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Application of Internet of Things (IoT) on Microclimate Monitoring System in The ALG Unpad Greenhouse Based on Raspberry Pi

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ABSTRACT

The Internet of Things (IoT) is currently influencing many facets of human life. Smart agriculture is one system that can use the IoT to improve production efficiency and consistency across agriculture, improve crop quality, and reduce negative environmental impacts. The architecture of an IoT-based microclimate monitoring system tailored for use with the Unpad ALG greenhouse is shown in this paper. The suggested system design can collect microclimate data using the SHT11 and GUVA-S12SD microclimate sensors and store it in a database on a Raspberry Pi with a cloud computing back-end idea. The Raspberry Pi is also used to process and analyze data in order to set up mist-based greenhouse cooling systems. The collected data is delivered to a web-based front-end node, where users can access from their own device. The results reveal that when the temperature rises beyond the predetermined threshold of 30°C or the humidity falls below 80%, the system can activate the mist-based cooling system. With a temperature difference of 6.25 degrees Celsius lower and humidity of 28.06 percent greater, the system is able to perform better than it was introduced before. The automation system's performance can reach 15.22% better, however it declines as the light intensity rises.

1. INTRODUCTION

Food security in Indonesia has become an issue that needs attention in corresponding to with the change in land use from agriculture to industry, which raises concerns about a food crisis due to population growth. The average land ownership of Indonesian farmers is only 0.25 hectares per farm family. Agricultural productivity has always experienced problems such as an inappropriate growing environment; inefficiency of farm production scale; limited quality of human resources in managing land and agricultural cultivation patterns that are difficult to change because they are inherent from year to year (Bafdal & Dwiratna, 2018; Saliem & Ariani, 2016).

Farmers always maintain conventional cropping patterns; namely a pattern that is oriented towards yield by ignoring the latest techniques in agriculture that can be used in proper planning, monitoring and management of their agricultural land (Ardiansah *et al*., 2017). The era of technological disruption also has an impact on the agricultural sector and needs the use of smarter agricultural systems to meet the rising demand for food (Jespersen *et al*., 2016).

The increasing demand for food, both quantity and quality, has increased the need for agricultural intensification and industrialization. The "Internet of Things" (IoT) is a promising technology capable of providing many solutions for the modernization of agriculture. Scientific organizations and research institutions, as well as industry, are competing to bring more IoT products to agricultural business stakeholders, a clear division of roles when IoT becomes the main choice in agriculture. Simultaneously, cloud computing, which has been used previously has provided sufficient resources and solutions to sustain, store and analyze data generated by IoT devices (Elijah *et al*., 2018; Tzounis *et al*., 2017).

The IoT data management and analysis can be used to automate processes, predict situations, and improve many activities in real time. Furthermore, the concept of inter-operability among heterogeneous devices inspires the development of appropriate tools, with which new applications and services can be created, adding value to the generated data streams at the network edge. The agricultural sector has been heavily influenced by Wireless Sensor Network (WSN) technology and is expected to benefit equally from IoT (Bafdal & Ardiansah, 2021; Kendarto *et al*., 2019; Ray, 2017). Internet of Things (IoT)-based smart greenhouse is one alternative that will allow farmers to manage their land more effectively and efficiently so in turn it will improve performance and productivity in a sustainable manner (Ardiansah *et al*., 2021).

1.1. Smart Greenhouse

A smart greenhouse or often called a precision greenhouse is a building that has been equipped with modern technology with the aim of increasing the quantity and quality of agricultural products (Bafdal & Ardiansah, 2021). In developed countries such as Europe, smart agriculture applies three types of interconnected technologies, namely management information systems; precision agriculture and automation (Gondchawar & Kawitkar, 2016). Castrignanò *et al*. (2020) stated that:

1. The information system in question is a system that collects, processes, stores and disseminates data in the form required to carry out land operations and functions.
2. Precision agriculture is the management of spatial and temporal variability to increase economic returns after the use of inputs and reduce environmental impacts
3. Agricultural automation is the process of applying robotics, automatic control and artificial intelligence techniques at all levels of agricultural production.

