International Journal of Reconfigurable and Embedded Systems (IJRES)
Vol. 12, No. 2, July 2023, pp. 248~259
ISSN: 2089-4864, DOI: 10.11591/ijres.v12.i2.pp248-259

Development of IoTs-based instrument monitoring application for smart farming using solar panels as energy source

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Article Info

Article history:

Received Dec 30, 2022
Revised Jan 14, 2023
Accepted Feb 18, 2023

Keywords:

Agricultural
Industrial revolution 4.0
Internet of things
Renewable energy sources
Solar energy

ABSTRACT

Indonesia is currently carrying out an industrial revolution 4.0. This revolution discusses the application of technology in the industrial sector, one of which is the agricultural sector. In addition to discussing the application of technology, this revolution also supports the use of renewable energy sources and one of them is the application of solar energy. The application of technology in the agricultural sector is expected to help farmers in maintaining crops to reduce the possibility of crop failure. The existence of this statement makes researchers conduct research in the design and construction of systems with internet of things (IoT) technology and utilize solar energy sources as energy sources for the system. The IoT system will utilize the ATmega328P+ESP8266 RobotDyn microcontroller by utilizing the DHT22, MD0127, soil moisture sensor, and BH1750FVI sensors and sending data to Thingspeak by utilizing the internet network with HTTP communication protocols. The system can monitor ecological factors in gardens with a fairly good degree of accuracy and the utilization of solar energy can run the system properly.

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1. INTRODUCTION

Indonesia is a country with the nickname "agrarian country". The handle was given because most of Indonesia's population works in the agricultural sector. This is also supported by Indonesia having large agricultural areas and fertile soil [1]–[3]. One agricultural sector area is the Lembang sub-district in West Bandung Regency [4].

Indonesia is currently in a transitional period towards the industrial revolution 4.0. This revolution can be applied to various industrial sectors, one of which is the agricultural sector. The application of this revolution talks about the application of technology or digitalization based on internet of things (IoT) [5], [6] technology which allows every device connected to this technology to communicate with each other or exchange data [7], [8]. IoT also aims to increase efficiency, effectiveness, and reduce the possibility of human error in the industrial sector [9]–[12]. The industrial sector is also a sector that has large energy uses.

Energy is a source of power needed by living things in carrying out their daily activities [13]. One type of energy is electricity. This energy is one of the most used types and cannot be separated from human activities [14]. This is because electricity can easily be converted into other forms of energy. However, the use of electrical energy in Indonesia has increased from year to year [15]. The increase in energy use is feared to have a negative impact on the environment because most power plants are still using fossil fuels. The use of this fuel can have a global warming effect due to an increase in carbon produced from the combustion process [16]. One solution to overcome the use of fossil fuels as a power plant is to utilize renewable energy sources. However, the utilization of this renewable energy is still not optimally utilized [17]. Renewable energy is the energy obtained from nature, used freely, renewed continuously, and unlimited energy. The use of renewable energy is also one of the supports for the application of the industrial revolution and one type of utilization of renewable energy, namely by utilizing solar power as an alternative source of electricity [18]. In Indonesia, solar power is a type of renewable energy with the potential for the highest utilization rate when compared to other types of renewable energy [19], [20]. Digitizing agriculture and utilizing renewable energy sources can be applied with the application of IoT technology [21] and the use of solar energy as the main energy source [22]. IoT supports every connected device that can communicate with each other or exchange data [7]. Meanwhile, solar energy can use solar panels or cells to convert solar energy (sun exposure) into electrical energy (photovoltaic process). Some of the previous studies were limited to designing and testing systems to increase efficiency and effectiveness in the agricultural sector. The application of this system monitors agricultural parameters in the form of soil moisture in a planting medium [23]–[25]

The research conducted by the authors is the development and application of previous research in actual conditions on open agricultural land. In the development and application of IoT technology, the authors utilize RobotDyn ATmega328P+ESP8266 as a microcontroller or mini-computer, router modem (internet) as a data transmission medium, DHT22 sensor for humidity and air temperature readings, capacitive soil moisture sensor for soil moisture readings, light intensity sensor (BH1750FVI) to take readings of sun exposure levels, and rain sensors to take readings of rain conditions around the planting media. On the other hand, the authors also make use of the application of renewable energy by using a 100 Wp solar panel as a conversion tool, a solar charge controller as a supply control device for converted energy, and a battery (ACCU) as a converted energy storage medium. The IoT system will read data every 6 minutes and the results will be sent to Thingspeak.com. The authors hope that the existence of an IoT system and the application of renewable energy can help in optimal plant care and increase the application of renewable energy.

