IMPLEMENTING IOT SYSTEM IN GROWTH MONITORING OF BENTONG GINGER

BY

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A REPORT
SUBMITTED TO
Universiti Tunku Abdul Rahman
in partial fulfillment of the requirements
for the degree of
BACHELOR OF COMPUTER SCIENCE (HONOURS)
Faculty of Information and Communication Technology
(Kampar Campus)

JANUARY 2024

UNIVERSITI TUNKU ABDUL RAHMAN

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FACULTY OF INFORMATION AND COMMUNICATION TECHNOLOGY

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ACKNOWLEDGEMENTS

I extend my heartfelt gratitude to my esteemed supervisors, Ts. Dr. Goh Hock Guan, for providing me with the invaluable opportunity to delve into the innovative field of Bentong ginger cultivation through IoT technology. This project marks a significant milestone as I embark on a journey to contribute to sustainable agriculture.

I am deeply indebted to a special individual, Ch’ng Shin Joe, whose unwavering patience, unconditional support, and love have been my pillars of strength throughout this endeavour. Your presence during challenging times has been truly uplifting.

Last but not least, my sincere thanks go to my parents and family for their unending love, support, and continuous encouragement. Their belief in my aspirations has been a driving force, and I am grateful for the foundation they've provided for this pursuit.

ABSTRACT

In the dynamic landscape of agriculture, Bentong ginger has earned a distinguished status, celebrated not only for its aromatic and culinary attributes but also cherished for its myriad medicinal benefits. However, the cultivation of this versatile plant encounters formidable challenges, particularly concerning limited land availability and protracted crop cycles. In response to these impediments, our proposed solution introduces an innovative IoT framework that harnesses the capabilities of state-of-the-art hardware components. This includes the utilization of the Raspberry Pi, sensors, and actuators, collectively forming a responsive and adaptable environment tailored for the optimal growth of Bentong ginger. This precision agriculture project addresses these challenges by developing an integrated IoT-based system tailored for precise environmental monitoring and automated cultivation management. The problem statement highlighted the need for a more efficient and sustainable approach to ginger cultivation, considering factors such as air temperature, humidity, light levels, soil moisture, and nutrient composition. The developed system encompasses a comprehensive data collection mechanism, leveraging high-quality sensors to gather real-time environmental data critical for optimal ginger growth. This data is then processed and analyzed to provide actionable insights, guiding automated adjustments to environmental conditions. Automation features include dynamic control of lighting, ventilation, watering, and fertilizing, all tailored to maintain optimal growth conditions for Bentong ginger. The system's operation is further enhanced by intuitive visualization tools, including dashboards and graphs, offering users a clear and comprehensive overview of the environmental conditions and growth trends. This enables informed decision-making, facilitating efficient management and optimization of cultivation processes. In short, this project offers a holistic solution to the challenges of Bentong ginger cultivation, combining advanced IoT technologies, automation capabilities, and data-driven insights to foster sustainable and efficient cultivation practices.

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LIST OF ABBREVIATIONS

AI	Artificial Intelligence
APE	Absolute Percentage Error
API	Application Programming Interface
AWS	Amazon Web Services
DB	Database
DC	Direct Current
EC	Electrical Conductivity
HDMI	High-Definition Multimedia Interface
GND	Ground
GPIO	General-Purpose Input/Output
GRU	Gated Recurrent Unit
GUI	Graphical User Interface
IoT	Internet of Things
LAI	Leaf Area Index
LDR	Light-Dependent Resistor
LED	Light-Emitting Diode
LSTM	Long Short-Term Memory
ML	Machine Learning
MP	Megapixel
MQTT	Message Queuing Telemetry Transport
MRE	Mean Magnitude of Relative Error
NoSQL	Not only Structured Query Language
NPK	Nitrogen, Phosphorus, Potassium
OpenCV	Open Source Computer Vision Library
OS	Operating System
pH	Potential of Hydrogen
RF	Random Forest
RNN	Recurrent Neural Networks
R^2	Coefficient of determination
SCL	Serial Clock

SDA	Serial Data
SDG	Sustainable Development Goals
SNS	Simple Notification Service
SSH	Secure Shell
SVR	Support Vector Regression
S3	Simple Storage Service
URL	Uniform Resource Locator
VCC	Voltage Common Collector
VNC	Virtual Network Computing
VTCI	Vegetation Temperature Condition Index
WOFOST	World Food Studies
WSN	Wireless Sensor Network

Chapter 1

Introduction

In this chapter, the project motivation, problem statements, objectives, scope, and expected contributions will be presented.

1.1 Motivation and Problem Statement

Bentong ginger is globally sought after, especially in China, where over 30,000 metric tonnes, primarily Bentong ginger, are exported annually [1]. Its premium flavor commands prices two to three times higher than regular ginger on international markets [2]. Beyond its economic significance, Bentong ginger plays a crucial role in Malaysian and international cuisines, known for enhancing the flavor of soups and stir-fries [3]. Its culinary importance, regarded as a gem, ensures its enduring presence in kitchens worldwide. Moreover, Bentong ginger is recognized for its well-documented medicinal properties, integral to traditional Chinese medicine for centuries [4]. Its health benefits, including improved digestion and anti-inflammatory properties, make it appealing to health-conscious consumers [5]. This presents opportunities for developing various ginger-based products aligned with current wellness trends, potentially diversifying the industry and improving livelihoods in Bentong.

Despite Bentong ginger's numerous advantages, it faces challenges hindering its expansion. The primary obstacle is the limited availability of agricultural land in Bentong, with over 70% allocated to other plantations [6], leading to deforestation and increased flood risk. Sustainable cultivation practices are urgently needed. Additionally, the prolonged crop cycle poses a challenge, requiring significant idle periods for soil replenishment [7]. While farmers optimize land use with fast-maturing vegetables during this phase, it reduces the frequency of ginger harvests, impacting overall production. Efforts to replicate Bentong ginger's distinct taste in different regions have encountered difficulties and yielded varying results. Reports suggest that ginger grown outside Bentong fails to capture the nuanced flavor profile [8], emphasizing the intricate connection between ginger quality and Bentong's specific terroir, highlighting its crucial role in shaping the ginger's unique taste and aroma.

The project problem statements are as follows:

I. Absence of a Dedicated IoT (Internet of Things) Framework for Bentong Ginger

The main challenge for the Bentong ginger industry is the absence of a dedicated IoT framework for ginger cultivation. Existing agricultural solutions are not precise enough for the unique needs of herbaceous plants like ginger, which is more dependent on soil conditions. The lack of a specialized IoT framework results in missed opportunities to optimize growth and harvest, impacting yield and crop quality and jeopardizing the economic sustainability of Bentong ginger farming.

II. Lack of Comprehensive Ginger Dataset

A major obstacle in the Bentong ginger industry is the absence of a complete dataset for monitoring ginger growth throughout its entire cycle and under diverse conditions. This lack of comprehensive data hampers the development of informed decision-making tools, predictive models, and Artificial Intelligence (AI)-powered advisory systems essential for efficient and sustainable farming practices. The absence of reference data also impedes progress in identifying optimal environmental conditions and hinders the advancement of technology-driven solutions for enhancing Bentong ginger cultivation.

III. Resource Optimization Challenge

The Bentong ginger industry grapples with a critical challenge in resource optimization, particularly in the management of energy, water, and fertilizer. Inadequate optimization of these resources results in heightened operational costs and increased pollution. Suboptimal allocation not only burdens farmers economically but also jeopardizes the environmental sustainability of Bentong ginger cultivation. The failure to optimize resources efficiently leads to economic strains for farmers and poses a significant threat to the ecological balance of Bentong ginger cultivation.

1.2 Project Objectives

I. Develop a Specialized IoT Framework for Bentong Ginger

The project aims to create a dedicated IoT framework tailored for Bentong ginger cultivation, emphasizing monitoring soil conditions critical for optimal growth. Utilizing a Raspberry Pi as the central control unit, the system integrates various sensors and actuators for meticulous environmental management. Python-based software facilitates real-time data collection and analysis to assess whether current environmental conditions are conducive to ginger growth, helping determine the need for adjustments in lighting, fertilization, and irrigation. Integration of Amazon Web Services (AWS) services enhances data storage, visualization, and notification capabilities within this comprehensive framework.

II. Create a Comprehensive Bentong Ginger Growth Dataset

The second project objective is to create a detailed dataset for Bentong ginger cultivation, including hourly environmental conditions collection (estimated at 0.2 KB per entry) and a separate dataset generated from daily high-resolution images (each approximately 2 MB). This image dataset will be used to calculate parameters such as the number of leaves, shoots, and the gap between upper and lower leaves. The environmental conditions dataset is expected to be around 432 KB with hourly entries for three months, while the daily image dataset is expected to be around 180 MB.

III. Establish an Adaptive Resource Optimization Framework

The third objective of the project entails the creation of an adaptive resource optimization framework for the Bentong ginger industry. Unlike conventional scheduled automation, this approach triggers resource optimization interventions based on optimal environmental conditions using thresholding for ginger plant growth. This dynamic system adjusts lighting, watering, and fertilizing processes in response to real-time assessments. By selectively implementing resource optimization, the goal is to enhance efficiency, reduce operational costs, minimize environmental impact, and ensure optimal conditions for Bentong ginger cultivation.

1.3 Project Scope and Direction

The main scope of the project is to develop an end-to-end IoT framework for monitoring and optimizing Bentong ginger growth, focusing on environmental conditions and growth parameters.

Environmental Conditions:

1. Air Temperature
2. Air Humidity
3. Light Level
4. Soil Moisture
5. Soil Temperature
6. Soil Electrical Conductivity (EC)
7. Soil pH
8. Soil Nutrient Levels (Nitrogen, Phosphorus, and Potassium (NPK))

Growth Parameters of Bentong Ginger:

1. Number of leaves
2. Number of shoots
3. Gap between upper and lower leaves

Figure 1.1. Growth parameters of Bentong ginger.

Project Focus:

1. **Hardware Development**: Integrate customized hardware with a Raspberry Pi serving as the central control unit. This setup should include sensors for soil, light, and air conditions, along with a camera for imaging. Additionally, incorporate actuators such as controllable LED grow lights, a ventilation fan, a water pump, and a fertilizer pump to complete the IoT framework.
2. **Software Development**: Python code will be written using Visual Studio Code to initialize sensors, collect readings, and transmit data. Remote access capabilities will be enabled through VNC Viewer. Node-Red dashboard will be built for automation and visualization purposes.
3. **AWS Integration:** Leverage AWS services for seamless connectivity between IoT devices and AWS (IoT Core), effective data storage (DynamoDB), and image archiving (S3).
4. **Deployment**: The IoT framework will be deployed within the Bentong ginger greenhouse, paying close attention to the layout and placement of sensors, actuators, and cameras.
5. **Data Collection**: Real-time sensor data, including air, light, and soil conditions, will be collected at 5-minute intervals. High-resolution images of the Bentong ginger plants will also be captured daily from seedling to maturity.
6. **Monitoring**: Continuous observation of plant health and sensor functionality is conducted to identify any signs of abnormal growth or malfunction. The system will automatically adjust the automation as necessary based on the collected data or manually controlled by humans.

1.4 Project Contributions

I. Customized IoT Framework for Bentong Ginger

This project contributes by developing a customized IoT framework for monitoring and optimizing the growth of Bentong ginger. Unlike generic IoT solutions, this customized system considers the specific needs and requirements of ginger farming. It combines hardware components like as sensors and actuators to capture real-time data on environmental conditions and the growth status of ginger plants and turn into data-driven decisions for lighting, fertilization, and irrigation. This customized IoT framework provides accurate management of ginger growth factors, increasing productivity and crop quality.

II. Dataset Foundation for Future Research

The project also contributes to the scientific knowledge base by creating a comprehensive dataset for monitoring the growth of Bentong ginger. This includes diverse environmental factors, plant parameters, and a collection of high-resolution images capturing key growth stages. This valuable dataset will serve as a foundation for future ginger cultivation research and innovation. Researchers and agricultural specialists can utilize this dataset to create predictive models and AI-powered advisory systems. It provides data-driven insights to the agricultural community, ultimately leading to more effective and sustainable farming practices not only for Bentong ginger but also for other agricultural products with similar growth requirements.

III. Advancement of Sustainable Agricultural Practices

The project's third contribution is the establishment of an adaptive resource optimization framework, advancing sustainable agricultural practices in the Bentong ginger industry. Real-time assessments trigger interventions in lighting, watering, and fertilizing based on predefined thresholds and a low-intensity-high-frequency approach. This methodology ensures that resources are provided to the plants only when needed, preventing overshooting of the optimal growth range. Beyond reducing operational costs, this adaptive approach addresses environmental concerns by minimizing unnecessary resource usage. These outcomes align with Sustainable Development Goals (SDG) 12 - Responsible Consumption and Production, promoting efficient resource use and fostering sustainable agricultural practices in Bentong ginger cultivation.

1.5 Report Organization

The report comprises several chapters that offer a comprehensive exploration of the subject matter. Chapter 2 presents a critical review of pertinent studies in precision agriculture, plant growth prediction models, and sensor technologies. Chapter 3 outlines the project methodology, encompassing system and functional requirements, as well as an Agile development approach. The system design is detailed in Chapter 4, elucidates the system architecture and workflow. Chapter 5 examines the system's operation, both hardware and software, and introduces a conceptual plant growth prediction model. Chapter 6 focuses on system testing and evaluates the overall system performance. Lastly, Chapter 7 summarizes the key findings and outlines the project's future direction.

Chapter 2

Literature Review

In this chapter, the focus is on reviewing and summarizing four existing systems, highlighting their respective pros and cons. Additionally, an in-depth examination of two deep learning models for predicting plant growth patterns based on environmental data will be presented and discussed.

2.1 Review of the Existing Systems

2.1.1 IoT-based Precision Farming Framework for Groundnut

The article in [9] presents an IoT framework designed to help farmers improve their farming practices in order to increase groundnut yield. The system utilizes wireless sensor networks to gather agricultural data, which is then transmitted to a decision support system for generating tailored advice to farmers, including irrigation timings, fertilizer usage, and weather forecasts delivered through a regional-language Android application.

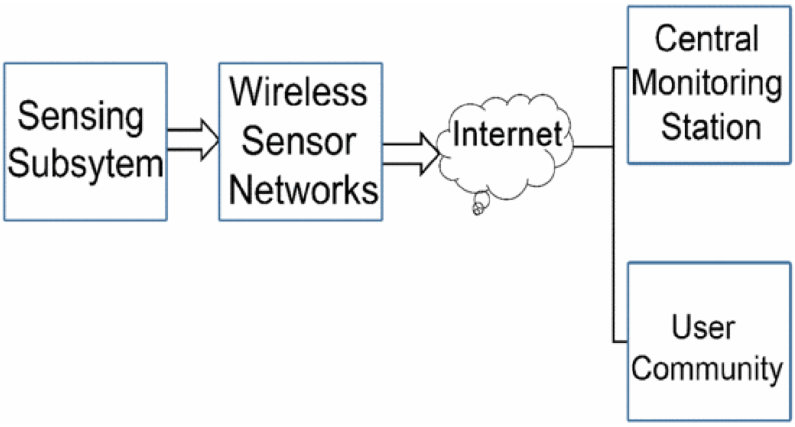


Figure 2.1 Overview of system architecture in [9].

The foundation of this precision agriculture system is its sensing subsystem, a network of sensors carefully placed to monitor crucial soil conditions. This sensor array includes soil moisture sensors, temperature sensors, and pH sensors, strategically positioned throughout the groundnut cultivation area. The sensing subsystem is essential for gathering data, which forms the basis for data-driven decision support.

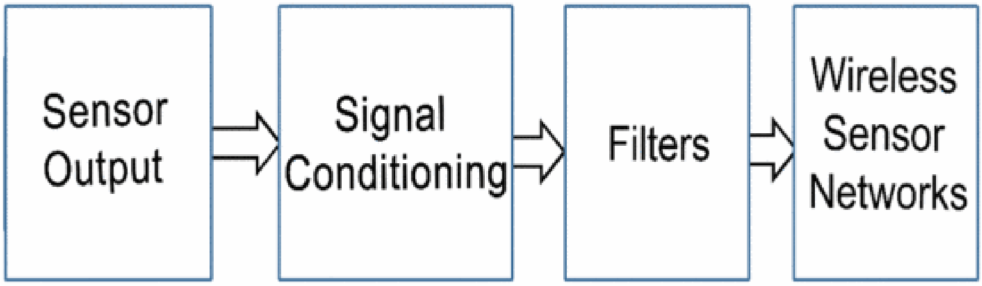


Figure 2.2. Architecture of sensing subsystem in [9].

Multiple sensors come into play to monitor and manage critical aspects of groundnut cultivation. The sensor array encompasses soil moisture sensors, temperature sensors, and pH sensors, strategically placed throughout the cultivation area. Soil moisture sensors continuously track moisture levels, providing crucial data for irrigation management. Temperature sensors closely monitor soil temperature, ensuring it remains within the optimal range for groundnut growth. pH sensors assess soil acidity and alkalinity, guiding precise pH adjustments for improved nutrient uptake by crops.

Wireless Sensor Network (WSN) is used to enable seamless data transmission and communication which is one of the critical parts of this precision farming system. The WSN architecture has been thoughtfully designed to optimize data flow and transmission efficiency within the cultivation area. It follows a hierarchical structure, involving lower-level nodes connecting directly to the soil sensors, intermediate nodes responsible for data routing, and gateway nodes that aggregate and transmit data to the central monitoring hub.

Data aggregation is another important aspect of the framework. Gateway nodes systematically collect data generated by sensors, resulting in reduced data volumes and optimized bandwidth usage. Once the data reaches the central monitoring station, advanced data processing techniques, including machine learning algorithms, take over. These analytical tools transform raw data into actionable insights, allowing the system to provide farmers with informed recommendations.

