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Utilization of Radio Frequency for Monitoring the Temperature of Hydroponic Plants Based on the Internet of Things

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Abstract
This research aims to develop a temperature monitoring system for hydroponic plants based on the Internet of Things (IoT), using the nRF24L01 radio frequency module. The system is designed to monitor the temperature of hydroponic plants, specifically spinach and chili, and to evaluate its range and efficiency compared to traditional methods such as GSM and Wi-Fi. With this technology, users can monitor and control the hydroponic environment in real-time through a smartphone, which can enhance the efficiency and effectiveness of plant cultivation. The research results indicate that the radio frequency module has a better data transmission range and higher reliability compared to traditional methods, making it an effective and practical solution for hydroponic monitoring. Additionally, this system provides significant benefits in improving plant growth and productivity by ensuring optimal environmental conditions. The use of IoT and radio frequency technology in this research demonstrates great potential for broader applications in agriculture, particularly in promoting more sustainable and efficient farming practices. These findings open up opportunities for further development in utilizing technology to support modern, connected, and smart agriculture.
Keywords: Hydroponic Plants, Radio Frequency, Monitoring System Internet of Things

Introduction
With the growth of the population, the demand for organic food, especially vegetables and fruits, has also increased. However, this increase is not accompanied by an adequate expansion of agricultural land. On the contrary, there has been a reduction in land due to its conversion into residential areas and the development of modern infrastructure. This challenge has spurred innovations in agriculture, one of which is the hydroponic farming system [1].

Hydroponics serves as a solution for urban communities with limited land, as it uses water as a substitute for soil. This system allows for easier monitoring and control through the use of Internet of Things (IoT) technology. With IoT, farmers can use their internet-connected mobile phones to monitor and control hydroponic systems in real-time, minimizing manual intervention [2].

However, some common data communication technologies used in hydroponic systems, such as GSM and Wi-Fi, have limitations. The use of GSM modules can sometimes be inefficient due to frequent network disruptions, while Wi-Fi requires additional installations like access points, which can be quite expensive for each hydroponic location. A more efficient alternative is the use of radio frequency (RF), which offers better range and lower costs [3].

The results of this research are expected to demonstrate that radio frequency is an effective solution for real-time monitoring and control of hydroponic environments, addressing the limitations of previous technologies. Thus, this research contributes to the development of more efficient and sustainable modern agriculture [4].

Literature Review
1. Monitory System
Monitoring is defined as a training pattern that combines the collection, surveying, disclosure, and follow-up of data about the ongoing cycle. In most cases, monitoring is used to compare performance against predetermined goals. The observations explored from relationships to board implementation represent an integrated interaction to ensure that the cycle operates as expected (on track). The continuity of the process can be monitored to determine the next steps towards continuous improvement [5].

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2. Objectives of the Monitoring System

The monitoring system has several objectives. The objectives of the monitoring system can be viewed from various perspectives, including the subjects and objects being monitored and the outcomes of the monitoring process. The following are some objectives of the monitoring system [6]:

1. To ensure that procedures are carried out according to relevant guidelines, so that the process stays on track.
2. To provide high data accuracy possibilities to the participants.
3. To quickly identify undesirable outcomes within a cycle (without assuming that the cycle will be completed).
4. To foster inspiration and a positive inclination among workers.

3. Functions of the Monitoring System

In the context of hydroponic systems, the monitoring system utilizes various sensors to measure plant conditions such as temperature, humidity, water pH, and nutrient content. Data from these sensors is sent to a server or IoT platform like ThingSpeak, where it can be accessed and analyzed by users through a smartphone or web application. Users can monitor plant conditions and perform remote control to ensure optimal growth. The following are the functions of the monitoring system [7]:

1. Performance Monitoring: Measuring the performance of various system components, such as CPU usage, memory, network bandwidth, and service availability.
2. Problem Detection: Quickly identifying issues or disruptions in the system, allowing for resolution before they escalate.
3. Reporting and Analysis: Providing reports and analysis on system performance and status to aid in decision-making and planning.
4. Alerts and Notifications: Sending alerts and notifications to administrators or users when issues or abnormal conditions are detected.
5. Maintenance and Repair: Assisting in planning and executing proactive maintenance and repairs based on monitoring data.