2. LITERATURE REVIEW

The research conducted by the authors refers to several studies that have been conducted previously by researchers in designing and developing IoT technology-based agricultural monitoring systems and implementing renewable energy sources. The research conducted by Sadowski and Spacos [26] carried out the design and construction of an IoT system in monitoring soil moisture levels, air humidity, and air temperature in the agricultural sector where the system is implemented. This study also applies solar panels to convert solar energy into electrical energy, which is then stored in a Li-Po battery with a capacity of 6,600 mAh. In the process of sending monitoring data, this study uses the XBee series 2 communication devices as a communication medium in the ZigBee network.

The subsequent research was conducted by Nayyar and Puri [27]. This research carries out the application of IoT in monitoring soil temperature and humidity levels where the monitoring data is sent to Thingspeak as the IoT service used. This research also applies solar panels to convert solar energy into electrical energy, which then converts the power to be stored in a Li-Ion type battery with a capacity of 2,200 mAh. The following research was conducted by Valecce *et al.* [28] in 2019. In this study, IoT was used to monitor soil moisture levels in several planting media by utilizing IoT devices with the node method so that each device with different media does not need to be connected to each other wired. The process of sending monitoring data in this study utilizes the MQTT protocol and applies solar panels as a medium for converting solar energy into electrical energy stored in NiMH-type batteries as an energy source for the IoT system at each node. Further research was conducted by Maheswari *et al.* [29] in 2019. This research carries out the application of IoT in the process of monitoring soil moisture, air humidity, and air temperature. In the process of sending monitoring data, researchers utilize the Wi-Fi network and connect to the internet network to send monitoring data. Based on previous research that has become a reference, the authors will conduct research development, design, and implementation of IoT systems and utilize solar energy as the main energy for IoT systems. The authors will monitor several ecological factors that affect the growth of a plant, including the level of soil moisture, the level of air humidity around the planting media, the air temperature level around the planting media, the intensity of sunlight around the planting media, and the level of rain around the planting media. The monitoring results will be sent to Thingspeak.com as the media the authors use as an IoT service in this study. Whereas in the utilization of renewable energy, the authors will apply solar panels with a capacity of 100 WP and a battery ACCU with a capacity of 35 Ah as a storage place for the conversion of solar energy into electrical energy.

3. METHOD

3.1. Research strategy

The authors conducted research using a quantitative method which is a research method in finding data in the form of numbers that can be utilized in the analysis process [30] and IoT-Method (IoT-Meth) as an IoT system development method [31]. IoT-Meth will be used as a method in building an IoT system by utilizing solar panels as a medium for converting solar energy into electrical energy. While the quantitative method will be used in evaluating the performance of the IoT system on data obtained from several sensors such as soil moisture sensors, humidity, and air temperature sensors, light intensity sensors, and raindrop sensors. The reading results of each sensor will be tested and compared by applying the black box testing method and calculating the accuracy level of sensor readings with the RMSE formula which will be assisted by the “JHL-9918 soil tester”. Figure 1 is a series of IoT-Meth that the authors will do. In the “cocreate” phase, the authors will conduct a survey or interview with the aim of identifying the problems to be solved by the system to be built. In the “Ideates” phase, the authors will conduct an elaboration regarding the problems that have been received to be developed into solutions, the “Q&A” phase is the phase of perfecting solutions and collecting data on system requirements that will be applied. The “IoT OSI” phase will focus on the process of mapping ideas resulting from designs on architecture and infrastructure in the IoT system development process. Furthermore, the “prototype” phase is the process of building an IoT system design that has been previously designed and an iterative system performance testing process is carried out. Finally, the “deployment” phase which is the phase of implementing the IoT system as a whole and improvements have been made in the previous phase.

