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Smart Greenhouse Design for Strawberry Cultivation in Pandanrejo, Batu City

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Abstract

Batu City, which is famous as a tourist city, is not only an urban area. Most of the Batu city area is a rural area, especially the northern area which is included in the Bumiaji sub-district. As a tourist area, Batu City has a large enough economic potential to improve the welfare of its people. Most of the people of Batu city who live in rural areas are fruit and vegetable farmers. Pandanrejo village in Bumiaji sub-district is an example of a strawberry-producing village in Batu city. Various problems are faced by strawberry farmers in Pandanrejo village. One of them is related to the uncertain weather conditions in their village. The ITS Physics department team provides solutions related to these weather conditions with an innovative climate conditioning technology that can be applied in agriculture. This technology is a smart greenhouse in which there is control of environmental conditions for strawberry plants. With the application of smart greenhouse technology, it is expected to increase the productivity of strawberries and the welfare of the farming community of Pandanrejo village, Batu city.

Keywords: *Smart greenhouse; Strawberry cultivation; Farming community; Farmer welfare; Pandanrejo village*

Background

Batu City, East Java, has long been known as a tourist city. Batu City does not only consist of urban areas, most of Batu City is a rural area. The northern area of Batu City, which is included in the Bumiaji sub-district, is mostly rural. As a tourist area, Batu City has the considerable economic potential to improve the welfare of the community. This economic potential needs to be managed properly by the Batu City government so that this potential can prosper the people of Batu City. Most of the people of Batu City who live in rural areas are fruit and vegetable farmers. This is due to the geographical conditions of Batu City which are in the highlands and cold temperatures. Pandanrejo Village in Bumiaji District is an example of such a rural area. The people of Pandanrejo village are mostly strawberry farmers. Realizing the uniqueness of Pandanrejo village, the leaders of Pandanrejo village have made their village a strawberry tourist area. Various supporting facilities have been built to support Pandanrejo village as a strawberry tourism area (UMM, 2018). As a tourist village, the farming community of Pandanrejo village needs to prepare itself with a modern agricultural system (Lee and Kim, 2022).

Strawberry cultivation, like other fruit cultivation, of course, there are various problems faced by farmers. These problems can be in the form of appropriate cultivation methods (Jones and Benton, 2005), and the provision of fertilizers and nutrients for plants (Fallovo et al, 2009). There are various ways to overcome problems in strawberry cultivation, for example, related to geographical conditions of land (Elenzano, et al, 2021) and rainfall conditions (Schattman et al, 2022). Some of the problems related to strawberry production in Pandanrejo village, Batu City which is the problems in this research are:

1. The change in air temperature is quite large between day and night.
2. The difference in soil moisture between the rainy season and the dry season.
3. Farmers still lack knowledge about agricultural technology.

In this paper, alternative solutions for these problems are presented by applying smart greenhouse technology. In a smart greenhouse, there is control of environmental conditions for plants. The application of smart greenhouse technology was adopted from previous research on kale (Indarto et al, 2018). The purpose of this study was to introduce and pilot smart greenhouse technology to strawberry farming communities in Pandanrejo village. The novelty of the research is the application of a smart greenhouse with microclimate settings for strawberry cultivation in Pandanrejo village, Batu City.

Literature Review

Pandanrejo Village, Batu City

Pandanrejo village is located at the foot of the mountain south of Mount Arjuna with an altitude of 700 - 800 m above sea level so the air temperature in Pandanrejo village is very cold. The optimum air condition in Pandanrejo village is between 15 - 25^{0}C and the minimum air temperature is between 3 - 5^{0}C, humidity is between 85 - 91%, sunlight is between 7.9 - 9.5 hours/day, and rainfall is around 500 - 900 mm/year. Pandanrejo village has a loose and fertile soil texture so the majority of the work of the Pandanrejo village community is in the agricultural sector.

The agricultural sector in Pandanrejo village is unique and has its characteristics in the economic structure of Batu City. The agricultural sector in Pandanrejo village plays an important role in the development to move the village economy. Therefore, the agricultural sector dominates the economic structure of Pandanrejo village. In 2017 the number of paddy fields in Pandanrejo village was 168 ha, with a technical irrigation area of 44 ha and 124 ha of technical irrigation. The area of dry land which includes land yards for buildings and dry land/gardens/fields is 188.37 ha. In addition, other sectors such as livestock are also growing in population, thereby increasing the economic growth of the Pandanrejo village community (UMM, 2018).

