IOT, First Semester, 2024

Final Report

Innovating Plant Care with IoT: A Journey Through Sensor-Based Environmental

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Table of Contents

Abstract 1
Introduction 2
Project Overview 3
Importance of Plant Environment Management 5
Review of Existing Solutions 6
Technologies and Implementation 7
Results and Demonstration 10
Challenges and Solutions 13
Conclusion 14
Future Directions 15
References 16
Appendices 17

Abstract

The integration of Internet of Things (IoT) technology in agriculture has opened new horizons for precision farming, enabling enhanced monitoring and management of plant environments. This project presents a novel approach to leveraging IoT and cloud computing technologies to develop a user-friendly system for real-time plant environment management. Utilizing environmental sensors, AWS cloud services, and the IoT MQTT Panel app, this system automates the monitoring and adjustment of temperature, humidity, and water levels, ensuring optimal growth conditions for plants.

The simplicity principle guided the system's design, ensuring ease of use and maintenance, making sophisticated technology accessible to users without extensive technical backgrounds. Through seamless integration with AWS services such as DynamoDB for data synchronization and Lambda for real-time data processing, the system offers a scalable solution capable of responding to environmental changes promptly.

Key components include temperature, humidity, and water level sensors, which collect data transmitted to AWS for processing against user-defined parameters. If deviations are detected, automated adjustments are triggered to rectify environmental conditions, thereby reducing manual intervention and enhancing plant health and productivity.

This project not only demonstrates the practical application of IoT in agriculture but also underscores the importance of simplicity in designing effective technological solutions. Future directions involve incorporating advanced sensors and machine learning algorithms to predict plant needs more accurately, enhancing the system's efficiency and sustainability.

Keywords: *Internet of Things, precision agriculture, AWS, cloud computing, environmental monitoring, plant environment management, simplicity principle, IoT MQTT Panel, real-time data processing, automated adjustments.*

Introduction

The Internet of Things (IoT) has revolutionized various sectors by enabling the connectivity of physical devices equipped with sensors and software, thus facilitating smarter decision-making and automation. This technological integration offers unprecedented control, efficiency, and insight into applications such as smart homes, healthcare, and industrial automation.

In agriculture, IoT represents a significant shift towards precision farming, addressing key challenges like the need for increased productivity and sustainability in the face of a growing global population and environmental concerns. By utilizing data from sensors and other devices, IoT enables farmers to closely monitor and manage resources, optimizing practices such as irrigation, fertilization, and pest control. This not only reduces labor costs but also enhances overall farm efficiency.

Moreover, IoT contributes to sustainable farming by minimizing resource waste and environmental impact. Smart irrigation systems, for example, adjust watering based on real-time data, significantly reducing water use. Similarly, IoT-driven pest management allows for precise pesticide application, lowering environmental chemical load.

Overall, IoT in agriculture opens up opportunities for more intelligent, efficient, and sustainable farming practices. It underscores the need for solutions that are accessible and scalable, ensuring global agricultural advancements that benefit farmers of all technical levels and resource availabilities.

Project Overview

This project embodies the integration of Internet of Things (IoT) technology with cloud computing to innovate plant care management. By harnessing the capabilities of IoT, the project aims to provide a comprehensive solution for monitoring and managing environmental conditions crucial for plant growth. The ultimate objective is to automate the adjustment of these conditions, leveraging sensor data and cloud computing services to optimize plant health and productivity.

Objectives:

- Implement IoT Technology: To monitor and manage plant environments, utilizing the precision and connectivity of IoT devices for real-time data collection.
- Automate Environmental Adjustments: Leveraging AWS cloud computing to analyze sensor data and automatically adjust environmental conditions to ensure optimal plant growth.

This structured approach underscores the project's primary goals: to harness IoT for detailed environmental monitoring and utilize cloud computing for the intelligent automation of plant care processes.

Key Components:

1. Sensors:
    - Utilization of the Raspberry Pi Pico as a microcontroller, interfaced with DHT11 (temperature and humidity) (Appendix-A) and HW-038 (water level) (Appendix-B) sensors. These sensors are pivotal for collecting real-time data on temperature, humidity, and water levels within the plant environment.
2. AWS Cloud Services:
    - Data Collection and Storage: Implementation of AWS DynamoDB to securely store the sensor data collected from the plant environment.
    - Data Processing and Analysis: Use of AWS Lambda to analyze the sensor data against user-defined parameters and make informed decisions on environmental adjustments.
3. User Application:
    - Using an application interface allowing users to specify desired environmental conditions and receive real-time updates and alerts on the status of their plants. This feature empowers users to maintain optimal growth conditions remotely.

