement place of the measuring device must also be relatively close to the standard tool's measurement area. This is done to compare the measurement values of solar irradiance obtained with each other. The measurement data is presented in graphical form to make it easier to analyze. The graph of IoT-based pyranometer measurement data can be viewable in Figure 8.

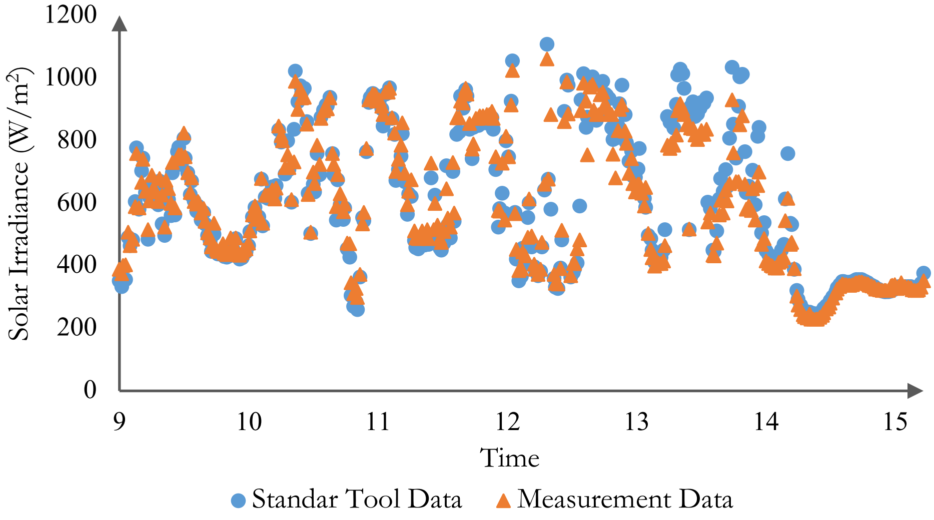

Figure 8. The graph of IoT-based pyranometer measurement data

Figure 8 shows the measurement data of the standard and measuring tools are not significantly different. This is confirmed by the data analysis, which reveals that the error percentage is only 4.87%. The figure also illustrates that the measurement of the measured solar irradiance value changes quite fluctuates. Ideally, the solar irradiance should reach its peak around 13:00 - 14:00 and then decline, but the actual measurements show a different pattern where the maximum value is recorded at 12:15. This is because there were many clouds in the sky at that time, and thus, the sun's rays were often covered by clouds. This is because direct irradiance is measured from one direction. Therefore, a barrier object (cloud) can block the irradiance component, making it possible if the value of direct irradiance changes significantly within a short span of time [3].

4. Conclusion

The IoT-based pyranometer sends the measured solar irradiance data to the ThingSpeak database and then displays it to App Inventor. The IoT-based pyranometer as a measuring tool for solar irradiance has taken measurements. The measurement results already have a value similar to the standard pyranometer at the BMKG Sicincin. The test's accuracy percentage is 98.19%, and the precision rate is 98.63%. From the results above, we can see that the tool can work well. From direct measurements on July 13, 2022 from 08:56 to 15:10, the percentage of error was determined to be 4.87%. Moreover, the data can be measured completely and stored securely on the internet, thus ensuring the quality of the measurement data.

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