Developed countries generally have farmers who are accustomed to using IoT-based smart greenhouses in particular ensuring monitoring of microclimate environmental conditions; managing proper and efficient irrigation system; enhancing soil conditions and determining harvest time (Zaida *et al*., 2017). The technology used is a technology system that utilizes a sensor network and connected to the internet known as the Internet of Things (IoT). This system is known as smart farming, if this system is carried out in a greenhouse, then it is called a smart greenhouse (Bafdal & Ardiansah, 2021). Farmers have realized the benefits of a greenhouse, especially a smart greenhouse if they want to develop their farming business towards industry;

because greenhouses do not only serve to protect plants from pests and diseases and from microclimate environment that is not favorable for plants, but the function of the smart greenhouse is more as a medium to stimulate plants with various engineering in the greenhouse such as regulating temperature, humidity, sun irradiation, controlling the water and nutrient needed by plants (Hafiz *et al.*, 2020; Ping *et al.*, 2018). In addition to providing the advantage such as obtaining data and controlling the microclimate environment inside the greenhouse, smart greenhouses also enable farmers to reduce agricultural costs and optimize profits (Paustian & Theuvsen, 2017).

Indonesian farmers have not fully implemented smart greenhouses; because there are still some obstacles for farmers to adopt related technology such as IoT. To overcome this problem, patience and continuous socialization to adopt this kind of technology needs to be introduced (Bafdal *et al.*, 2019; Sujadi & Nurhidayat, 2019). The significant benefits of smart greenhouses include reducing labor, increasing production, and facilitate access to existing technology, but farmers are required to be more adaptable in terms of the use of technology that has begun to develop very rapidly (Bafdal *et al.*, 2019; Nawandar & Satpute, 2019).

1.2. Internet of Things (IoT)

The question that is always raised by farming communities, especially in Indonesia is "Does the agricultural sector need to recognize and utilize the Internet of Things?". The Food Agriculture Organization (FAO) recommends that the future agricultural sector needs to be managed by using information technology to obtain optimal yields and profit. The green revolution that have been developing in developing countries have to be accompanied by applying Internet of Things-based technology starting from pre-harvest, harvest and post-harvest technology (Ardiansah *et al.*, 2020).

One of the information technologies that can help farmers in managing agricultural land is the Internet of Things (IoT). Internet of Things (IoT) is a new paradigm that transforms traditional lifestyles into high-tech lifestyles. Smart cities, smart homes, pollution control, energy saving, smart transportation, and smart industries are examples of IoT transformation. However, there are many challenges and issues that must be overcome before IoT can reach its full potential. These challenges and issues must be addressed from multiple perspectives, including the application of technologies that enable social and environmental impacts (Kumar *et al.*, 2019; Zuraiyah *et al.*, 2019). The conventional way is replaced with an IoT-based smart greenhouse with completeness supported by IoT and connected to the internet. This IoT technology has an important role, especially for a country like Indonesia, where most of its citizens still rely on their livelihood as farmers (Burange & Misalkar, 2015; Ping *et al.*, 2018). If it can be realized, IoT technology greatly facilitates the work of farmers (Gondchawar & Kawitkar, 2016). Hidayat (2017) argues that IoT is a system that uses sensor technology to process data into information. The application of IoT in the agricultural sector along with the application of smart greenhouses makes modern agricultural systems more effective and efficient. This is a solution to the problem of limited agricultural land and global climate change which in turn the food crisis can be overcome (Jung *et al.*, 2021). Figure 1 below shows IoT applications, especially in the agricultural sector. All of the applications shown in the Figure are very feasible to be applied in Indonesia which consists of various islands, so using IoT-based smart agriculture can make it easier to monitor and control agricultural land or greenhouse.