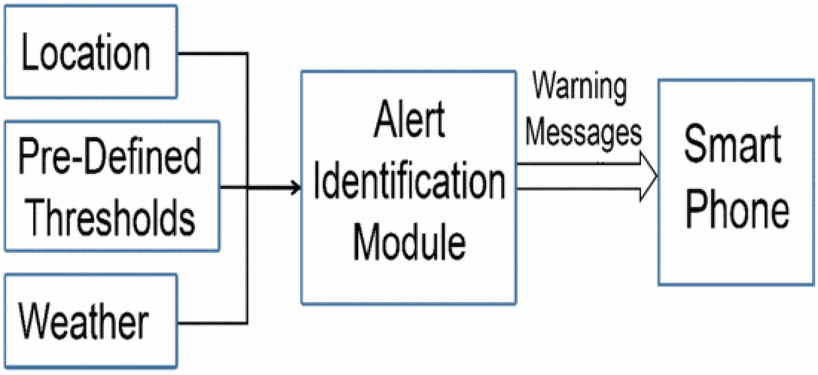


Figure 2.3. Diagram of end user services in [9].

A standout feature of this precision farming system is its user-friendly mobile application, designed to deliver accessible, actionable, and real-time information to farmers. This application serves as the primary means of sharing data, insights, and recommendations with end-users, particularly farmers. Its multifunctionality includes providing irrigation scheduling advice, weather forecasts, and expert guidance on fertilizer application practices. Importantly, the application accommodates local languages, ensuring accessibility for technologically less-savvy farmers.

Another remarkable feature of this precision agriculture framework is its ability to offer real-time decision support to farmers. Continuous monitoring of soil moisture levels, temperature, and pH is key to this capability. Such vigilant monitoring enables precise recommendations regarding optimal irrigation timing, crucial for efficient water resource management and ensuring crops receive the right amount of water. Additionally, integrating weather forecasts empowers farmers to adapt their farming practices proactively based on changing weather conditions.

To maximize crop yield, this framework goes beyond data collection by providing crop-specific nutrient recommendations. The pH sensors within the Sensing Subsystem play a significant role here. By analyzing soil pH data, the system formulates tailored directives for fertilizer application, aligning them with the unique nutrient needs of groundnut cultivation. This ensures that the right nutrients are delivered for robust crop growth.

Strengths

The proposed solution excels in several aspects, contributing to its effectiveness in precision farming. It leverages wireless soil sensors with high sampling frequencies to enable continuous real-time monitoring of crucial soil parameters such as moisture, temperature, and pH. This real-time data collection surpasses traditional manual or weekly methods, providing farmers with up-to-date insights into field conditions. Moreover, the framework integrates sensor observations with precise weather forecasts, empowering it to generate customized irrigation advisories tailored to local field conditions and real-time situations. This personalized guidance is more effective than generic recommendations, offering individualized support to farmers. Furthermore, the system adopts a comprehensive approach by simultaneously monitoring multiple essential soil parameters, providing a holistic view of field health. Lastly, the development of a user-friendly mobile app interface that delivers advisories in local languages enhances accessibility and usability, setting it apart from technical SMS or website-based approaches.

Limitations

Notably, it does not incorporate automation features, relying on farmers to manually act upon the advisories provided. Additionally, the system primarily concentrates on monitoring key soil parameters, such as moisture, temperature, and pH, leaving out other crucial environmental conditions like air quality and lighting levels. Furthermore, the data aggregation process is limited in scope, with no mention of comprehensive crop health data integration like leaf color analysis. These limitations highlight areas where further enhancements may be needed to provide a more comprehensive and automated agricultural monitoring solution.

2.1.2 IoT-enabled smart farming and Irrigation System

The authors of article in [10] have developed a comprehensive IoT-based system that integrates various sensors, an Arduino board, voltage regulator, relay, and a Wi-Fi module to monitor and optimize the growth of crops, particularly focusing on tomato plants as a case study.

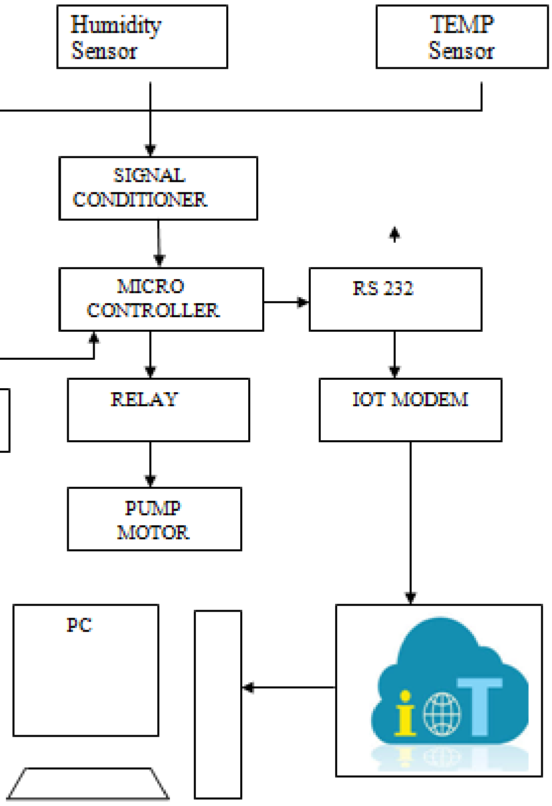


Figure 2.4. Architecture diagram in [10].

One of the key components of their system is the utilization of sensors to collect real-time data on environmental conditions, providing valuable insights for crop management. The article discusses the deployment of three crucial sensors: temperature sensors for monitoring atmospheric temperature, moisture sensors for assessing soil water content, and humidity sensors to gauge atmospheric humidity levels. These sensors are strategically placed to provide accurate measurements, which are fundamental for effective irrigation and crop management.

The IoT framework devised by the authors continuously collects data from these sensors and sends it to an Arduino board, which serves as the brain of the system. This board is programmed with if-else conditions that analyze the incoming data, demonstrating their proficiency in embedded systems. When specific thresholds are crossed, the system automatically triggers actions. For instance, if the soil moisture level drops below a certain point (e.g., 1000), the Arduino activates a relay, turning on a motor responsible for irrigating the plants. Similarly, if the atmospheric temperature exceeds a predefined value (e.g., 40 °C), the system initiates the motor to maintain optimal growing conditions.

Furthermore, the authors highlight the integration of a Wi-Fi module into their system, which enhances its functionality by enabling remote monitoring and control. The ESP8266 Wi-Fi module establishes a connection to the user's mobile device via an MQTT (Message Queuing Telemetry Transport) dashboard application, showcasing their adeptness in IoT communication frameworks. MQTT serves as a lightweight and efficient messaging protocol that facilitates real-time communication between the system and the user. This connectivity feature enables farmers to remotely track the condition of their fields and receive real-time updates through a dedicated smartphone application. By connecting to the MQTT dashboard application, users can monitor temperature, humidity, moisture levels, and motor status, all of which contribute to informed decision-making.

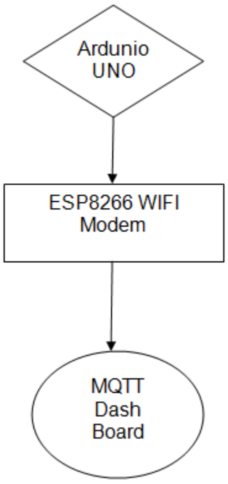


Figure 2.5. Flow diagram of WIFI modem in [10].

Moreover, the system operates within the broader IoT ecosystem, where data is transmitted to an MQTT server hosted at IOT.eclipse.org. This server acts as a middleware, facilitating seamless communication between the system and the user's mobile application. The app interface is customized to display vital parameters such as soil moisture, temperature, humidity, and motor status, promoting informed decision-making by providing users with crucial insights into their agricultural environment.

Strengths

The proposed solution boasts numerous strengths, with real-time monitoring, automation, resource optimization, and wireless connectivity standing out as its prominent features. Real-time monitoring ensures that farmers have access to crucial environmental data as it unfolds, enabling them to make well-informed decisions promptly. Automation, powered by advanced algorithmic logic, ensures the precise execution of tasks like irrigation when specific conditions are met, substantially reducing the need for manual intervention. This not only enhances efficiency but also minimizes the potential for human errors. Furthermore, the system excels in optimizing resources, conserving water and energy by activating irrigation only when necessary, resulting in cost savings and environmentally friendly practices. By harnessing wireless connectivity through Wi-Fi technology and MQTT protocols, the solution offers farmers convenient, mobile-based field oversight and irrigation control options, simplifying crop management. In summary, these strengths firmly establish the system as a promising innovation in the domain of precision agriculture.

Limitations

The proposed solution exhibits several limitations. Firstly, it lacks the capacity to capture crucial tomato health data through visual or image-based sensors, limiting its ability to assess the overall well-being of the crops. Secondly, while the system effectively monitors atmospheric temperature, soil moisture, and humidity levels, it falls short in providing a comprehensive view of environmental conditions by omitting sensors for parameters like light intensity and soil nutrient levels, which are pivotal for precise crop management. Lastly, the system primarily utilizes the collected data for irrigation automation but the system does not fully leverage the potential of the data for more comprehensive decision-making. Integrating data analytics and predictive modeling could provide farmers with insights beyond irrigation. Addressing these limitations by incorporating additional sensors and expanding the use of data analytics could significantly enhance the system's capabilities and its overall utility to farmers.

2.1.3 IoT-based Environment Change Monitoring & Controlling

Greenhouses offer controlled environments ideal for crop cultivation. However, maintaining the appropriate environmental conditions manually can be an arduous and demanding task for farmers. Therefore, the authors of article in [11] propose a solution that leverages the IoT and wireless sensor nodes to automate the monitoring and control of these critical parameters within a greenhouse setting. This IoT framework is implemented for both tomato and brinjal plants.

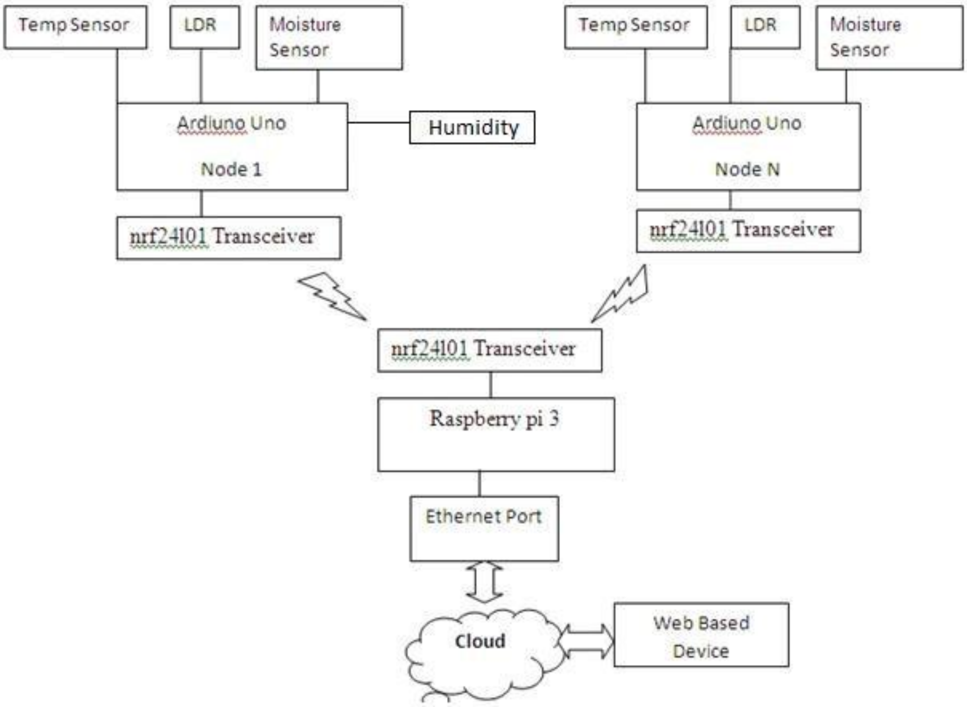


Figure 2.6. Overview of system architecture in [11].

The heart of the system consists of several key components, each playing a vital role in ensuring the optimal growth of crops. The central component is the Raspberry Pi 3, a versatile and widely used single-board computer. This device serves as the core control unit for collecting data from various sensors and orchestrating the necessary control actions. Alongside the Raspberry Pi, the system utilizes Arduino Uno nodes, which act as distributed sensor hubs within the greenhouse.

The critical data-gathering components are the sensors themselves, strategically placed throughout the greenhouse. These include LM 35 temperature sensors, soil moisture sensors, humidity sensors, and light-dependent resistors (LDRs). These sensors provide real-time data on the environmental conditions necessary for plant growth. The article highlights the significance of careful sensor placement to ensure accurate and comprehensive data collection.

The system's data acquisition process is a pivotal aspect of its functionality. Wireless sensor nodes, primarily Arduino Uno nodes, are responsible for collecting data from multiple locations within the greenhouse. These nodes transmit this data to the central Raspberry Pi 3 node in real-time. This two-tiered architecture facilitates efficient and synchronized data collection and processing. The Raspberry Pi 3 serves as a central repository for sensor data, enabling real-time monitoring and control.

One of the most crucial aspects of the system is its ability to take specific actions based on the data collected from the sensors. These actions are contingent on the real-time assessment of environmental parameters. For example, if the temperature within the greenhouse surpasses the optimal range for a particular crop, the system autonomously activates fans to regulate the temperature. Conversely, if humidity levels drop or rise beyond the desired range, the system can activate heaters or open windows, ensuring that the greenhouse environment remains conducive to crop growth. Soil moisture and light intensity are equally critical parameters closely monitored and controlled by the system. Soil moisture sensors provide data on the moisture content of the soil. When the system detects that soil moisture levels are below or above the prescribed range, it initiates corresponding actions such as turning on or off water pumps. The LDRs, responsible for measuring light intensity, enable the system to adjust artificial lighting within the greenhouse. If light levels are insufficient or excessive, the system can control a slider to regulate light exposure for the plants.

The article underscores the importance of tailoring the system's settings to specific crops. Notably, different crops have varying environmental requirements for optimal growth. To illustrate this point, the article provides examples for tomatoes and brinjals. For instance, tomatoes thrive at temperatures between 22-27°C and require a humidity range of 49-60%. In contrast, brinjals flourish in slightly higher temperatures (24-28°C) and prefer humidity levels between 65-75%. This ability to customize parameters for different crops ensures that each receives the precise conditions necessary for optimal growth and yield.

Beyond real-time monitoring and control, the system offers data analysis capabilities that enable farmers to make informed decisions. It provides the valuable feature of predicting power consumption and estimating annual costs associated with controlling devices within the greenhouse. This predictive aspect allows farmers to plan and budget more effectively.

By knowing the expected power usage and related expenses, they can make financially sound decisions regarding crop management.

Strengths

A notable strength of this solution lies in its advanced automation capabilities for greenhouse management. Unlike manual or basic automated systems, this IoT-based approach can handle various plants in the same greenhouse with crop-specific control. It continuously collects data from multiple sensors, analyzes it in real-time, and makes instant decisions to adjust environmental conditions precisely. For example, if the temperature rises above the ideal range for one crop while it's optimal for another, the system can adapt seamlessly to these diverse requirements. This level of automation not only reduces the farmer's workload but also minimizes the risk of human error and ensures that different crops in the same greenhouse thrive in their respective optimal conditions required for a bountiful harvest. This adaptability to crop-specific needs within a shared environment makes the system a valuable asset for enhancing agricultural productivity.

Limitations

This proposed solution has similar limitations with the previous article. Firstly, it does not incorporate a mechanism to capture detailed data regarding the health of tomato or brinjal plants through images or other means. While it excels in automating and controlling greenhouse conditions, it lacks a comprehensive assessment of crop health, potentially missing crucial insights into stress factors affecting the plants. Secondly, while the system collects valuable environmental data, it primarily employs this data for immediate automation purposes and predicting energy consumption. However, it does not exploit the full potential of the gathered information for more extensive analysis or predictive modeling.

2.1.4 IoT-based Monitoring of Temperature and Humidity with Fuzzy Control

Article in [12] discusses a comprehensive solution employing the IoT and fuzzy logic control to monitor and optimize the microclimate which are the temperature and humidity levels within a greenhouse to enhance cherry tomato yields.

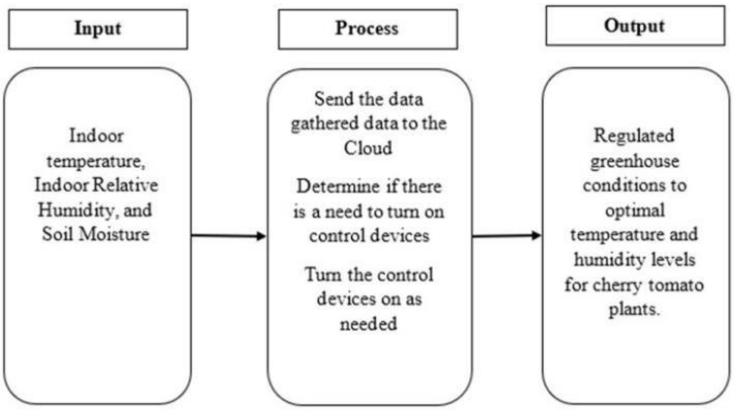


Figure 2.7. Conceptual framework in [12].

The greenhouse is designed to replicate real-world conditions for cherry tomato cultivation, with rows of cherry tomato plants strategically positioned. This innovative solution lies a sophisticated network of IoT-enabled sensors strategically positioned throughout the greenhouse. These sensors encompass a temperature sensor, a relative humidity sensor, and a soil moisture sensor, collectively forming a web of data sources continuously capturing real-time information about the microclimate within the greenhouse.

The data collected by these sensors is then transmitted to a centralized hub, which operates on Arduino technology, serving as the central control and data transmission unit. This hub is responsible for both gathering data from the sensors and relaying it to a cloud-based platform for storage and further analysis. This cloud platform acts as a repository for the sensor data and hosts the critical fuzzy logic control system that control the operation of actuators like mist humidifier, sprinkler, and exhaust fan.

