

# Design of temperature-soil moisture control and monitoring system for chili cultivation in greenhouse

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**Abstract.** One form of plant care is to measure the microclimate when cultivating chilies in a greenhouse. The aim of this research is to design a control system to make it easier for farmers to access information on temperature and soil moisture on chili cultivation land. The microcontroller is integrated with email in monitoring and controlling climate factors in the greenhouse at a low cost. The sensors used are the DHT22 sensor and soil moisture sensor. Application Programming Interface (API) Pushingbox is used to simplify the system for sending data from the microcontroller to the website. The system can be accessed via the website monitoringcabai.weebly.com. Validation of the soil moisture and temperature sensors resulted in an RMSE of 6.04. Validation of the three greenhouse temperature sensors produced RMSE of 0.16, 0.14, and 0.16. The accuracy rate for greenhouse temperature control is 98.61% and soil moisture control is 99.95%. The greenhouse temperature control time was 47 minutes 44.4 seconds and the soil moisture control time was 41 minutes 51.6 seconds. The stability of the tool results in stable performance. The height growth of chili plants with the control system (in the greenhouse) was better than without the control system (outside the greenhouse).

## 1. Introduction

Chili is a type of horticultural plant that grows and develops in Indonesia. Therefore, many Indonesian farmers cultivate it. The need for chilies in Indonesia continues to increase from year to year. Chili production in 2022 will reach 1.48 million tons, an increase of 8.47% (115.25 thousand tons) from 2021 [1]. Chilies contain bioactive compounds such as phenols, flavonoids and capsaicinoids as antioxidants and antimicrobials [2]. Chilies contain carbohydrates, fat, protein, calcium, vitamins A, B1 and vitamin C which are needed by the body and contain lasparaginase as an anti-cancer [3]. Chili is an agricultural product that has a high water content of around 60-85% [4]. As the population increases, demand for chili products continues to increase. Therefore, farmers plant chilies continuously without paying attention to environmental factors and nutritional factors in chili cultivation so that chili production continues to decline. In chili cultivation, nutrients and soil moisture greatly influence plant growth. The nutrients available in the soil will be easily absorbed by plants if the soil moisture is optimal according to the needs of chilies [5]. Farmers must also be able to implement zero waste agriculture to support a sustainable agricultural system. Several studies have developed the use of biomass waste into useful products such as organic fertilizer [6] and biomass pellets [7].



Indonesian farmers generally grow chilies in an open environment so weather factors have a big influence on production. Extreme weather conditions as well as pest and disease attacks have an impact on reducing chili production. Hot environmental temperatures and dry air cause the growth and development of chili plants to be suboptimal [8]. Water availability is very important in the growth and development of chili plants both vegetatively and generatively [9]. Chilies can grow well at humidity of 65-70% [10]. Farmers cannot monitor environmental temperature and soil moisture consistently and continuously due to the long distance between their land and house and various other farmer activities. Protection of cultivated plants can be done with an intensive farming system through greenhouses. A greenhouse system is a design structure that can control plant growth parameters thereby increasing profits towards sustainable agriculture [11]. Developing a greenhouse control system can minimize operational costs, optimize resources and increase production yields [12]. Microclimate control will be easier to do in a greenhouse so that optimal growth conditions for chili plants are achieved [13]. In addition, the use of this control system can reduce maintenance costs to be cheaper with microcontroller. The use of a microcontroller can make this system easier to assemble, accurate, tough, stable and cheap. Microcontroller able to control the microclimate (air temperature and soil humidity) [5], monitor temperature and water automatically [14] and water irrigation in the greenhouse [15]. However, farmers have several challenges in greenhouse chili cultivation. Building a greenhouse requires higher investment costs compared to open land. Apart from that, not all chili varieties are suitable for growing in a greenhouse. Chili cultivation in a greenhouse can only be done on certain cultivars that can thrive in shade [16]. The color of the greenhouse building must also be considered so as not to prevent sunlight from entering the greenhouse. Green net shading in a greenhouse can reduce light intensity thereby reducing plant height and number of chili plant segments [17].

A monitoring system that can be used in the agricultural sector based on the Internet of Things (IoT). Advances in smart sensor technology and wireless sensor networks minimize data corruption and are economical solutions in greenhouse monitoring through various applications [11]. Several studies use the Internet of Things in greenhouse climate control by integrating sensors and displaying them in applications. Increasing chili cultivation has also been carried out by designing an IoT-based automatic watering tool for chili plants using an Arduino Uno microcontroller connected to the internet [18]. Greenhouse climate monitoring systems using IoT can control irrigation, humidity and plant nutrition [19]. IoT systems can also be developed with automatic scheduling systems to optimize growth [20]. To protect plant tissue and crop yields from insect pests, several integrated pest control alternatives use environmentally friendly organic materials that are affordable [21]. Another support system is through automatic pest devices that have high precision in catching pests [22, 23]. To obtain maximum results, the pest trap system must be integrated with a microclimate control system. If chili plants do not grow well, they will show color changes in the plant tissue. Changes in plant color can be measured using a camera [24]. The red, green and blue colors for each plant can indicate the fertility characteristics of the plant. The DS18B20 temperature sensor and IoT-based pH sensor can be combined with Geographic Information System (GIS) algorithms to provide soil fertility data for chili cultivation via a website in real time [25]. [26] measured soil temperature and moisture using wireless sensors.