Figure 1. Smart Greenhouse with IoT Integration

1.3. IoT-Based Smart Greenhouse Application

The IoT-based smart greenhouse makes the management of agricultural cultivation more controlled and accurate. The most significant examples are precise sensing of crop water and nutrient requirements, microclimate control according to crop requirements; pH; humidity; sunshine until harvest estimation (Hafiz *et al*., 2020). IoT applications in smart greenhouses allow farmers to monitor crops in greenhouses from anywhere without having to come to the greenhouse all the time with the help of the necessary sensors and observations (temperature, humidity; sunlight and irrigation automation), thereby reducing labor costs needed (Carrión *et al*., 2013).

The application of IoT in smart greenhouses can handle recording plant growth data, digitally managing data and making decisions in the pre-harvest and harvest processes. Data collection, data processing and decision using IoT will allow planning of planting time, minimizing the risk of production failure and being able to predict agricultural yields with more precision. By using IoT, farmers get accurate data so they can control irrigation systems that save water and provide nutrition more efficiently on the basis of crop needs (Angelopoulos *et al*., 2020; Gondchawar & Kawitkar, 2016).

Each plant requires different microclimate conditions, for example tomato plants grown in a greenhouse require temperatures between 18 ^{o}C to a maximum of 24 ^{o}C, but when the dry season comes the temperature in the greenhouse reaches a maximum of 36 ^{o}C, as a result, plant physiology will change, and the growth will be disturbed and greatly interfered (Bafdal *et al*., 2018). This impact is indicated by suboptimal leaf growth (curly leaves); evapotranspiration increases which causes the need for water (consumptive use) to increase, and when fertigation is carried out, the nutritional needs also increase (Bafdal & Dwiratna, 2018; Kendarto *et al*., 2019). The dynamic changes in greenhouses require farmers to implement an IoT-based system that can act as a microclimate data monitoring device using the Arduino UNO microcontroller and Raspberry Pi microcomputer. These devices are integrated with a fog-based air conditioning system that is connected to a relay and controlled by microclimate changes detected by the SHTII sensor and the GUVA-S12SD sensor (both are to detect changes in temperature, humidity and light intensity). The data from the microclimate monitoring is then sent to the cloud server to be stored in the database and processed to produce a decision whether or not the automation system is active based on the limits that have been previously set in the system. Moreover; the monitoring data can be accessed through a website that is integrated on the Raspberry Pi (Hafiz *et al*., 2020).

2. MATERIALS AND METHODS

2.1. Research Instruments

This research used instruments in the form of hardware and software to build a microclimate monitoring system. The hardware used was a Raspberry Pi 3 version B+ microcomputer which was used to regulate microclimate conditions in a greenhouse using a mist-based cooling system. The device was also used to store microclimate monitoring data and display web-based microclimate information. The SHT11 microclimate sensor was used to detect changes in temperature and relative humidity of the air in the greenhouse. This sensor was digital type so that the acquired value is in degrees Celsius.

The GUVA-S12D sensor (analog type) was used to detect changes in the index of sunlight intensity in the greenhouse. To make the misting system, an emitter was used to spray water (the particle size of which is 3 microns) into the greenhouse. In addition, to draw water from the water storage into the greenhouse, a low pressure water pump was used. To turn the pump off and turn on, a relay connected to the Raspberry Pi was used. If the microclimate conditions in the greenhouse were outside the set points, the Raspberry Pi would trigger the relay and turn the pump on. On the contrary, if the microclimate conditions were within the set points, the Raspberry Pi would trigger relay to turn the pump off.

The software used in this study was the Raspbian operating system to run the Raspberry Pi. The Python 3 programming language was used to acquire microclimate data from sensors and store microclimate data in the MariaDB database. The MariaDB database is a data storage system that supports accessibility through Python 3 and PHP. While, PHP itself is a programming language used to build websites based on data stored in the MariaDB database. Putty and WinSCP applications were used as a bridge to connect a Windows-based laptop with a Linux-based Raspberry Pi.