As a tourist village, the farming community of Pandanrejo village needs to prepare itself with a modern agricultural system. The development of modern agriculture requires a framework for investment and research and development collaboration by the government in the modern agricultural sector. Once the framework has been established, the next step is to implement these work steps in modern agricultural work programs (Lee and Kim, 2022).

Strawberry cultivation

Strawberry cultivation is carried out due to an increase in public demand. Improving crop quality is also important because it has an impact on health, economic income, and food quality. There are various efforts to improve crop quality. The Coinoculation method is one of the efforts to increase flower and fruit production. Coinoculation of plants can increase the concentration of sugar, ascorbic acid, and folic acid in the fruit it produces. This shows that rhizosphere microorganisms can affect the quality of fruit crops (Bona, 2014).

Another way to increase crop production is the use of vermicompost. Worms play an important role in reducing nutrient-related disorders and diseases in plants. Fruits harvested from vermicompost plants were found to be superior to vermicompost plants. Some of the advantages are that the fruit looks firmer, has lower acidity content, and more attractive color (Singh, 2008).

Strawberry cultivation is usually done on the ground with conventional cultivation methods which can have an impact on environmental problems related to the use of chemical pesticides and fungicides. Soilless cultivation is one of the recommended production methods for these environmental reasons. A research result shows the difference between strawberry cultivation with soil growing media system and substrate growing media system. In the soil system, more fruit is obtained than in the substrate system, while in the substrate system the fruit quality is superior to that of the soil system (Cecatto, 2013).

Strawberries and other small fruits require an increase in water during a certain growth period i.e. the period of fruit formation. The distribution of rainfall has implications on yield and fruit quality especially in agroecological systems without additional irrigation. The relationship between water availability, changes in rainfall patterns, and plant physiology have implications for strawberry production in particular. Sustainable production of strawberry plants requires proper water management to ensure soil fertility and strawberry plant health (Schattman et al, 2022).

Another research related to strawberry cultivation is research related to the latitude position of the cultivated area. The duration of fruit growth was longer for areas at high latitudes. Fruit quality standards in northern regions (high latitudes) are generally higher than fruit quality standards in low latitudes. Fruits that grow in the south are redder than those in the north (Kruger, 2012).

Smart Greenhouse Technology

A greenhouse is a form of controlled environmental monitoring that is optimal for plant growth. Environmental monitoring in the greenhouse includes light intensity, air temperature, humidity, wind speed, and heat transfer. Greenhouses can be integrated with the Internet of Things (IoT) for real-time monitoring. Greenhouses with such system equipment are called smart greenhouses. Wahyu et al have developed a smart greenhouse system for plant cultivation by utilizing solar panels as a source of electrical energy for the system. Tests on the smart greenhouse system show good accuracy, so the smart greenhouse system can be used for plant cultivation (Wahyu, 2022).

Regarding temperature and humidity measurements in greenhouses, Jeong et al have developed temperature and humidity measurements with aspiration radiation shielding (ARS). In this study, Jeong et al compared the accuracy of ARS with systems made by companies that are widely circulated in the community. The temperature measurement by the company's system is slightly higher than that of ASR. The relative humidity measurement by the company's system is slightly lower than that of ARS (Jeong, 2019).

Plant diseases cannot be predicted accurately simply by analyzing the causes of individual diseases. Only through the creation of a comprehensive analysis system can predictions of diseases that are very likely to occur can be obtained. It is necessary to develop cloud-based technology capable of collecting, analyzing, and predicting plant diseases in one common platform. The Farm as a Service (FaaS) integrated system is capable of operating and monitoring the environment and plant growth. The FaaS system can be used for the analysis of disease infection prediction systems in strawberries (Kim, 2018).

The public's fondness for strawberries stems from their unique fragrance, vibrant red hue, succulent texture, and sweet flavor. Yet, strawberries stand out as the most delicate fruit concerning the quality of their product. Presently, an increasing number of strawberry farmers are exploring the adoption of a smart control mechanism to enhance the overall quality of their strawberries. Among these advancements is an irrigation control system specifically designed for strawberries cultivated in internet-connected cloud-based greenhouses. The cloud-based smart greenhouse design was able to control soil moisture and water consumption in strawberry plants (Angelopoulos, 2021).