The aim of this research is to design automatic control with a wireless system to make it easier for farmers to access information on temperature, soil moisture and monitoring on chili cultivation in the tropics. Currently, cultivation through precision farming is a way to increase the quality and quantity of production results. Greenhouse cultivation which involves controlling temperature and humidity is one of the precision farming activities. The technological novelty here is the use of a microcontroller integrated with email and website in monitoring and controlling climate factors in the greenhouse. All information on microclimates is integrated with the website, so it can be monitored anywhere. The microcontroller used in development is an affordable or low-cost technology that has been successfully designed and proven to be successful in controlling microclimate factors during research.

This can certainly change people's views to switch from manual to technology that is low cost but has high accuracy.

## 2. Method

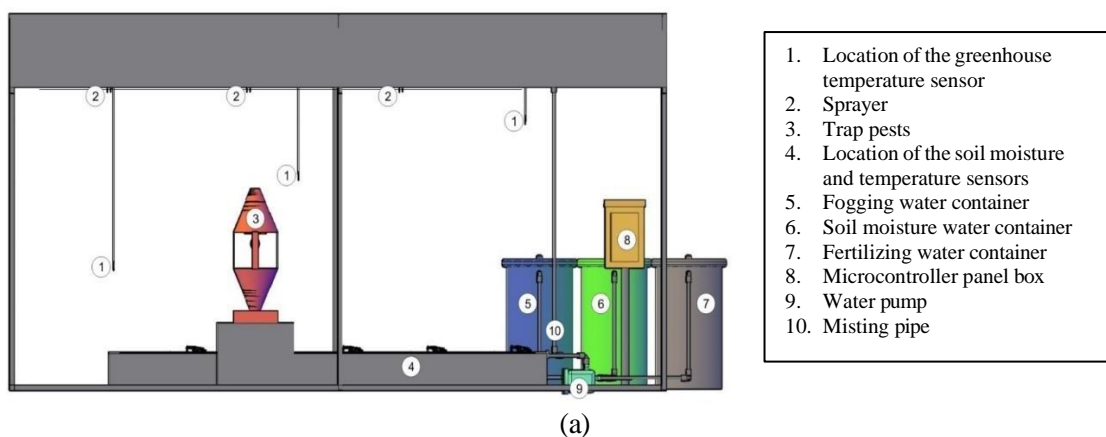
### 2.1. Places, materials, and equipment

This research was carried out at the Agricultural Tools and Machinery and Greenhouse Laboratory, Department of Agricultural Engineering, Faculty of Agriculture, University of Lampung, Indonesia. The tools used in this research were a computer, greenhouse, soldering iron, cutting pliers, clamping pliers, scissors, PCB drill, saw, motherboard, multimeter, glue, thermometer, water pump, fan and water tank. The materials used are soil, curly red chilies (*Capsicum Annum* L.) seeds, microcontroller Arduino Mega 2560, cables, DHT22 sensor, soil moisture sensor, Liquid Crystal Display (LCD), Real Time Clock, I2C DS1307, SD card module, TP-Link modem, SIM card, relay module, PCB, LED indicators, resistors, capacitors, switches, batteries, hoses, pipes and nozzles.

### 2.2. Design criteria

Cultivating chili plants in a greenhouse can be done without paying attention to environmental seasonal factors. Chili cultivation can be done especially during the rainy season and produces high productivity. Meanwhile, in open land, crop failure and disease attacks are very high during the rainy season. Factors that influence the growth of chili plants in the form of temperature, humidity, nutrition and disease can be monitored through a greenhouse. The design criteria for this research's greenhouse control system use technology in the form of equipment that is low cost but has high accuracy. The control system design is a combination of several systems for regulating temperature, humidity, applying fertilizer and controlling pests and diseases to increase the productivity of chili plants.

This automatic control system is designed to control the greenhouse temperature in the range of 32-35°C and control soil moisture in the range of 33%. Microcontrollers are used in control systems because they are easy to assemble, tough and stable for use in measurement data acquisition and control systems [27]. Liquid fertilizer is given using a pump for 63 seconds with a timer once every nine days. When the greenhouse temperature exceeds the specified limit, the microcontroller activates the relay to turn on the mist water pump. The mist water pump sprays water to lower the temperature. The target time for temperature control is < 50 minutes. The irrigation water pump will be active to drain water and control soil moisture so that it is in the range of  $\pm 33\%$ . The target time for controlling soil moisture is under 50 minutes. This pump sprays water in an effort to increase soil water levels. The IoT-based microclimate data delivery system is expected to have delivery accuracy > 90%, delivery time < 3 minutes, and cost less than 0.5 USD.