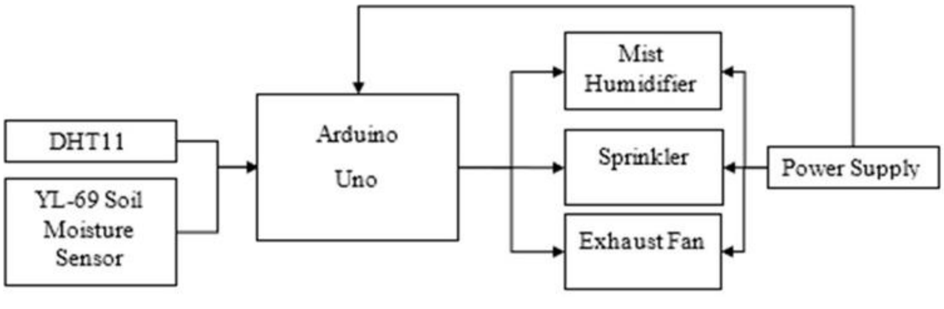
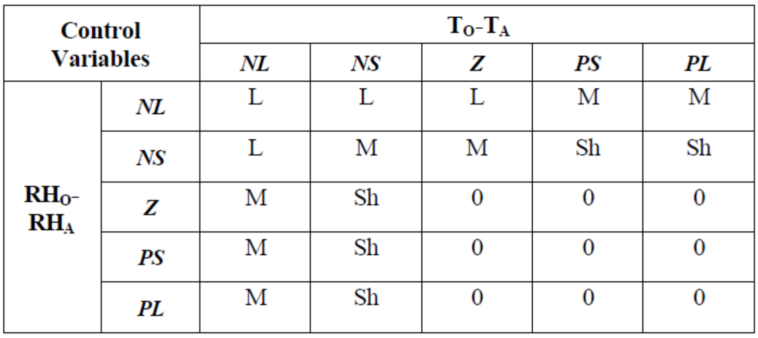


Figure 2.8. Hardware block diagram in [12].

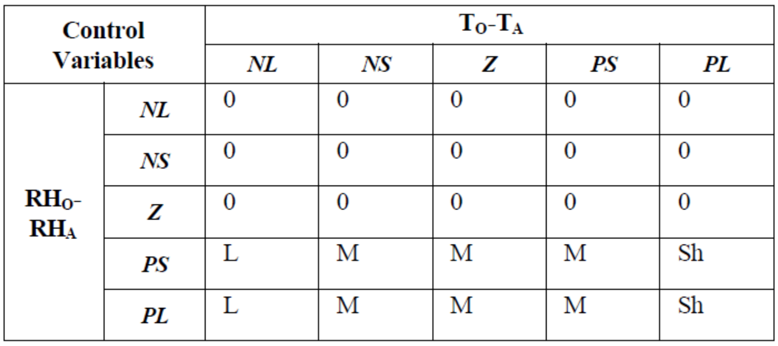
The core of the system lies in its employment of fuzzy logic control as the decision-making mechanism that dynamically responds to environmental data. This fuzzy logic controller functions based on a predetermined set of rules. It takes its cues from three essential input variables: temperature deviation, humidity deviation, and soil moisture deviation. These deviations signify the disparities between the ideal values and the actual values recorded. The fuzzy logic controller uses these rules to determine the most appropriate actions to take, depending on the deviations.

The process involves fuzzification of these input variables, which essentially transforms them into fuzzy sets. Fuzzy sets utilize descriptors like NL (Negative Large), NS (Negative Small), Z (Zero), PS (Positive Small), and PL (Positive Large) to effectively encapsulate the inherent imprecision and variability present in the data. Conversely, the system's output, derived from these fuzzy sets, comprises 0 (No Change), Sh (Short), M (Medium), and L (Long) in order to obtain precise values for the exhaust fan duration, humidification duration and irrigation duration.



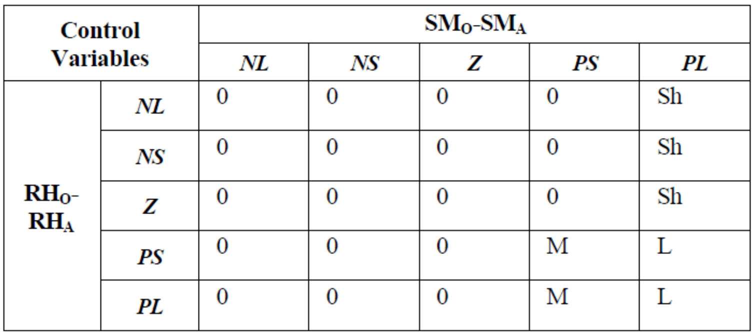
Control Variables		**T_O-T_A**				
		NL	***NS***	***Z***	***PS***	***PL***
RH_O-RH_A	***NL***	L	L	L	M	M
	NS	L	M	M	Sh	Sh
	Z	M	Sh	0	0	0
	PS	M	Sh	0	0	0
	PL	M	Sh	0	0	0

Figure 2.9. Exhaust fan fuzzy rules in [12].



Control Variables		**T_O-T_A**				
		NL	***NS***	***Z***	***PS***	***PL***
RH_O-RH_A	***NL***	0	0	0	0	0
	NS	0	0	0	0	0
	Z	0	0	0	0	0
	PS	L	M	M	M	Sh
	PL	L	M	M	M	Sh

Figure 2.10. Humidification fuzzy rules in [12].



Control Variables		**SM_O-SM_A**				
		NL	***NS***	***Z***	***PS***	***PL***
RH_O-RH_A	***NL***	0	0	0	0	Sh
	NS	0	0	0	0	Sh
	Z	0	0	0	0	Sh
	PS	0	0	0	M	L
	PL	0	0	0	M	L

Figure 2.11. Irrigation fuzzy rules in [12].

The control devices within the greenhouse play pivotal roles in maintaining the desired microclimate. When temperature and humidity levels deviate from the optimal conditions, the system takes swift action, activating the exhaust fan. Similarly, should relative humidity drop below the desired level, the system initiates the humidifier to augment moisture levels in the greenhouse air. Any deviation from the optimal soil moisture level triggers the irrigation system. What sets this system apart is its ability to compute the duration of operation for each of these control devices. This calculation is made by the fuzzy logic controller itself, ensuring not only precision but also adaptability in response to evolving environmental conditions.

In summary, this integrated system creates a closed-loop environment where real-time data collection, dynamic fuzzy logic decision-making, and adaptive control devices work in harmony. Together, they are dedicated to creating and sustaining an optimal growth environment for cherry tomato plants within the greenhouse.

Strengths

The article’s strengths is around its pioneering use of fuzzy logic control and data-driven decision-making. The integration of fuzzy logic control as the decision-making mechanism ensures precise and adaptive responses to evolving environmental conditions within the greenhouse. By employing a predefined set of rules and utilizing key input variables like temperature deviation, humidity deviation, and soil moisture deviation, the system dynamically activates control devices such as exhaust fans, humidifiers, and irrigation systems. What sets this approach apart is the system's ability to compute the optimal duration of operation for each of these devices, enhancing resource efficiency and crop yield. Moreover, the emphasis on data-driven decision-making ensures that actions are based on real-time sensor data, optimizing the microclimate for cherry tomato cultivation.

Limitations

Firstly, the system relies solely on predefined rules and fuzzy logic for decision-making, which may not fully account for the complex and nuanced interactions within the greenhouse microclimate. As the number of sensors capturing environmental conditions increases, the complexity of the fuzzy logic system grows, potentially becoming an excessive burden in determining and validating these predefined rules. Additionally, it can be challenging to ascertain whether the predefined rules accurately reflect the optimal time duration for each control device's operation. This uncertainty raises questions about the system's ability to consistently maintain the desired microclimate conditions and may require further refinement and validation in practical applications.

2.1.5 Summary of the Existing Systems

Table 2.1 Comparison table between existing systems with critical comments

System	Strengths	Weaknesses	Critical Comments
1	• Real-time soil monitoring. • Customized irrigation advice with weather data. • Comprehensive soil health assessment. • User-friendly mobile app.	• No automation, manual farmer actions. • Primarily soil-focused, excludes other factors. • Limited crop health assessment.	• The absence of automation underutilizes the potential of comprehensive soil health assessment and fails to significantly alleviate the farmers' workload. • Great visualization is important in offering valuable insights.
2	• Real-time monitoring. • Automation. • Resource optimization. • Mobile-based monitoring.	• Limited crop health assessment. • Missing key environmental sensors. • Underutilized data for decisions.	• Neglecting comprehensive crop health assessment and vital environmental sensors constrains the potential to deliver truly optimized outcomes.
3	• Advanced greenhouse automation. • Real-time data analysis. • Adaptability to diverse crops.	• Limited crop health data. • Underutilized data for decisions.	• Exploring potential synergies or competition among different crops within the shared environment could be useful on optimizing the resource usage

4	• Innovative use of fuzzy logic control. • Data-driven decision-making. • Optimal control device operation.	• Complexity with more sensors. • Fuzzy rule validation uncertainty.	• Design a more dynamic algorithm to mitigate the scalability and accuracy issues arising from the limited dimension and predetermined nature of fuzzy rules.

where system A is IoT-based Precision Farming Framework for Groundnut,
system B is IoT-enabled smart farming and Irrigation System,
system C is IoT-based Environment Change Monitoring & Controlling,
system D is IoT-based Monitoring of Temperature and Humidity with Fuzzy Control.

2.2 Review of the Deep Learning Models

2.2.1 LSTM

Recurrent Neural Networks (RNNs) serve as powerful tools for sequence modeling but grapple with challenges related to long-term dependencies and vanishing gradients. LSTM networks strategically address these issues by incorporating purpose-built memory cells within their architecture. These cells, featuring input, output, and forget gates, meticulously regulate information flow through the cell state, enabling effective preservation of error signals across extensive time steps. This unique feature positions LSTMs to excel in capturing intricate temporal patterns within sequential data, particularly evident in domains like time series analysis.

The intricate architecture of an LSTM cell revolves around the cell state—an information conveyor modulated by three gates, each comprising sigmoid and tanh layers. The forget gate crucially decides which old information to discard, achieved by combining input and the previous hidden state through sigmoid activation. The resulting value undergoes element-wise multiplication with the cell state. Simultaneously, the input gate, utilizing sigmoid for relevance and tanh for values, determines the incorporation of new information. Its output undergoes element-wise multiplication with a tanh activation of new candidate values. The interplay of candidate and forget gates orchestrates the regulation of the cell state. This regulated state, following a tanh activation, undergoes multiplication by the output gate's sigmoid output, ultimately generating the hidden state. This intricate process within an LSTM cell encapsulates its robust architecture and sophisticated information processing capabilities.

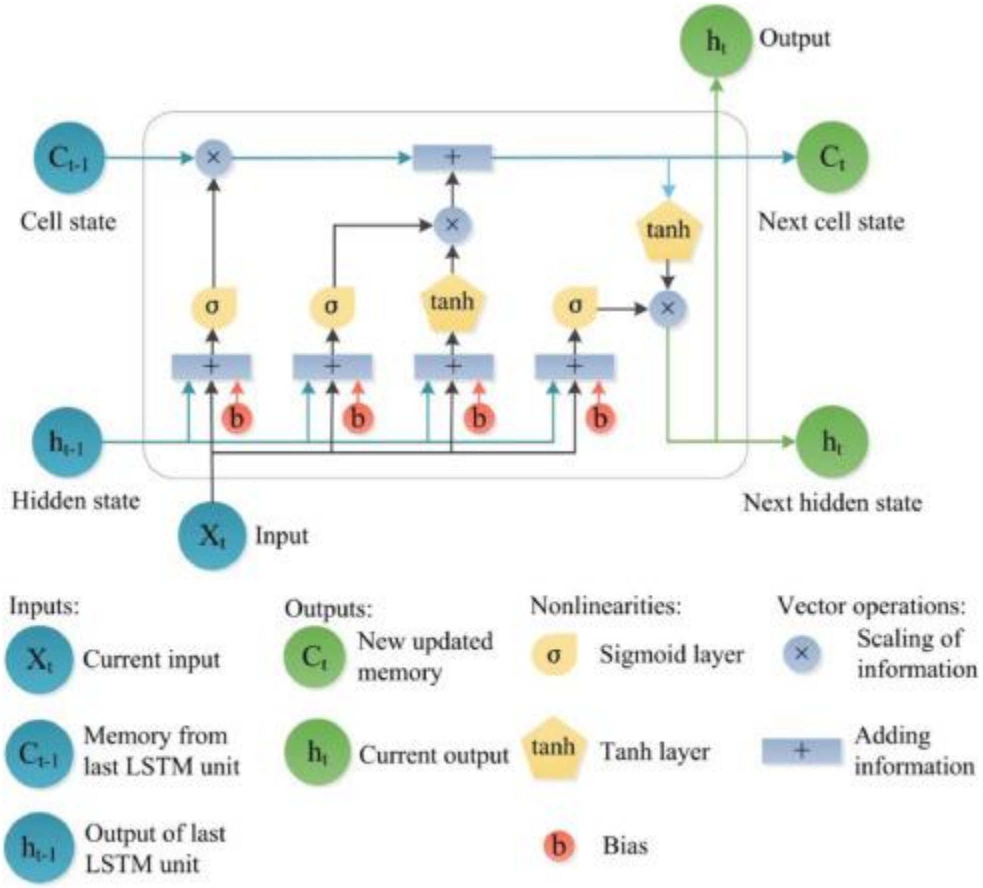


Figure 2.12. Structure of LSTM neural network.

The integration of LSTM models in agriculture, exemplified in the article in [13], demonstrates significant progress in yield estimation. In the Guanzhong Plain, the LSTM model, incorporating Vegetation Temperature Condition Index (VTCI), Leaf Area Index (LAI), and meteorological data, displayed superior accuracy (Root Mean Square Error (RMSE) = 357.77 kg/ha, R^2 = 0.83) with a time step of 2. The LSTM model excels in approximating complex functions, offering robust yield estimates and adapting to interannual climate variations.

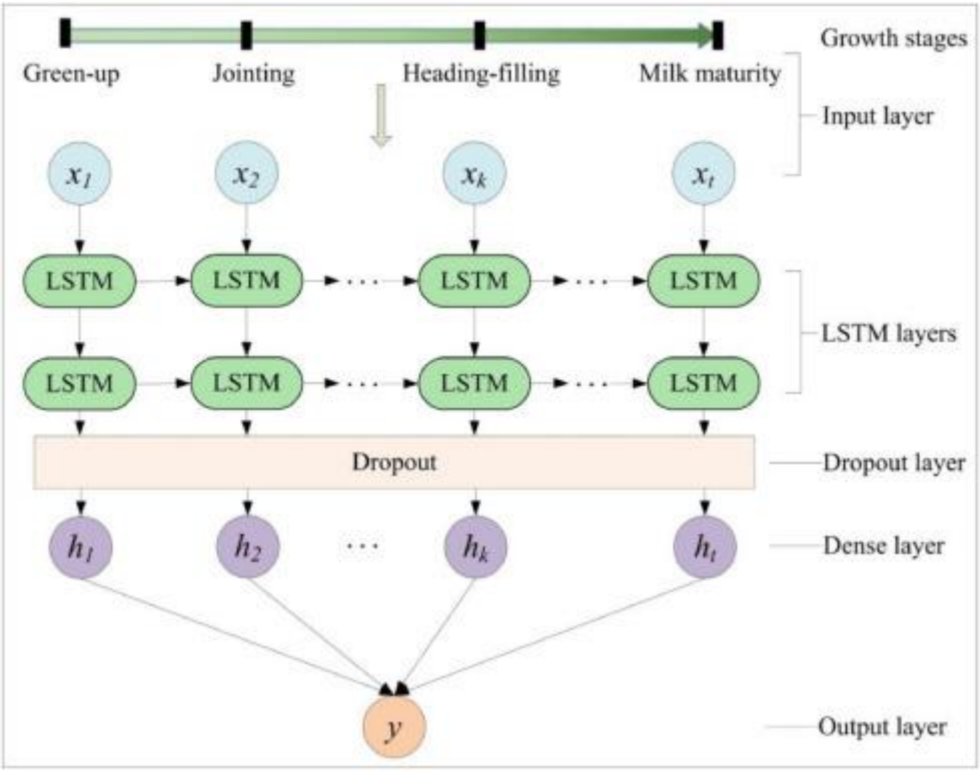


Figure 2.13. Architecture of the LSTM model in [13].

Comparatively, the article in [14] focuses on LSTM applications in greenhouse environments, pitting LSTM against traditional Machine Learning (ML) techniques like Support Vector Regression (SVR) and Random Forest (RF). LSTM's superiority is evident in tomato yield prediction (MSE = 0.002, RMSE = 0.047, Mean Absolute Error (MAE) = 0.03) and ficus growth (MSE = 0.001, RMSE = 0.042, MAE = 0.03). In contrast, SVR exhibits higher errors in tomato yield prediction (MSE = 0.015, RMSE = 0.125, MAE = 0.087) and in ficus growth (MSE = 0.006, RMSE = 0.073, MAE = 0.07). These results highlight LSTM's consistent outperformance of SVR, emphasizing its efficacy in capturing intricate relationships and dependencies within data.

In the realm of agriculture, LSTM models encounter challenges, particularly with text data, such as overfitting on limited datasets and computational complexity. Addressing these challenges is crucial for determining the viability of LSTMs in optimizing agricultural processes through textual information analysis, requiring innovative solutions tailored to smart farming applications.

Techniques like dropout and transfer learning prove instrumental in mitigating overfitting and accelerating convergence during LSTM model training. Ensembling, combining multiple model variants trained on augmented data, aims to enhance diversity and reduce prediction variance. This multifaceted evaluation strategy provides a nuanced understanding of an LSTM model's effectiveness in capturing temporal patterns within textual agricultural data.