The application of Internet-of-Things (IoT) in agriculture can not only increase productivity and optimize resources, but it can also increase efficiency and minimize production costs. The application of sensors and IoT in smart greenhouses can make automation in agricultural systems. Various parameters such as humidity, the solubility of nutrients in water, pH and EC values, temperature, UV light intensity, CO2 level, fog, and the amount of insecticide or pesticide can be monitored through various sensors so that these data can be used for fault detection and early diagnosis. Development of a Decision Support System (DSS) which acts as a central operating system for the regulation and coordination of various activities. With a smart farming system like this, environmental changes can be adapted easily (Tripathy, 2021).

Greenhouse cultivation systems are becoming increasingly popular due to unpredictable climatic conditions and their ability to control the micro and macro environment. However, limitations such as a hazardous working environment and labor shortages are a problem in such agricultural production. Woo et al proposed the use of a robotic system for this problem. The average hourly production of robots is about five times lower than that of skilled workers. However, robots are more productive because they can work around the clock (Woo, 2020).

Methodology

Greenhouse Building Design

In making the smart greenhouse frame, it is adjusted to the size of the plant rack in it. The plant rack contains several strawberry plants. The dimensions of the greenhouse are 100 cm long, 150 cm wide and 200 cm high. Hollow Galvalume greenhouse construction frame. The roof is made of ultraviolet plastic. The material can conduct light by about 75 - 80% and reduce heat by about 40%. The walls of the greenhouse use ultraviolet plastic with a thickness of 0.8 millimeters. This is so that predatory animals cannot enter the greenhouse. The plastic walls are also intended to keep the temperature and humidity in the greenhouse from changing too quickly.

Temperature and Soil Moisture Control System Design

In this smart greenhouse, there are temperature and humidity sensors to maintain the condition of the plants in the greenhouse. The temperature and humidity control system in the greenhouse is made according to climatic factors that can affect plant growth, namely air temperature, and soil moisture. The temperature sensor used is DHT11 and the soil moisture sensor used is YL-69. This sensor detects changes in air temperature and soil moisture that occur in the greenhouse (Indarto, 2021).

Figure 1
The sensor of temperature and humidity DHT11

The DHT sensor in Figure 1 is a sensor that can measure air temperature and humidity. The working principle of DHT11 is like an NTC (Negative Temperature Coefficient) thermistor which utilizes changes in resistance when the temperature changes. The working principle of the DHT11 air humidity measurement is like the working principle of a capacitive sensor that utilizes changes in capacitance when there is a change in air humidity.

Figure 2
The sensor of soil moisture YL-69

The YL-69 soil moisture sensor is an ideal sensor for monitoring city gardens or water levels in garden plants. This sensor consists of two probes for passing electric current in the soil as shown in

Figure 2. The more water content in the soil, the lower the resistance. Conversely, the less water content in the soil, the higher the resistance. This sensor is widely used for monitoring soil moisture in city parks or gardens.

In this smart greenhouse, there is a temperature control system and a soil moisture control system. The temperature control system is used to regulate the air temperature in the greenhouse. Temperature regulation is done with a fan to regulate air circulation. The temperature control system functions to turn the fan on and off for a duration according to air temperature conditions based on temperature sensor readings.

A soil moisture control system is used to regulate plant watering. For plants to grow well, it is necessary to water regularly every day. In a conventional greenhouse, watering is done manually by the owner by scheduling continuous watering so that the owner must take the time to water the plants. In this smart greenhouse, the process of watering plants is carried out automatically according to the soil moisture conditions that have been set in the design.

Observation of Strawberry Smart Greenhouse and Ordinary Greenhouse

The farming community of Pandanrejo village, Batu city, is accustomed to using an ordinary greenhouse in strawberry cultivation. To attract farmers to try smart greenhouses, it is necessary to compare the results of strawberry cultivation using smart greenhouses and ordinary greenhouses. To get an idea of the advantages of smart greenhouses compared to ordinary greenhouses, comparisons were made between the two on the growth and quality of the strawberries they produce. Observations were made based on the calculation of the average number of flowers and fruit per plot, measurement of water use per plant per day, and surveys to respondents in the form of a questionnaire.

The survey method was carried out on 40 respondents who had visited and enjoyed strawberries from the smart greenhouse and ordinary greenhouse in Pandanrejo village. The survey was in the form of filling out a questionnaire consisting of 12 questions with a composition of 4 questions related to the quality of strawberries in general, 4 questions related to the taste of strawberries, and 4 questions related to the sweet taste of strawberries. The answer to each question consists of 5 choices, namely very bad, bad, adequate, good, and very good. The score for each answer is very bad = 2, bad = 4, moderate = 6, good = 8, and very good = 10.