Functionality:

- Real-Time Monitoring: The system is designed to continuously monitor the environmental conditions around the plants, leveraging the sensors to provide timely and accurate data.
- User-Defined Conditions: It offers users the flexibility to set specific ranges for essential growth parameters like temperature, humidity, and water levels, ensuring that the plants can thrive in customized environments.
- Automated Adjustments: Central to the project is the capability of AWS to process the collected sensor data and, upon detecting deviations from the user-defined conditions, automatically initiate corrective actions to maintain the desired environmental balance.

Impact:

The project ensuring that plants are cultivated under optimal conditions, significantly reducing the need for manual monitoring and adjustments. Moreover, it introduces a scalable solution to precision agriculture, potentially benefiting a wide range of agricultural practices from small-scale indoor gardens to large-scale farming operations. Through this endeavor, the project not only demonstrates the practical application of IoT in agriculture but also highlights the significance of integrating cloud computing for data-driven plant environment management.

Importance of Plant Environment Management

Plant environment management holds paramount importance in agricultural practices, as it directly influences the growth, health, and yield of crops. Scientifically balancing environmental factors such as temperature, humidity, and water is imperative for ensuring optimal plant physiology and productivity. Each of these factors plays a crucial role in biochemical processes, nutrient uptake, and overall plant metabolism.

- **Temperature:** This pivotal environmental parameter profoundly influences enzymatic activities, photosynthesis rates, and respiratory processes within plants. Extreme temperatures, whether too hot or cold, can induce stress responses in plants, leading to impaired growth and reduced yields.

- **Humidity:** The moisture content in the air, represented by humidity, significantly impacts transpiration rates and water uptake by plants. Correct humidity levels are essential for maintaining plant turgor pressure, facilitating nutrient transport, and preventing diseases caused by fungal pathogens.

- **Water:** Water serves as the lifeblood of plants, facilitating photosynthesis, nutrient absorption, and metabolic processes. However, improper watering practices, such as over-irrigation or drought stress, can disrupt cellular functions, hinder root development, and compromise plant health.

Challenges in manually managing these environmental parameters are abundant, characterized by the labor-intensive and error-prone nature of traditional monitoring methods. Furthermore, subtle fluctuations in environmental conditions demand continuous vigilance, making manual intervention impractical and often ineffective.

Benefits of IoT integration in agriculture:
The integration of IoT technologies offers a paradigm shift in plant environment management, providing real-time monitoring, precise control, and automated adjustments tailored to plant needs. By employing sensors and cloud-based analytics, IoT solutions enable data-driven decision-making, facilitating informed adjustments to environmental conditions in real-time. This proactive approach not only optimizes plant growth and resource utilization but also mitigates the risks associated with environmental variability.

Moreover, IoT integration aligns with broader sustainability objectives in agriculture, promoting efficient resource use, reducing waste, and enhancing the resilience of food systems in the face of climate change. By fostering sustainable practices and enhancing the efficiency of agricultural operations, IoT contributes to the long-term viability of global food production systems.

Review of Existing Solutions

The integration of technology into agricultural practices has yielded a diverse array of solutions aimed at enhancing productivity and sustainability. Below, we examine several key innovations that are currently transforming the sector.

1. **Smart PolyTunnels**: Smart PolyTunnels represent a cost-effective IoT solution designed to control the microclimate in small-scale agricultural settings [1]. These systems utilize sensors to meticulously manage temperature, humidity, and other critical environmental variables, thus enabling farmers to optimize plant growth conditions and potentially extend growing seasons [1].
2. **Wireless Sensor Networks (WSN)**: Serving as the foundation of smart agriculture, Wireless Sensor Networks consist of distributed sensors that collect and communicate vital environmental data [2]. These networks enable real-time environmental monitoring, which supports informed and timely decision-making processes in agricultural management [2].
3. **Precision Farming Tools**: Leveraging IoT for real-time monitoring, Precision Farming Tools empower farmers with precise control over resource distribution, directly affecting crop monitoring and yield optimization [3]. The strategic application of resources, informed by IoT data, can lead to a significant reduction in waste and an increase in crop productivity [3].
4. **Greenhouse Automation**: Greenhouse Automation systems are at the forefront of agricultural innovation, automatically regulating climate to bolster plant growth [4]. By maintaining ideal growth conditions, these systems not only enhance productivity but also improve the overall efficiency of resource utilization within greenhouse environments [4].
5. **Disease Detection**: IoT applications are also making strides in the early detection of plant diseases, utilizing a combination of sensors and data analytics [5]. These technologies are instrumental in identifying disease patterns early on, which can lead to more effective and timely interventions, ultimately preserving crop health and yields [5].