In conclusion, LSTMs show promise for learning temporal patterns underlying plant growth when properly optimized. Further work addressing overfitting, data scarcity, and deployment challenges is crucial for realizing their broader applicability to smart agriculture.

2.2.2 GRU

Gated Recurrent Units (GRUs) emerge as powerful tools for overcoming challenges associated with long-term dependencies and vanishing gradients in sequence modeling, mirroring the capabilities of RNNs. GRUs represent a streamlined alternative to Long LSTM networks, featuring a simplified architecture while retaining the ability to effectively model sequential data. The core innovation lies in the incorporation of reset and update gates within the GRU structure, facilitating selective information capture and propagation across different time steps.

The architecture of a GRU revolves around its reset and update gates, which dynamically modulate the flow of information. The reset gate dictates the degree to which the previous hidden state should be forgotten, enabling the model to prioritize new information. Simultaneously, the update gate determines the proportion of new candidate values to be integrated into the updated hidden state. This dynamic gating mechanism equips GRUs to strike a balance between capturing short-term dependencies and retaining crucial long-term information. The simplicity of GRUs, characterized by fewer parameters compared to LSTMs, contributes to expedited training convergence and reduced computational complexity.

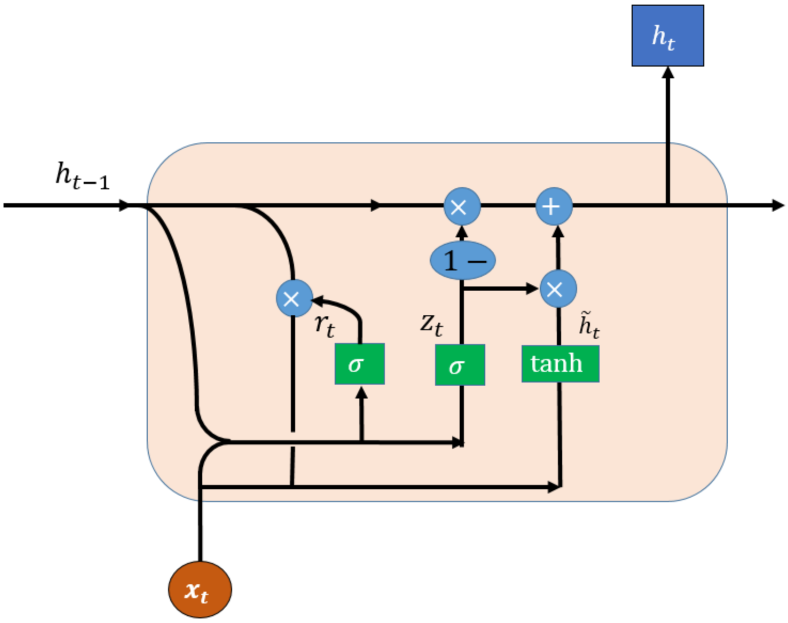


Figure 2.14. GRU architecture.

The article in [15] incorporated GRUs into the deep learning models to capture the temporal dependencies in the simulated crop growth process data over different phases. The

GRUs helped improve yield prediction potential, with key results including the flowering phase model achieving R^2=0.53, RMSE=554.84 kg/ha, Mean Magnitude of Relative Error (MRE) =8.27%, indicating moderately strong prediction ability after kernels begin forming. More importantly, the milk maturity phase model substantially outperformed with a higher R^2=0.89, lower RMSE=268.76 kg/ha and MRE=4.01%, suggesting the GRU effectively modeled how environmental conditions at this critical stage influenced yield. Ultimately, the maturity phase GRU model achieved the best statistical performance of R^2=0.98, RMSE=102.65 kg/ha and MRE=1.53%, demonstrating highly accurate yield forecasting capability when the GRU learned growth dynamics from the World Food Studies (WOFOST) simulations, especially after flowering and milk maturity phenological milestones.

While GRUs excel in sequence modeling, they face challenges in capturing intricate long-term dependencies, lagging behind more complex models like LSTM. Tuning GRU hyperparameters is crucial, and their sensitivity to parameter choices adds complexity, especially in agriculture with diverse data characteristics. GRUs struggle with very long data sequences, impacting their ability to capture extended dependencies, a significant limitation in agriculture where seasonal patterns require extended analysis. The interpretability of GRUs is challenging due to intricate gating mechanisms. Additionally, like other recurrent models, GRUs may overfit with limited agricultural data, hindering generalization. Overcoming these challenges is vital for maximizing the potential of GRUs in smart agriculture, necessitating focused research on model refinement, robust training strategies, and improved interpretability.

2.2.3 Summary of the Technologies Review

Table 2.2 Comparison table between LSTM and GRU

Feature	**LSTM**	**GRU**
Architecture	More complex with separate memory and cell states	Simplified architecture with reset and update gates
Gating Mechanism	Three gates: input, output, forget	Two gates: reset, update
Memory Usage	More memory-intensive due to separate cell state	Less memory-intensive with a single hidden state
Training Speed	Slower training due to complex structure	Faster training owing to simpler architecture
Performance	Better at capturing long-term dependencies	May perform better on less complex tasks
Interpretability	More challenging due to intricate architecture	Relatively more interpretable with fewer parameters
Overfitting	More prone to overfitting with limited data	Generally less prone to overfitting

2.3 Concluding Remark

In this chapter, a comprehensive review of existing IoT systems in agriculture has been conducted, extracting valuable insights and advantages that are assimilated into the proposed solution's features. The exploration of deep learning models contributes significantly to laying the groundwork for the future development of the plant growth prediction model. By synthesizing the strengths observed in various IoT systems and leveraging the capabilities of deep learning, the proposed solution aims to enhance the effectiveness and precision of plant growth predictions in agricultural contexts.

Chapter 3

System Methodology

In this chapter, The system development model, system requirements such as hardware and software, functional requirements, expected system testing and performance, expected challenges, project milestones, and estimated costs will all be covered.

3.1 System Development Model

The Agile Methodology is adopted as the system development model, emphasizing concurrent and iterative development of various components. The methodology envisions the simultaneous construction of hardware elements, software code, and an adaptive resource optimization framework, emphasizing flexibility and adaptability throughout the development process.

Following the Agile principles, hardware development occurs in iterative cycles, allowing for the continuous integration and refinement of components such as Raspberry Pi microcomputers, diverse sensors, and actuators. This incremental hardware development aligns with the Agile philosophy of delivering a minimum viable product swiftly and subsequently enhancing it based on ongoing feedback.

The software development aspect adheres to Agile principles by embracing iterative coding practices. Python code is written and refined incrementally using Visual Studio Code, ensuring adaptability to the evolving needs of monitoring Bentong ginger growth. The integration of AWS services for data storage, along with the development of the Node-RED dashboard, represents a collaborative and incremental approach.

In essence, the Agile Methodology involves iterative cycles encompassing planning, design, development, testing, deployment, and review. These iterative steps allow for constant reassessment and adjustment, promoting a dynamic and responsive development process in line with the principles of Agile methodologies.

3.2 System Requirement

3.2.1 Hardware

Raspberry Pi 3 Model B

The Raspberry Pi 3 Model B serves as the data collection and processing hub. It communicates with all of the sensors, managing data collection. Its computational power enables real-time data transfer, ensuring uninterrupted communication among the numerous components of the monitoring system.

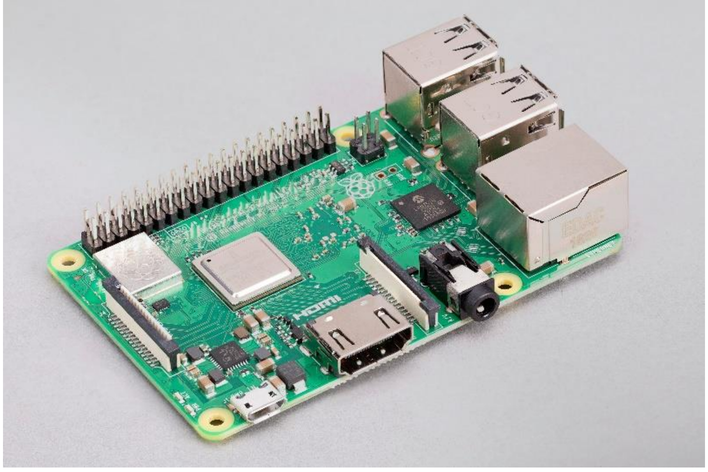


Figure 3.1. Raspberry Pi 3 Model B.

Table 3.1 Specification of Raspberry Pi 3 Model B

Description	**Specifications**
Processor	Quad Core 1.2GHz Broadcom BCM2837 64bit CPU
Memory (RAM)	1GB
Storage (ROM)	16GB Micro SD Card
Connectivity	- BCM43438 wireless LAN and Bluetooth Low Energy (BLE) on board - 100 Base Ethernet

DHT22 Temperature and Humidity Sensor Module Breakout

The air temperature and humidity sensor, which is installed within the ginger plantation area, collects real-time temperature data in degrees Celsius (°C) and humidity data in percentage (%). Temperature and humidity readings provide information about environmental factors influencing plant transpiration rates.

Figure 3.2. DHT22 temperature and humidity sensor module breakout.

Table 3.2 Specification of DHT22 temperature and humidity sensor breakout

Description	**Specifications**
Input Voltage	3.3V - 6V
Operating Range	Humidity: 0 to 100% Temperature: -40 to 80 °C
Accuracy	Humidity: +-5% Temperature: <+-0.5 °C

BH1750 Digital Light Intensity Sensor Module

The light sensor module is carefully placed to measure the lighting conditions in lux (lx). It measures the illuminance to ensure that ginger plants get enough light for photosynthesis. This data assists in making decisions about shading or additional lighting to improve plant health and yield.

Figure 3.3. BH1750 digital light intensity sensor module.

Table 3.3 Specification of BH1750 digital light intensity sensor module

Description	**Specifications**
Input Voltage	3V - 5V
Operating Range	Luminance: 1 - 65535 lx
Accuracy	Luminance: +/- 20%

5MP Camera Module for Raspberry Pi

The 5MP camera board acts as the project's visual component, capturing high-resolution images of the ginger plantation. These images serve multiple purposes, including growth stage monitoring and visual assessment.

Figure 3.4. 5MP camera module for Raspberry Pi.

Table 3.4 Specification of 5MP camera module for Raspberry Pi

Description	**Specifications**
Photosensitive Module	Omni Vision 5647
Still Picture Resolution	2592 x 1944
Video	1080p @ 30fps, 720p @ 60fps and 640x480p 60/90 Recording

Soil Detector Sensor

This all-in-one pedometric sensor is placed in the soil and performs a variety of soil tests. It measures nutrient levels such as NPK in milligrammes per kilogramme (mg/kg), soil EC in deciSiemens per metre (dS/m), soil moisture in percentage (%),soil temperature in degrees Celsius (°C), and soil pH value. These data provide an in-depth view of soil condition and help to guide decisions about nutrient ratio of fertiliser supplementation, soil amendments, and irrigation schedule.

Figure 3.5. RS485 soil detector sensor.

Table 3.5 Specification of RS485 soil detector sensor

Description	**Specifications**
Power Supply	DC power supply 9-18V
Communication Method	RS485/ Analog 0-5V/ 0-10V/ 4-20mA
Measuring Range	Temperature: -40 ℃ - 80 ℃ Humidity : 0 - 100% (non-condensing) PH : 0 - 14PH NPK : 0 – 1999 mg/kg Conductivity: 0 – 2000 us/cm
Precision	Temperature: ± 0.5 ℃ Humidity: ± 3 % PH : 0.01 PH NPK : ± 2% Fs Conductivity : ± 3% in the range of 0 - 1000 us/cm, ± 5% in the range of 1000 – 2000 us/cm
Response Time	≤15s
Operating Temperature	-40℃ - 85℃
Working Humidity	15%RH - 90%RH (relative humidity), non-condensing
Waterproof Level	IP67

LED Grow Light

The LED grow light takes charge of delivering essential lighting to the ginger plants, featuring both red and blue spectra. The red spectrum promotes photosynthesis, whereas the blue spectrum stimulates vegetative growth and leaf development. By automating the operation of the LED grow light, it ensures consistent and even lighting, allowing the ginger plants to maintain photosynthetic activity and robust growth even in low-light conditions.

Figure 3.6. LED grow light.

Table 3.6 Specification of LED grow light

Description	**Specifications**
Light Source	LED
Input Voltage	DC 12-24V
Working Temperature	-20 – 50 ℃

Cooling Fan

The cooling fan is to regulate temperature and humidity for optimal Bentong ginger growth. By circulating air and managing heat, it maintains stable conditions, preventing plant stress and potential damage. Additionally, it helps control humidity, reducing the risk of fungal growth. Integrated into the automated system, the fan adjusts based on real-time data to ensure consistent and ideal conditions for healthy plant development.

Figure 3.7. Cooling fan.

Table 3.7 Specification of cooling fan

Description	**Specifications**
Bearing Type	Hydraumatic
Rated Voltage	DC 12V
Rated Current	0.13±0.02 Amp
Air Flow	32 CFM
Noise	11 dBA±10%

Water Pump for Irrigation and Fertilizing

The water pump serves a dual purpose in the project: irrigation and fertilizing. For irrigation, the pump delivers a controlled amount of water to the soil, ensuring consistent moisture levels essential for plant growth. This automated watering system eliminates the guesswork and manual labor associated with traditional watering methods, ensuring the Bentong ginger plants receive the right amount of hydration at optimal times.

In terms of fertilizing, the water pump facilitates the distribution of water-based fertilizers to the plants, ensuring they receive essential nutrients for robust growth. This automated fertilizing process helps maintain soil fertility levels, promoting healthier and more productive plants.

Figure 3.8. Water pump.

Table 3.8 Specification of water pump

Description	Specifications
Input Voltage	DC 3V-5V
Flow Rate	1.2-1.6 L/min
Operation Temperatur	80 Deg.C
Operating Current	0.1-0.2A
Suction Distance	0.8 meter (Max)

Power Supply

The power supply delivers consistent and reliable electrical power to the connected automation control devices, ensuring uninterrupted operation and optimal functionality.

Figure 3.9. Power supply.

Table 3.9 Specification of power supply

Description	**Specifications**
Input Voltage Range	100 – 240V (AC)
Output Voltage	24V (DC)
Output Current	2A
Plug Type	UK 3-Pin

8-Channel Relay Module

The 8-channel relay allows the Raspberry Pi to control multiple automation devices by switching different circuits on and off. This feature offers accurate control over connected devices, enabling automated actions based on predefined conditions or user commands.

Figure 3.10. 8-channel relay module.

Table 3.10 Specification of 8-channel relay module

Description	**Specifications**
Trigger Voltage	DC 5V
Maximum Current	10A

Voltage Stepdown Converter

The step-down converter adjusts the voltage from the power supply to different levels suitable for various automation devices. By converting the voltage to match the operating requirements of each device, it ensures efficient and safe operation of the entire system.

Figure 3.11. Voltage stepdown converter.

Table 3.11 Specification of voltage stepdown converter

Description	**Specifications**
Input Voltage Range	4V to 40V (DC)
Output Voltage Range	1.25V to 37V (DC)
Output Current	2A

3.2.2 Software

Programming Language (Python)

Python is a flexible and widely used programming language known for its accessibility and simplicity. It will be the project's core programming language, allowing for the creation of scripts and programmes for sensor data collection, analysis, and system control.

VNC Viewer

VNC Viewer is used to allow remote access to the Raspberry Pi's GUI (Graphical User Interface) from other devices. This remote access feature simplifies the configuration and management tasks by allowing users to interact with the Raspberry Pi's desktop environment.

Linux OS Installed on Raspberry Pi

The Raspberry Pi will be installed with a Linux-based OS, which is chosen over Windows OS due to its lightweight nature. This option ensures compatibility with Raspberry Pi hardware and provides the necessary environment for running software components such as as Python programmes and sensor drivers. Linux provides resource-efficient performance, making it an excellent choice for the Raspberry Pi's operating system while preserving system resources for other tasks.

Visual Studio Code

Visual Studio Code is a lightweight and customisable code editor developed by Microsoft. It is essential to the project as the IDE for editing, debugging, and managing Python scripts. The extensibility of Visual Studio Code offers a more efficient development workflow.

AWS Cloud Services

AWS offers a set of cloud services that are required for a number of project components, including IoT connectivity, data storage, visualisation, and reporting.

IoT Core: A service for seamless connectivity between IoT devices and AWS for transmitting real-time data from sensors to the cloud.

DynamoDB: A NoSQL database used to store structured sensor data.

S3: An object storage used to store unstructured data such as images of the Bentong ginger plant.

Telegram Bot API (Application Programming Interface)

The API is used for real-time notifications, alerting users to extreme abnormal conditions in the environmental parameters for swift user awareness and timely responses.

YouTube

YouTube serves as a hosting platform for live streams to easily share the real-time observation of the Bentong ginger with a wider audience, providing convenient access to real-time information.

Node-RED

Node-RED is a visual programming tool that offers a browser-based editor for connecting devices, APIs, and online services through flow-based development. Node-RED serves as a versatile platform for creating interactive dashboards to monitor real time environment data, automating control actions, and integrating YouTube live streams for real-time visualization.

Keras

Keras is an open-source library for artificial neural networks with a Python interface that serves as a frontend for TensorFlow. Keras contributed to the experimental development of the conceptual LSTM model for processing time-series data from sensors, providing valuable insights into the growth patterns of Bentong ginger plants.

Google Colab

Google Colab serves as a cloud-based platform for executing Python code, specifically for developing the conceptual LSTM models in the project. Developed by Google, it offers a convenient and interactive environment for tasks such as model training, enhancing the overall efficiency and flexibility of the development process.

