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Page: 70-80

Designing Plant Monitoring System Using Arduino

Agus Trihandoyo[1], Nadia Rahmadina Aristawati[2]
[1]Institut Teknologi dan Bisnis Bank Rakyat Indonesia, Jakarta, Indonesia
[2]Labschool Kebayoran, Jakarta, Indonesia
Corresponding email: a.trihandoyo@yahoo.com

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Abstract. Plants, crops, and flowers are living organisms that contribute to the productivity and beauty of our planet. They require a healthy habitat that provides adequate light, air, temperature, water, and nutrients for optimal growth. However, many plants are unable to adjust to extreme changes in their environment, which can negatively impact their growth. Ensuring that plants have the proper habitat is essential for their well-being and success. Additionally, in times of water scarcity, it is important to use available water efficiently. To address this issue, an efficient automation system must be developed. With advances in technology, it is now possible to customize environmental conditions to meet the specific needs of each plant. Technology can also be utilized to accurately monitor and control environmental factors in accordance with the requirements of the plants. This study presents a temperature and water system that utilizes programming to optimize water usage, control ambient temperature, and increase plant productivity while minimizing human intervention. The system is constructed using an Arduino kit, which includes a moisture sensor, a temperature sensor, a fan, and a water pump. Users can choose to operate the system in either manual or automatic mode, depending on their preferences. The Arduino-based prototype effectively managed soil moisture, but the fan was less successful in regulating temperature in open spaces. To improve cooling capabilities, the system should incorporate a larger fan or other more efficient components. Adopting this technology can lead to the development of precision agriculture and smart lifestyles in the future.

Keywords: Arduino; Moisture Sensor; Temperature Sensor; Irrigation System; Plant Monitoring

INTRODUCTION

Plants have specific environmental needs for optimal growth, including sufficient light, air, temperature, water, and nutrients. The environment, including temperature and soil moisture, can impact plant development (Lee, Bhandari, Lee, & Lee, 2019; Onwuka, 2018). Different plants have optimal temperatures for growth, and deviations from these optimal temperatures can affect plant growth and development. High temperatures can cause plant stress and reduced growth, while low temperatures can cause plant dormancy and delay flowering and fruiting (Niu & Xiang, 2018). Light intensity is also important for plant growth and development. Plants use light as an energy source for photosynthesis, the process by which they convert light energy into chemical energy. Different plants have different light requirements, with some needing high light intensity for optimal growth and others able to thrive in low light conditions (Paradiso & Proietti, 2022). Soil moisture is another crucial requirement for plant growth and development. Plants need water for various physiological processes, such as photosynthesis, transpiration, and nutrient uptake. Water scarcity can affect plant growth and development, leading to wilting, leaf shedding, and reduced yield (Dai, Yang, Patch, Grozinger, & Mu, 2022). Plants also require various nutrients for their growth and development, including elements like nitrogen, phosphorus, and potassium, which are essential for plant growth and development. Deficiency of these nutrients can affect plant

ISSN:2828-4925
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Page: 70-80

growth and development, causing stunted growth, reduced yield, and other issues. Therefore, it is important to provide plants with their specific requirements for growth and development, including optimal temperature, light intensity, soil moisture, and nutrition. Proper plant care can ensure healthy growth and development, resulting in increased productivity and better yields.

Plant monitoring is an essential aspect of agriculture, horticulture, and botanical research. It involves the regular observation and measurement of various physiological, environmental, and growth parameters of plants. This helps in understanding the plant's health, growth rate, and overall performance. Traditional plant monitoring involves the manual observation and measurement of various plant parameters by human experts. This involves regular visits to the plants' location, where the experts observe and measure the plant's physiological, environmental, and growth parameters. This method of plant monitoring has several advantages. It allows for the direct observation and assessment of the plant's health and growth rate. The experts can use their knowledge and expertise to identify any problems or abnormalities in the plants and take appropriate measures to address them. Additionally, traditional plant monitoring allows for the collection of detailed and comprehensive data on the plants. This can help in understanding the plants' growth patterns, response to environmental conditions, and overall performance. The data can be used for further analysis and research to improve plant productivity and yield.