2.2. Device Design

The method used in this research was the engineering design method in the manufacture of automation systems. Engineering design method according to the Sugandi *et al.* (2018) is a series of activities consisting of planning, design, development, and implementation which in its application will result in new modifications in the form of processes or products. This method will make the manufacture of automation tools more structured and focused at each stage. The use of this method can also be strengthened by Surakusumah (2009) regarding "Design of Automatic Bottle Filler", which concludes that the system can control the volume of water filled with precision.

Figure 2 shows the proposed design scheme in which the greenhouse is integrated with a mist-based cooling system connected to a low-pressure water pump to deliver water into the emitter which emits 3 micron water particles. The pump was wired to a relay that is also connected to the Raspberry Pi. If the microclimate data set was outside the set threshold, the Raspberry Pi would trigger the relay to turn the pump on. Cloud-based servers were used to store microclimate data which can then be monitored by users remotely via their own devices such as smartphones, laptops or desktop computers.

2.3. Research methods

The research was carried out in the Unpad ALG Greenhouse located in North Pedca, Padjadjaran University with coordinates: 6°55'13.9" (S) and 107°46'27.5" (E) as shown in the image Figure 3.

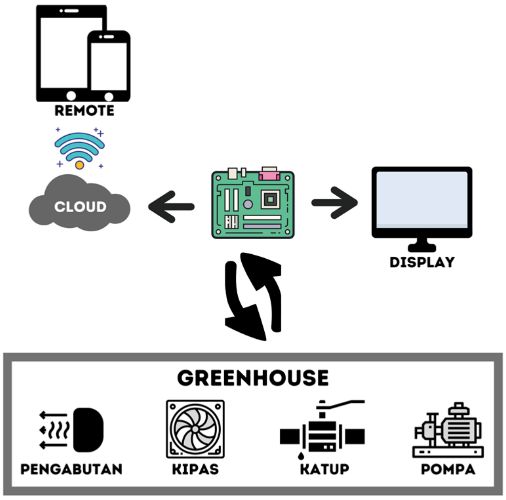


Figure 2. Schematic of micro climate monitoring system in Unpad ALG greenhouse

Figure 3. Location of Unpad's ALG greenhouse

The research was conducted to design and build a device that took 3 (three) months, and to test the monitoring system in the ALG Unpad greenhouse for 25 (twenty five) days with the microclimate data acquisition process carried out every 1 (one) minute, and stored in the database. The data stored in the database can then be downloaded in Comma Separated Values (CSV) format, to facilitate data processing in a spreadsheet application, then analyzed statistically and described in the form of charts.

2.4. Research Procedure/Implementation

The automation device that has been built was then integrated into the ALG Unpad greenhouse as shown in Figure 4. The misting system pipe was designed in the form of a trident with a total of 18 (eighteen) fogging valve points so that the mist distribution can reach all points in the greenhouse when conditions are not ideal. The device was run from 06.00 – 18.00 every day, all sensor data is directly read every minute and stored into the database. The data was then processed and displayed in tabular form on a website so that can be accessed via the internet using the services provided by DynDNS. Parameters of temperature and relative humidity were set through the admin page which is directly updated on the system.

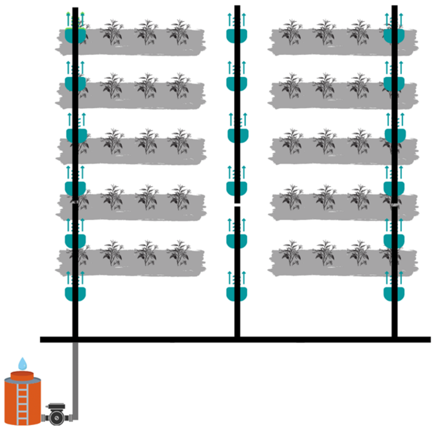


Figure 4. Microclimate monitoring system installation design in greenhouse

3. RESULTS AND DISCUSSION

The design of this automation system includes the stages of design, mechanism design, functional design, assembly and programming of tools and integration of the web. Programming is done in Python 3, Html5, PHP and SQL. This microclimate automation system is divided into two main parts, namely the technical environment and the information environment. The technical environment processes microclimate data and executes commands that will be sent to the automation device, while the information environment displays data information about the microclimate and sets the temperature or humidity in the greenhouse.