3.3 Functional Requirement

I. Text Data Collection and Image Data Capture

The system's text data collection functionality involves the systematic gathering of real-time environmental parameters crucial for Bentong ginger cultivation. This includes monitoring air temperature, humidity, and light levels to gain insights into the ambient climate. Additionally, the system records data on soil moisture, temperature, pH, EC, and NPK, creating a comprehensive dataset for assessing the root environment and soil composition. This approach ensures detailed insights into growing conditions. Image data capture entails the systematic collection of high-resolution images of Bentong ginger plants at daily intervals. This process serves the purpose of closely monitoring the growth patterns of the plants, providing valuable visual insights into their development over time.

II. Automation

The functional requirement for automation involves optimizing the growth of Bentong ginger through automated adjustments, guided by predefined threshold values for optimal Bentong ginger growth compared to current environmental conditions. Users can also manually trigger the automation process via mobile devices. The focus is on automating the process and, when possible, guiding the ginger towards optimal values for each environmental parameter. This approach ensures precision in resource allocation, contributing to overall efficiency and sustainable cultivation of Bentong ginger.

III. Visualization

A visualization is essential to offer a real-time overview of environmental data in statistical form, display previous growth trends through graphs, and present the current plant status via livestream. The integration of visual and statistical data enables users to gain deeper insights, aiding them in decision-making.

3.4 Expected System Testing and Performance

I. IoT Sensors Accuracy

The accuracy of recorded sensor data is crucial for effective environmental monitoring. For IoT sensors, an advanced data collection device will be used to calculate the Mean Absolute Percentage Error (MAPE) by comparing sensor-recorded values with device-recorded values. Professional-grade instruments serve as benchmarks for comparison, enhancing the reliability and precision of sensor measurements. The expected MAPE for all sensor data over a certain period is set at 5%, ensuring that the environmental monitoring system delivers accurate and trustworthy measurements.

$$\boldsymbol{MAPE = \frac{1}{N}\sum_{i=1}^{N}\left|\frac{y_i-\hat{y}_i}{y_i}\right| \times 100\%} \tag{1}$$

where

N = number of data points

y_i = actual value

$\hat{y}_i$ = predicted value

II. Software Response Time

The time taken between triggering the action and its actual execution, such as starting a YouTube livestream or executing a Telegram command, will be calculated using a simple mean formula.

$$\boldsymbol{Mean = \frac{1}{N}\sum_{i=1}^{N} x_i} \tag{2}$$

where

N = number of data points

x_i = response time

III. Conceptual LSTM Model Accuracy

The LSTM model's assessment relies on MSE, measuring the average squared difference between predicted and actual Bentong ginger growth scores for validation and test sets. A lower MSE reflects greater predictive accuracy, guiding model refinement for effective generalization across different Bentong ginger datasets. Notably, predefined MSE thresholds are avoided, with appropriateness determined based on simpler models like the constant, linear regression, and naïve models. This ensures the LSTM model's superiority, substantiating its effectiveness in dealing with Bentong ginger growth intricacies.

$$\mathbf{MSE} = \frac{1}{N} \sum_{i=1}^{N} (y_i - \hat{y}_i)^2 \tag{3}$$

where

N = number of data points

y_i = actual value

$\hat{y}_i$ = predicted value

3.5 Expected Challenges

I. Undefined Metrics for Measuring Bentong Ginger Growth

Assessing Bentong ginger's growth effectively poses a significant hurdle due to a lack of clear benchmarks and comprehensive understanding of its optimal environmental conditions. The absence of established metrics and defined criteria for successful growth makes it challenging to accurately evaluate the well-being of Bentong ginger plants. This limited baseline knowledge hinders the ability to discern between healthy and suboptimal growth, impeding the development of precise assessment methodologies. The ambiguity surrounding what constitutes optimal growth further complicates the evaluation process, highlighting the need for robust benchmarks and indicators to effectively gauge the success of Bentong ginger cultivation.

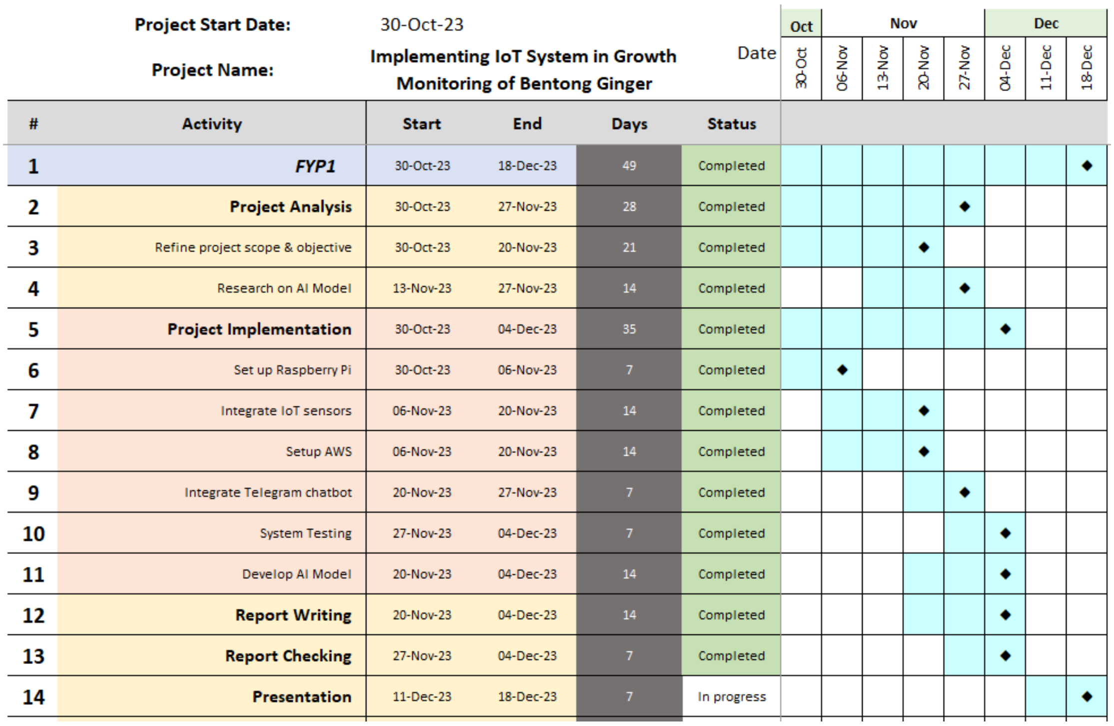
II. Unavailability of a Comparable Dataset

The absence of a suitable dataset for training a predictive model to assess Bentong ginger's growth creates a substantial roadblock. Currently, there is a lack of existing datasets that accurately mirror the diverse conditions affecting Bentong ginger cultivation, and a similar void exists for datasets from other plant species. To address this issue, a temporary solution involves generating a synthetic dataset. This allows for overcoming technical challenges and refining techniques while awaiting the discovery or creation of a more pertinent and representative dataset for training the growth prediction model. The predictive accuracy of the model heavily relies on environmental conditions, further emphasizing the significance of obtaining an authentic and relevant dataset for optimal results.

III. Absence of Control Dataset for Obtaining Optimal Values

The project grapples with a significant challenge due to the absence of a control dataset. Without this crucial dataset, the ability to perform comprehensive data analysis and build a precise model to identify optimal environmental conditions for Bentong ginger growth is severely hindered. The lack of control data deprives the project of the foundational information required to understand the nuanced factors influencing ginger cultivation. Consequently, uncertainty arises in determining the ideal allocation of resources, such as water and lighting, during the automation phase. This challenge underscores the pivotal role of control data in not only facilitating accurate data analysis and modeling but also guiding effective resource allocation for optimal Bentong ginger cultivation.

3.6 Project Milestone

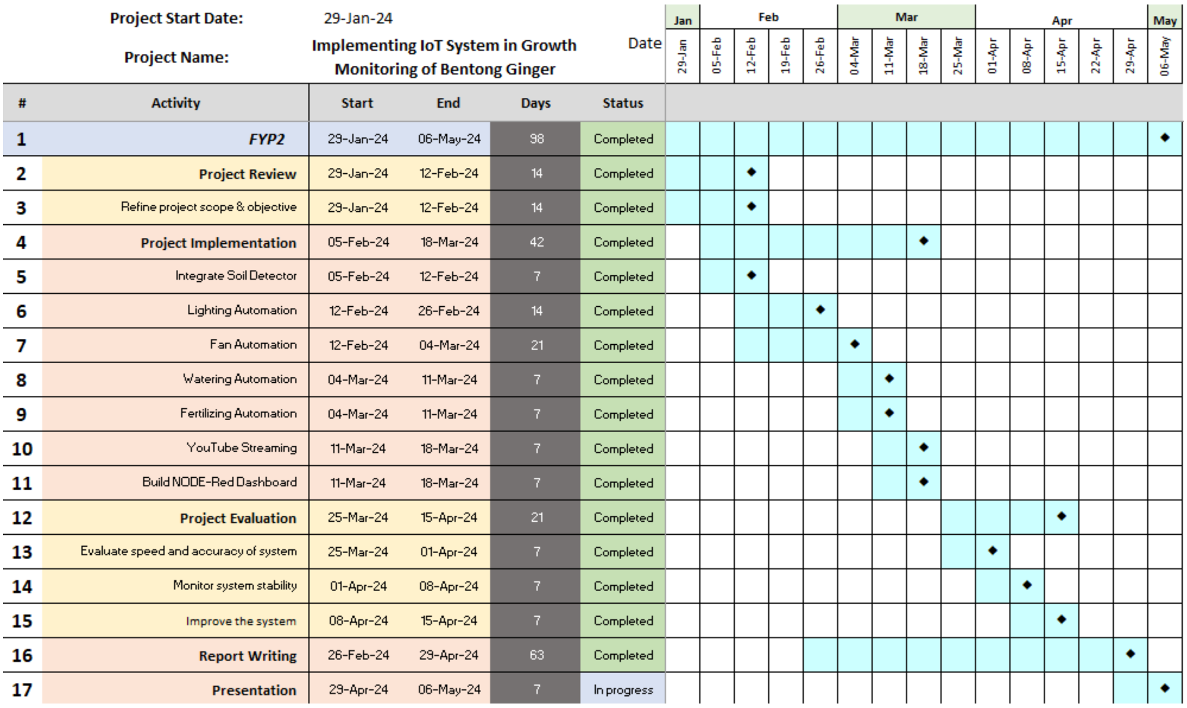


Project Start Date: 30-Oct-23

Project Name: Implementing IoT System in Growth Monitoring of Bentong Ginger

#	Activity	Start	End	Days	Status	Oct	Nov				Dec		
					Date	30-Oct	06-Nov	13-Nov	20-Nov	27-Nov	04-Dec	11-Dec	18-Dec
1	*FYP1*	30-Oct-23	18-Dec-23	49	Completed								◆
2	**Project Analysis**	30-Oct-23	27-Nov-23	28	Completed					◆			
3	Refine project scope & objective	30-Oct-23	20-Nov-23	21	Completed				◆				
4	Research on AI Model	13-Nov-23	27-Nov-23	14	Completed					◆			
5	**Project Implementation**	30-Oct-23	04-Dec-23	35	Completed						◆		
6	Set up Raspberry Pi	30-Oct-23	06-Nov-23	7	Completed		◆						
7	Integrate IoT sensors	06-Nov-23	20-Nov-23	14	Completed				◆				
8	Setup AWS	06-Nov-23	20-Nov-23	14	Completed				◆				
9	Integrate Telegram chatbot	20-Nov-23	27-Nov-23	7	Completed					◆			
10	System Testing	27-Nov-23	04-Dec-23	7	Completed						◆		
11	Develop AI Model	20-Nov-23	04-Dec-23	14	Completed						◆		
12	**Report Writing**	20-Nov-23	04-Dec-23	14	Completed						◆		
13	**Report Checking**	27-Nov-23	04-Dec-23	7	Completed						◆		
14	**Presentation**	11-Dec-23	18-Dec-23	7	In progress								◆

Figure 3.12. FYP1 timeline.



Project Start Date: 29-Jan-24

Project Name: Implementing IoT System in Growth Monitoring of Bentong Ginger

#	Activity	Start	End	Days	Status	Jan	Feb				Mar				Apr					May
					Date	29-Jan	05-Feb	12-Feb	19-Feb	26-Feb	04-Mar	11-Mar	18-Mar	25-Mar	01-Apr	08-Apr	15-Apr	22-Apr	29-Apr	06-May
1	*FYP2*	29-Jan-24	06-May-24	98	Completed															◆
2	**Project Review**	29-Jan-24	12-Feb-24	14	Completed			◆												
3	Refine project scope & objective	29-Jan-24	12-Feb-24	14	Completed			◆												
4	**Project Implementation**	05-Feb-24	18-Mar-24	42	Completed								◆							
5	Integrate Soil Detector	05-Feb-24	12-Feb-24	7	Completed			◆												
6	Lighting Automation	12-Feb-24	26-Feb-24	14	Completed					◆										
7	Fan Automation	12-Feb-24	04-Mar-24	21	Completed						◆									
8	Watering Automation	04-Mar-24	11-Mar-24	7	Completed							◆								
9	Fertilizing Automation	04-Mar-24	11-Mar-24	7	Completed							◆								
10	YouTube Streaming	11-Mar-24	18-Mar-24	7	Completed								◆							
11	Build NODE-Red Dashboard	11-Mar-24	18-Mar-24	7	Completed								◆							
12	**Project Evaluation**	25-Mar-24	15-Apr-24	21	Completed												◆			
13	Evaluate speed and accuracy of system	25-Mar-24	01-Apr-24	7	Completed										◆					
14	Monitor system stability	01-Apr-24	08-Apr-24	7	Completed											◆				
15	Improve the system	08-Apr-24	15-Apr-24	7	Completed												◆			
16	**Report Writing**	26-Feb-24	29-Apr-24	63	Completed														◆	
17	**Presentation**	29-Apr-24	06-May-24	7	In progress															◆

Figure 3.13. FYP2 timeline.

3.7 Cost

Table 3.12 Project cost

No.	**Item**	**Development Cost (RM)**	**Estimated Commercialization Cost (RM)**
1.	Raspberry Pi 3 Model B	179.00	250.00
2.	DHT22 Air Temperature and Humidity Sensor	4.90	8.00
3.	BH1750 Light Intensity Sensor	6.60	10.00
4.	5MP Camera Module for Raspberry Pi	30.00	45.00
5.	RS485 Soil Detector Sensor	500.00	750.00
6.	LED Grow Light	20.00	30.00
7.	Cooling Fan	10.90	20.00
8.	Water Pump	3.80	7.00
9.	8-Channel Relay Module	16.90	25.00
10.	Stepdown Converter	8.70	17.50
11.	Power Supply	5.90	10.00
	Grand Total	**786.70**	**1172.50**

3.8 Concluding Remark

In summary, this chapter outlines the Agile-based methodology adopted for the Bentong ginger precision agriculture project. It details the hardware, software, and functional requirements. Anticipated challenges are acknowledged, and project milestones, along with estimated costs, provide a roadmap for development. This lays the groundwork for the system's practical implementation in subsequent chapters.

Chapter 4

System Design

In this chapter, the intricate details of the system architecture, hardware connections, functional modules, system flow, database, and GUI design that govern the Bentong ginger project will be discussed in depth.

4.1 System Architecture

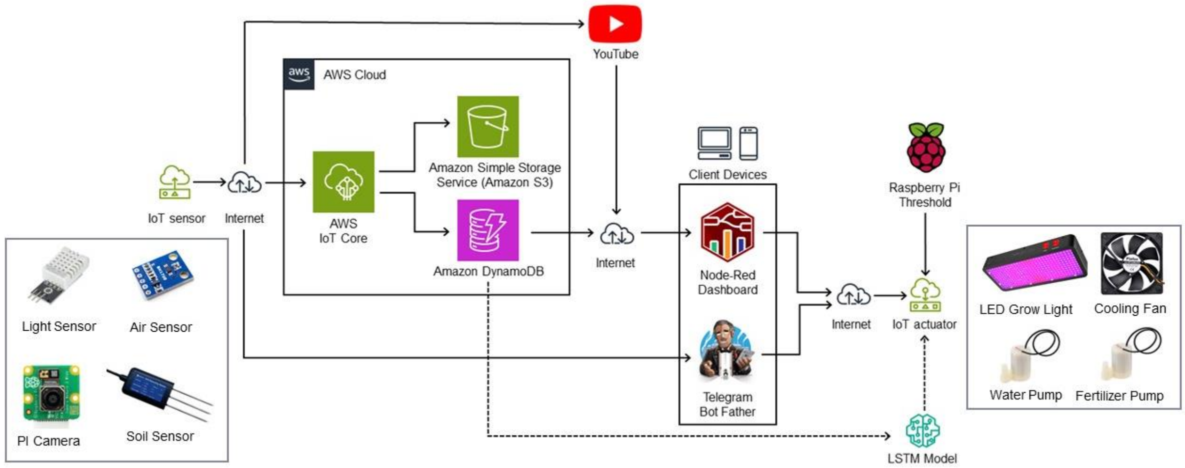


Figure 4.1. System architecture diagram.

The IoT framework collects diverse sensor data, including air quality, light levels, and soil conditions, along with image data of the Bentong ginger plant. These datasets are transmitted to **AWS IoT Core**, with text data stored in **Amazon DynamoDB** and images in **Amazon S3**. Additionally, video data are directly streamed to **Google YouTube** for livestreaming purposes. Current data values are sent to users via a **Telegram Bot** upon request and alert notifications are triggered due to abnormal condition detection. A **Node-RED dashboard** serves as the platform for livestreaming the plant, displaying current environmental data, and visualizing previous data through graphs. The Telegram bot is limited to providing current environmental data and alert notifications. Users can utilize the Node-RED dashboard and Telegram to trigger automation devices such as LED grow lights, cooling fans, water pumps, and fertilizer pumps without being physically present. The system will perform automation using predefined values in the **Raspberry Pi**. Additionally, a conceptual **LSTM model** can perform analysis on current data and determine the need for automation.