However, traditional plant monitoring has several limitations. It is labor-intensive and time-consuming, requiring regular visits to the plants' location. It is also prone to human error, as the measurements and observations are dependent on the expertise and accuracy of the experts. In a typical irrigation system, farmers apply consistent irrigation without addressing field variations or crop water needs. This strategy saves less water and might over-irrigate certain portions of the farm while under-irrigating others, causing water stress on the plants (Mitchell, Weersink, & Erickson, 2018). Moreover, traditional plant monitoring is not suitable for large-scale plant monitoring applications, such as agricultural fields and greenhouses. It is also not suitable for remote locations where access to human experts is limited. Therefore, while traditional plant monitoring has its advantages, it is not suitable for all plant monitoring applications. Alternative methods, such as automated plant monitoring systems, are needed to overcome the limitations of traditional plant monitoring. The published literature over the past 15 years indicates that greenhouse agricultural researchers have been increasingly interested in smart controlled environment agriculture (Shamshiri et al., 2018). Recent research has been particularly focused on automatic plant monitoring systems due to their potential applications in developing technologies (Kishore, Sai Kumar, & Murthy, 2017). Smart agriculture also lowers the negative environmental consequences of farming, improves soil health and resilience, and reduces farmers' expenses (Santiteerakul, Sopadang, & Tippayawong, 2020).

A variety of commercial plant monitoring systems have become available in the market. For instance, most commercially available irrigation controllers are pre-programmed to provide water at predetermined intervals, allowing for irrigation scheduling based on empirical knowledge of the dynamics of meteorological factors and soil and plant properties (Lozoya et al., 2014). These pre-programmed irrigation controllers may not take into account real-time conditions that can affect watering needs, such as recent rainfall or unusually high temperatures. Additionally, pre-programmed controllers may not be able to adapt to changes in the landscape, such as the addition of new plants or a change in the type of soil. This has spurred several researchers to build inexpensive plant monitoring devices.

ISSN:2828-4925
DOI:10.47841/icorad.v2i1.84
Page: 70-80

These monitoring systems are meant to receive, transmit, and display data automatically through internet or mobile devices, facilitating farm monitoring and data collecting.

This paper presents the design and development of a monitoring system for plants that can maintain a consistent level of soil moisture and temperature in their immediate surroundings. The focus is to develop a prototype of an Arduino-based monitoring system that aims to provide an environment that suits the needs of each plant and the stages of its development. Arduino is a popular open-source platform for developing electronic circuits and microcontroller-based projects. It provides a simple and user-friendly interface for programming and interfacing with various sensors, actuators, and other electronic devices. The system is designed to be low-cost, easy to use, and capable of providing accurate and reliable plant monitoring data.

The use of Arduino in a plant monitoring system is expected to significantly improve the efficiency and reliability of data collection compared to traditional methods. This is because Arduino systems can be easily programmed to automatically collect data at regular intervals, without the need for manual intervention. This can save time and resources, and can also help to reduce the potential for human error in data collection. From the important elements above, we limit the scope of the prototype to regulate the environment temperature and soil moisture by providing air circulation and watering to achieve the desired value. Thus, we did not specifically make observations on certain types of plants.

The hypotheses for this research are the following: A plant monitoring system designed using Arduino can accurately measure various physiological parameters of plants, such as temperature and moisture. The use of Arduino in a plant monitoring system can significantly improve the efficiency and reliability of data collection compared to traditional methods. The implementation of a plant monitoring system using Arduino can provide valuable insights into the growth and health of plants, allowing for more effective optimization of cultivation conditions. The proposed plant monitoring system can enable real-time monitoring and remote control of plants, allowing for more efficient and effective plant management. The integration of sensors and actuators can provide a cost-effective solution for automating various tasks in plant cultivation, such as irrigation and fertilization.

METHOD

The research methodology for this study employed design and development research approaches, including the stages of Analysis, Design, Development, Implementation, and Evaluation. The literature review of existing plant monitoring systems, including traditional and automated systems, their performance, and their limitations, informed the design of the hardware and software components of the new system, including the sensors, actuators, and the Arduino microcontroller. Based on these specifications, a plant monitoring system was designed using Arduino, an open-source hardware kit with a microcontroller and software development environment. The Arduino Uno R3 development board was selected for its simplicity and versatility. It features 20 digital input/output pins, 6 analog input pins, a 16 MHz crystal oscillator, USB connectivity, a power jack, and a reset button. Programs can be uploaded to the board using the Arduino Integrated Development Environment (IDE).