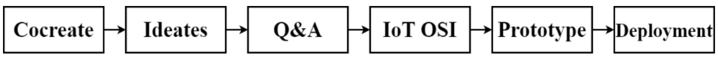

Figure 1. IoT-method

3.2. Solar panel implementation flow

The authors apply solar panels as a medium for utilizing solar energy into electrical energy as an energy source to generate the applied IoT system. Using solar panels as a conversion medium will store the converted energy into batteries as an energy source for the IoT system. The authors will use a solar panel with a capacity of 100 WP as a medium for converting solar energy into electrical energy. Solar panels also require several supporting devices such as a watt meter, solar charge controller (SCC), battery, and buck converter.

Figure 2 shows the design flow of the application of solar panels as an energy source for IoT devices. The conversion results from the solar panels will pass through the watt meter device, which functions as a direct monitoring tool regarding the number of conversion results obtained by the solar panels and will enter the SCC. When the converted power enters SCC, there will be a process of decreasing the amount of voltage and electric current so that it is safe to distribute power to the battery to be stored as an energy source for the IoT system. The process of sending the energy source from the battery to the IoT system will pass through the SCC again, and then the voltage will be reduced using a buck converter device. This device will limit the voltage and electric current according to the specifications required by the IoT system.

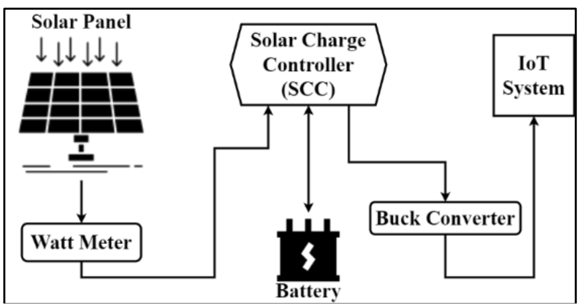

Figure 2. Solar panel design flow

3.3. Data collecting process

The authors use experimental methods to collect data from system readings. Readings from the applied IoT system will be sent to Thingspeak.com with delivery intervals every 5 minutes. The reading data that will be stored in Thingspeak.com is in the form of soil moisture data, air humidity, air temperature, sunlight intensity level, and rain occurrence data.

Figure 3 shows the system workflow. First, the system will turn on and get data from sensors (air humidity, air temperature, soil moisture, light intensity level, and rain sensor). Second, the system will classify the received data. Third, the system will connect to Wi-Fi. Fourth, if the system cannot successfully connect to Wi-Fi, the system will reconnect to Wi-Fi again. If the system is successfully connected to Wi-Fi, the system will send data to Thingspeak by using hypertext transfer protocol (HTTP) for messaging protocol. After sending data, the system will go into “sleep” mode for 5 minutes and repeat back to the first state.

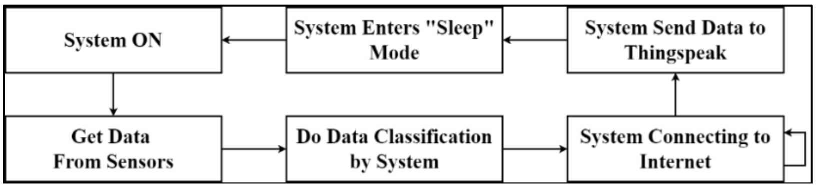

Figure 3. Data collecting process

3.4. Data validation process

In this study, the authors will conduct the sensor reading data analysis by applying 2 methods, namely: the black box testing method and calculating accuracy with the RMSE formula. The authors will carry out black box testing by testing the performance of the readings from each sensor and comparing the results of the sensor readings with the JHL-9918 soil tester which the authors used as a reference for testing. Black box testing will be carried out with the aim of testing the functionality of the system applied by the authors without requiring technical knowledge about the main system such as programming languages [32]–[34]. In the process of testing the maximum level of battery life without recharging, the authors will apply the calculation formula like this.