Schematic is an arrangement of patterns and a series of components that make up a system. The schematic of this automatic microclimate control system consists of a Raspberry Pi 3b+ as a microcomputer and 3 main sensors, namely the SHT11 sensor, the GUVA-S12SD sensor, and a Relay which is connected to a microcomputer using a T cobbler plus and a breadboard. The relay will be connected to the misting cooling system adapter so that when the SHT11 sensor detects the greenhouse temperature is higher than 30˚C or the humidity is less than 80%, the relay automatically activates the misting cooling system. The supply of misting cooling system water is obtained from a water tank which is flowed by a water pump with a pressure of 80-100 psi so that the water released from the nozzle becomes dew. This system is connected to the web so that supervision and regulation of the automation system can be carried out with gadgets such as smartphones or laptops.

The layout of misting cooling system used in the greenhouse form a three-arrowed structure (trisula) having 6 nozzles for every row. This formation is used so that the mist released from the nozzle can reach all plants in the greenhouse.

There are two comparisons made between the automation system and the previous greenhouse system, namely the comparison of greenhouse microclimate data collection and comparison of greenhouse microclimate conditions. Greenhouse microclimate data collection with an automated system is carried out every one minute per day. The data is stored in the database and displayed through the website. The data that can be stored in the database can be in the thousands. For example, the data stored in the database for 25 days is 278,880. If the average data that can be stored per day reaches ± 11,115. That much data is sufficient to accurately describe the daily greenhouse microclimate conditions and the data collection is carried out automatically by the system.

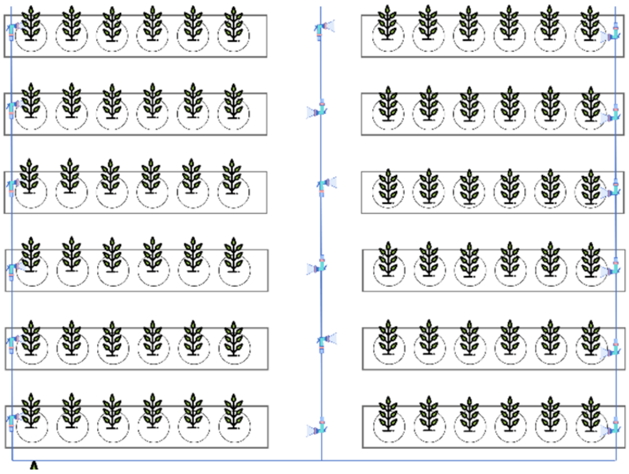


Figure 5. Layout design of misting cooling system

The greenhouse microclimate data collection was previously done manually three times per day, namely at 07:00, 12:00 and 17:00. Data collection is done by writing it down on a small blackboard which allows for some errors, namely miswriting/reading a comma (,) or a period (.). Small whiteboards cannot store a lot of data and could be accidentally erased. Such manual data collection also requires the user to go to the greenhouse every day according to the specified hours as shown in Figure 6. On the other hand, an automated system can conduct greenhouse microclimate data collection more effectively and accurately. This is further strengthened by an increase in performance which reached 370,400%. In this case, the data measured manually one month earlier than the automatic data recorder, but still in the same greenhouse. However; manual measurement data includes the data of sunlight intensity entering the greenhouse, while the automatic measurement records the sun's uv index. Automatic recording using IoT devices and the microclimate conditioning process using this fog misting system convince greenhouse users if the temperature and humidity in the greenhouse are accurately measured and inside the threshold that can be tolerated by plants.