4. Arduino Nano

Arduino Nano is a small-sized board designed based on the Atmega 328 or Atmega 168. This board is one of the most popular microcontrollers due to its small size and ease of use. Additionally, Arduino is an open-source electronic platform with hardware and software that are easy to use. One of the reasons Arduino captivates many people is its open-source nature, both for hardware and software. The main component inside the Arduino board is an 8-bit microcontroller branded Atmega, manufactured by Atmel Corporation [8].

5. Internet of Things

The Internet of Things (IoT) is the idea of objects that can transfer data over a network without requiring human-to-human interaction or communication with a computer. The Web of Things (WoT) is a construct of items endowed with selective characteristics and the capacity to move information through an organization without requiring two-way human-to-human communication, particularly source to destination or human-to-computer cooperation [9].

6. Real Time Clock (RTC)

RTC is an electronic circuit that serves as a time reference. Typically, RTCs are used in electronic devices that require precise timekeeping in accordance with world time. RTCs differ from conventional clocks because they usually exist as integrated circuits (ICs). The system can focus on its primary functions while utilizing the RTC. Additionally, the RTC has a separate power source from the system. Therefore, even when the system is powered off, the RTC continues to operate, and restarting the system will not cause the time to stop or be reset [10].

Materials & Methods

1. Research Steps

he first stage is preparation, which includes initial planning in the form of a research proposal. There are several general steps in this research plan. The second type of research is called literature research. In literature research, references from scientific journals, articles, and official websites discussing hydroponic plants and the Internet of Things are used to gather data for the case study of the system device. The third stage involves testing the tool, where data collection is based on the results from testing the nRF24L01 as a radio frequency module to transmit sensor data to the microcontroller gateway and hydroponic automation system.

2. Research Steps

The type of data used by the author is primary data. Data collection is based on the results of specific tool testing, and primary data is obtained from these results, specifically from the nRF24L01 as a radio frequency module to transmit sensor data to the microcontroller gateway and the hydroponic automation system.

3. System Schematics

The system diagram used in this research illustrates how the author can operate the sensors within the monitoring system using the Arduino IDE, which will function to read temperature and humidity levels in hydroponic plants. The system diagram can be described as follows:

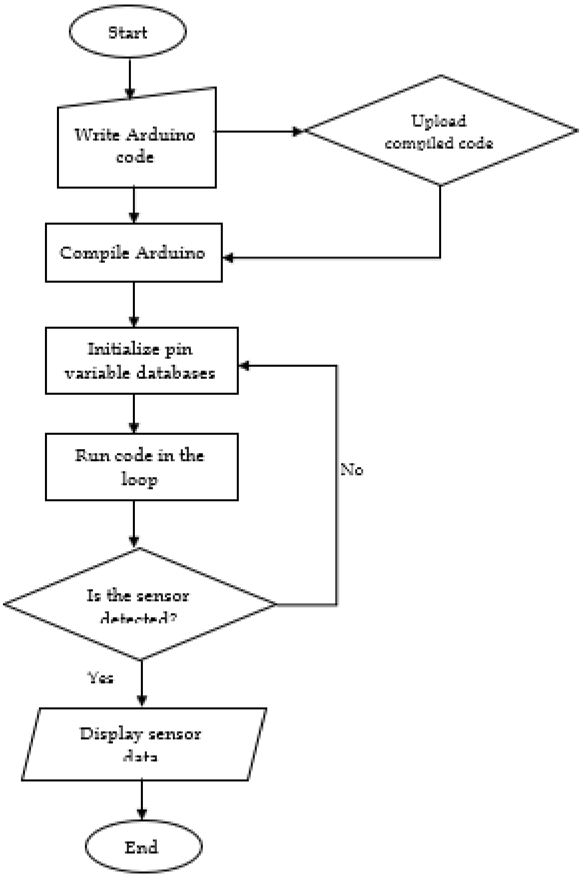

Figure 1. System Schematics

Description:

1. Process Begins: The development process starts by preparing the Arduino hardware and connecting it to the computer for programming.
2. Writing Code: The first step is to write the Arduino code using the Integrated Development Environment (IDE) software. In this step, the programmer writes the instructions that will be executed by the Arduino in C/C++ programming language.
3. Compilation**:** After the code is completed, the next step is to compile the code. Compilation is the process of converting the source code into binary code that can be understood by the Arduino microcontroller. This process also checks for syntax errors and ensures that there are no bugs in the code.
4. Uploading Code to Arduino: If the compilation is successful without errors, the code is uploaded to the Arduino board via USB cable. If there are errors, the programmer goes back to the code writing step to fix them.
5. Setup Function: The setup() function is part of the code that is initialized first. This is where variables, pin modes (such as input or output), and libraries are initialized. The setup() function is only executed once each time the Arduino is powered on or reset.
6. Loop Function: The loop() function is the part of the code that runs repeatedly while the Arduino is operational. This function ensures that the Arduino continuously executes the instructions.
7. Running Code in Loop: The code written within the loop() function will be executed repeatedly. This includes various instructions specified by the programmer.
8. Reading Sensor Data: One common task in loop() is to read data from sensors connected to the Arduino. These sensors can include temperature, humidity, light sensors, and others.
9. Sending Output to Actuators: Based on the data received from the sensors, the Arduino sends signals to actuators such as LEDs, motors, and other devices. These actions may include turning devices on or off, changing motor speeds, or controlling other devices.
10. End: After one cycle of the loop() function is completed, the process returns to the beginning of the loop() function and continues to run until the Arduino is powered off or reset. This process runs continuously while the system is operational.

Results and Discussion

The analysis of the current system aims to understand the workflow and processes of the existing system. In this case, the analysis involves document review and procedural system analysis, allowing for evaluation and providing an overview of a new system as part of problem-solving. The system design process is necessary because the current system

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is not yet computerized.

1. Evaluation of the Current System

After analyzing the running information system, several issues have been identified, including:

1. Advantages of the IoT-Based Monitoring System
   The IoT-based monitoring system can assist farmers in monitoring temperature and humidity during hydroponic planting.
2. Disadvantages of the IoT-Based Monitoring System
   It cannot output data via SMS or Telegram, so it is still reliant on the website.

2. Problem Analysis

The demand for plants and crops that are staple foods has risen due to the increasing human population. This, in turn, affects the shrinking available land, making it difficult for farmers to cultivate. Especially in urban areas like Lhokseumawe, where the population is dense and residential land is limited, farmers and households who wish to grow vegetables face greater challenges. The system developed by the author is a monitoring system to observe the stability of temperature and humidity for plants, as hydroponic plants are sensitive to air conditions and struggle to survive in unstable environments. Therefore, an accurate and real-time monitoring system is needed to provide easily accessible information regarding temperature for users.

3. System Analysis

The system developed by the author uses the DHT-22 or AM2302 sensor, which measures temperature and humidity. This sensor outputs a digital signal, with conversion and calculation performed by an 8-bit MCU. The DHT22 sensor has accurate calibration with room temperature compensation, with coefficient values stored in integrated OTP memory. The DHT22 sensor has a wide range for measuring temperature and humidity and can transmit output signals over cables up to 20 meters. However, if the cable length exceeds 2 meters, a 0.33µF buffer capacitor should be added between pin 1 (VCC) and pin 4 (GND).