Result and Discussion

Greenhouse Building Form

The area of strawberry land in Pandanrejo village is about 7 - 8 hectares. Previously, farming communities carried out conventional strawberry cultivation. After that, the Kanjuruhan University Malang team introduced strawberry cultivation with a greenhouse to the Pandanrejo farming community. The types of strawberries grown in the greenhouse are Sweet Charlie and Rosalinda. Both types of strawberries were chosen because of their sweet taste and large size. Figure 3 shows the greenhouse that has been used by farmers in Pandanrejo village for the cultivation of Sweet Charlie and Rosalinda strawberries.

Figure 3
The form of a strawberry greenhouse that has been applied by Pandanrejo farmers

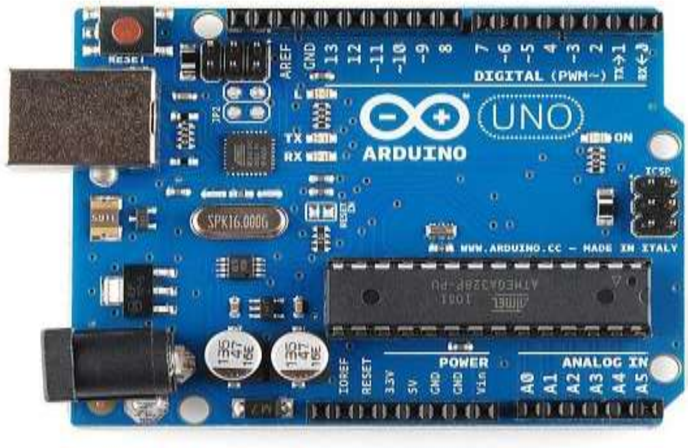
Figure 4
The form of a smart greenhouse offered to Pandanrejo farmers

In this research activity, the Institut Teknologi Sepuluh Nopember (ITS) team introduced further technology in strawberry cultivation to the Pandanrejo farming community. The technology introduced is a smart greenhouse with automatic settings for air temperature and soil moisture. The advantage of a smart greenhouse is that it can adjust the climatic conditions in the greenhouse according to the needs of the plant. Unlike the greenhouse that has been used by Pandanrejo farmers (ordinary greenhouse), the smart greenhouse is closed. The closed form aims to ensure that the air and environmental conditions inside the greenhouse are not affected by the air and environmental conditions outside the greenhouse so that air and environmental conditions can be controlled inside the greenhouse. Figure 4 shows the form of a smart greenhouse offered by the ITS Surabaya team to strawberry farmers in Pandanrejo village.

Microcontroller Arduino Uno

The Arduino Uno microcontroller is the brain of the control system in this smart greenhouse. Arduino serves as the control center of the entire trigger control line. The GSM module will send a notification to the YL-69 soil moisture sensor which functions as a determinant of soil water content. The purpose of sending a trigger signal to the microcontroller is to trigger the solenoid valve which functions as a watering valve. In addition, the GSM module will send notifications to the DHT-11 temperature and humidity sensor which functions as a determinant of the temperature and humidity levels in the greenhouse. In the system program. The air temperature and soil moisture values can be set in the Arduino Uno microcontroller system program. Figure 5 shows the Arduino Uno microcontroller which is used to control the fan and water pump and has been calibrated with the YL-69 soil moisture sensor and the DHT-11 air temperature sensor.