$$\text{Time of usage}=\frac{Battery(ACCU)\ Ampere}{System\ Ampere} - Dieficiency\ of\ battery\ (ACCU)\ 20\% \quad (1)$$

Formula (1) is the process of calculating the maximum power consumption contained in the battery ACCU. The calculation process carried out by the authors refers to research previously carried out by Putra *et al.* [35].

$$RMSE = \sqrt{\frac{1}{m}\sum_{i=1}^{m}(Xi - Yi)^2} \quad (2)$$

Formula (2) is the process of calculating the accuracy of sensor readings refers to research previously carried out by Chicco *et al.* [36]. This formula is an evaluation method for estimating the value of the final result. This method has provisions if the final calculation results using this formula are smaller, the more accurate [34], [36].

3.5. Hardware needed

In this study, the authors utilize hardware requirements that can be divided into 2 types, such as hardware requirements for systems and hardware requirements for the utilization of solar energy sources to be converted become a source of electrical energy for the system. The hardware needed for an IoT-based system includes: i) RobotDyn ATmega328P+ESP8266 microcontroller; ii) temperature and humidity sensor (DHT22); iii) soil moisture sensor; iv) light intensity sensor (BH1750FVI); v) raindrop sensor (MD0127); vi) cable+hoses; and vii) router modem. While the hardware for utilizing renewable energy sources in the application of solar panels as a means of converting solar energy into electrical energy, includes: i) buck converter; ii) solar panel 100 WP; iii) battery ACCU 35 Ah; iv) solar charge controller (SCC); and v) watt meter; and vi) cable.

4. RESULTS AND DISCUSSION

4.1. System design

Figure 4 shows the design of IoT and solar panel implementation, topological design for the system, and design of deployment box that the authors will implement. Figure 4(a) shows the design of the system applied by the author. The authors apply solar panels as a medium for utilizing solar energy as a renewable energy source for the main energy source for the IoT system. Utilization of solar energy applies to a solar panel with a capacity of 100 WP and the results of the conversion will be stored in a battery ACCU with a capacity of 35 Ah with the help of a SCC. Whereas in the IoT system, the authors apply a microcontroller based on ATmega328P+ESP8266 as the main component to collect data readings and transmit data to Thingspeak.com. As for the media for reading agricultural conditions, the authors use the DHT22 sensor as a medium for detecting humidity and air temperature levels, soil moisture sensor as a medium for monitoring soil moisture levels, BH1750FVI as a sensor for detecting light intensity, and a raindrop sensor as a rain detection sensor. Figure 4(b) shows the topological design of the system. The authors will read the agricultural conditions from the previously described sensors with the help of a microcontroller and will transmit data readings every 5 minutes to Thingspeak.com by using HTTP for messaging protocol via the internet network with the help of a Wi-Fi router and an API that has been connected to the programming process. Various devices can access the results of the data that has been stored on Thingspeak.com only by going through an internet network that is connected to the related Thingspeak.com. Design of IoT device that will implement and application of solar panels as a medium for converting solar energy into electrical energy which we can see in Figure 4(a) will be applied to a box that is stored around the application media who's the design in Figure 4(c). The deployment box will protect the whole of the system from direct exposure to sunlight which can cause the system to error, protected from rain, and from possible theft.