The circuit diagram of the monitoring system is shown in Figure 1. The main components of the system include a breadboard, an Arduino R3 microcontroller, a soil moisture sensor, a DHT11 temperature sensor, an LCD display, a water pump, and a fan. The LCD is used to show the temperature and humidity of the environment. The water pump continuously circulates water through the system to keep the environment cool. The fan

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Page: 70-80

blows air into the system to maintain a steady temperature close to the plant. If the soil moisture level in the pot falls below a certain threshold, the water pump will automatically turn on to replenish the water. Similarly, if the temperature of the environment exceeds a certain threshold, the fan will turn on to blow cool air to the plant.

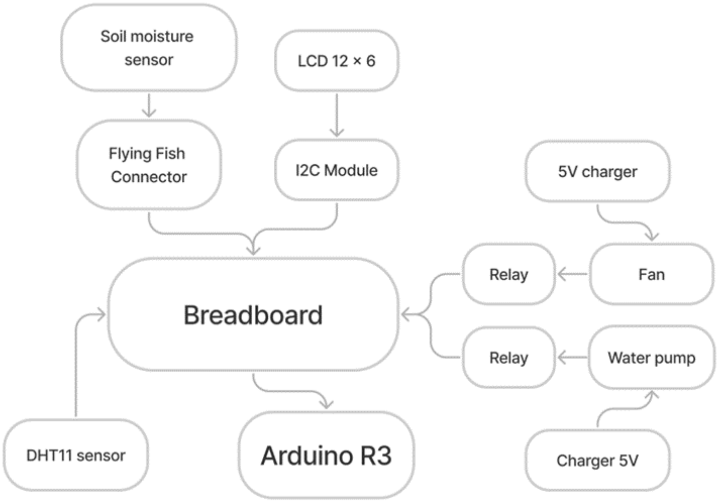

Figure 1. Schematic Plant Monitoring System Diagram

A relay is an electrical device that functions as a switch, allowing a circuit or multiple circuits to be controlled by a separate, low-power signal. In long-distance communication systems, relays were used to amplify and transmit signals from one circuit to another. In our current application, relays are used to interrupt or establish the flow of electricity to components such as water pumps and fans that require separate power.

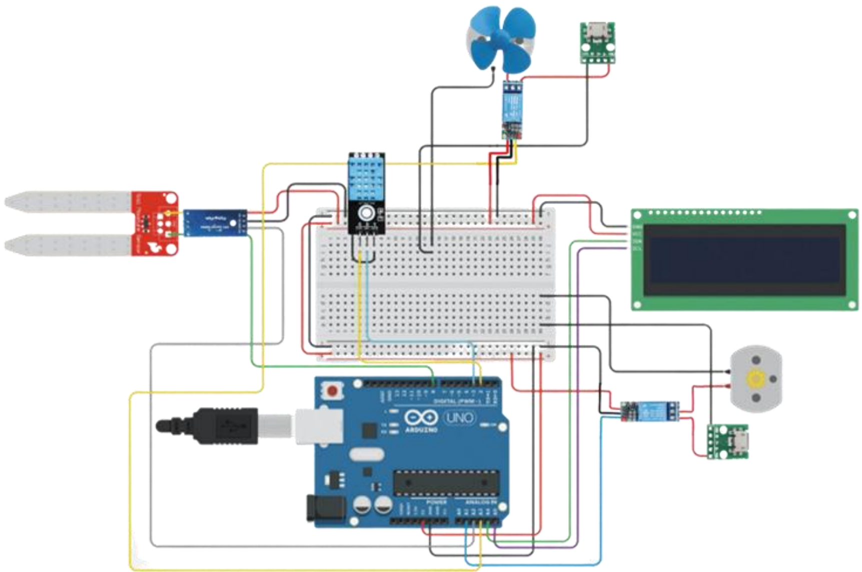

Figure 2. Arduino-based Monitoring System Circuit

The complete Arduino circuit diagram of the system, as illustrated in Figure 2, comprises several key components: an Arduino Uno R3, an LCD, a temperature sensor, a soil moisture sensor, a fan, and a water pump. Each component plays a specific function in the plant monitoring system:

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Page: 70-80

- The Arduino Uno R3 serves as the microcontroller board, providing a user-friendly interface for programming and interfacing with various sensors and actuators. It is the central unit of the system, controlling the functions of the other components and processing the data collected by the sensors.
- The LCD is a display screen that shows plant monitoring data, such as temperature, humidity, soil moisture, and other parameters. It is connected to the Arduino board and receives data for display.
- The temperature sensor measures the temperature of the plants and their surroundings. It is connected to the Arduino board, which reads the sensor data and processes it for display on the LCD.
- The soil moisture sensor measures the moisture content of the soil where the plants are growing. It is also connected to the Arduino board, which reads the sensor data and processes it for display on the LCD.
- The fan controls the ventilation of the plants' surroundings. It is connected to the Arduino board through a relay which can turn it on or off based on the temperature and humidity readings from the sensors.
- The water pump controls the watering of the plants. It is also connected to the Arduino board through a relay which can turn it on or off based on the soil moisture readings from the sensors.

The plant monitoring system circuit involves connecting these components to the Arduino board, programming the Arduino board to control the functions of the sensors and actuators, and displaying the collected data on the LCD. The system monitors the plants' temperature, humidity, soil moisture, and ventilation and watering needs, and provides accurate and reliable plant monitoring data. The implementation of the proposed system prototype, including its setup for experimentation, is shown in Figure 3.

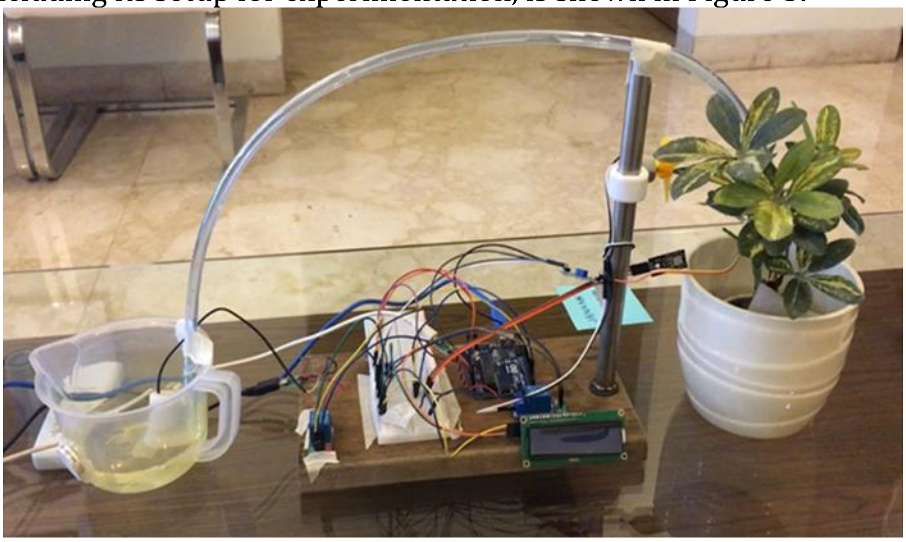

Figure 3. Hardware Setup

Figure 3 shows the setup of the proposed system prototype in an experimental environment, and how the different components interact with one another to monitor and control the environment of the simulated plant. The plant monitoring system connected to a water reservoir and water pump on the left side. A water pump is connected to a watering hose that runs to a simulated plant which is placed on a tray on the right side. The simulated plant

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Page: 70-80

is equipped with a soil moisture sensor, a temperature sensor, and a fan which is placed above the plant. LCD display shows the data of temperature and soil moisture. In order to determine the amount of soil dryness, the soil humidity sensor begins by reading soil moisture level. The sensor then transmits the data to Arduino Uno R3. Afterwards, the temperature sensor reads the temperature data from the plant environment. The sensors subsequently transmit both data, i.e. moisture level and temperature level, to the Arduino microcontroller. The proposed monitoring system is capable of operating in two distinct modes, automated and manual operation. The system enables the user to have full control and monitoring capabilities over soil moisture and ambient temperature, allowing for customization of moisture and temperature threshold values for each sensor. The user may manually execute the watering operation by pressing the watering button on the Arduino. When the watering operation is complete, a moisture meter's display will indicate a real-time increase in moisture level. The entire procedure is depicted in Figure 4's flowchart.

