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LOW-COST ENERGY HARVESTING FOR SMART GARNUS

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ABSTRACT

Recently, several countries have experienced an energy crisis due to a lack of energy supply. one of them is the low power-based Garden Binus (GARNUS) system in energy harvesting. This Study is used to determine the energy consumption needs of the Internet of Things (IoT). One method of harvesting energy uses solar cells because of their availability during the day. Energy harvesting can be used as a source to enable the Internet of Things (IoT) systems, especially using low-cost materials. Several previous studies did not use IoT tools based on energy harvesting by utilizing the increment waterfall method to make low-cost solar cell-based energy harvesting. It is still rare for research to combine IoT such as Smart GARNUS tools with platforms that produce their own energy or what is called energy harvesting, especially low-cost energy harvesting for $8. This paper will provide many benefits: the use of IoT devices combined with low-cost energy harvesting (IoT with clean resources) and some energy demand data on IoT devices. This data can be used for future IoT studies. The aim of this paper is the application of low-cost energy harvesting to operate the Smart GARNUS platform. Energy harvesting using solar cells can charge up to 1,88 Wh of free energy from sunlight. At the same time, the IoT power requirement of the Smart GARNUS is 0.33. So it can meet the energy needs of more than 5 hours. This is expected to help this study in caring for support ornamental plants and support renewable energy processes.

Keywords: *Energy Harvesting, Smart GARNUS, IoT, Low-Cost*

1. INTRODUCTION

The need for energy has recently increased. In some countries, there is a shortage of energy [1]. Indonesia is nice because the availability of natural resources creates energy from Indonesia. Nearly every field of advancement requires electrical energy within the process of its exercises. This can be justifiable since advancement development in each nation is characterized by mechanical development rates, both medium and huge businesses, and all of which require electrical vitality for lighting and motor impetus. The rummage around for vitality can be done by energy harvesting. One source of quality energy harvesting is solar energy. By utilizing powered solar cells, sun-oriented energy can be changed over into electrical vitality, both within the trading world, within the mechanical world, and in increasing sources of electrical energy. The use of harvesting energy in the industry can also be used for simple components such as Internet of Things (IoT) technology .

IoT [2]–[4] is also a tool that people often hear in education, offices, the military, and the government. IoT technology is becoming a trend and machine to machine and artificial. The advancement of renewable energy always accompanies it. Communication is also very much needed in IoT, including measurement of delay, speed, reliability, etc. [5], [6]. Because of the high demand for alternative energy to support the power that must be given to IoT devices.

The city of Bandung in Indonesia is an example of the application of low-cost energy harvesting with the shape of the valley area like a large lake so that the mountains surround it. On the other hand, solar radiation can be new energy for energy harvesting and many offices, so that the equipment usually should not be large. Smart GARNUS (GARDEN BINUS) sees the needs of life and the community in the form of trends in planting ornamental plants. Existing plants can thrive if planted in the original land of Bandung, but not for hanging ornamental plants. The need for regular watering and fertilizing makes residential areas into fields sought after by outsiders in ornamental plant monitoring systems energized by IoT devices through low-cost energy harvesting.

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Figure 1. Technological 4.0. [7]

In the growth of ornamental plants, nutrient monitoring plays an important role. Soil moisture is one of the factors that affect nutrients [8]. Soil moisture determines whether plants easily absorb nutrients. The lack of awareness of ornamental plant managers has also caused damage to these plants. In previous studies, it was still rare to do hydroponic and aeroponic plantings based on detailed information using the IoT devices. The control so that the expected automation has not been achieved. A new hobby of planting ornamental plants has emerged for homemakers, office employees, and building cleaners to restore houses, apartments, and buildings—each by planting ornamental plants, creepers, etc. [8].

Energy use is highly prioritized, especially after the pandemic, several companies have used fossil energy again to meet energy needs. One way to minimize energy use is to do energy harvesting using solar panels[9]. The use of solar also depends on the cross-sectional area, tool materials, and solar radiation. Some low-cost solar cells can already be used as an energy source in IoT. Especially IoT in health was used in this Study. In implementing this study, a platform to register online using low power energy, using clean energy [10]–[13].