(b)

**Figure 1.** Design of locations for placing sensors, actuators, plants in research (a) and design of a microclimate control system for chili plants in a greenhouse (b)

The design of the automatic control system for chili plants in the greenhouse is an integration of temperature control systems, the use of insect pest trapping systems, fogging system settings and automatic fertilizer application (Figure 1a dan 1b). The greenhouse control system connects interrelated variables and is arranged in a control operating model. Greenhouse microclimate control is structured in a mathematical model from a comparison of predicted and experimentally measured air temperature and soil temperature data [28]. The humidity mathematical model and the air temperature model using fogging [29] can also be predicted with good accuracy. Controlling the temperature and humidity of chili plants in the greenhouse uses the fuzzy method automatically with temperature settings of 25-27 °C and humidity of 50-70% [30].

### 2.3. Tool performance test

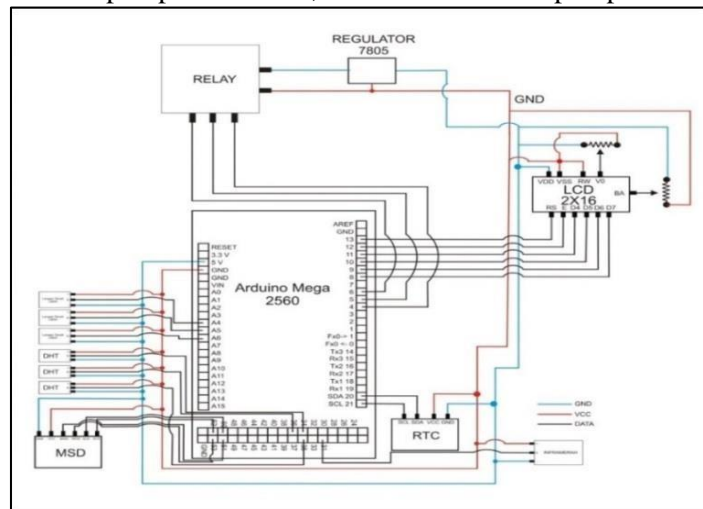
The performance test stage is a testing stage carried out to analyze the performance of the actuator and the reliability of the control system. Calibration shows the validity of the data coming from the tool by comparing sensors and calibrators with high accuracy. Calibration of the soil moisture sensor is carried out by using a comparison between the temperature variation for each moisture content and the output value of the sensor and thermometer readings for each variation in temperature and moisture content. Calibration of the DHT22 temperature sensor is carried out by comparing the sensor output value with a thermometer measuring instrument. Validation shows that the value coming out of the sensor is in accordance with the actual value. Validation of the soil moisture sensor is carried out by measuring the soil water content, comparing it with the reading value of the soil moisture sensor and the Root Mean Square Error (RMSE) test. Validation of the DHT22 temperature sensor is carried out by measuring the greenhouse temperature for each variation, taking sensor output value data and RMSE test. Control system stability is used to determine the durability of the system in producing constant performance or not. Accuracy shows the performance of a control system in achieving a predetermined setting point value. Control time shows the speed of the tool's performance in controlling the actuator to reach the setting point. Plant growth was observed by measuring changes in height of chili plants cultivated with an automatic microclimate control system and without a microclimate control system. The measurement data obtained will be stored on the SD card in \*txt format, with a data storage interval of 1 hour or 60 minutes. Data recording during performance testing was carried out for 720 hours or 30 days. The data that has been saved will be analyzed using Microsoft Excel software and displayed in the form of

tables and graphs. Chili plant growth data was carried out by measuring plant height every 4 days for 31 days.

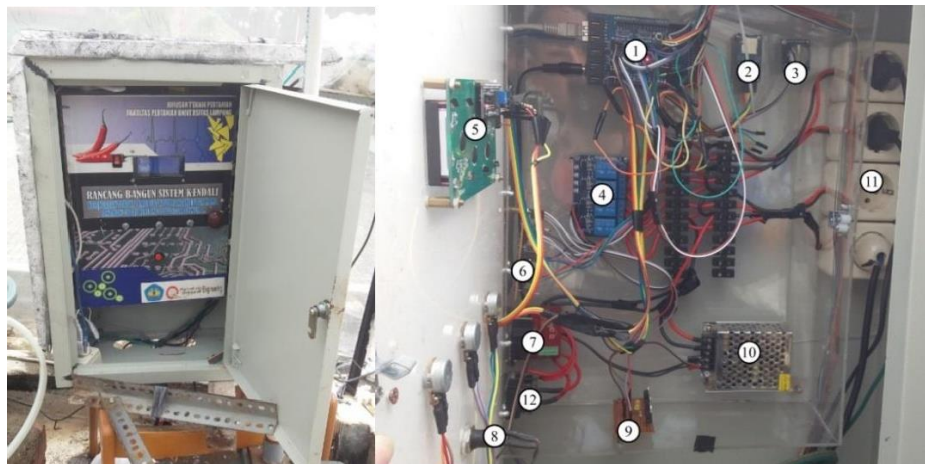
### 3. Results and Discussion

#### 3.1. Design results

The control tool is a box made of acrylic plastic with dimensions of 40 cm x 30 cm x 10 cm. The acrylic box is placed in an iron box measuring 60 cm x 40 cm x 20 cm. The iron box will be able to protect the control system from bad influences such as rain, heat or other unwanted technical disturbances. Making a water pump installation is divided into three parts, namely soil moisture water pump installation, mist water pump installation, and fertilizer water pump installation (Figure 2 and 3).