These technological advancements contribute significantly to the smarter, more sustainable agricultural practices that are essential for meeting the growing global food demands. By minimizing waste and optimizing resource use, the agricultural industry is set to become more productive and environmentally friendly [6].

Technologies and Implementation

Technologies Used

The project leverages a combination of IoT devices, cloud computing, and local processing technologies to offer a comprehensive system for real-time plant environment management. The system architecture is designed to ensure reliability and continuity of service, even in scenarios where cloud services may be unavailable. Key components include:

1. **Sensors, Actuators, and Power Management**:
    - **DHT11 Sensor**: For measuring temperature and humidity.
    - **HW-038 Water Level Sensor**: To monitor soil water levels.
    - **Water Pump**: Adjusts water levels as per environmental needs, essential for both manual and automated irrigation processes.
    - **Raspberry Pi Pico**: Acts as the microcontroller, interfacing with sensors, controlling the water pump, and managing data transmission.
    - **Ion Battery and Li-Po Charger Module**: Powers the system, ensuring continuous operation. The charger module is specifically used to manage the power needs of the water pump, which requires a higher current than the other components.

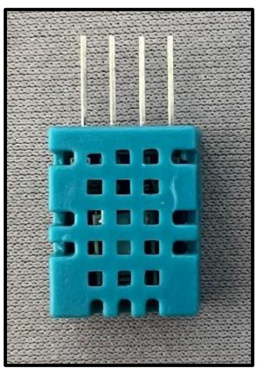

Figure 1-DHT11 Sensor

Figure 2-HW-038 Water Level Sensor

Figure 4-Raspberry Pi Pico

Figure 5-Ion Battery and Li-Po Charger Module

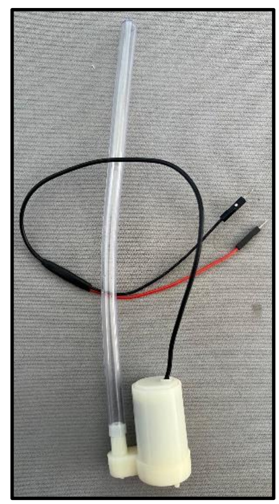

Figure 3-Water Pump

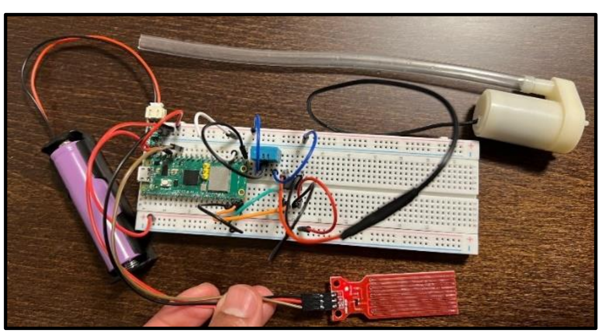

Figure 6-IoT Plant Environment Monitoring and Irrigation Kit

1. **MQTT Protocol:** For efficient and flexible data transmission, the MQTT (Message Queuing Telemetry Transport) protocol is employed. This lightweight messaging protocol is ideal for IoT applications due to its low bandwidth usage and high reliability.

2. **Local and Cloud Processing:**
   - **Local Processing:** Utilizing an IP broker, data is sent to two local destinations for immediate visualization and interaction. This approach ensures that critical monitoring and control functionalities remain operational, even without cloud connectivity.
   - **Cloud Processing:** AWS cloud services are used for advanced data analysis and storage, providing a scalable and secure backend for processing plant environment data.

Implementation

The implementation strategy is designed to optimize data flow, ensuring both local and cloud-based data processing and visualization.

1. **Data Collection and Transmission:** Sensors connected to the Raspberry Pi Pico collect real-time data on temperature, humidity, and water levels. This data is then simultaneously transmitted to three destinations using the MQTT protocol:
   - Two local destinations for immediate visualization and control.
   - AWS cloud services for further processing and storage.