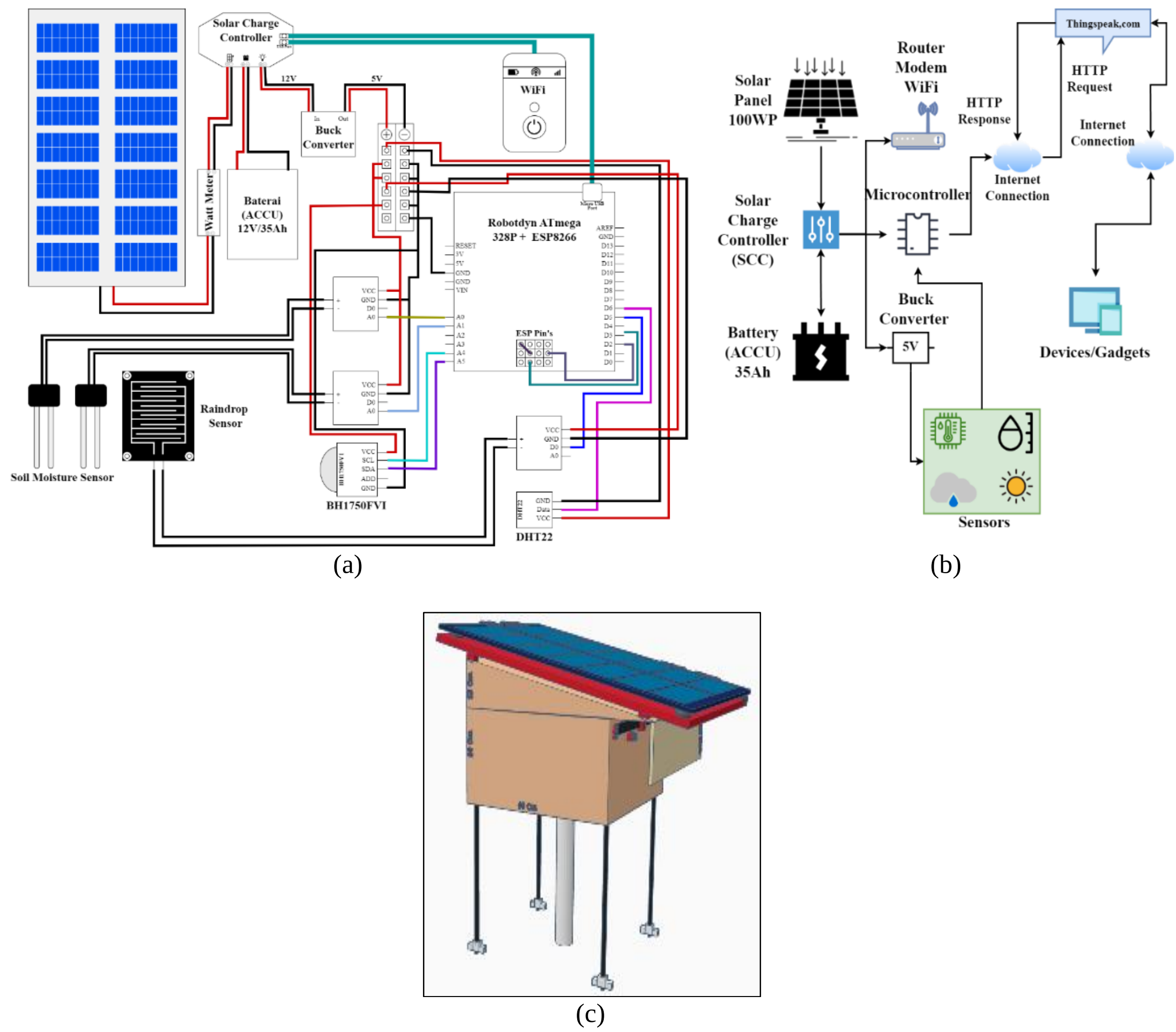

Figure 4. Design for (a) system design, (b) system topology, and (c) system deployment box

4.2. Data collecting

Figure 5 shows the result of sensor readings from the IoT system implemented by the authors. The reading results can be accessed through Thingspeak.com or with 3rd party applications. Such application is Thingsview which can be downloaded on Android or IOS-based devices.

Figure 5. Thingspeak data show

4.2.1. RMSE formula calculation

Testing the accuracy of the results of reading the IoT system applied by the authors will be carried out by utilizing the RMSE formula. In this process, the authors tested the accuracy of the BH1750FVI sensor and DHT22 sensor. BH1750FVI sensor used for detecting the light intensity level, while DHT22 sensor used for detecting humidity and temperature levels.