**Figure 2.** Schematic of the greenhouse control system circuit

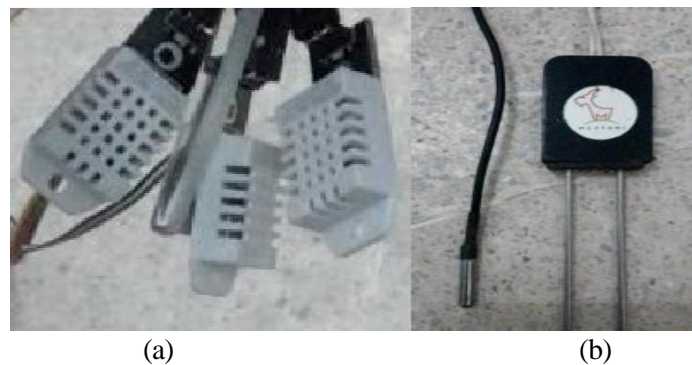


**Figure 3.** Results of designing a microclimate control system for chili plants

Information:

- |                                              |                            |
|----------------------------------------------|----------------------------|
| 1. Microcontroller and Arduino Sensor Shield | 7. AC socket               |
| 2. Micro SD card module                      | 8. Reset button            |
| 3. RTC DS1307                                | 9. Regulators              |
| 4. 4-channel relay module                    | 10. Power supplies         |
| 5. LCD                                       | 11. Pump and fan terminals |
| 6. Transistor                                | 12. ON/OFF switches        |

DHT22 sensors are placed at three different locations to measure temperature. The three locations are placed in a greenhouse at the front, middle and back. The optimal temperature for cultivating chili plants is 18-30 °C [20]. Pre-research results show that chili plants can still grow well at temperatures of 35-36 °C during the day. Therefore, the temperature set point value is set at 35 °C. When the greenhouse temperature is > 35 °C, the mist water pump will turn on. Then the water pump turns off when the greenhouse temperature is  $\leq$  32 °C.

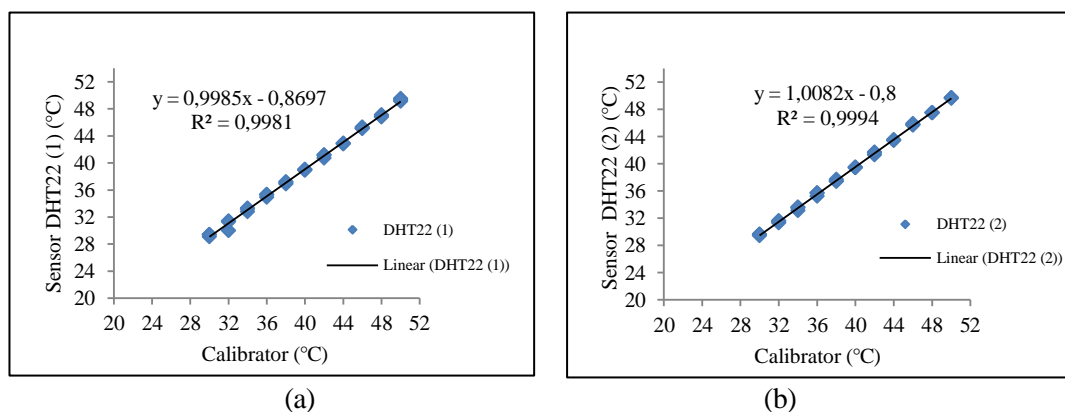


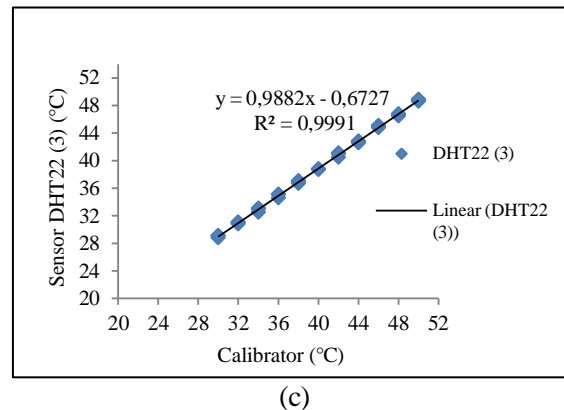
**Figure 4.** Sensor DHT22 (a) and soil moisture sensor (b) [5]

Soil moisture control is carried out by installing a soil moisture sensor probe and an LM35 temperature sensor into the soil near the chili plants. The ideal soil moisture for various types of chili plants is around 33-80% [31]. Conditions that are too wet or too dry are not suitable for chili plants. Determination of this setting point is supported by data obtained in pre-research that chili plants can grow well in soil moisture of 33%. High humidity can disrupt the growth of chili plants. When the water content value is > 31%, the soil moisture pump will turn on. Then the water pump stops at a water content value  $\leq$  33%. This system is also equipped with a fertilizer pump that turns on once every 9 days for 63 seconds (Figure 4).