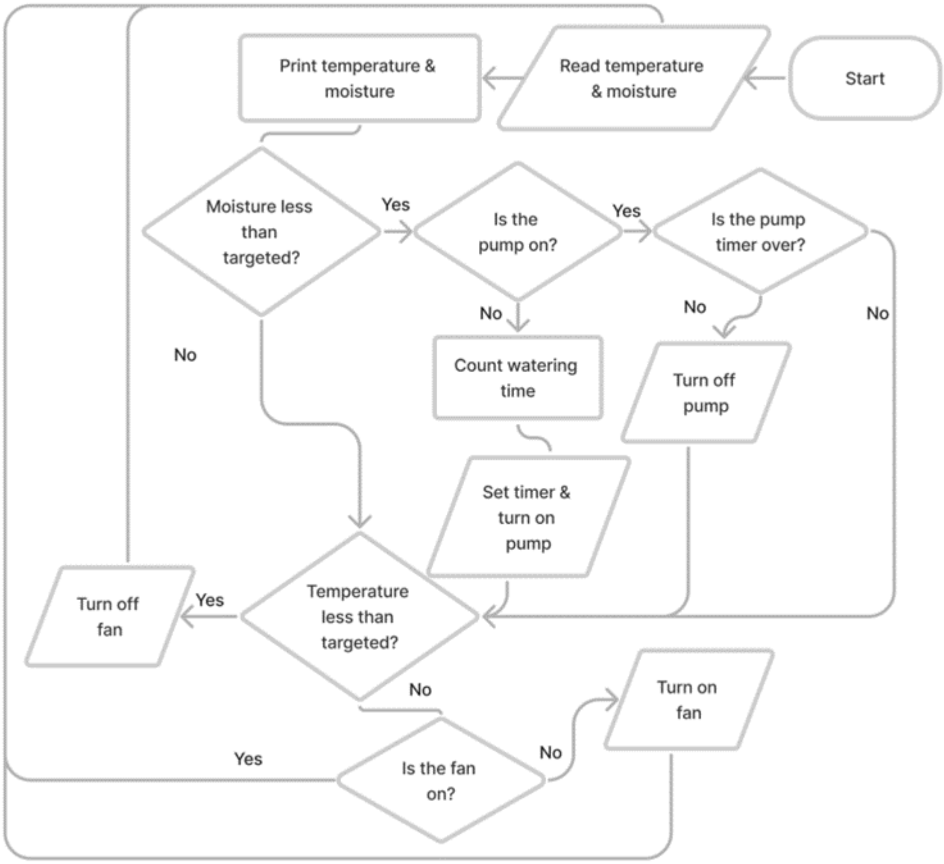

Figure 4. Flow Chart of the Monitoring Process

When the system is running, the temperature sensor will read the air temperature and soil moisture sensor will read soil moisture. The obtained value will be sent to the serial port monitor and LCD. The program will check if the soil moisture is less than the target, then the program will further check whether the pump is on. If the humidity is more than the target, it will continue to check whether the temperature detected is less than the target.

When the pump is on, then the program checks whether the pump timer has run out. If the pump is off, the program will calculate the time needed to irrigate, activate the timer

ISSN:2828-4925
DOI:10.47841/icorad.v2i1.84
Page: 70-80

and turn on the water pump. The program then continues to monitor whether the detected temperature is below the target.

If the humidity falls below the target and the pump timer expires, the system will shut off the pump. If the pump timer has not yet elapsed, the program will continue to monitor whether the temperature is below the target. If the temperature is less than the target, the fan will turn off and the program will return to the beginning and loop. If the temperature is not less than the target, then the program will check whether the fan is on or not. If not, then the fan will be turned on and the program returns to the beginning. If the fan is already on, then the program will immediately return to the beginning.

Soil moisture sensor measures the moisture content in the soil. We used a measurement based on volumetric water content (VWC), which is the ratio between the volume of water and the volume of soil (Clayton et al., 2021).

$$\mathrm{VWC} = \frac{\mathrm{VoW}}{\mathrm{VoS}} \quad (1)$$

Where:

VWC = Volumetric water content
VoW = Volume of water
VoS = Volume of soil

For a given surface area, the volumetric water content can be expressed as a ratio of water depth to soil depth.

$$\mathrm{VWC} = \frac{\mathrm{DoW}}{\mathrm{DoS}} \quad (2)$$

Where:

DoW = Depth of water
DoS = Depth of soil

The equation (2) can further be expressed in percentage.