Table 1 is a table of test results and calculations for the accuracy of the BH1750FVI sensor as a light-level detection sensor used to calculate the intensity of sun exposure. The authors conducted a test by comparing the sensor value with the ambient light sensor (ALS) found on the smartphone. The results of the testing process and accuracy calculations state that the accuracy value of the sensor is 803.5240.

Table 1. Validation of light intensity sensor

Case	BH1750FVI (LUX)	Ambient light sensor	Absolute differences	Square differences
06:05	3,384	2,764	620	384,400
06:10	14,140	13,749	391	152,881
06:15	13,330	13,476	146	21,316
06:20	16,162	15,725	437	190,969
06:25	11,515	12,648	1,133	1,283,689
06:30	8,570	8,309	261	68,121
11:05	27,665	24,689	2,976	8,856,576
11:10	15,272	14,226	1,046	1,094,116
11:15	16,079	16,287	208	43,264
11:20	16,108	16,083	25	625
11:25	15,527	14,878	649	421,201
11:30	8,319	7,925	394	155,236
13:05	10,035	8,968	1,067	1,138,489
13:10	7,914	7,035	879	772,641
13:15	10,239	9,837	402	161,604
13:20	11,019	10,773	246	60,516
13:25	9,910	9,824	86	7,396
13:30	6,012	5,631	381	145,161
15:05	6,524	6,241	283	80,089
15:10	4,016	4,739	723	522,729
15:15	3,313	4,011	698	487,204
15:20	3,372	3,518	146	21,316
15:25	4,520	4,633	133	12,769
15:30	6,882	7,076	194	37,636
15:35	5,747	5,893	146	21,316
		RMSE		803,5240

Table 2 is a table of test results and calculations for the accuracy of the DHT22 sensor in reading the humidity level around the planting medium. The results of analyses using the RMSE formula, it results that the accuracy level of the reading results has a value of 0.7680 and can be said to be accurate. Table 3 is a table of test results and calculations for the accuracy of the DHT22 sensor in reading air temperature levels around the planting medium. The results of calculations using the RMSE formula, it results that the accuracy level of the reading results has a value of 0.6000 and can be said to be accurate.

Table 2. Validation of air humidity sensor

Case	DHT22	Soil tester (Humidity)	Absolute differences	Square differences
06:05	99	99	0	0
06:10	99	99	0	0
06:15	99	99	0	0
06:20	99	98	1	1
06:25	98	98	0	0
06:30	93	95	2	4
11:05	61	60	1	1
11:10	62	61	1	1
11:15	60	60	0	0
11:20	59	60	1	1
11:25	61	61	0	0
11:30	60	61	1	1
13:05	75	76	1	1
13:10	75	75	0	0
13:15	79	78	1	1
13:20	77	77	0	0
13:25	79	79	0	0
13:30	77	78	1	1
15:05	70	70	0	0
15:10	70	70	0	0
15:15	70	71	1	1
15:20	71	71	0	0
15:25	73	72	1	1
15:30	74	74	0	0
15:35	75	75	0	0
		RMSE		0.7680

Table 3. Validation of air temperature sensor

Case	DHT22	Soil tester (Temperature)	Absolute differences	Square differences
06:05	17	17	0	0
06:10	17	18	1	1
06:15	18	18	0	0
06:20	21	20	1	1
06:25	21	20	1	1
06:30	22	22	0	0
11:05	30	30	0	0
11:10	30	31	1	1
11:15	29	30	1	1
11:20	30	30	0	0
11:25	29	30	1	1
11:30	29	29	0	0
13:05	27	27	0	0
13:10	26	26	0	0
13:15	25	26	1	1
13:20	25	26	1	1
13:25	25	25	0	0
13:30	25	25	0	0
15:05	26	26	0	0
15:10	26	25	1	1
15:15	25	25	0	0
15:20	25	25	0	0
15:25	24	25	1	1
15:30	24	24	0	0
15:35	24	24	0	0
		RMSE		0.6000