2. **Visualization and Control:**
   - **Control Room Visualization:** A local dashboard presents real-time data through interactive graphs for each plant, displaying temperature, humidity, and water levels over time. This setup enables immediate access to environmental conditions without relying on cloud connectivity.
   - **IoT MQTT Panel Application:** This application offers a comprehensive view of all plants, displaying the latest metrics and historical data trends, and allows users to manually activate the pump to add water. Users can set ideal environmental parameters for each plant directly within the app, which are then transmitted to the cloud for processing.
   - **Cloud Visualization:** Expanding beyond local interfaces, the system integrates AWS QuickSight for an enhanced cloud-based visualization experience. AWS QuickSight taps into the vast computational resources of the cloud to transform raw data into intuitive, interactive dashboards and visualizations.

3. **Cloud Processing:**
   - After receiving the ideal parameters and latest metrics from the IoT MQTT Panel application, AWS services, including DynamoDB for data storage and Lambda for data processing, compare current conditions with ideal parameters. If discrepancies are detected, automated adjustments are initiated to align with the user-defined optimal conditions.

4. **Automated and Manual Adjustments:**
   - The system supports both automated adjustments based on cloud processing results and manual interventions via the IoT MQTT Panel app, ensuring flexibility and user control over the plant environment.

Resilience and Reliability

A key emphasis of this project is the resilience of the system, ensuring its operational integrity even in the absence of cloud services. By integrating local control and visualization capabilities, the system provides uninterrupted access to environmental monitoring and control. This dual approach—leveraging both local and cloud resources—enhances the system's reliability, ensuring that users can maintain optimal plant growth conditions under all circumstances.

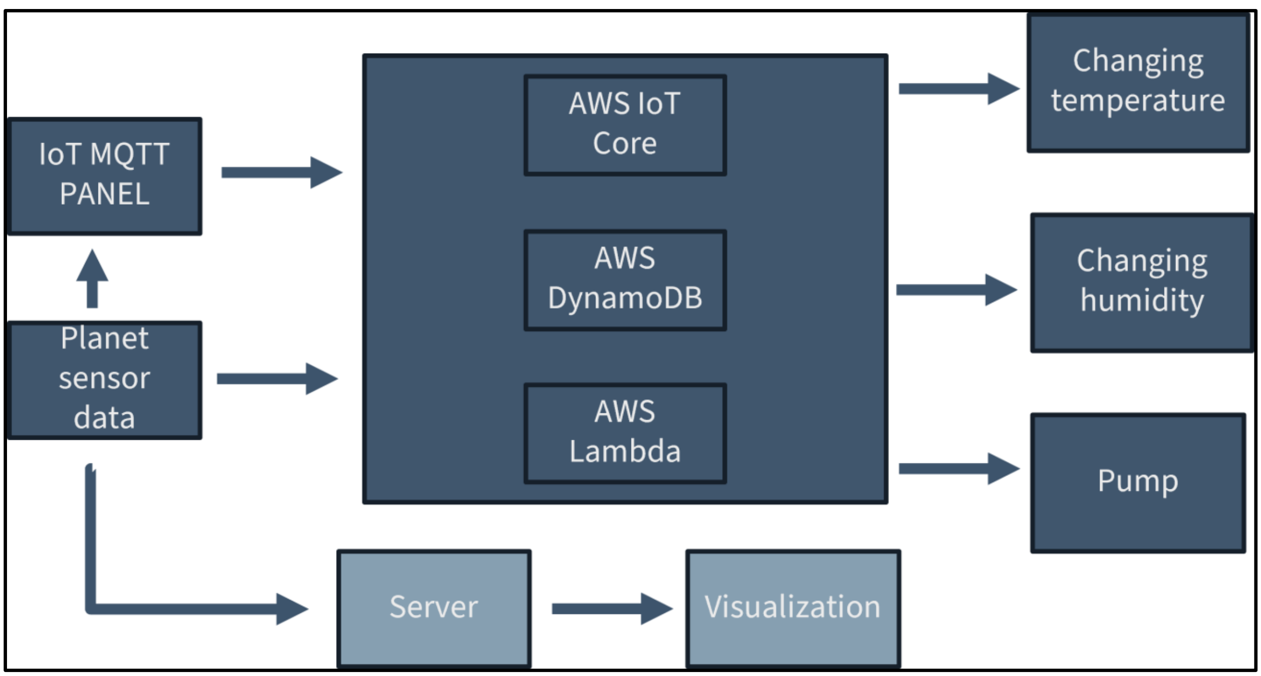

Figure 7-Model architecture

Results and Demonstration

Results:
The project's implementation phase concluded with significant findings, affirming the system's capability to monitor and regulate key environmental factors for plant growth. The integration of IoT technology facilitated precise management of temperature, humidity, and water levels, leveraging both local and cloud-based controls.