In previous studies[14], researchers made Smart GARNUS only to automate ornamental plant care, in contrast to the current research which focuses on low-cost energy harvesting which is a renewable energy source.Per the explanation, the author's goal is to make cheap energy harvesting for energy needs in Smart GARNUS tools. This smart technology has functions to monitor soil moisture, monitor soil, monitor water availability, and install sensors in the form of sensors. Sensors function around flowers and plants to protect plants and send data to the IoT Website System application. In this way, it can automatically help aquatic plants make soil fertilization decisions, provide water volume information, and protect plants [15].

The current situation is the lack of tools that can be produced from clean energy such as solar, wind, water, and other clean energy that can be used in IoT devices. The reality is that some countries are experiencing energy scarcity, so a lot of fossil fuels are being used again. Some workarounds are using low-cost IoT tools based on energy harvesting for smart GARNUS because some of these energy harvesting components are expensive instruments and not easy to obtain.

The previous Study on energy harvesting has rarely been done with low-cost instruments and has focused on Green IoT. Usually, apps use a disposable battery, which causes a lot of junk and new problems with weather changes. Study using photovoltaic in the manufacture of energy harvesting.

Therefore, this paper has the benefit of the combination carried out on IoT such as Smart GARNUS-based ornamental plant care combined with low-cost energy harvesting based on solar cells that can be purchased in any market. A harvesting-based energy generation platform, working by utilizing renewable technology in the form of solar cells. The energy produced into clean energy supports the world's efforts to reduce waste based on fossil energy.

In this Study, a low-power system from simple energy harvesting will be created that can help become an energy source for IoT queue applications in the clinic. This Study aims to characterize the variables and how long this energy harvesting can be used in IoT. But before that, the author must find out how many IoT devices need when fully active, deep sleep, and light sleep[16], [17]. After using this energy-saving system, an evaluation was carried out to see how much solar energy could produce, other results were also evaluated with a focus on using BlackBox on all components so that an evaluation of the results of features and energy utilization instruments could be carried out.

2. LITERATURE REVIEW

The use of harvesting energy has been applied for a long time, usually using wind, radiofrequency to the most widely solar cell as a source of power to activate the IoT platform [18], many applications with Solar Charge Control, Battery, Inverter then load.

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Previously Study [19] used a raspberry pi controller as an intermediary for the automation of student absenteeism and assisted by facial recognition. Therefore, the use of automation is widespread and a natural thing. Arduino for house plants has also been carried out by [20].

In this session, several types of Study on energy harvesting and their use on platforms such as:

Tabel 1. Literature Review

No	Ref	Conclusion	Comparison
1	[21]	This paper presents an item to form domestic planting exceptionally simple and convenient. Users are exhorted of the leading plants to sow for their zone at that time of year	This paper need more contribution in renewable energy
2	[22]	A real-time automatic watering system, very helpful. Therefore, this paper assumes that this approach will help our farmers through the mechanization of the agricultural sector	This paper need utilization more in other area
3	[23]	A method in flexible programming (DP) is a program step that aims to be developed in finding blocks for existing Schemes	Papers focus on Wireless systems, not on IoT devices
4	[24]	Utilization website using intelligence technology.	Have not used the IoT system
5	[25]	The use of a microcontroller in queue management.	Good use of microcontrollers but not used in small or rural clinics

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No	Ref	Conclusion	Comparison
6	[26]	Technologies utilization queueing and other utilization	Usage does not include energy harvesting
7	[27]	Solar energy is is utilized, which is much more solid and effective	The use of Solar Cells is still an experiment. It has not been applied directly as in health

In contrast to other papers, this Study focuses on the manufacture of the IoT Smart GARNUS device combined with a clean energy source using solar cell-based energy harvesting, but this Study has limitations. Namely, the solar cell component cannot be used directly when the component is performing harvesting. Another hand, the components can't be used in real-time.

After seeing several studies in table 1, the authors of this Study used all the attached studies and applied them in the city of Bandung. Therefore, this paper demonstrates to run a framework that uses energy harvesting for power requirements and then collects information using sensors. The proposed IoT is based on exploratory work to meet robotization needs and real-time observation of natural parameters. In this way, a clear picture can be obtained to make smart choices in monitoring harvests and increasing energy efficiency by implementing power-based energy harvesting. To realize the purpose of the paper, the search after asking for several purposes such as:

- O1. Identification of parameters energy harvesting based on solar cell
- O2. Implementation of the proposed platform energy harvesting and testing smart GARNUS in ornamental plants monitoring system;

3. METHODOLOGY

These study methods by making tools so that they can be operated properly. Using the Increment Waterfall method in the program development stage.[17], [28] and [29].