### 3.2. Calibration

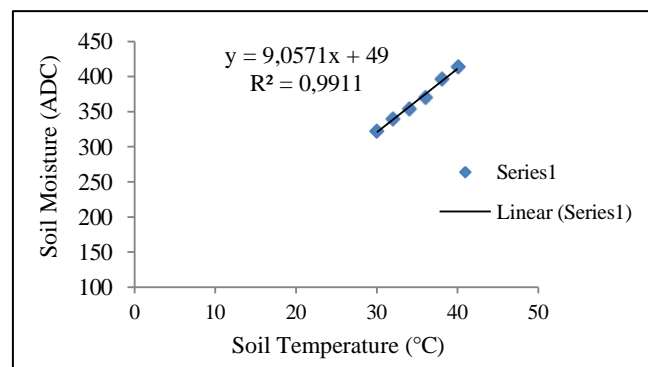
Calibration of the DHT22 sensor and soil moisture sensor is carried out before the sensors are assembled in the control system. Tool calibration is a procedure to determine the validity of the data from the tool. The calibration method is carried out by comparing the tool to be calibrated with a calibrator that has high accuracy. Calibration should be carried out on tools that are frequently used periodically, especially new tools. The measurement results are displayed on the Arduino software serial monitor.





**Figure 5.** Calibration of the temperature sensor DHT22 1 (a), sensor DHT22 2 (b) and Sensor DHT22 3 (c)

Figure 5 shows the calibration between the DHT22 temperature sensor (1) and the calibrator. The results of observing the readings of the three temperature sensors and calibrators produced a coefficient of determination  $R^2$  of 0.9981, 0.9994 and 0.9991 respectively. The  $R^2$  value is good if it is close to 1, meaning the calculated value is close to the measurement data.



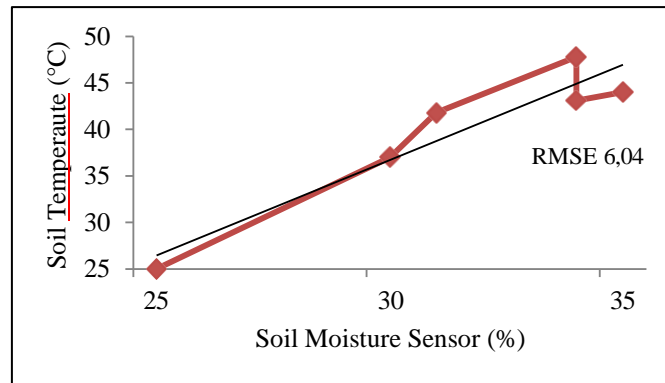
**Figure 6.** Calibration of the temperature sensor and soil moisture sensor at soil temperature 40-30 °C.

Figure 6 shows the relationship between temperature and soil moisture values. This figure was compiled to obtain a relationship or correlation between soil temperature and soil moisture. Soil temperature is needed as compensation or correction to detect real-time soil moisture precisely through an electrical conductance system. Electrical conductance can change depending on temperature factors, so to produce moisture values with high accuracy, a soil temperature sensor is needed to correct the conductance value. This relationship is translated/written in the form of a mathematical model which is written into equations in the microcontroller program. These results show that the soil moisture value read from conductance can be influenced by soil temperature. The soil moisture sensor value will be corrected by soil temperature, so that real-time soil moisture values are obtained. The relationship between temperature and soil moisture produces a coefficient of determination  $R^2 = 0.9911$ .