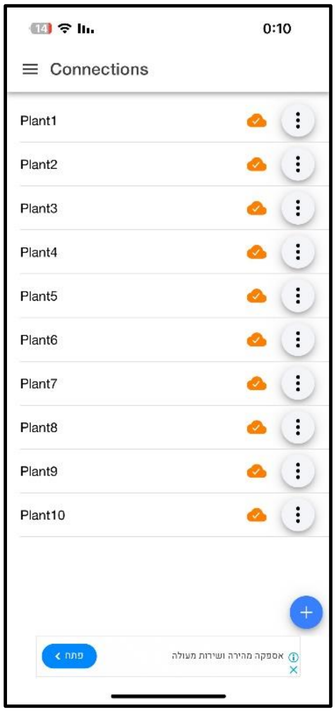

Figure 8-IoT MQTT Panel Application-choose plant

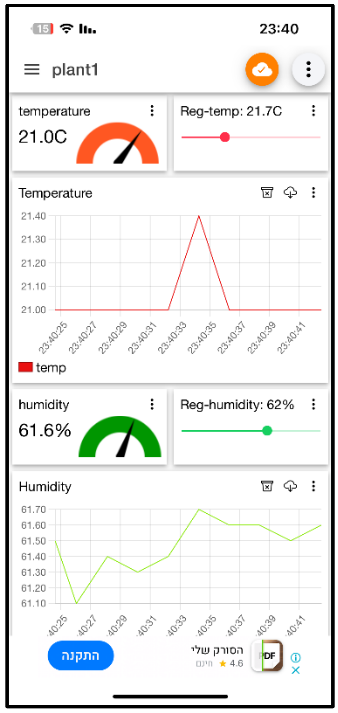

Figure 9-IoT MQTT Panel Application-plant1 visualization

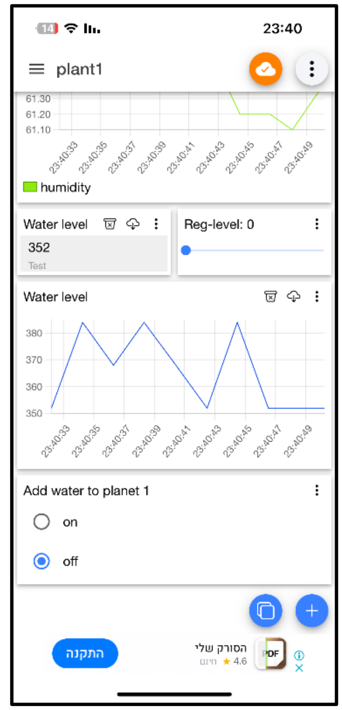

Figure 10-IoT MQTT Panel Application-plant1 visualization and adding water manually

The IoT MQTT Panel app provided a user-centric dashboard, allowing for real-time monitoring and manual intervention. In the app's interface, users could readily observe the current conditions of individual plants and manually activate the pump to adjust the water supply. This manual control is a testament to the system's responsiveness and user accessibility.