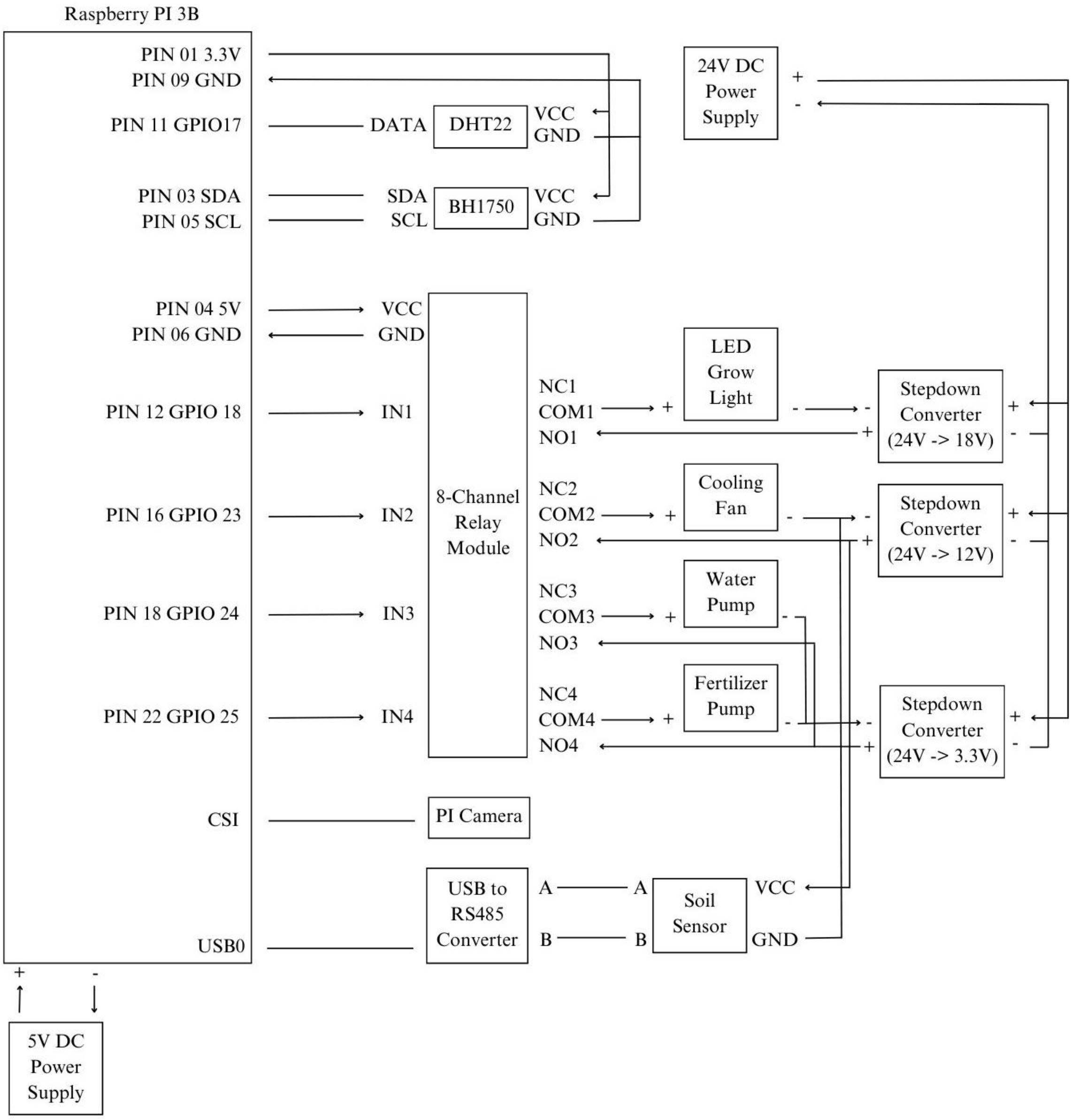


Figure 4.2. Hardware connection diagram.

The hardware connection diagram shows the connection between the Raspberry Pi Model 3B, DHT22 sensor, BH1750 sensor, Pi camera, 8-channel relay module, and soil sensor through a USB to RS485 converter. The diagram also shows the connection between a power supply and different voltage step-down converters to the 8-channel relay and automation devices such as LED grow lights, cooling fans, water pumps, and fertilizer pumps.

4.2 System Functional Modules

Module 1: Environmental and Image Data Collection

This module encompasses the systematic gathering of real-time environmental parameters crucial for Bentong ginger cultivation, including air temperature, air humidity, light levels, soil moisture, temperature, pH, EC, and NPK. Continuous data collection enables statistical pattern analysis, deviation detection, and informed adjustments for successful Bentong ginger cultivation. Image data capture involves the systematic collection of high-resolution images of Bentong ginger plants at daily intervals. This process provides valuable visual insights into growth patterns, enhancing data analysis.

Module 2: Automation Control

This module optimizes Bentong ginger growth through automated adjustments, guided by the predefined optimal range for plant growth. After evaluating current environmental conditions, the system performs automation tasks such as adjusting lighting, ventilation, watering, and fertilization. Additionally, users can trigger automation device actions using either the Node-RED dashboard or Telegram on mobile devices.

Module 3: Visualization

Utilizing the Node-RED dashboard, this module generates statistical dashboards and graphs to provide a real-time overview of environmental statistics, previous growth trends, and plant status. The statistical visualization tools enhance comprehension through graphical representation of data trends. A concurrent feature provides the current video of Bentong ginger plants, merging visual and statistical insights. This module aims to equip users with a holistic understanding for informed decision-making in ginger cultivation.

Module 4: Reporting

A Telegram chatbot is integrated for real-time reporting of abnormal conditions, ensuring swift user awareness and enabling timely responses. Users can also receive the latest environmental data upon request. The reporting module delivers essential insights and alerts directly to stakeholders, promoting proactive decision-making in Bentong ginger cultivation.

Module 5: Conceptual LSTM Model Development

Focusing on creating a predictive LSTM model, this module analyzes time-series data to assess the suitability of prevailing environmental conditions for optimal Bentong ginger growth. The LSTM model generates a statistical predictive score, serving as a quantitative foundation for decision-making within the adaptive resource optimization framework.

4.3 System Flow

This subsection will present high-level abstract flowcharts outlining the key components of the system handled by different threads.

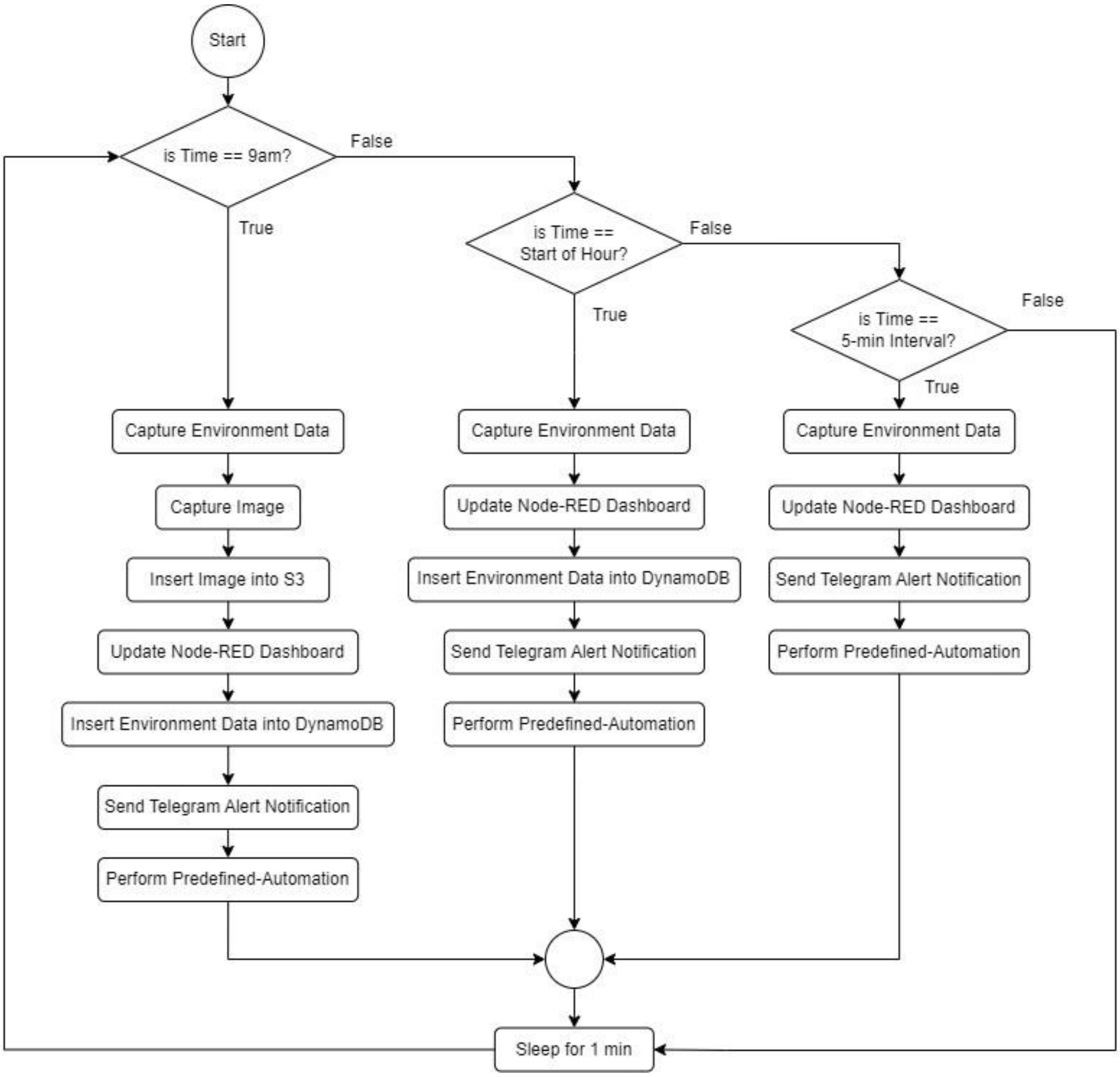


Figure 4.3. Flowchart of interval task thread.

The interval task thread will perform various combinations of tasks at different times—every 5 minutes, every 1 hour, and at 9 am. These tasks include capturing environmental data, updating the Node-RED dashboard, sending Telegram alert notifications, executing predefined automation, inserting environmental data into DynamoDB, capturing images, and inserting them into S3. The system then waits for 1 minute before performing the next check.

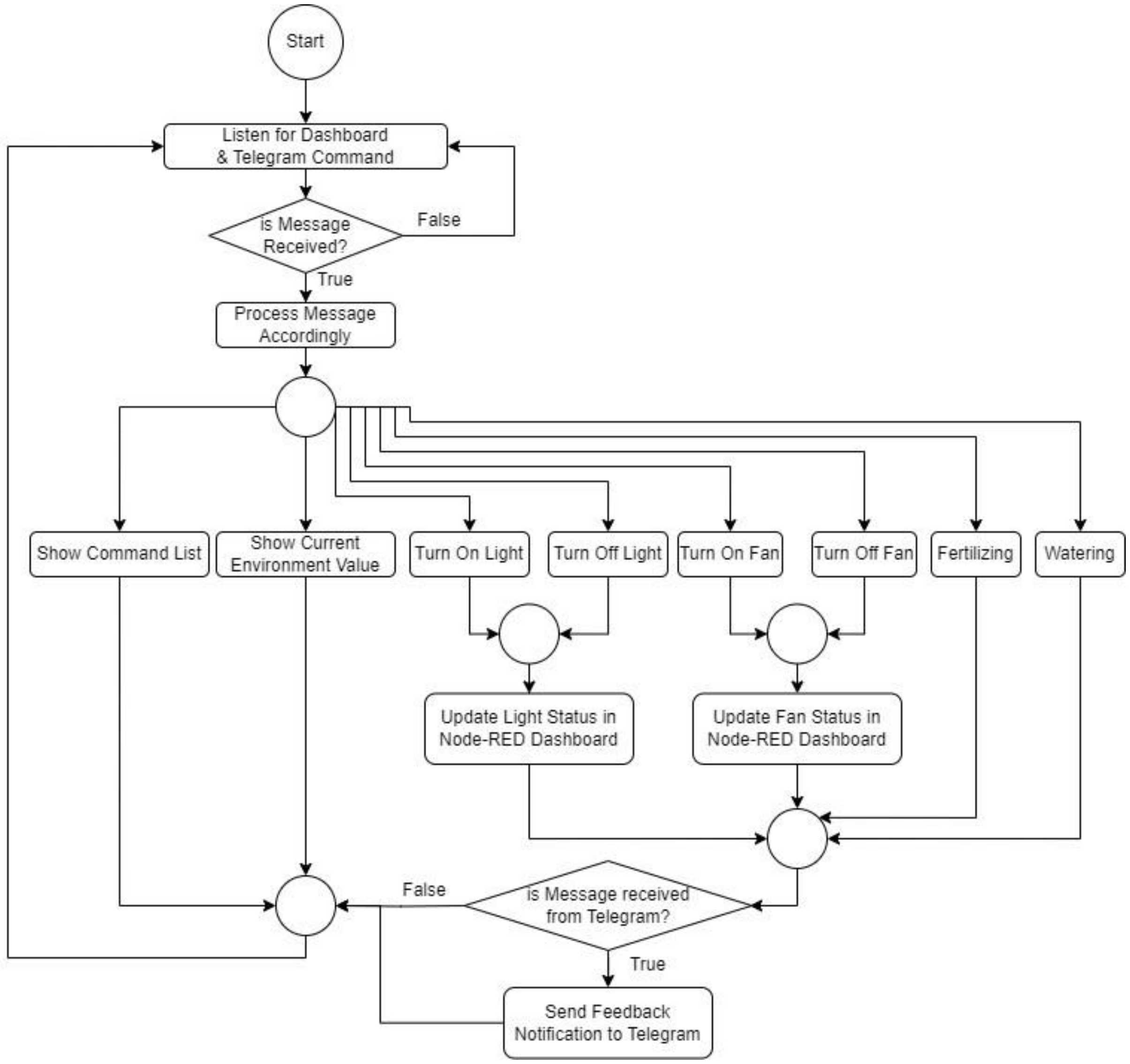


Figure 4.4. Flowchart of automation control thread.

The automation control thread will continuously listen for instructions from the Node-RED dashboard and Telegram commands initiated by users to perform automation tasks. It processes commands accordingly, performing either the display of a command list to users on Telegram, showing current environmental values, or controlling the light, fan, watering, and fertilizing, executing only one action at a time. If the automation involves the light or fan, it updates their statuses in the Node-RED dashboard. When users initiate automation via Telegram, a feedback message is sent to notify them.

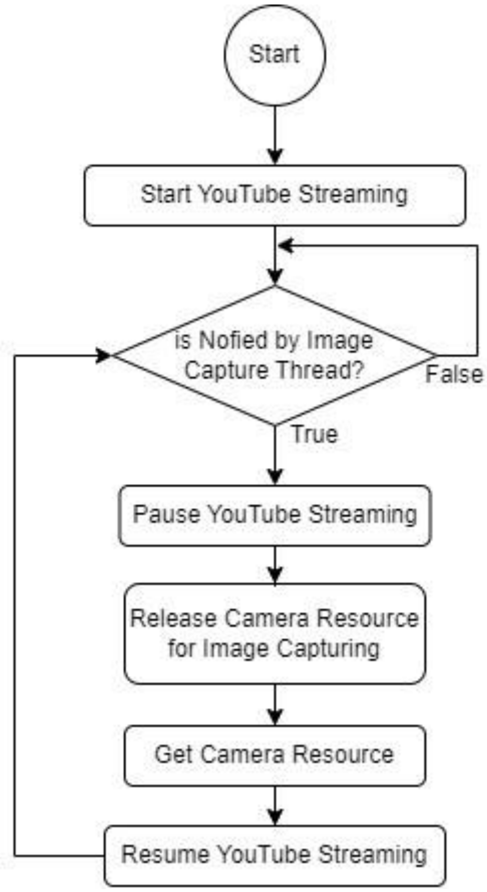


Figure 4.5. Flowchart of livestreaming thread.

The system will start the YouTube streaming and wait to be notified by the thread handling the image capture. Upon receiving the notification, it will pause the YouTube streaming, release the camera resource to the thread, and wait to regain the camera resource before resuming livestreaming.

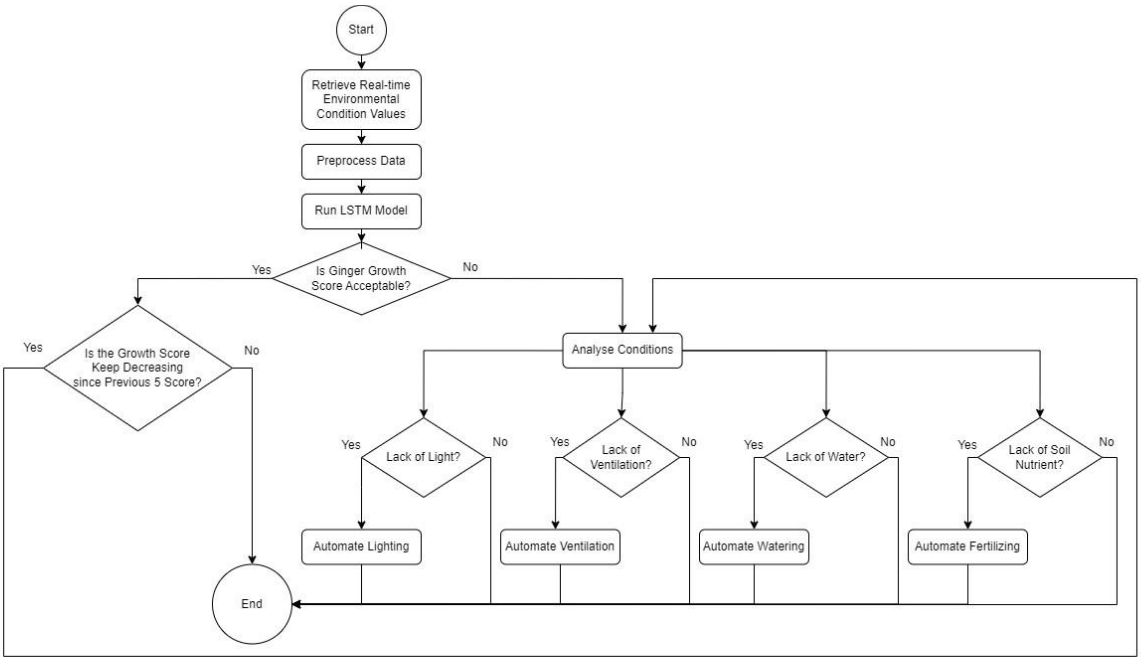


Figure 4.6. Flowchart of conceptual LSTM model prediction with automation control.