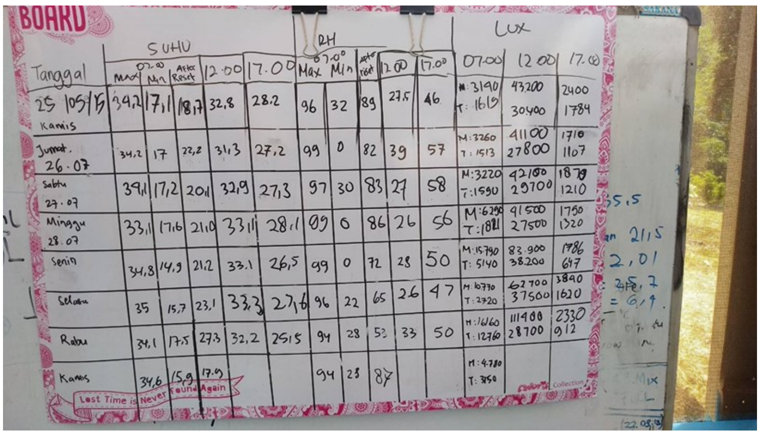
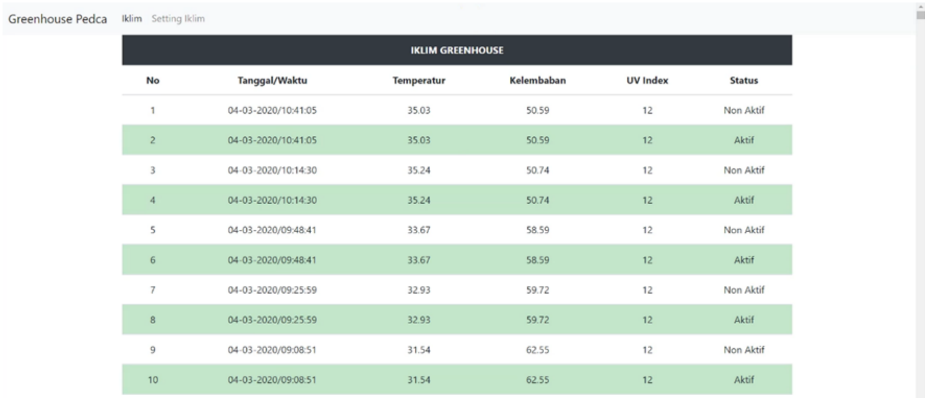


Figure 6. Previous greenhouse microclimate data collection

Comparison of the data from the automation system and the previous system includes temperature, average humidity, maximum temperature, minimum humidity of the greenhouse microclimate for 25 days at 06.00 – 18.00. Comparison of sunlight cannot be done because the automation system measures the sun's UV index while the previous system measures the intensity of sunlight.


Greenhouse Pedca Iklim Setting Iklim

IKLIM GREENHOUSE					
No	Tanggal/Waktu	Temperatur	Kelembaban	UV Index	Status
1	04-03-2020/10:41:05	35.03	50.59	12	Non Aktif
2	04-03-2020/10:41:05	35.03	50.59	12	Aktif
3	04-03-2020/10:14:30	35.24	50.74	12	Non Aktif
4	04-03-2020/10:14:30	35.24	50.74	12	Aktif
5	04-03-2020/09:48:41	33.67	58.59	12	Non Aktif
6	04-03-2020/09:48:41	33.67	58.59	12	Aktif
7	04-03-2020/09:25:59	32.93	59.72	12	Non Aktif
8	04-03-2020/09:25:59	32.93	59.72	12	Aktif
9	04-03-2020/09:08:51	31.54	62.55	12	Non Aktif
10	04-03-2020/09:08:51	31.54	62.55	12	Aktif