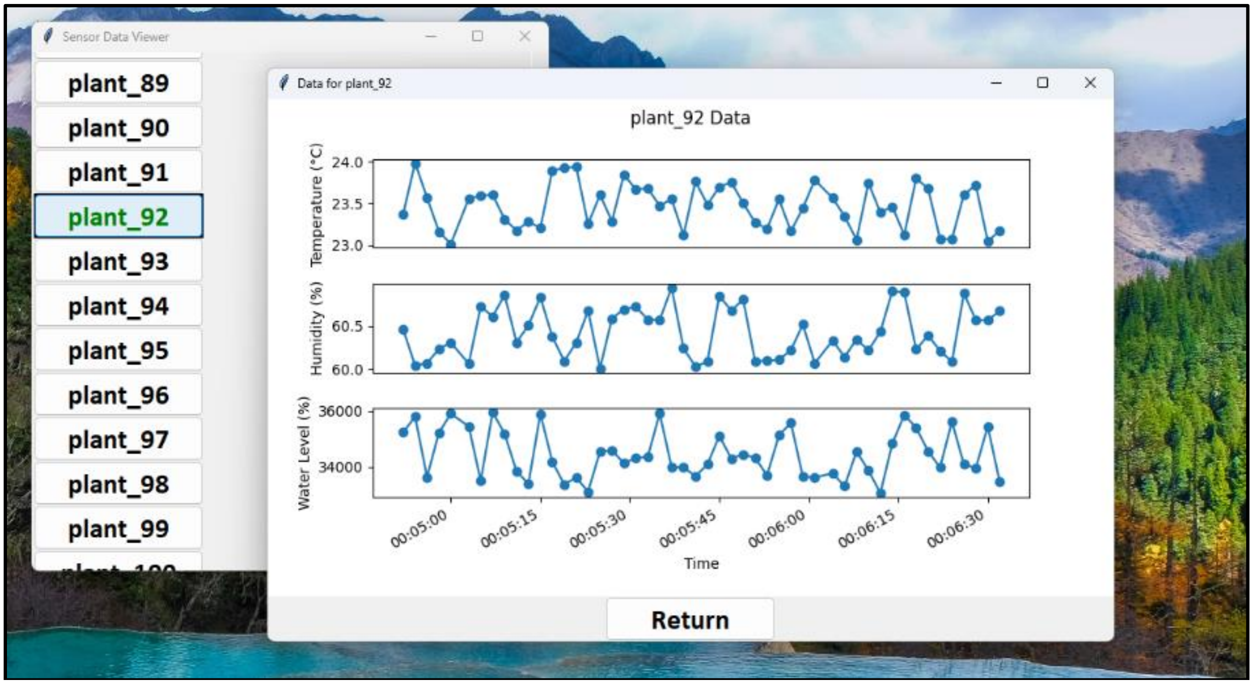

Figure 11-Control Room Visualization

Conversely, the control room offered a local visualization for real time monitoring on the plants. This view is independent to the AWS Cloud.

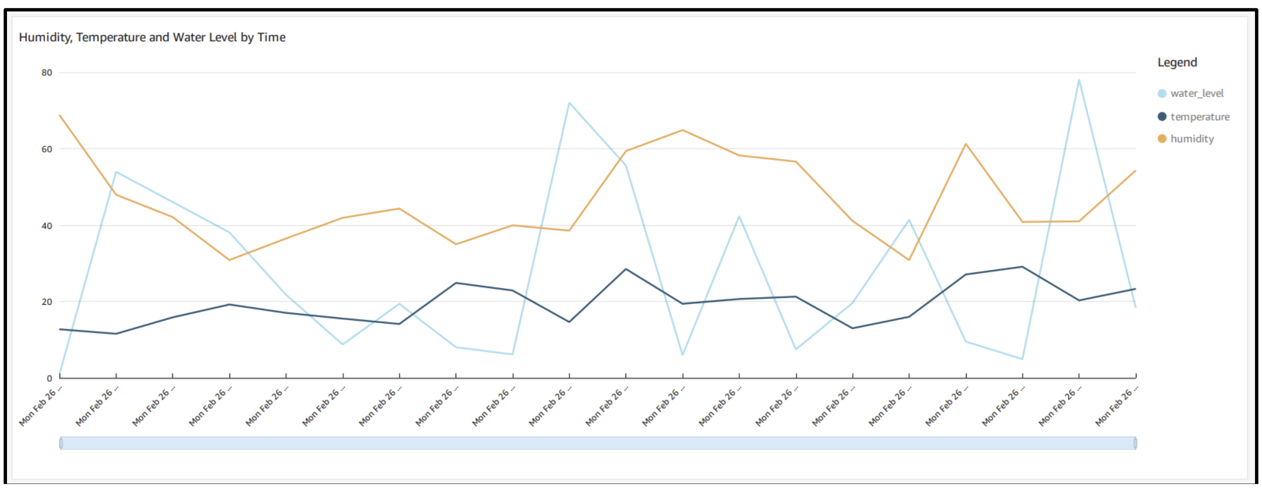

Figure 12- Cloud Visualization using AWS QuickSight

This graph delineates the relationship between humidity, temperature, and water level over time, providing a clear, comprehensive view that allows for immediate interpretation of environmental trends. Through QuickSight's dynamic visualizations, users gain the ability to not only monitor but also analyze and forecast plant conditions, enabling proactive and informed decision-making for optimal plant care.

sensor/data


```
{
  "plant_id": "plant_37",
  "temperature": 23.614850410547124,
  "humidity": 60.963579846279856,
  "water_level": 34974.264919864094,
  "time": "Mon Apr  1 15:05:20 2024"
}
```


Properties

Figure 13-Packet of data sent from one of the sensors recorded by AWS Core

Demonstration:
A video demonstration, which can be viewed on [GitHub](), was created to illustrate the system's functionality. This visual guide walks through the following operational modes:

1. **Manual Control**: It demonstrates how users interact with the IoT MQTT Panel app to manually trigger the water pump, offering immediate and precise watering control.
2. **Cloud-Controlled Adjustments**: The video further explains how the system calculates the perfect environmental settings for each plant and communicates these adjustments to AWS IoT Core for execution. Although the current setup lacked the visual element for changes in temperature and humidity, the cloud's computational role was crucial in processing these adjustments.