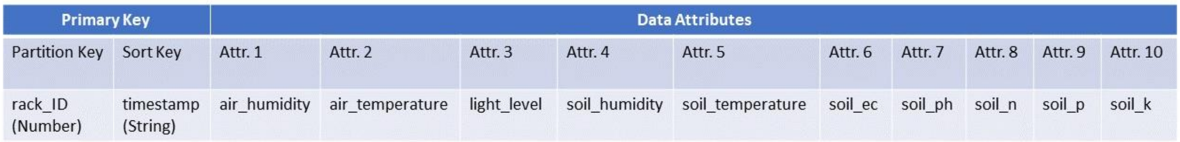
The flow begins by retrieving real-time environmental condition values from DynamoDB. The data undergoes preprocessing, and the LSTM model predicts the growth score of Bentong ginger based on the current environmental conditions. If the predicted growth score meets the acceptance criteria (above the threshold), it is then compared with the previous five scores to check for a consistent decrease. If there is a continuous decrease or if the predicted score falls below the threshold, the current environmental conditions are reviewed. Subsequently, the system automates corresponding controls, such as adjusting lighting, ventilation, watering, or fertilizing, to address any deficiencies in light, ventilation, water, or soil nutrients for the plant.

4.4 Database Design

The system is using DynamoDB is the AWS which is a NoSQL database service. There are no relationship feature in DynamoDB.

Ginger Table

Table 4.1 Ginger Table in DynamoDB

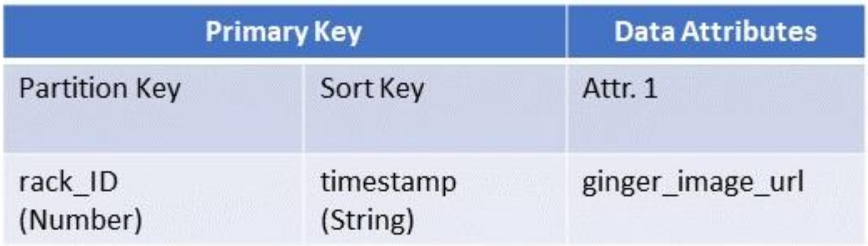


Primary Key		Data Attributes									
Partition Key	Sort Key	Attr. 1	Attr. 2	Attr. 3	Attr. 4	Attr. 5	Attr. 6	Attr. 7	Attr. 8	Attr. 9	Attr. 10
rack_ID (Number)	timestamp (String)	air_humidity	air_temperature	light_level	soil_humidity	soil_temperature	soil_ec	soil_ph	soil_n	soil_p	soil_k

The Ginger Table is used to store all the environmental data. The primary key consists of a partition key, rack_ID, and a sort key, timestamp. Other data attributes include air_humidity, air_temperature, light_level, soil_humidity, soil_temperature, soil_ph, soil_n, soil_p, and soil_k.

Ginger Image Table

Table 4.2 Ginger Image Table in DynamoDB



Primary Key		Data Attributes
Partition Key	Sort Key	Attr. 1
rack_ID (Number)	timestamp (String)	ginger_image_url

The Ginger Image Table is used to store the URL of the ginger image in S3 for easier retrieval in the future. The primary key consists of a partition key, rack_ID, and a sort key, timestamp. The only data attribute in the table is ginger_image_url.

4.5 GUI Design

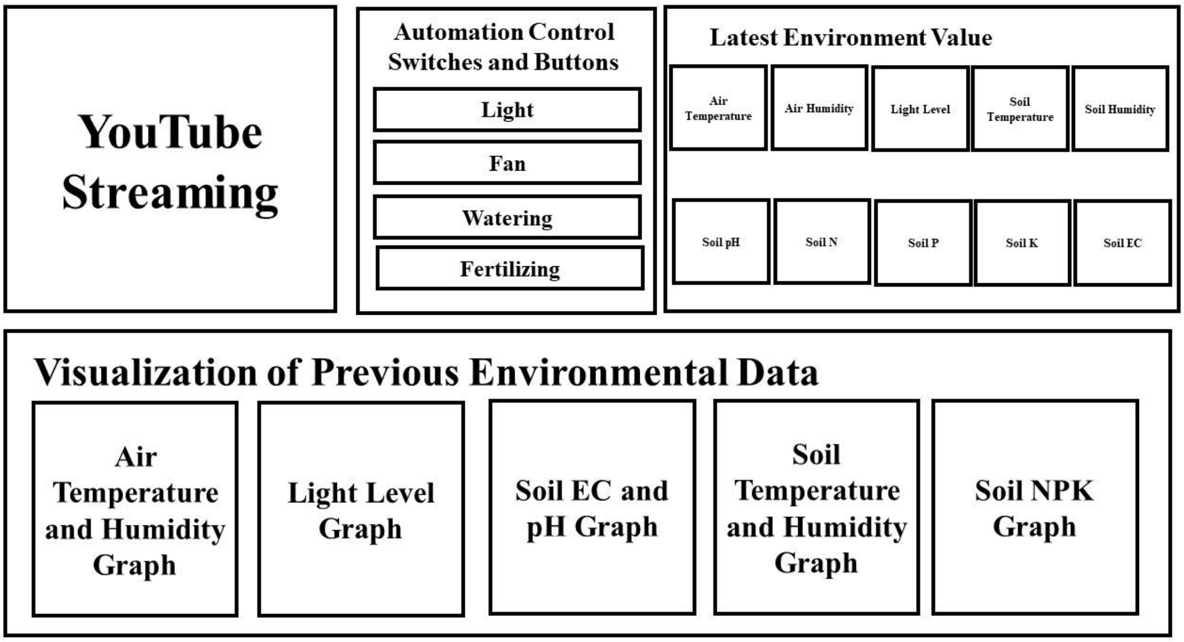


Figure 4.7. GUI design of Node-RED dashboard.

The GUI design for the Node-RED dashboard includes a YouTube livestream frame at the top left corner. Automation control switches and buttons are placed on the right-hand side of it. All the latest environmental values are shown separately using different widgets. The bottom part of the dashboard visualizes previous environmental data in line charts, separated into different combinations of data attributes.

4.6 Concluding Remark

This chapter provides an explanation of the Bentong ginger project, encompassing system architecture, hardware connections, functional modules, system flow, database design, and GUI design. The proposed framework seamlessly integrates IoT, AWS services, and Node-RED, with high-level abstract flowcharts illustrating the systematic processes. This chapter serves as a crucial guideline for implementing the project.

Chapter 5

System Implementation

In this chapter, we will discuss the hardware setup, software setup, configurations, system operations, and the development of a conceptual plant growth pattern prediction model. Additionally, we will address various implementation issues and challenges encountered during the project.

5.1 Hardware Setup

The project's hardware setup and connections will be explained using additional figures for clearer illustration.

The DHT22 air humidity and temperature sensor, as well as the BH1750 light intensity sensor, are connected to the Raspberry Pi using male-to-female jumper wires. The positive and ground connections are shared through the breadboard's common rails.

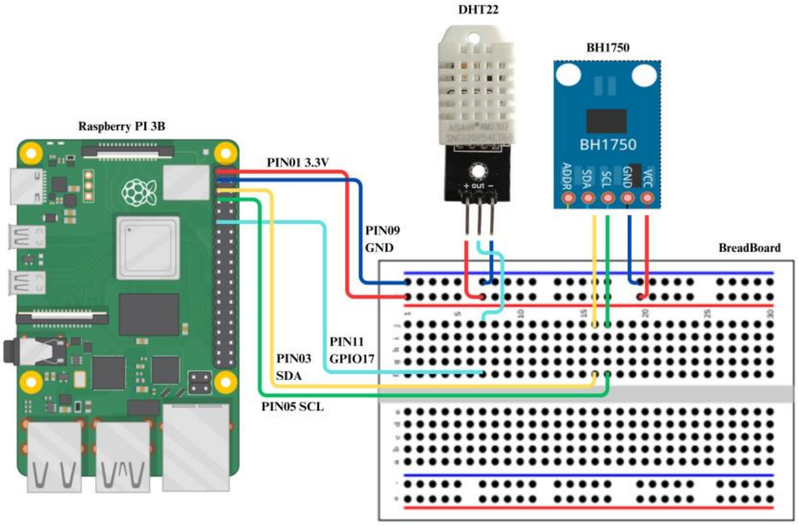


Figure 5.1. Raspberry Pi connection with DHT22 and BH1750 sensors.

The 5MP Pi Camera is assembled in an acrylic case holder for protection purposes and connected to the Raspberry Pi through the CSI port, with the silver connector of the FFC cable facing the micro-HDMI port on the Raspberry Pi.

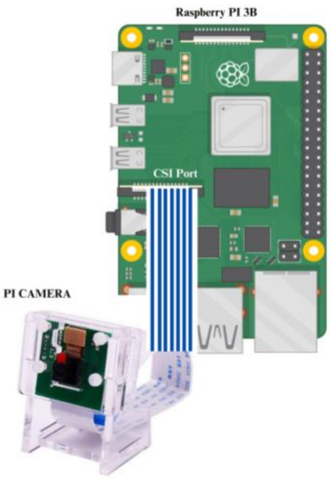


Figure 5.2. Raspberry Pi connection with Pi camera in acrylic case holder.

The soil sensor is connected to the Raspberry Pi through the USB to RS485 converter. The RS485 A and B wires of the soil sensor are connected to the A and B ports of the converter respectively. The VCC and GND wires are connected to the positive and negative output points of a step-down converter, which is adjusted to convert 24V down to 12V to match the operating voltage of the soil sensor.

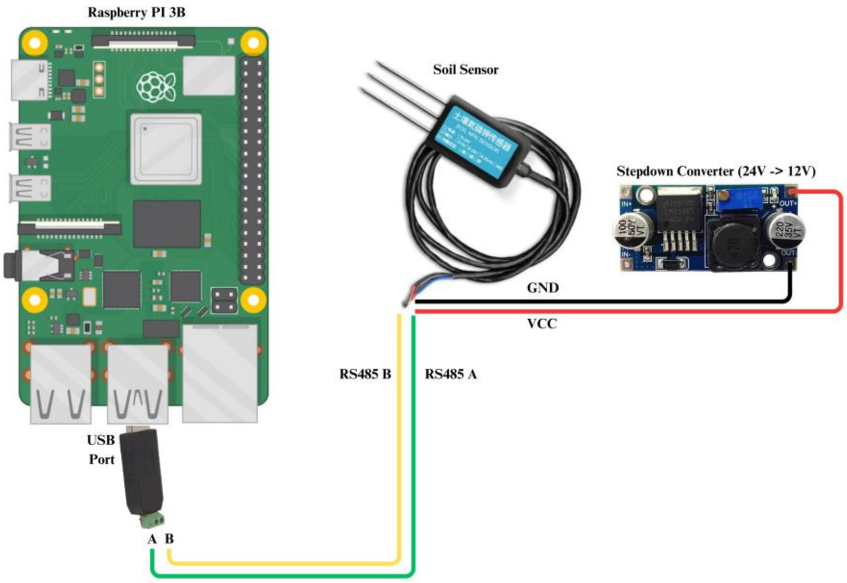


Figure 5.3. Raspberry Pi connection with soil sensor.

The 8-channel relay module is connected to the Raspberry Pi using female-to-female jumper wires directly. The relay is powered by the 5V supply from the Raspberry Pi. Four GPIO pins on the Raspberry Pi are connected and used to control each channel for different automation devices.

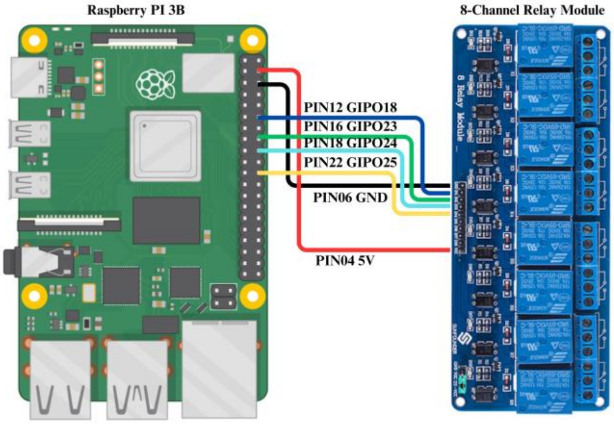


Figure 5.4. Raspberry Pi connection with 8-channel relay module.

The wire of the 24V power supply is connected to a female DC power plug connector to split it into positive and negative terminals. The power and ground from the power supply are shared in parallel using wire connectors to the input faces of the step-down converters, which adjust the power supply to the different voltages required by the various automation devices.

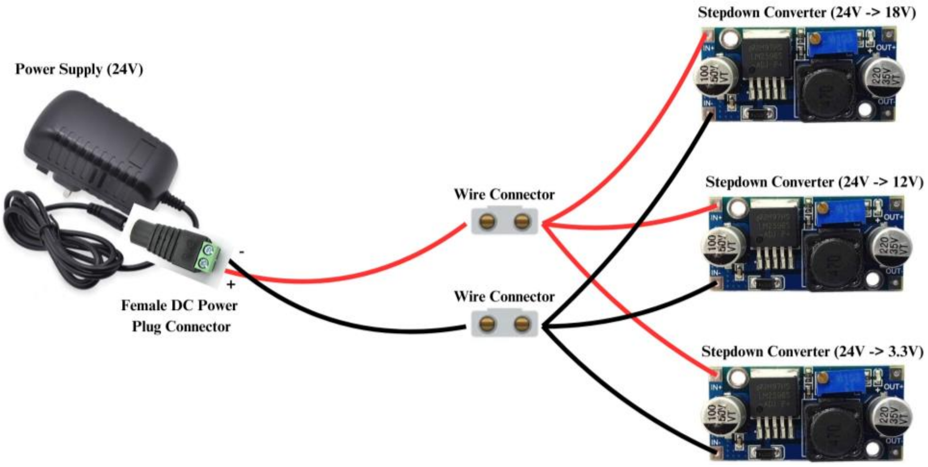


Figure 5.5. Power supply connection with stepdown converters.

The output interfaces of the step-down converters are connected to the 8-channel relay module and automation devices, such as the LED grow light, cooling fan, water pump, and fertilizer pump. Some output positives and negatives from the step-down converters are shared in parallel among the devices using wire connectors. The circuit in the relay is normally open.

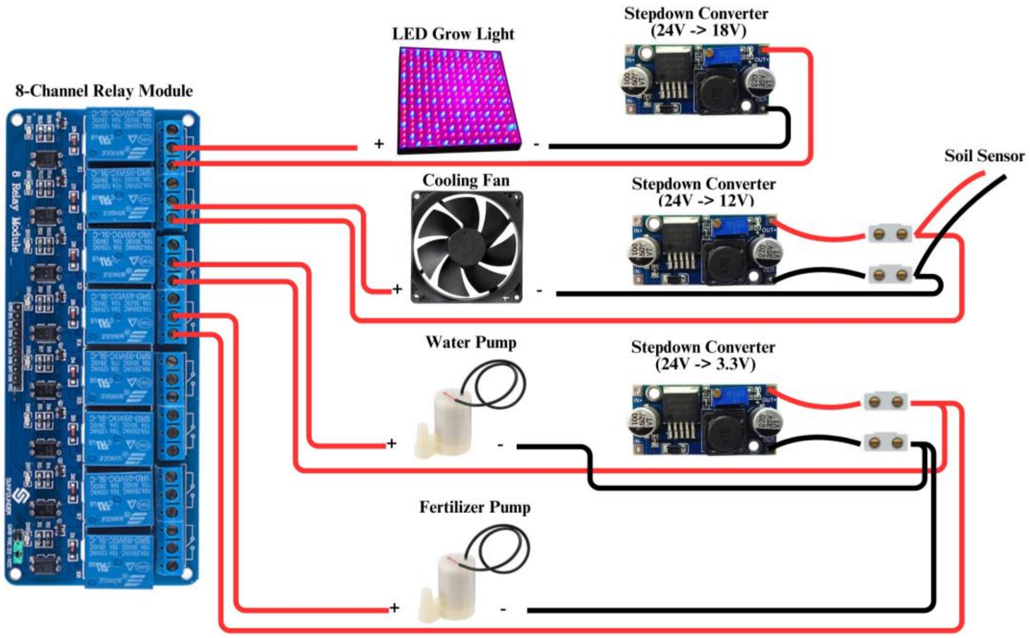


Figure 5.6. 8-channel relay module connection with IoT actuators and stepdown converters.