The performance of the plant monitoring system's performance was evaluated through a controlled experiment using a plant vase measuring 100 cm^2 in surface by 10 cm in height as the experimental environment. The vase was supplied with water through a water pump, and the experiment was conducted in an open area with a room temperature as the ambient condition.

RESULTS AND DISCUSSION

The evaluation of the proposed plant monitoring system includes assessing the system's accuracy and effectiveness. In the experiment, the plant monitoring system was configured to maintain a target humidity of 50% and a target temperature of 25°C. The performance of the plant monitoring system was assessed by conducting tests in various conditions where the humidity deviated from the target value, both above and below. The results of these tests are summarized as follows:

Table 1: Result of watering system experiment

ISSN:2828-4925
DOI:10.47841/icorad.v2i1.84
Page: 70-80

No.	Initial Humidity	Target Humidity	Watering Time	Resulted Humidity	Volume of Water Given	Result
1	33%	50%	7 seconds	50%	165 ml	Successful
2	65%	50%	0 seconds	65%	0 ml	Successful
3	25%	50%	11 seconds	50%	290 ml	Successful
4	12%	50%	15 seconds	50%	400 ml	Successful

Table 1 shows the results of the watering system experiment. The "Initial Humidity" column indicates the starting humidity level, the "Target Humidity" column indicates the desired humidity level, and the "Watering Time" column indicates the length of time that the watering system was in use. The "Resulted Humidity" column shows the final humidity level after the test, the "Volume of Water Given" column shows the amount of water used in each trial, and the "Result" column indicates whether the watering system was successful in achieving the target humidity. According to the data in Table 1, the watering system was able to achieve the target humidity level of 50% in all four trials. The "Resulted Humidity" column demonstrates that the final humidity level was 50% in each case. The only exception is the second trial, in which the initial humidity was already 65%, and thus no watering was required. Overall, the experiment was successful in achieving the desired humidity level through the use of watering system.

Table 2: Result of cooling system experiment

No.	Initial Temperature	Target Temperature	Fan Status	Resulted Temperature	Result
1	29°C	25°C	On	28°C	Unsuccessful
2	28°C	25°C	On	28°C	Unsuccessful
3	25°C	25°C	Off	25°C	Successful
4	24°C	25°C	Off	24°C	Successful

Table 2 shows the results of the cooling system experiment. The "Initial Temperature" column indicates the starting temperature of the system, the "Target Temperature" column indicates the desired temperature, and the "Fan Status" column indicates whether the fan was on or off during the test. The "Resulted Temperature" column shows the final temperature after the test, and the "Result" column indicates whether the cooling system was successful in reaching the target temperature. Based on the results shown in the table, the cooling system was unsuccessful in reaching the target temperature of 25°C in the first two trials despite the fan was on. On the contrary, the cooling system was successful in maintaining the target temperature of 25°C in the third and fourth trials while the fan was off. These results suggest that the cooling system is not effective at achieving the desired temperature in an open space environment.

CONCLUSION

The proposed plant monitoring system was implemented and rigorously evaluated to determine its accuracy and effectiveness by conducting experiments under various conditions where the humidity and temperature deviated from the target values. The results of the experiments indicate that the system is highly effective in achieving the target

ISSN:2828-4925
DOI:10.47841/icorad.v2i1.84
Page: 70-80

humidity levels. This finding confirms the conclusions of previous research (Kumar & Magesh, 2017) that automatic plant irrigation based on soil moisture using Arduino can be implemented successfully. However, the results of the temperature monitoring system were not as favorable and suggest that further improvements in the cooling system are necessary to make it more effective in open space environments. This research identified some limitations of the system, such as its limited temperature monitoring and control capabilities within a certain range, which may be problematic in large-scale and open-air plant monitoring applications. These limitations can potentially be addressed through further research and development efforts, such as improving the cooling system with larger fans or more advanced cooling systems, and enhancing the system's performance with advanced algorithms and signal processing techniques.

In addition, we found that the proposed system was user-friendly and easy to set up and operate. The user interface and controls were intuitive and straightforward, making it accessible for users with limited technical expertise. Overall, our research shows that the plant monitoring system using Arduino has the potential to provide accurate and reliable plant monitoring data, and its low cost, efficiency, and ease of use make it a valuable tool for increasing plant productivity and yields

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Page: 70-80

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