The author uses the increment waterfall software development method in terms of software system development and planning. The following is a diagram of the increment waterfall model and its explanation:

Incremental Waterfall [17], [28] and [29] describes the method of this Study to build a smart monitoring system based on GARNUS. The next Study is how to make a low power energy system. To carry out this experiment, the following steps can be carried out according to:

1. Requirements: at this stage, adjustments are made to the needs where the needs are in accordance with the requirements [30].
2. Design: a design that fits the needs of ornamental plants and energy harvesting needs is carried out, assuming they understand how the GARNUS smart tool works
3. Coding: coding using IDE UNO and several components of energy harvesting based on solar cells.
4. Testing: using the evaluation of the initial needs of the device and BlackBox to see that the tool is working as needed.
5. Maintenance: carry out maintenance on an ongoing basis if there is damage and make updates if needed. After that, it can also be added by doing an increment and returning to the requirements process if needed.

Taking this into account, the proposed model is solar-based energy harvesting, renewable energy that will not support the government and use less power.

This tool uses cheap and affordable materials, only costs $8.2. This technology has a cover that will secure the circuit from rain or wind. After harvesting, the power on the solar will be charged into the 15000mAH battery. Now researchers then

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use this system efficiently to power the IoT GARNUS devices that are energy-efficient, low-cost and provide low power. The sensor is connected to a router with the ability of a raspberry pi microcontroller to display Smart GARNUS.

Figure 2. Low-Cost Solar Panel

Figure 2, is the energy harvesting component used. The price of this component is very low-cost, which is $8. Researchers can buy it in any market so that it is cheap and easy to get. The microcontroller module is connected directly to the cable and routing to cloud computing. The solar panels are found in an ideal position to get the greatest daylight, but there are weaknesses in harvesting this energy, one of which is the Intensity of the sun in October in Indonesia, which is entering the transition season from hot to rainy. The author utilizes Li-ion Rechargeable Batteries. These charged batteries have the ability to stop receiving energy when the energy has been overcharged, so the battery will not bulge.

Figure 3 shows a solar panel with a size of 10x5.5 cm with a maximum that can be done by energy harvesting is 200 mA with Monocrystalline material

A. Sleep Mode

In an effort to save battery power, the author considers several system models. Raspberry pi chips usually use four models as in [31], [32]:

1. DEEP SLEEP MODE: it is used when the raspberry is on but not used for anything, the energy used is usually 80 mA

2. LIGHT SLEEP MODE This is used when there is already a micro SD, and the LED light is on. The energy consumption is about 100 mA

3. NORMAL MODE, This is used when it is in normal times such as the display is on, the keyboard, and the wifi adapter is all running smoothly, the power consumption is 310 mA

4. CPU OVERLOAD MODE, this is used when the raspberry is in full use using all existing boards such as sensors, etc., energy consumption is about 980 mA

After knowing some of the modes that exist in the raspberry pi. The following is a simple formula for charging energy harvesting

$$P = V \times I \quad (1)$$

Where P is power charging, V is the voltage of the solar panel, and last I is the electrical current. :

In this Study, Low-Power is used based on low prices, so it is also necessary to consider factors such as in this equation:

$$P_{in} = I_{rad} \; x \; A \quad (2)$$

Where Pin is the power that enters the solar panel (W)

Irad = Intensity of sunlight (W/m2)

A = Cross-sectional area of the solar panel (m2).

After equation 3 is used, there are several other parameters that affect the results of the light intensity as in the equation below [33]:

$$N = (1.25 \text{ x } E \text{ x } L \text{ x } W) / (k\Phi \text{ x } \eta \text{ LB x } \eta \text{ R}) \quad (3)$$

N = Number of armature

1.25 = Planning Factor

E = Illumination Intensity (Lux)

L = Space Length (meter)

W = Room Width (meter)

Φ = Light Flux (Lumen)

η LB = Armature efficiency (%)

η R = Room Utilization Factor (%)

To determine the light flux itself can be known through the formula:

$$\varnothing = W \text{ x } L/w \quad (5)$$

Ø = Light Flux (Lumen)

W = lamp power (Watt)

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L/w= Luminous Efficacy Lamp (Lumen / watt)

This Study also uses a solar cell material called Monocrystalline. These particles have a solar efficiency of up to 14-17%.