This video serves as a practical showcase of the system's capabilities, underscoring the potential for extensive environmental control with additional hardware integration.

Cloud Computing's Role and System Potential:
The absence of direct physical components for temperature and humidity adjustments didn't diminish the cloud computing's vital role in environmental control. Through the cloud, simple algorithm processed and issued commands, ready to be implemented by connected devices. The results suggest a system poised for expansion, with the only limit being the range of actuators integrated for full environmental management.

Challenges and Solutions

Challenges in IoT-Based Agricultural Systems

1. **Complexity in Integration**: Combining sensors, actuators, and cloud services often leads to complexities in system integration, which can be daunting for users with limited technical expertise.
2. **Reliability and Resilience**: Ensuring the system remains operational in the face of connectivity issues or cloud service outages is crucial for continuous plant monitoring and irrigation.
3. **Energy Management**: Powering the water pump requires careful consideration, especially since it demands a high current draw that can exhaust battery life swiftly.
4. **User Interface Usability**: Providing a user interface that is intuitive and simple enough for non-technical users, while offering comprehensive functionality, can be challenging.
5. **Data Privacy and Security**: Safeguarding the transmission and storage of data collected from IoT devices is imperative to protect against unauthorized access and potential breaches.

Solutions Implemented

1. **Simplified Design Principle**: By adhering to the simplicity principle in design, we've developed a user-friendly system that abstracts the complexity of the underlying technologies. This allows users to interact with a straightforward interface without needing in-depth knowledge of the IoT architecture.
2. **Local Control and Visualization with Cloud Integration**: To tackle the reliance on cloud connectivity, our system employs local control and data visualization, allowing users to maintain control even during cloud service downtime.
3. **Efficient Power Management**: The incorporation of an Ion battery paired with a Li-Po Charger Module ensures that the water pump has a dedicated power source that can sustain high-current operations without compromising the system's overall power efficiency.
4. **Intuitive IoT MQTT Panel Application**: We designed the IoT MQTT Panel application with ease of use in mind. The interface allows for simple navigation and control, including manual water pump activation, making it accessible for all user levels.
5. **Robust Security Measures**: We implemented end-to-end encryption for data transmission, and we are using AWS which known by its high security protocols for cloud storage. We still must improve the security of the controller we are using for the data gathering.

Conclusion

The culmination of this project illustrates a significant stride forward in the realm of precision agriculture through the integration of Internet of Things (IoT) technology. We have successfully demonstrated that the complexity inherent in advanced technological solutions, such as cloud computing and real-time data processing, can be elegantly simplified to serve practical, on-the-ground agricultural needs.

By distilling sophisticated cloud computing processes into user-friendly interfaces and automating the management of plant environments, the system we have developed embodies the principle of simplicity. This design philosophy not only makes the technology accessible to users with varying levels of technical expertise but also ensures that the advantages of cloud computing—scalability, reliability, and efficiency—are leveraged to their fullest.

The project's approach to simplicity in cloud computing does not merely serve as an advantage; it is a transformative element that changes how users interact with and benefit from IoT in agriculture. The system allows for the seamless automation of tasks that would otherwise require significant manual effort, such as monitoring and adjusting environmental conditions for optimal plant growth. Consequently, it provides a solution that is not only robust in the face of potential cloud service downtimes but also ensures continuous local operation, thus enhancing the resilience of agricultural operations.

Looking ahead, the project's framework sets a precedent for future advancements. The potential integration of more sophisticated sensors and machine learning algorithms could yield even greater efficiencies and predictive capabilities, paving the way for a new era of smart agriculture. As we continue to refine these technologies, the principle of simplicity will remain central to our efforts, ensuring that the evolution of IoT in agriculture remains inclusive, user-oriented, and impactful.

In closing, this project has not only achieved its aim of enhancing plant environment management through IoT but has also contributed to the broader dialogue on the importance of simplicity in the design and implementation of cloud-based systems. It stands as a testament to the power of user-friendly innovation in addressing some of the most pressing challenges in modern agriculture.