Figure 7. Information displayed on the website

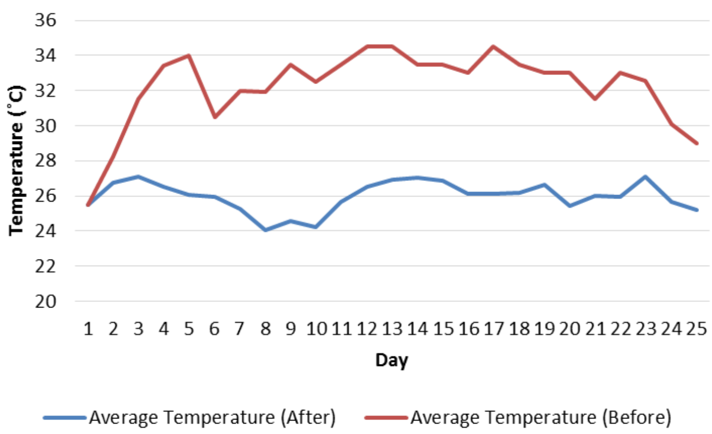


Figure 8. Results of average temperature measurement in greenhouse

The data on the comparison chart of greenhouse temperatures shows that the automation system can work better than the previous system that has not used a cooling system by recording using a whiteboard. In the previous system, microclimate data was recorded manually by reading a thermometer and an analog hygrometer using the eyes and the results were written on the whiteboard three times a day.

This is evidenced by the difference in average temperature per day which reaches 6.25˚C. In addition, using the automation system also makes the average daily greenhouse temperature below the maximum temperature you want to maintain (30˚C) which is 25.97˚C, 4.03˚C smaller than the previous system. The average daily greenhouse temperature exceeds the maximum temperature to be maintained (30˚C), which is 32.23˚C, greater than 2.23˚C. More than that; The maximum temperature is 2.68˚C lower than before. If we calculate the percentage increase in the performance of the automation system compared to the previous system in maintaining the greenhouse temperature, the values obtained are 19.42% at the average temperature and 6.65% at the maximum temperature.

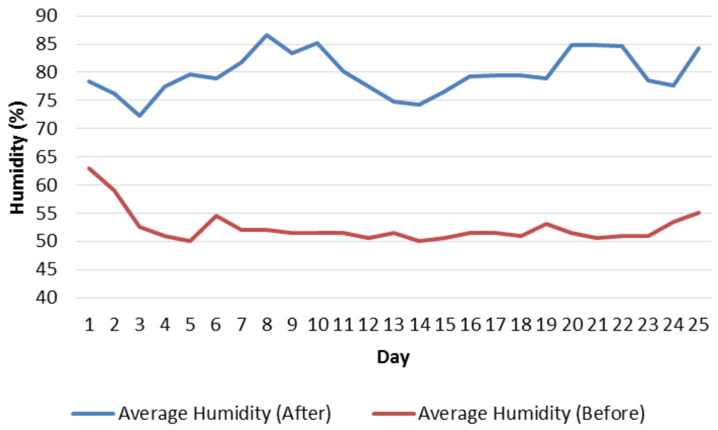


Figure 9. Average humidity measurement in green house

The data on this greenhouse humidity comparison chart (Figure 9) shows that the automation system can also work better than the previous system. This is evidenced by the difference in the average humidity per day which reaches 28.06%. The automation system makes the average humidity very close to the minimum humidity to be maintained (80%) which is 79.79%, only 0.31% smaller. Meanwhile, the previous system provided that the average daily greenhouse humidity was very far from the minimum humidity to be maintained (80%) which was 51.73%, the difference in value was 28.27%. On the other hand, the minimum daily greenhouse humidity from both systems shows a value that is very far from the minimum humidity to be maintained (80%) which is only ±21%, the difference is 59%. However, the minimum average humidity after using the automation system is still 0.72% better than the previous system. Improved performance of the automation system over the previous system in maintaining greenhouse humidity; however, 54.24% for the average humidity and 3.42% for the minimum humidity.

4. CONCLUSION

The conclusion that can be drawn from this research is that data collection on greenhouse microclimate conditions can be carried out more effectively and accurately using an automated system. The automation system can maintain and regulate the greenhouse microclimate to suit the optimum conditions of plants effectively every day but there will be a decrease in performance when the intensity of sunlight is high. The mist-based cooling system can be turned on automatically when the microclimate is outside the set threshold. It is advisable to provide additional tools to adjust the amount of incoming sunlight intensity, because when the solar intensity index is too high, the mist-based cooling system cannot reduce the greenhouse temperature properly.

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