In the next stage, several criteria for the results to be analyzed will be explained, namely:

1. Smart Garnus Hardware Results: The analysis to be carried out is in the form of a suitable form for low-cost energy harvesting
2. Instrument Result: here will discuss what observations will be made to support the experimental results, in the form of energy harvesting data in normal mode, deep sleep, light sleep and when the data has been maximized
3. Blackbox Analysis: used to test all components whether they can be used properly or not

4. EXPERIMENTAL RESULT

A. GARNUS Hardware

In Study [22], [23], [25], [26] derived from the previous literature review only focused on the manufacture of IoT tools for plant care, aquatic plants, and automation of IoT devices, while the results of this Study This not only explains the automation of IoT but also applies it to harvesting solar cell-based energy

In Study [24], [28]. researchers make a little difference from the price used. Researchers focus on using low-priced components. Furthermore, researchers conducted Study on the need for GARNUS smart devices, which can be used as a database for further Study.The following are the results of this Study (see Figure 3):

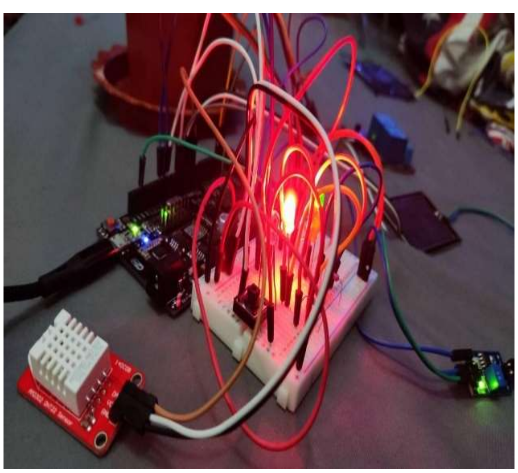

Figure 3. GARNUS Devices [14]

In the temporary development stage, where the assembly begins, we use a breadboard as a medium for all existing components.

B. Instruments Result

After designing and assembling the Low-Cost Energy Harvesting instrument for Smart GARNUS (see Figure 3), the next step is to test and analyze the results of the design of this tool. By following some steps like:

- Observing the harvesting energy produced from solar cells by measuring every 1 hour for approximately 12 hours from 06.00 to 18.00.
- After observing the results of the energy produced per hour from the solar cell, then the battery is tested. The test is carried out by conducting an experiment to charge the battery when it is empty, assuming the weather is unstable
- Record and observe the measurement results that have been carried out

The things that will be observed in this test are the amount of V, Ah, Wh produced by the solar panel for 12 hours. Measurements were made from 06.00 to 18.00. What is the highest Wh displayed by the wattmeter at 10.00 – 12.00. In the test, the thing to do is observe each parameter generated by the solar panel every 2 hours for 12 hours a day.

The power on the battery of about 20000 mAH it takes a long time to warm up to the sun. From the results of the table, the effect of harvesting on the power produced is

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- Solar cell materials
- Solar Radiation
- Cross-sectional Area of Solar Cell
- Air temperature
- Measuring methods and measuring tools

Mathematically, it is also possible to measure the energy requirements of GARNUS smart devices assuming no water pump, solenoid, or router (12-volt device).

Table 2. Smart Garnus Energy Result[34]

Device	V	mAh	Wh
Robodyne (Mega + ESP)	3.3	50	0.165
Soil Moisture Hygrometer YL-69	3.3	10	0.033
Light Intensity Sensor	3.3	10	0.033
DHT22 module	3.3	10	0.033
Rain Sensor	3.3	10	0.033
16 x 2 LCD	3.3	10	0.033
		Total	0.33

With the need for GARNUS devices of 0.33 in 1 hour, the energy in the solar cell can power the device for more than 5 hours. Then the device will turn off

This Study used a solar cell with an output energy specification of 5V/2.1A with maximum harvesting of 200 mA made from Monocrystalline solar panels. The experiment was carried out by looking at how long it took to charge the battery with a maximum of 15000 mAH with a solar panel. The consumption used by the Study has four scenarios, namely

1. Normal mode
2. Maximum mode
3. Light sleep mode
4. Deep sleep mode

Table 3. Normal Mode Scenario

Component	Consumption
Robodyne (Mega + ESP)	50 mA
Soil Moisture Hygrometer YL-69	10 mA
Light Intensity Sensor	10 mA
DHT22 module	10 mA
Rain Sensor	10 mA
16 x 2 LCD	10 mA
Total	100mA

With a normal total of 100 mA, it can be concluded that a battery with a capacity of 150000 mA can power IoT Instruments for 150 hours. The next table is the scenario when the instrument is experiencing maximum mode.