4.2.2. Black box testing

Table 4 is a table of electrical power requirements for the IoT system applied by the author. Based on the results of calculating the total electricity demand, the IoT system requires 8.3 watts of power. For this power requirement, the authors utilize a battery ACCU with a capacity of 35 Ah and a voltage of 12 volts. Table 5 is a table for calculating the battery's maximum power [20]. A battery with a capacity of 35 Ah has a maximum power rating of 420-watt hour so that the IoT system can survive only by utilizing the energy in the battery without charging it with the following calculations:

$$\text{Time of usage} = \frac{Battery(ACCU)\ Ampere}{System\ Ampere} - Dieficiency\ of\ battery\ (ACCU)\ 20\%$$
$$= \frac{35}{0{,}71762} - 20\%$$
$$= 48{,}77 - 20\%$$
$$= 48{,}77 - 9{,}754$$
$$= 39{,}016$$

Based on the calculation results, it can be concluded that the IoT system built by the authors by utilizing energy from a 35 Ah battery can last for 39 hours without recharging the battery. However, the test results do not take into account the efficiency of implementing the "sleep" mode applied by the authors to the entire IoT system. Table 6 is a table of test results using the black box testing method by comparing the soil moisture sensor reading results with the soil tester reading results that the authors use. The results of this test concluded that the sensor readings are good. Soil moisture content can be categorized into 3, namely 80%-100%, which is a wet condition, 60%-80% is a normal condition, and below 60% is a dry condition.

Table 7 is a table of test results using the black box testing method by comparing the results of reading the humidity level of the DHT22 sensor with the readings of the soil tester that the authors use. The results of this test state that there are differences in data at some time. Differences in the data comparison results have a maximum difference value of 1%-2%.

Table 4. Device electrical power requirements

Devices	Voltage	Ampere	Watt
ATmega328P	5	0.5	2.5
ESP8266	3.3	0.17	0.561
Soil moisture sensor 1	5	0.015	0.075
Soil moisture sensor 2	5	0.015	0.075
DHT22 sensor	5	0.0025	0.0125
Raindrop sensor	5	0.015	0.075
BH1750FVI (light sensor)	3	0.00012	0.00036
Router modem	5	1	5
Watt total			8.29886

Table 5. Battery capacity

Voltage	Ampere/hour	Watt Hour
12	35	420

Table 6. Black box testing of soil moisture sensor

Case	Soil dester (Soil moisture)	Soil moisture sensor
Normal soil	NOR	70%
5 ml	NOR	72%
10 ml	NOR	78%
15 ml	WET	86%
20 ml	WET+	93%
Extra dry soil	DRY+	2%
5 ml	DRY+	7%
10 ml	DRY+	12%
15 ml	DRY+	16%
20 ml	DRY	24%
25 ml	DRY	29%
30 ml	NOR	38%
35 ml	NOR	47%
40 ml	NOR	59%
45 ml	NOR	63%
50 ml	NOR	72%
55 ml	WET	77%
60 ml	WET	82%
65 ml	WET	88%
70 ml	WET+	92%
75 ml	WET+	99%
80 ml	WET+	100%

Table 7. Black box testing of air humidity sensor

Case (time)	DHT22 (humidity)	Soil tester
06:05	99	99
06:10	99	99
06:15	99	99
06:20	99	98
06:25	98	98
06:30	93	95
11:05	61	60
11:10	62	61
11:15	60	60
11:20	59	60
11:25	61	61
11:30	60	61
13:05	75	76
13:10	75	75
13:15	79	78
13:20	77	77
13:25	79	79
13:30	77	78
15:05	70	70
15:10	70	70
15:15	70	71
15:20	71	71
15:25	73	72
15:30	74	74
15:35	75	75

Table 8 is a table of test results using the black box testing method by comparing the results of the DHT22 sensor readings regarding the air temperature level with the results of the soil tester readings that the authors use. The results of this test state that there are differences in data at some time. Differences in the data comparison results have a maximum difference value of 1°C. Table 9 is a table of test results using the black box testing method by comparing the results of reading the light intensity level in "lux" units carried out by the BH1750FVI sensor and the ALS on the smartphone. Table 10 is a table of test results using the black box testing method by testing the MD0127 rain detection sensor. This sensor will provide results in the form of binary numbers "1" or "0". The binary value "1" indicates that the sensor condition does not detect rain around the sensor installation media, while the binary value "0" indicates the sensor detects rain that occurs around the sensor installation media.