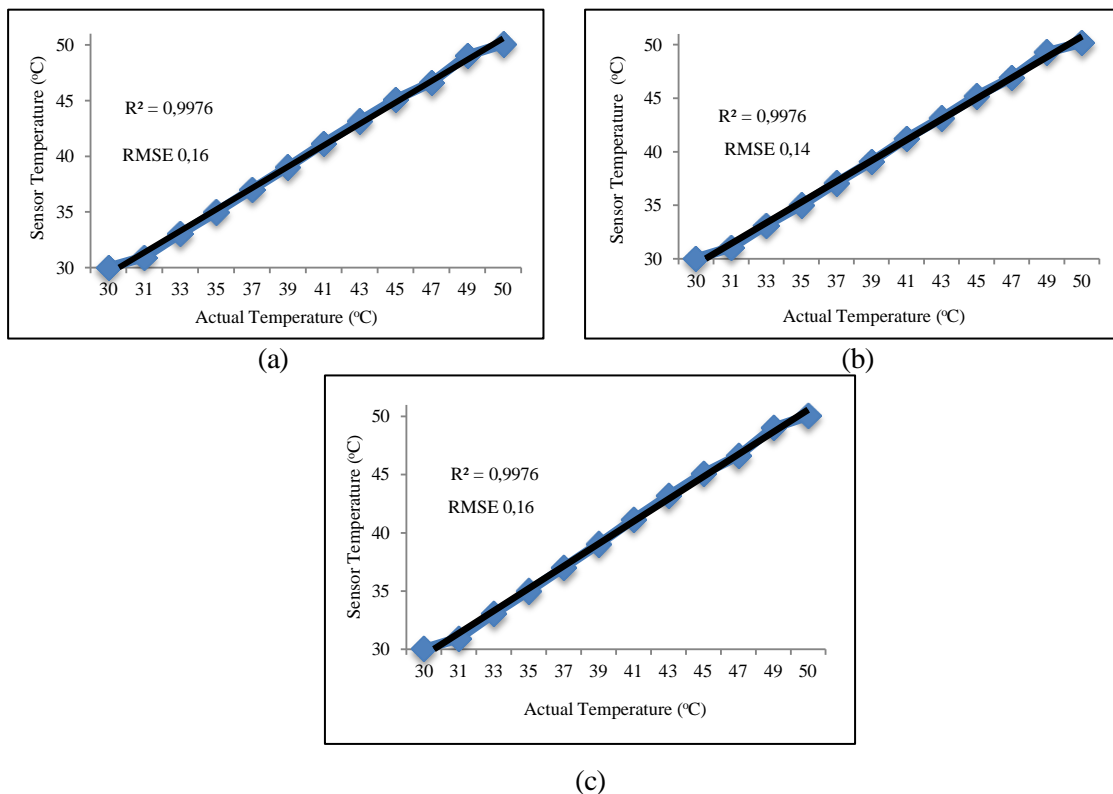
### 3.3. Validation

Validation shows that the value coming out of the sensor matches the actual value of the tool. Validation of temperature sensors and soil moisture sensors aims to ensure that the values coming out of the sensors are in accordance with the actual values. Temperature sensor validation aims to ensure

that the value coming out of the sensor is in accordance with the thermometer measuring instrument. Data from validation of sensor moisture levels and actual moisture levels show that the soil moisture sensor readings are close to the actual moisture content figures (Figure 7). The reading of the soil moisture value is on a diagonal line. The error value obtained by the Root Mean Square Error (RMSE) test is 6.04.



**Figure 7.** Validation of the soil moisture sensor



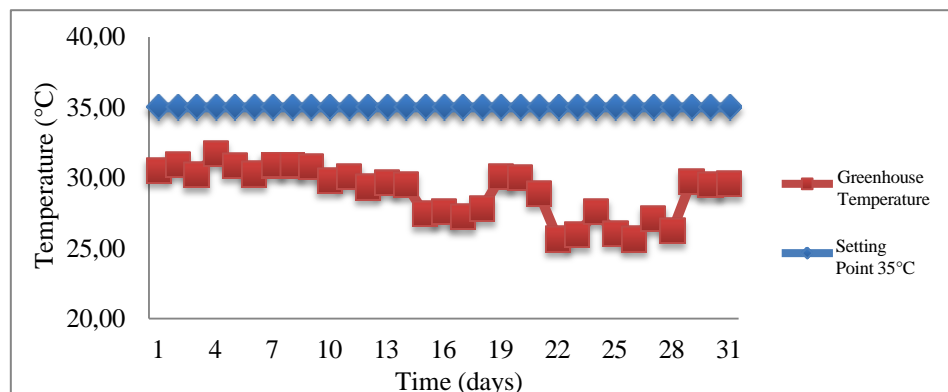
**Figure 8.** Validation of temperature sensors 1 (a), sensor temperatures 2 (b) and sensor temperature 3 (c)

Figure 8 shows the validation of the sensor against actual temperature. The validation results of the readings of the three temperature sensors and the actual temperature (calibrator) produced a coefficient of determination  $R^2$  of 0.9976, 0.9976 and 0.9976 respectively. This result is the same as research by [32] which validated the DHT22 temperature sensor and produced an  $R^2$  of 0.9885 on a microcontroller-based environmental condition monitoring tool. The RMSE values for each sensor are

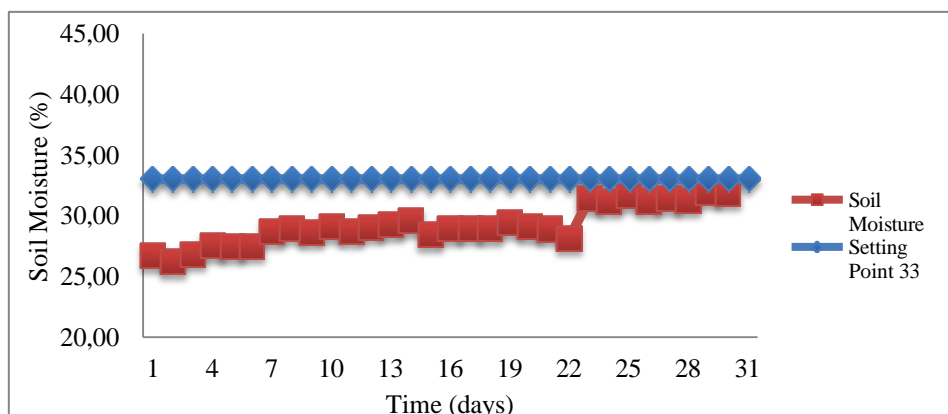
0.16, 0.14 and 0.16. This RSME value is the same as research by [33] which obtained RSME values from the three DHT22 sensors of 1.65, 1.86 and 0.92.