Table 4. Maximum Mode Scenario

Component	Consumption
Robodyne (Mega + ESP)	400 mA
Soil Moisture Hygrometer YL-69	100 mA
Light Intensity Sensor	100 mA
DHT22 module	100 mA
Rain Sensor	100 mA
16 x 2 LCD	100 mA
Total	900mA

With a normal total of 900 mA, it can be concluded that a battery with a capacity of 150000 mA can power IoT Instruments for 16.6 hours. The next table is the scenario when the instrument is in light sleep mode

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Table 5. Light Sleep Mode Scenario

Component	Consumption
Robodyne (Mega + ESP)	40 mA
Soil Moisture Hygrometer YL-69	10 mA
Light Intensity Sensor	10 mA
DHT22 module	10 mA
Rain Sensor	10 mA
16 x 2 LCD	10 mA
Total	100 mA

Same wit Normal mode total of 100 mA, it can be concluded that a battery with a capacity of 150000 mA can power IoT Instruments for 150 hours. The last table for scenarios When the instrument is in deep sleep mode.

Table 6. Deep Sleep Mode Scenario

Component	Consumption
Robodyne (Mega + ESP)	20 mA
Soil Moisture Hygrometer YL-69	5 mA
Light Intensity Sensor	5 mA
DHT22 module	5 mA
Rain Sensor	5 mA
16 x 2 LCD	5 mA
Total	330 mA

With a total of 45 mA, it can be concluded that a battery with a capacity of 150000 mA. So it can be simulated if the battery can be used for 1 full day under normal conditions when the IoT tools are used.

Meanwhile, batteries need to be added in high traffic conditions, or solar panels must quickly charge energy. This happens because the low-power solar cell device used is low-cost.

The next experiment is how long energy harvesting is used to fulfill this 15000 mAh. But it needs to be reminded again that the effects of energy harvesting include:

- Solar cell materials
- Solar Radiation
- Cross-sectional Area of Solar Cell
- Air temperature
- Measuring methods and measuring tools

Table 7. Energy Harvesting based on Solar Cell 1st day

Hour	V	mAh	Wh
06.00	4.385	32	0,1416
08.00	4.43	75	0,3325
10.00	4.35	164	0,7134
12.00	4.505	299	1,3455
14.00	4,54	393	1,774
16.00	4,01	437	1,752
18.00	4,02	471	1,888

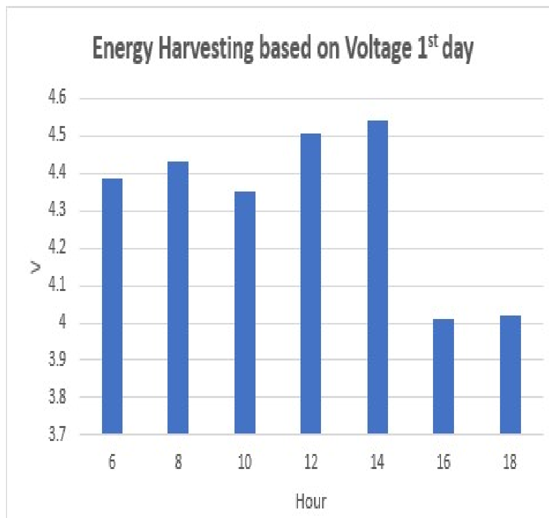

Figure 4. Voltage Harvesting Result

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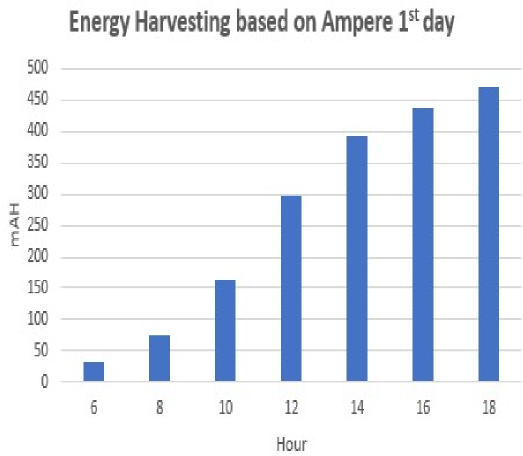