4. Algorithm Analysis

In analyzing the system for establishing two-way communication between the gateway node and the client node in the RF-based monitoring system, several important steps and components must be considered. Below is a general guide on how to implement two-way communication. Implement a communication protocol that enables data transmission and reception. This protocol could be a simple one, such as serial communication with specially formatted messages, ensuring that the RF module at the gateway and client nodes are configured with the same address and frequency for successful communication using the nRF24L01 module, with a unique address assigned to each node. Data transmission requires the client node to have code to read data from the sensor and send it to the gateway node. For example, when using the nRF24L01 module, the RF24 library can be utilized on Arduino for data transmission. Command reception requires the client node to have code to receive commands from the gateway node. After receiving a command, the client node can take appropriate actions (e.g., activating a relay or changing sensor configurations).

5. Data Processing Analysis

In the monitoring system using the DHT22 sensor, the algorithm includes steps to read data from the sensor, validate the data, handle errors, and store or send data for further monitoring. The initialization of the DHT22 sensor involves specifying the pin used for the data connection. Serial communication is initialized to allow data transmission to a computer or other devices. The monitoring system can provide notifications or alarms when it detects anomalies or conditions that require immediate attention, enabling a quick response and problem-solving before broader impacts occur. Data can be sent to monitoring platforms like ThingSpeak or Blynk by adding code to transmit data using HTTP or MQTT. This creates a simple monitoring system that uses the DHT22 sensor to monitor temperature and humidity and sends this data to an online monitoring platform for real-time tracking. Data readings from the sensor can be visualized as shown in the image below:

```
// Uncomment the type of sensor in use:
//#define DHTTYPE    DHT11     // DHT 11
#define DHTTYPE    DHT22     // DHT 22 (AM2302)
//#define DHTTYPE    DHT21     // DHT 21 (AM2301)

DHT dht(DHTPIN, DHTTYPE);

// current temperature & humidity, updated in loop()
float t = 0.0;
float h = 0.0;

// Create AsyncWebServer object on port 80
AsyncWebServer server(80);

// Generally, you should use "unsigned long" for variables that hold time
// The value will quickly become too large for an int to store
unsigned long previousMillis = 0;    // will store last time DHT was updated

// Updates DHT readings every 10 seconds
const long interval = 10000;

const char index_html[] PROGMEM = R"rawliteral(
<!DOCTYPE HTML><html>
<head>
```

Figure 2. Sensor Data Analysis Process

It can be seen from the image above that the sensor will send valid data via serial communication for local monitoring. In the example code, data is read every 10 seconds. Continuous data reading requires efficient memory usage, especially on microcontrollers with limited resources like Arduino. This interval can be adjusted according to the application needs. Initialization involves reading the temperature and humidity levels around the water of hydroponic plants.

6. Monitoring System Data Analysis

The data obtained can be stored on local storage, such as an SD card connected to the Arduino, for further analysis. The system also sends data to a server, ensuring that the collected information is available for future reference. Data is taken at 2-second intervals during a 10-minute testing period. Below is an example of the data results obtained:

Table 1. Monitoring System Data Output

TIME	TEMPERATURE (°C)	HUMIDITY (%)
2024-06-20 10:00:00	25.3	55.2
2024-06-20 10:00:10	25.4	55.1
2024-06-20 10:00:20	25.4	55.1
2024-06-20 10:00:30	25.5	55.1
2024-06-20 10:00:40	25.5	55.2
2024-06-20 10:01:20	25.5	55.3
2024-06-20 10:00:50	25.6	55.2
2024-06-20 10:00:60	25.6	55.3
2024-06-20 10:01:10	25.5	55.3
2024-06-20 10:01:30	25.6	55.1

Table 2. Monitoring System Data Output (Continued)

TIME	TEMPERATURE (°C)	HUMIDITY (%)
2024-06-20 10:01:40	25.6	55.1
2024-06-20 10:01:50	25.3	55.1
2024-06-20 10:01:60	25.4	55.2
2024-06-20 10:02:10	25.4	55.2
2024-06-20 10:02:20	25.5	55.3
2024-06-20 10:02:30	25.5	55.3
2024-06-20 10:02:40	25.6	55.3
2024-06-20 10:02:50	25.6	55.2