### 3.4. Stability

Stability aims to determine the ability of a device to produce consistent (stable) performance over a long period of time. Performance parameters stability is very necessary in testing control systems with the aim of seeing whether the performance results of the equipment last for a long period of time or not.



**Figure 9.** Stability of temperature control



**Figure 10.** Stability of soil moisture control

The results of the temperature reading values are shown in Figure 9, the sensor readings are stable at a temperature of 25-33 °C. Figure 10 shows the results of stable soil moisture sensor readings at 25-35%. The performance of the tool can be said to be stable because the temperature and soil moisture values displayed do not experience significant changes. The system can control temperature and soil moisture stably from a specified set point [23].

### 3.5. Accuracy

The accuracy value produced by the control system is needed to determine the level of accuracy of the tool's performance in controlling greenhouse temperature and soil moisture. The accuracy of the control system can be calculated by the formula:

$$Accuracy = \left( 1 - \frac{\sum_{i=1}^n |SP - NA1|}{n \cdot SP} \right) \times 100\%$$

**Information :**

SP = *setting point value*  
 $NA_1$  = actual value 1  
 N = amount of data

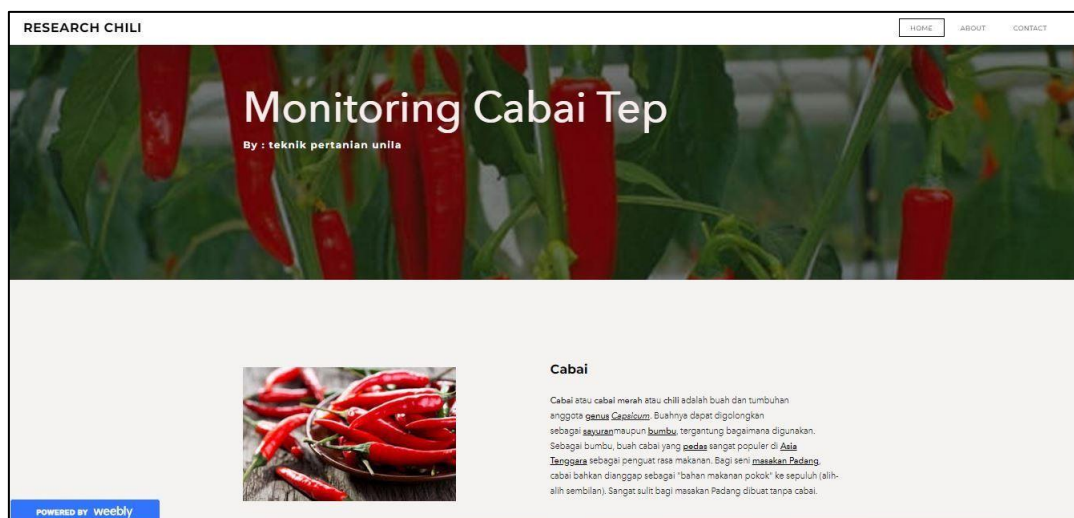
Calculation of temperature sensor accuracy is obtained from temperature data for 31 days at a setting point of 35 °C. The temperature sensor accuracy results for 31 days were 98.61%. Soil moisture accuracy was obtained within 31 days at a setting point of 33% with an accuracy value of 99.95%. The accuracy value of the temperature sensor and soil moisture sensor is 98-99%. Good accuracy is demonstrated by accuracy results above 80% [23]. The high accuracy value of the tool's performance shows that the use of actuators to control soil temperature and humidity has been able to work well.

**3.6. Actuator control time**

The value of the control time shows the length of time needed to control the greenhouse temperature and soil moisture beyond the setting point limit and returning to the setting point value range in a sustainable manner. The results of calculating the temperature control time for 31 days at a setting point (SP) of 35 °C were 47 minutes 44.4 seconds. The calculation results for controlling soil moisture for 31 days at a setting point (SP) of 33% were 41 minutes 51.6 seconds.