Figure 5. Ampere Harvesting Result

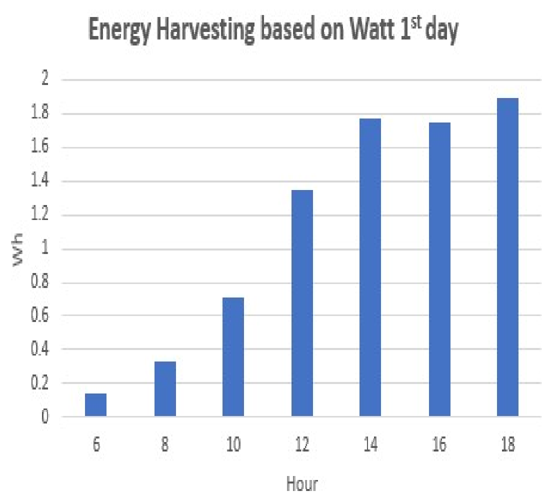

Figure 6. Watt Harvesting Result

In Figure 4-6, on the first day, the highest increase is found in the 12-14 hour range, then the increase is not too high in the afternoon because there is little sunlight that appears. The results in table 6 only get 471 mA because of the conditions on October 18, 2021; many clouds cover the sun. The results in table 7 will be stored in a high place and assisted by the glass to increase the radiation.

Table 8. Energy Harvesting Based On Solar Cell 2nd Day

Hour	V	mAh	Wh
06.00	4,38	80	0,35
08.00	4,42	380	1,679
10.00	4,3	598	2,57
12.00	4,43	901	3,99
14.00	4,03	1122	4,521
16.00	4,03	1243	5,009
18.00	4,02	1388	5,579

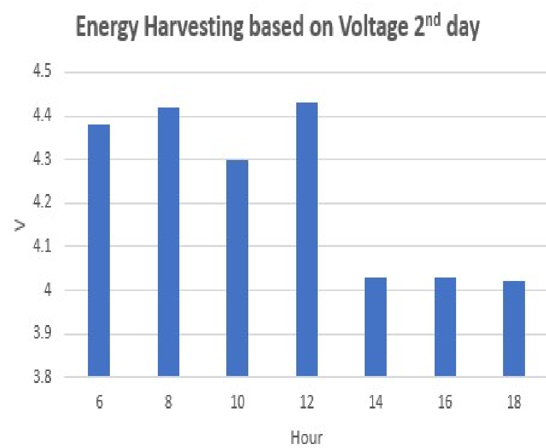

Figure 7. Voltage Harvesting Result

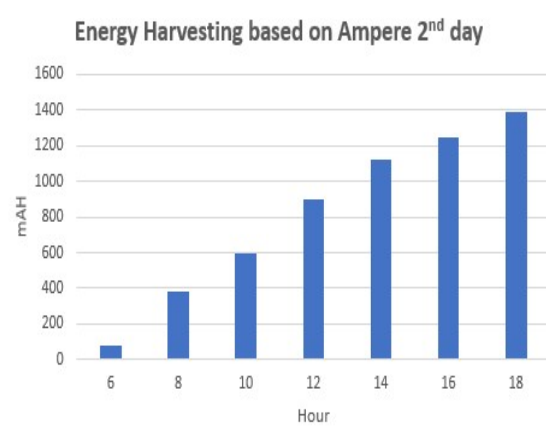

Figure 8. Ampere Harvesting Result

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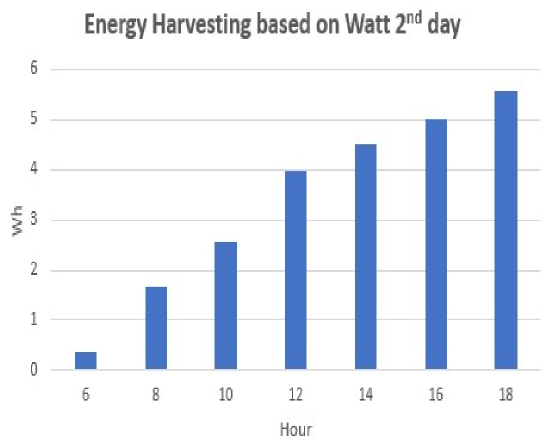

Figure 9. Voltage Harvesting Result

In Figure 7-9 on the second day, the highest increase is also same in the 12-14 hour range, then the increase is not too high in the afternoon because there is little sunlight that appears. The results in table 8 get an increase of 1388 mA. This is because it is still constrained by cloudy weather and was taken on October 19, 2021, where the sun was hot and the afternoon began to dim. According to the specifications, the solar panel should produce 200mA for every hour. Here are the best assumptions if solar panels, weather, sun degrees, etc., are obtained in the best case.