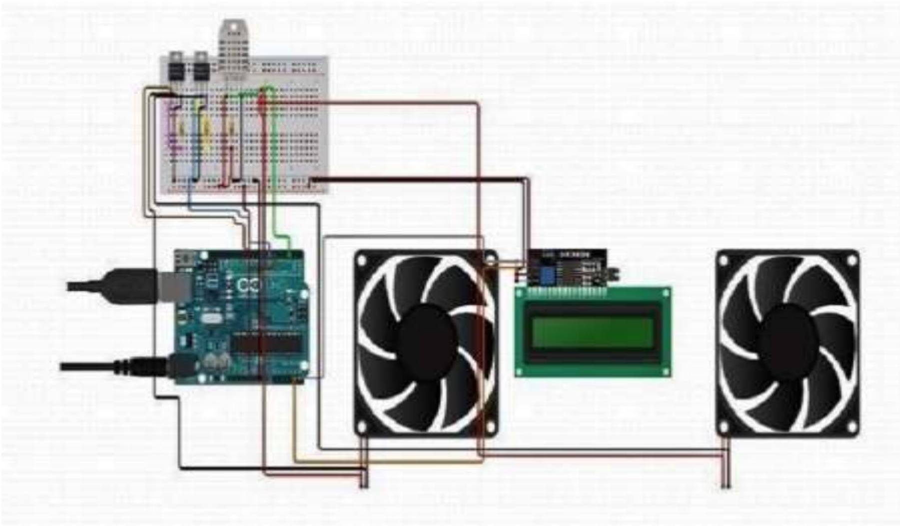
Figure 5
Microcontroller Arduino Uno



Temperature Control System Design

The air temperature setting is based on the results obtained by the DHT-11 temperature and humidity sensor. The air temperature sensor works like an NTC (Negative Temperature Coefficient) thermistor that takes advantage of changes in resistance when the temperature changes. When the temperature increases, the sensor resistance value will decrease. The use of the DHT-11 temperature and humidity sensor in the detection of air temperature and humidity is quite compatible with the Arduino Uno microcontroller. The design of this air temperature control system is calibrated and set based on the needs of the strawberry fruit air temperature. Data on the need for air temperature for strawberries can be obtained from strawberry cultivation experts. The measurement results of the DHT-11 air temperature sensor will be sent to the microcontroller to trigger the solenoid switch which functions as a fan switch. When the air temperature reaches 37°C, the DHT-11 sensor sends a signal to the microcontroller to turn off the fan sprinkler. On the other hand, when the air temperature reaches 40°C, the DHT-11 sensor sends a signal to the microcontroller to turn on the fan sprinkler. Figure 6 shows the temperature control system design used in this study.

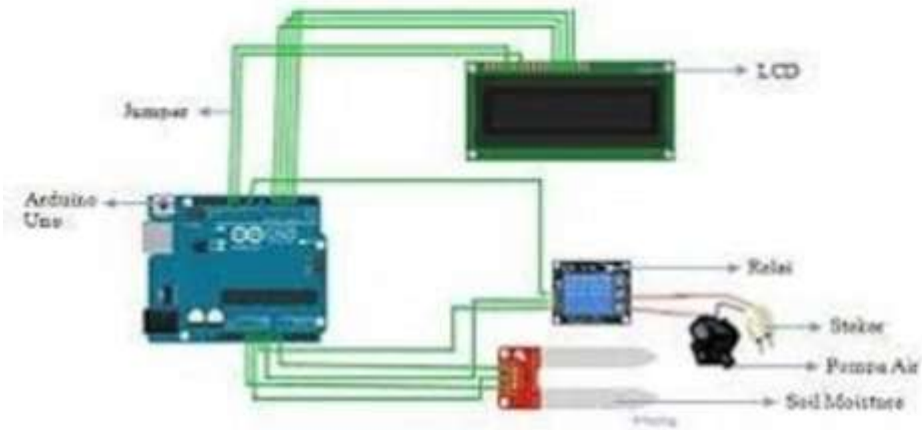
Figure 6
Temperature Control System Design



Soil Moisture Control System Design

Soil moisture regulation was carried out based on the results obtained by the YL-69 soil moisture sensor. The soil moisture sensor works based on changes in the sensor capacitance value caused by changes in soil moisture. In use, this sensor is inserted into the soil to be measured. The sensor measures the water content in the soil in percent. The use of the YL-69 soil moisture sensor in detecting soil moisture is quite compatible with the Arduino Uno microcontroller. The design of this soil moisture control system is calibrated and set based on the water needs of strawberries per day. Data on the water needs of strawberries can be obtained from strawberry cultivation experts. The measurement results of the YL-69 soil moisture sensor will be sent to the microcontroller to trigger the solenoid valve which functions as a watering valve. When the soil moisture reaches 55%, the YL-69 sensor sends a signal to the microcontroller to open the watering valve. On the other hand, if the soil moisture reaches 57%, the YL-69 sensor sends a signal to the microcontroller to close the watering valve. Figure 7 shows the soil moisture control system design used in this study.