Future Directions

The successful implementation of the IoT-based plant environment management system lays the groundwork for several promising avenues of development. As we project into the future, the following directions are anticipated to drive the evolution of precision agriculture:

1. **Integration of Advanced Sensory Technologies**: The current sensor suite provides a solid foundation for monitoring basic environmental parameters. Future iterations may incorporate sensors with greater precision and the ability to detect a broader spectrum of environmental factors, such as soil pH, nutrient levels, and specific plant health indicators.
2. **Machine Learning and Predictive Analytics**: Leveraging machine learning algorithms can transform reactive systems into predictive ones. By analyzing historical data, the system could forecast future environmental conditions and plant needs, automating adjustments even before deviations occur, thus optimizing plant growth preemptively.
3. **Energy Efficiency Improvements**: With the incorporation of solar panels or other renewable energy sources, future systems could be designed to operate more sustainably. Energy storage and management will also be an area of focus to ensure that the system can function reliably in a variety of settings, including those with limited access to power.
4. **Enhanced User Experience**: User interfaces can be further refined to offer more intuitive control and insights. This could include the development of mobile apps with more advanced features, personalized alerts, and interactive tutorials for users with less technical expertise.
5. **Interoperability with Farm Management Software**: Integration with existing farm management systems and software could streamline operations, allowing for a holistic approach to farm management where data from various sources informs decision-making processes.
6. **Robustness and Security**: As reliance on IoT systems increases, ensuring the security and robustness of these systems against cyber threats and technical failures will become increasingly important.
7. **Community and Educational Outreach**: Facilitating community-based programs and educational initiatives to spread awareness of IoT benefits in agriculture could catalyze the adoption of technology in regions that have yet to benefit from such advancements.
8. **Policy and Ethical Considerations**: Engaging with policymakers to ensure that the development of IoT in agriculture aligns with ethical standards and promotes equitable access to technology will be essential.

By pursuing these directions, the project aims not only to enhance plant environment management systems but also to contribute to sustainable and efficient agricultural practices on a global scale. The envisioned advancements will ensure that the agricultural sector can meet the rising food demands of a growing population while maintaining environmental stewardship.

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Appendices

Appendix A-DHT11 Specifications:

Overview:

Item	Measurement Range	Humidity Accuracy	Temperature Accuracy	Resolution	Package
DHT11	20-90%RH 0-50 ℃	±5%RH	±2℃	1	4 Pin Single Row

Detailed Specifications:

Parameters	**Conditions**	**Minimum**	**Typical**	**Maximum**
Humidity				
Resolution		1%RH	1%RH	1%RH
			8 Bit	
Repeatability			±1%RH	
Accuracy	25℃		±4%RH	
	0-50℃			±5%RH
Interchangeability	Fully Interchangeable			
Measurement Range	0℃	30%RH		90%RH
	25℃	20%RH		90%RH
	50℃	20%RH		80%RH
Response Time (Seconds)	1/e(63%)25℃, 1m/s Air	6 S	10 S	15 S
Hysteresis			±1%RH	
Long-Term Stability	Typical		±1%RH/year	
Temperature				
Resolution		1℃	1℃	1℃
		8 Bit	8 Bit	8 Bit
Repeatability			±1℃	
Accuracy		±1℃		±2℃
Measurement Range		0℃		50℃
Response Time (Seconds)	1/e(63%)	6 S		30 S

Appendix B- HW-038 water level Specifications:

HW-038 Analog Water Level Sensor Specifications : –

The Liquid Level Detection Sensor is very easy to use. Water Level Sensor can connect to a microcontroller, such as an Arduino, using just a few wires.

The HW-038 is Simple Water Level Indicator that has a series of parallel wires that are exposed to the water. These wires are connected to a circuit that measures the electrical resistance between the wires. When the wires are dry, the resistance is very high. However, when the wires are wet, the resistance decreases. This is because the water ions create a conductive path between the wires. The HW-038 water sensor module has the following specifications:

- Operating voltage: DC 3.3V to 5V
- Working current: <20mA
- Sensor type: Analog
- Detection area: 40mm x 16mm
- Working temperature: -10°C to 30°C
- Operating humidity: 10% to 90% non-condensing
- Output voltage: 0V to supply voltage (proportional to water level)

Appendix C- 5v Water Pump Specifications:

Specifications:

1. Operating Current : 130 ~ 220mA
2. Operating Voltage : 2.5 ~ 6V
3. Flow Rate : 80 ~ 120 L/H
4. Maximum Lift : 40 ~ 110 mm
5. Driving Mode : DC, Magnetic Driving
6. Continuous Working Life : 500 hours
7. Material : Engineering Plastic
8. Outlet Outside Diameter : 7.5 mm
9. Outlet Inside Diameter : 5 mm