Table 9. Energy Harvesting Best Case

Hour	V (assumption)	mAh	Wh
06.00	5	400	2
08.00	5	800	4
10.00	5	1200	6
12.00	5	1600	8
14.00	5	2000	10
16.00	5	2400	12
18.00	5	2800	14

Table 9 is the best case that solar panels can use and produces 2800 mA. With this assumption, the battery will be charged in 5.3 days. But this can be realized because cheap solar panels can produce this much power very well.

C. Blackbox Analysis

In this Study, the BlackBox test was used to see the results. IoT devises that had been energized by energy harvesting:

Table 10. Blackbox Testing Result

Test Case	Testing Details	Numbe r of tests	Result
Power on Microcontroll er	Identify light	10x	Accepte d
Power on Sensor	Identify light and connectio n	10x	Accepte d
16X2 LCD	Show data	10x	Accepte d

Table 10 shows if the evaluation carried out using the Blackbox was successful, this is because all applications are integrated with appropriate electricity where the DC current continues to flow properly.

5. CONCLUSION

GARNUS Smart Farming which is supported by low-cost energy harvesting, can provide energy of around 5,579 Wh on the second day, But on the first day, it can only harvest around 1,888 due to cloudy weather conditions. Harvesting is done to provide approximately 18-50 hours more energy in GARNUS smart devices incorporated into maintenance practices to increase efficiency. However, Low-Cost Energy Harvesting has a weakness. Namely, it cannot provide energy to the device by 12 V. The results of sensors and tools that are provided with energy show that they have been able to meet the needs of ornamental plants in the Bandung area, Indonesia.

The manufacture of energy harvesting tools for the automation of IoT tools has several obstacles, such as the high price of the tool, the need for capable sensors and microcontrollers. In this Study, an energy harvesting prototype was made to be applied to GARNUS (Garden Binus), which aims to help energy efficiency in IoT devices. The prototype is used to answer the energy harvesting platform on low-cost IoT. This prototype is also used to answer the challenge of using batteries that can create new waste because they are single-use.

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Therefore, the benefit of this paper is focused on the use of automation tools for smart GARNUS by combining a low-cost solar cell-based energy harvesting platform at a very low price of $8 and can be purchased in the market. Some results show that the use of solar cells can be used to meet the energy needs of IoT Smart GARNUS devices. The data from the results of IoT needs can also be used as a data sheet for further research.

This Study also aims to create low-cost smart devices using the incremental waterfall method, microcontrollers, and other sensors. After the tool, low-cost energy harvesting GARNUS was successfully made. The author conducted several experiments on the low-cost GARNUS instrument and got results. Using this low-power solar panel can power the device for 150 hours if the battery in the energy harvester is fully charged. Under normal conditions, the GARNUS device requires about 100mAh, but when conditions are needed, the maximum power is 900mAh. Keep in mind that components are not always in a normal, maximum, or deep sleep state. In terms of their ability to do energy harvesting, researchers get fewer results because in 1 day, they only get 471 mA or 1388 mA. But this is also caused by the weather and conditions.

Study has several drawbacks, one of which is that energy cannot be used while harvesting. This is because several components are required to do so. In the future, it can be used as further Study,

Furthermore, the GARNUS experiment successfully passed the evaluation using a BlackBox with 3 experimental components that were tested 10 times, thus getting good reception by users. Furthermore, GARNUS has succeeded in producing a chart for several months of detection. With this, the user can determine the cause of the ornamental plants growing well or not

After conducting the Study, the author provides several possibilities for further Study such as:

1. Using of collecting innovation other than solar cell-based
2. Using of other efficiencies such as energy transfer
3. Using of energy management in the form of conservation

6. ACKNOWLEDGMENT

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