Figure 7.
Soil Moisture Control System Design



Strawberry Observation Results Smart Greenhouse and Ordinary Greenhouse

The results of observations on strawberries from smart greenhouses and ordinary greenhouses based on the calculation of the average number of flowers and fruits per plot, measurements of water use per plant per day, and surveys of respondents in the form of a questionnaire are shown in Table 1.

Table 1
Comparison of strawberries from smart greenhouses and ordinary greenhouses

No	Observations	Smart Greenhouse	Ordinary Greenhouse
1	Flower bud emergence (flowers per plot)	60	35
2	Fruit emergence from flowers (grams per plot)	72	18
3	Water consumption (liters per plant per day)	2	8
4	Fruit quality (questionnaire score)	7.75	6.25
5	Fruit taste (questionnaire score)	6.25	5.00
6	Sweetness (questionnaire score)	5.75	4.75

The application of smart greenhouse technology in strawberry cultivation is to overcome the constraints of climatic factors such as temperature, seasonal production, and short shelf life. Various benefits of implementing smart house technology in tropical areas such as Malaysia have been obtained (Elijah, 2019). Indonesia, which has climatic conditions similar to Malaysia, will certainly get the same benefits when applying smart greenhouse technology.

The optimal production of strawberries is highly dependent on the growing environment. Smart greenhouse technology by controlling plant environmental conditions plays an important role in increasing production. In addition, the physiological parameters of strawberry plants also determine the amount of strawberry production. Modeling of plant physiological parameters and environmental conditioning of plants using machine learning can be used to predict the increase in strawberry production (Kim, 2022). The results of modeling by Kim et al have become an impetus for the application of smart greenhouse technology to increase strawberry production in Pandanrejo village.

The smart greenhouse designed by Aurel et al with the Arduino microcontroller can adjust the height of the water tank, soil moisture, and the position of the solenoid valve. The output value of each sensor is transmitted to the microcontroller. The microcontroller gives the command to open or close the solenoid valve. Smart greenhouses can produce throughout the season (Aurel, 2021). In this study, a smart greenhouse design with an Arduino microcontroller has been tested and the setting of Batu city climate conditions for production throughout the season.

Observations on the growth of strawberry plants in each plot at week 6 showed that flower buds had appeared and were ready to start bearing fruit. The average number of flower buds per plot in the smart greenhouse was 60, while the average number of flower buds per plot in the ordinary greenhouse was 35. At week 8 it was found that fruit had emerged from the flower buds. The average yield of fruit in a smart greenhouse per plot was 72 grams, while the average yield of fruit in an ordinary greenhouse per plot was 18 grams.

Observations on water use are based on measurements of the total volume of water usage per day. Water consumption in ordinary greenhouses was 8 liters per plant per day, while water consumption in smart greenhouses was 20 ml per minute for dripline watering and 200 ml per minute for fogger watering (on average total water usage is about 2 liters per plant per day). So the use of water in an ordinary greenhouse was much more than the use of water in a smart greenhouse.

Based on the results of the questionnaire, the quality of the smart greenhouse strawberry got the highest score with an average value of 7.75 with a good quality description by the respondents. The quality of ordinary greenhouse strawberries got a score with an average value of 6.25 with a fairly good quality description by the respondents. The results of the questionnaire on the taste of fruit, smart greenhouse strawberries got an average value of 6.25 and can be accepted by the respondents. Ordinary greenhouse strawberries got an average score of 5.00 and were quite acceptable to the respondents. While the results of the questionnaire on sweetness, smart greenhouse strawberries got an average value of 5.75 and were quite liked by the respondents. Ordinary greenhouse strawberries have an average value of 4.75 and were quite liked by the respondents.

Research by Elenzano et al showed differences in the aroma of strawberries from smart greenhouses and ordinary greenhouses based on olfactory tests. The aroma of strawberries from the smart greenhouse has an average aroma value of 5.85, while the aroma of strawberries from the ordinary greenhouse has an average aroma value of 5.62. This shows that the smell of smart greenhouse strawberries is more fragrant than ordinary greenhouse strawberries (Elenzano, 2021).

Conclusion

Smart greenhouses can work well, namely in controlling temperature and soil moisture. Setting by Arduino Uno Microcontroller goes well between temperature and soil moisture. Smart greenhouses can monitor and maintain the right temperature and soil moisture content in the greenhouse. Arduino Uno Microcontroller has successfully demonstrated its ability to control temperature and soil moisture. The application of the smart greenhouse is expected to increase the productivity of strawberries and the welfare of the farming community of Pandanrejo village, Batu city.

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