**3.7. Wireless system**

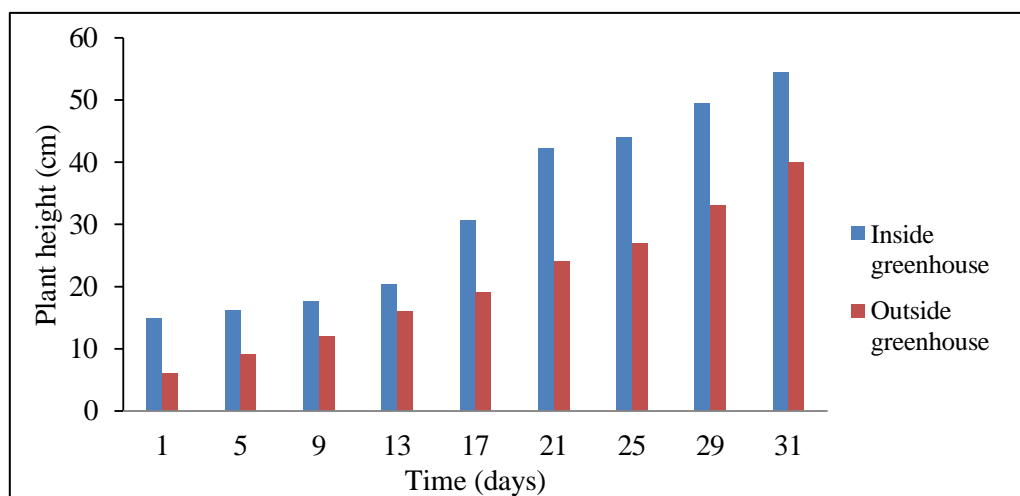
The data transmission system uses a D-Link modem, DWP 157, and Telkomsel provider card. Soil temperature and humidity data sent by the Arduino and Ethernet shield is converted into a microcontroller program. Data sending method using web client method. This web client method uses a microcontroller as a controller to open the website address that has been created. For this reason, the microcontroller must be connected to a target server such as Google Forms, Google Spreadsheet, and Google Drive. The microcontroller uses the application programming interface (API) on Pushingbox to access the Google server. The soil temperature and humidity data that has been sent from the microcontroller is then written into Google Spreadsheet. Soil temperature and moisture data can be accessed via [monitoringcabai.weebly.com](http://monitoringcabai.weebly.com) (Figure 11). The experiment was carried out for 10 days of observation. The amount of data received by the website was 212 data with a total cost of 0.17 USD. Data transmission accuracy was in the range of 95 – 97% with an average speed of < 2 minutes during the study.



**Figure 11.** Website appearance

### 3.8. Height plant

Observation of the development of chili plants was carried out by measuring the height (cm) of chili plants using a measuring ruler. Measurements were taken every 4 days for 31 days. Chili growth was better when controlled by a control device (in the greenhouse) compared to without a control device (outside the greenhouse) (Figure 12). The temperature inside the greenhouse is higher than the temperature outside the greenhouse. The high temperature is caused by the use of concrete around the greenhouse. The shelter on the roof causes short rays to be trapped and the concrete below can absorb and reflect the heat received. This causes the microclimate in the greenhouse to be higher. To make it easier to reduce the temperature in the greenhouse, streamin is used as a wall. The aim of using streamin is so that air can go in and out easily, especially in tropical climates.



**Figure 12.** Average height of chili plants inside and outside greenhouse



**Figure 13.** Chili plants with a control system (inside greenhouse) (a) and without a control system (outside the greenhouse) (b)

Controlling greenhouse temperature affects plant growth so that the greenhouse temperature should be uniform vertically and horizontally in space. Plant parts such as roots, fruit, shoot tips and flowers are sensitive to temperature changes, especially in extreme temperature conditions. Plants can experience tipburn due to lack of calcium and water as well as heat generation so that calcium translocation from the roots is reduced at hot temperatures  $> 35\text{ }^{\circ}\text{C}$ . Temperature regulation is necessary, especially in hot climate areas with a fogging system. The use of a mist/fogging system can reduce indoor air temperatures more than in open areas [34]. The greenhouse control system in this

study showed faster growth in height and produced lots of leaves (Figure 13). Plants can grow well with a supportive environment and the availability of nutrients and good insect pest control. Several studies also show good plant productivity results with climate control systems in greenhouses. The greenhouse temperature control system influences fruit growth and fruit sugar accumulation in melons and watermelons and encourages leaf and flower bud differentiation [35]. The fogging system in a greenhouse can increase the photosynthetic capacity of lettuce leaves so that it can increase yields higher than in open fields [36].

#### 4. Conclusion

Validation of the soil moisture sensor resulted in an RMSE of 6.04. Validation of the three temperature sensors produces RMSE of 0.16, 0.14, and 0.16. The accuracy rate for temperature control is 98.61% and soil moisture control is 99.95%. The temperature setting time is 47 minutes 44.4 seconds and the soil moisture setting time is 41 minutes 51.6 seconds. The stability of the tool results in stable performance. Observation data during the research was successfully displayed on the website. The accuracy of the IoT system's data delivery system is 95 – 97%, the data delivery speed is < 2 minutes, and the cost is 0.17 USD. Through the use of this tool, the growth rate of chili plants with a control system is better than chili plants without climate control. The average height of chili plants with a control system is 54.50 cm, while chili plants without a control system is 41.33 cm. The use of this microclimate control system certainly has the potential to increase plant productivity during the rainy season or long dry season.

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