Table 8. Black box testing of air temperature

Case (time)	DHT22 (Temperature)	Soil tester
06:05	17	17
06:10	17	18
06:15	18	18
06:20	21	20
06:25	21	20
06:30	22	22
11:05	30	30
11:10	30	31
11:15	29	30
11:20	30	30
11:25	29	30
11:30	29	29
13:05	27	27
13:10	26	26
13:15	25	26
13:20	25	26
13:25	25	25
13:30	25	25
15:05	26	26
15:10	26	25
15:15	25	25
15:20	25	25
15:25	24	25
15:30	24	24
15:35	24	24

Table 9. Black box testing of light intensity

Case (time)	BH1750FVI (Light intensity sensor)	Ambient light sensor (ALS)
06:05	3,384	2,764
06:10	14,140	13,749
06:15	13,330	13,476
06:20	16,162	15,725
06:25	11,515	12,648
06:30	8,570	8,309
11:05	27,665	24,689
11:10	15,272	14,226
11:15	16,079	16,287
11:20	16,108	16,083
11:25	15,527	14,878
11:30	8,319	7,925
13:05	10,035	8,968
13:10	7,914	7,035
13:15	10,239	9,837
13:20	11,019	10,773
13:25	9,910	9,824
13:30	6,012	5,631
15:05	6,524	6,241
15:10	4,016	4,739
15:15	3,313	4,011
15:20	3,372	3518
15:25	4,520	4,633
15:30	6,882	7,076
15:35	5,747	5,893

Table 10. Black box testing of raindrop sensor

Case (Water)	MD0127 (Raindrop sensor)
1 mL	1
2 mL	1
3 mL	1
4 mL	0
5 mL	0
6 mL	0
7 mL	0
8 mL	0
9 mL	0
10 mL	0

4.2.3. Solar energy conversion result

Table 11 is data obtained from solar energy conversion into electrical energy carried out by solar panels and monitored manually through a watt meter device. Based on Table 11, the authors conclude that the conversion results are influenced by the level of light intensity received by the solar panel. There are also several other factors that can affect the number of conversion results obtained.

Table 11. Solar panel harvesting data

Case (time)	Lux	Voltage	Ampere	Watt
09.28	7,328	20.3	0.94	19
09.31	5,295	20.31	0.83	16.31
09.33	4,704	20.28	0.92	18.8
09.34	3,963	20.09	0.79	16
09.36	3,525	20.05	0.81	16.2
09.38	1,548	19.64	0.74	14.5
09.43	1,957	19.41	0.71	13.8
09.48	3,011	20.42	0.86	17.5
09.51	3,887	20.61	0.85	17.6
09.54	7,154	20.98	0.86	18
09.57	29,781	21.68	0.87	18.9
10.00	28,250	21.22	1.09	23.3
10.07	12,869	20.27	0.9	18.3

5. CONCLUSION

Based on the results of the research conducted by the authors, it can be concluded that the application of IoT technology and the utilization of solar energy can assist in the process of monitoring ecological factors in gardens with a good degree of accuracy. The system can monitor several ecological factors, including soil moisture, air humidity, temperature, rain intensity, and sunlight. Monitoring result data can be accessed via Thingspeak.com. Also, the utilization of solar energy which is converted into electrical energy by solar panels and stored in a battery with a capacity of 35 Ah, can run the system properly and can last for 39 hours without recharging. It is hoped that this system can assist in crop monitoring. However, this research still uses small batteries and sensors that are common and not yet on an industrial scale. It is hoped that further research can monitor in real time and utilize technology such as artificial intelligence (AI) to carry out automatic plant care processes (smart farming). Then research can use better sensors and microcontrollers in carrying out the process of monitoring and reading data, and larger batteries so that they can increase system resilience if they only rely on energy from batteries and add several devices that can assist in monitoring or maintenance processes in the future.

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