The data shows consistency in temperature and humidity measurements with very small fluctuations. This indicates that the DHT22 sensor performs well in a stable environment. The temperature ranges from 25.3°C to 25.8°C, which is a small and acceptable variation for room temperature measurements. Humidity ranges from 55.0% to 55.4%, demonstrating high consistency in humidity measurements. The DHT22 sensor has a temperature accuracy of approximately ±0.5°C and a humidity accuracy of around ±2-5%. The small variations in measurement results fall within the expected accuracy limits. Readings are taken every 10 seconds, and the data shows good responsiveness of the sensor to changes in temperature and humidity, even though these changes are very minor. The implementation of the monitoring system using the DHT22 sensor on Arduino has successfully measured the environmental temperature and humidity in real-time. The data produced is consistent and meets the specifications of the sensor. This system is suitable for environmental monitoring applications, home automation, and particularly for hydroponic plants involved in this research.

7. System Advantages Analysis

The implementation of the monitoring system using the DHT22 sensor on Arduino provides an effective and economical solution for temperature and humidity monitoring. With adequate accuracy and the ability to integrate with various platforms, this system has broad applications in various fields. However, it is important to consider potential errors and ensure proper calibration and error handling to maintain system reliability. The DHT22 sensor has a temperature accuracy of about ±0.5°C, which is quite good for general applications, allowing for adequate precision in temperature monitoring. The humidity accuracy of this sensor is approximately ±2-5%, enabling fairly accurate monitoring of environmental humidity.

This sensor has low power consumption, making it suitable for battery-powered applications. This is essential for remote monitoring applications or IoT devices that need to operate for extended periods without frequent battery replacements. With available libraries like Adafruit DHT, developing systems using this sensor becomes easier. This library provides functions that simplify reading data from the sensor. The DHT22 sensor is relatively inexpensive compared to other temperature and humidity sensors with similar accuracy, making it an economical choice for many

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DIY projects, educational purposes, and commercial applications. The DHT22 sensor is known for its stability and reliability in various environmental conditions. It has a good response time and can provide consistent readings over time.

8. Results of the Monitoring System Implementation

The development of plants, as indicated by the implementation of the monitoring system, can assist in evaluating whether the established system effectively monitors hydroponic plants.

Figure 3. Plants Without Monitoring

The spinach and chili plants shown in the above image were grown using a hydroponic system without temperature and humidity monitoring. As a result, their conditions could not be monitored, leading to unstable growth and uneven development, with leaves wilting easily.

In contrast, plants grown with a monitoring system thrive well and grow uniformly, with no wilting leaves. This is because temperature and humidity are monitored every 10 seconds. The following image illustrates this difference:

Figure 4. Plants with Monitoring

Conclusions

The use of radio frequency technology in the IoT-based hydroponic system has proven to enhance the efficiency of monitoring and controlling plant conditions. With more accurate real-time monitoring, the productivity of hydroponic plants can be increased. This system allows users to monitor and control hydroponic conditions remotely through mobile devices, providing convenience for farmers to check on their plants without needing to be physically present.

The implementation of two-way communication between the gateway node and the client node using the nRF24L01 module has been successfully achieved. This allows for data transmission from the sensors to the gateway and the reception of commands from the gateway to the client node. The use of external antennas on the nRF24L01 PA LNA module is recommended to optimize communication range and reliability.

The use of radio frequency as a data transmission medium replaces wired connections, GSM, and Wi-Fi. The system built with the nRF24L01 radio frequency module is more practical and economical compared to the use of access points or GSM modules, which are relatively more expensive and susceptible to network interference. Thus, this research demonstrates that the application of radio frequency technology and IoT in hydroponic systems provides significant benefits in enhancing efficiency, accuracy, and ease of managing hydroponic plants. The implementation of this system can serve as a practical and effective solution for farmers in optimizing hydroponic agricultural yields.

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