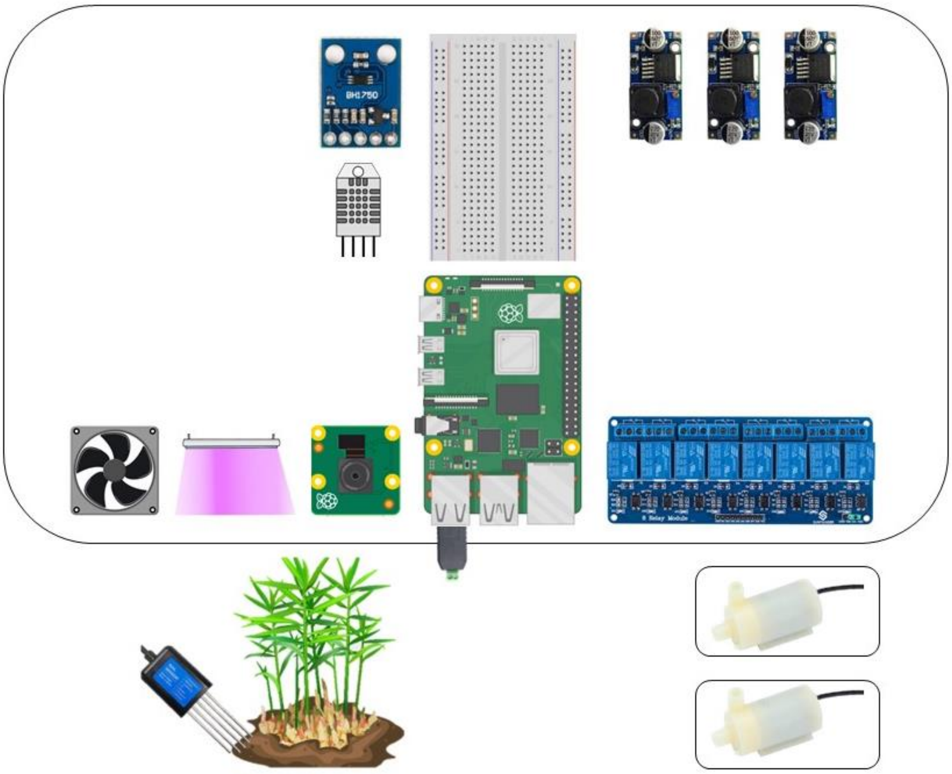


Figure 5.7. Top-down overview of project hardware placement.

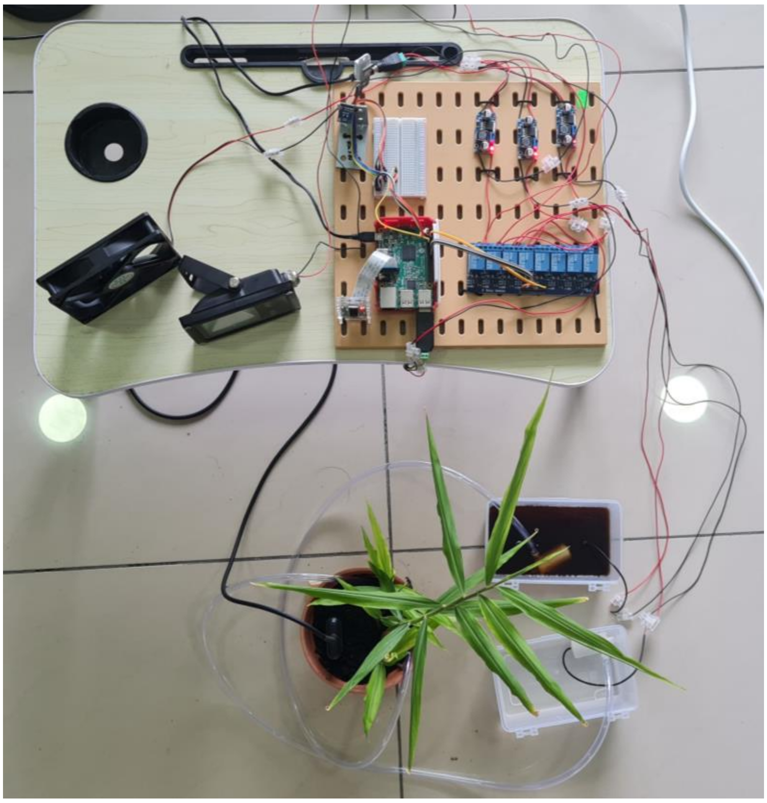


Figure 5.8. Fully connected hardware used in the project.

5.2 Software Setup

I. Install Bulleye OS on the Raspberry Pi

The latest Raspberry Pi OS, codenamed "Bullseye," is installed. The installation process includes downloading the OS image and flashing it onto the microSD card. Opting for Bulleye OS on the Raspberry Pi is driven by its tailored fit and efficiency. As a minimal Debian-based OS, it optimally utilizes the Pi's limited resources for seamless performance. Its focus on stability ensures reliability in various production scenarios, making it a dependable choice. Regular updates keep software and drivers current, emphasizing a commitment to security and compatibility. The lightweight design, stability, and proactive updates make Bulleye OS a strategic and reliable foundation for the project.

II. VNC Viewer Installation

VNC Viewer installation enables remote access to the Raspberry Pi's GUI from the laptop, streamlining configuration and management tasks. This addition facilitates seamless interaction with the Raspberry Pi's desktop environment, contributing to a more efficient development workflow.

III. WinSCP Installation

WinSCP is installed in the laptop to streamline file transfer. This user-friendly tool simplifies the process of moving files between the laptop and the Raspberry Pi. Additionally, the installation involves generating and placing an SSH key, an essential security measure. SSH key authentication ensures a secure and encrypted connection between WinSCP and the Raspberry Pi, enhancing the overall integrity of file transfers. This setup contributes to efficient project management and secure data exchange.

5.3 Setting and Configuration

The libraries listed below are installed separately because they are not included in the default Python installation on a Raspberry Pi running the Bulleye OS:

I. **AWSIoTPythonSDK**

Usage: AWS IoT SDK for Python, specifically the MQTT library for communication with AWS IoT Core.

II. **Adafruit_DHT**

Usage: Library for interfacing with DHT series sensors, specifically DHT22 in this project.

III. **aiohttp**

Usage: Asynchronous HTTP client for sending Telegram messages.

IV. **boto3**

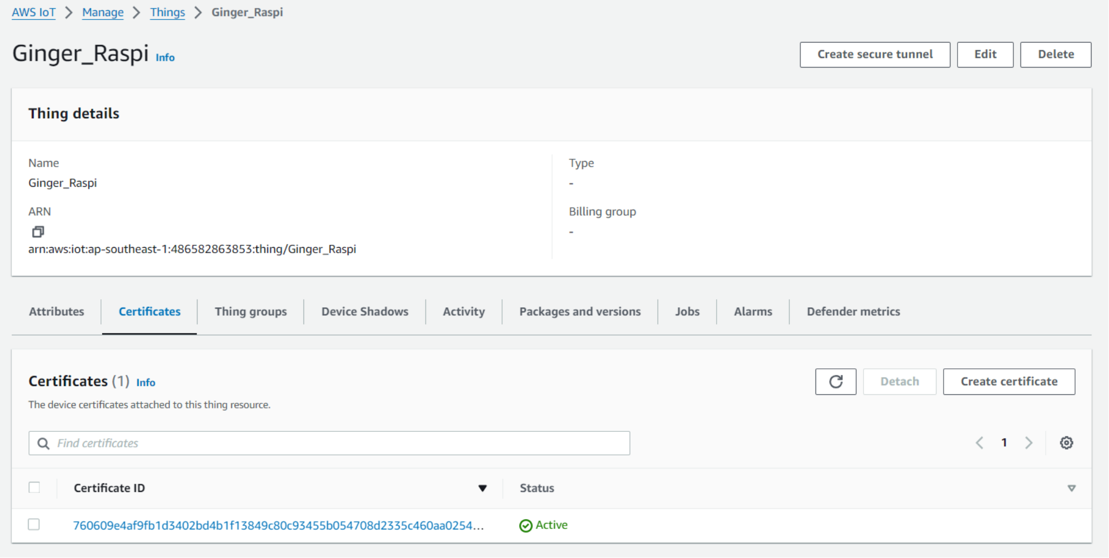
Usage: AWS SDK for Python, provides easy-to-use Python interfaces for AWS services like AWS S3.

The libraries listed below are needed to be installed in the laptop**:**

I. **Node-RED**

Usage: It serves as a versatile platform for creating interactive dashboards, automating workflows, and integrating various IoT components seamlessly.

The Raspberry Pi used in the project is registered as an AWS IoT Things device by storing the generated certificates and private key in the "certs" folder.



Thing details

Name
Ginger_Raspi

ARN
arn:aws:iot:ap-southeast-1:486582863853:thing/Ginger_Raspi

Type
-

Billing group
-

Certificates (1) Info

The device certificates attached to this thing resource.

☐	Certificate ID	Status
☐	760609e4af9fb1d3402bd4b1f13849c80c93455b054708d2335c460aa0254...	Active

Figure 5.9. Screenshot of Raspberry Pi registration.

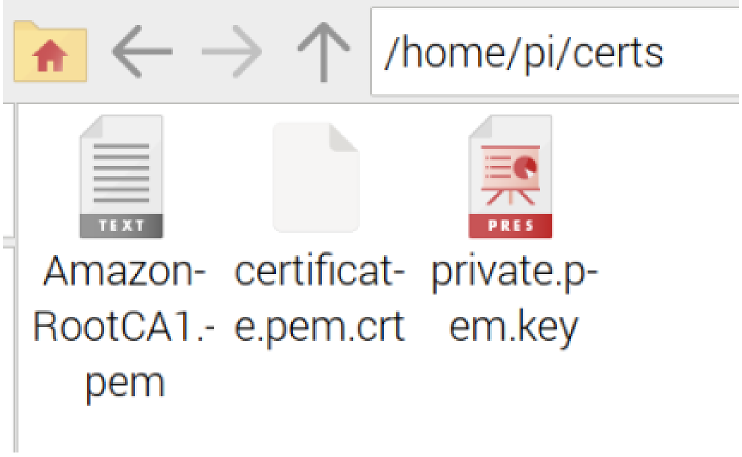
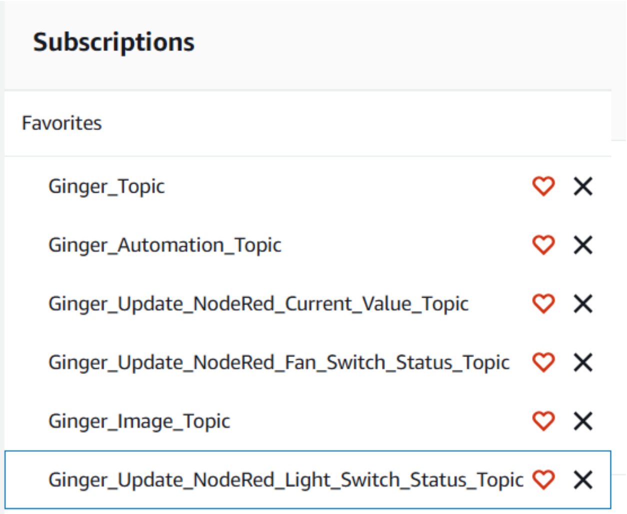


Figure 5.10. Certificates and private key on the Raspberry Pi.

The same steps are conducted on Node-RED to register as an IoT Thing for dashboard purpose. However, the certificates and private key can be shared by many users by sharing the Json text file which includes all the nodes configuration.

Several MQTT topics are created to be subscribed by Raspberry Pi or Node-RED for data transfer purposes, including inserting values in DynamoDB, performing automation, updating values, and updating the status of automation devices in the Node-RED dashboard.



Subscriptions

Favorites

Ginger_Topic

Ginger_Automation_Topic

Ginger_Update_NodeRed_Current_Value_Topic

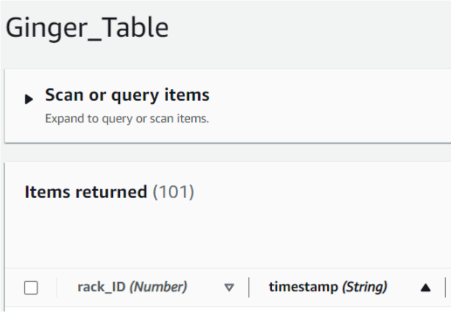
Ginger_Update_NodeRed_Fan_Switch_Status_Topic

Ginger_Image_Topic

Ginger_Update_NodeRed_Light_Switch_Status_Topic

Figure 5.11. MQTT Topics shown in AWS IoT Core.

Two DynamoDB tables are configured, namely "Ginger_Table" and "Ginger_Image_Table," utilizing rack_ID as the partition key and timestamp as the sort key. The rack_ID attribute is for future scalability. "Ginger_Table" is used to record environmental data, capturing air temperature, humidity, light levels, and more. Meanwhile, "Ginger_Image_Table" records the object URL of plant images stored in S3.



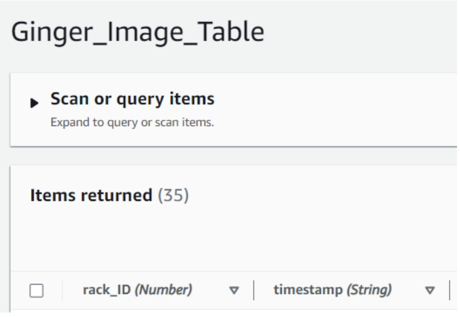
Ginger_Table

Scan or query items

Expand to query or scan items.

Items returned (101)

☐ rack_ID *(Number)* ▽ | timestamp *(String)* ▲



Ginger_Image_Table

Scan or query items

Expand to query or scan items.

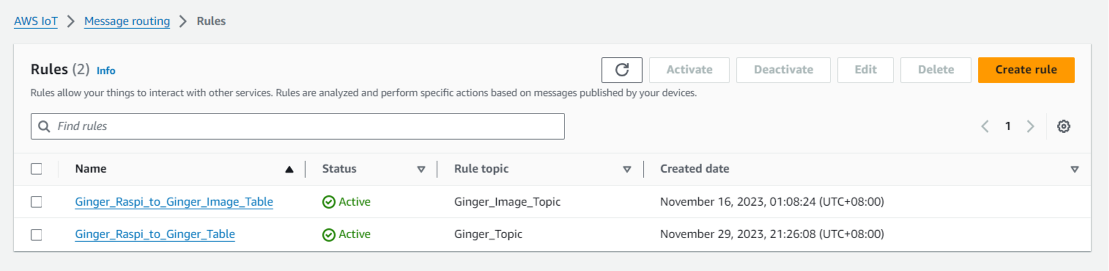
Items returned (35)

☐ rack_ID *(Number)* ▽ | timestamp *(String)* ▽

Figure 5.12. Screenshot of “Ginger_Table” creation.

Figure 5.13. Screenshot of “Ginger_Image_Table” creation.

IoT Rules are configured to allow message routing from the Raspberry Pi to the DynamoDB tables.



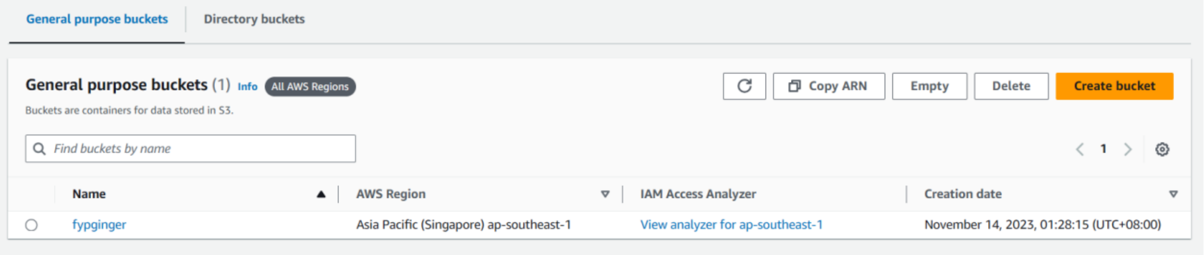
Rules (2) Info

Rules allow your things to interact with other services. Rules are analyzed and performed specific actions based on messages published by your devices.

☐	Name	Status	Rule topic	Created date
☐	Ginger_Raspi_to_Ginger_Image_Table	Active	Ginger_Image_Topic	November 16, 2023, 01:08:24 (UTC+08:00)
☐	Ginger_Raspi_to_Ginger_Table	Active	Ginger_Topic	November 29, 2023, 21:26:08 (UTC+08:00)

Figure 5.14. Screenshot of IoT Rules creation.

The S3 bucket "fypginger" is created to store the ginger plant images.



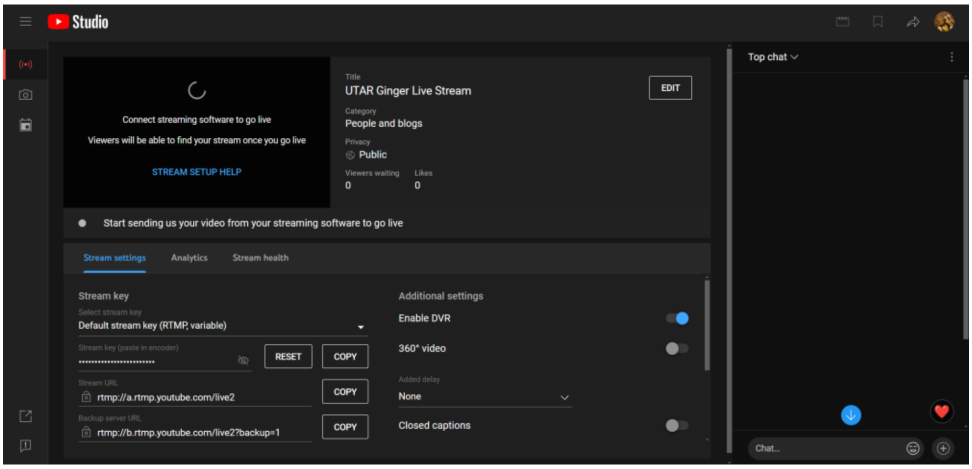
General purpose buckets (1) Info All AWS Regions

Buckets are containers for data stored in S3.

	Name	AWS Region	IAM Access Analyzer	Creation date
○	fypginger	Asia Pacific (Singapore) ap-southeast-1	View analyzer for ap-southeast-1	November 14, 2023, 01:28:15 (UTC+08:00)

Figure 5.15. Screenshot of S3 buckets creation.

Several actions are required to enable the embedding of the YouTube livestream in the Node-RED dashboard. These include registering as an advanced YouTube content creator and obtaining a stream key, which facilitates data transfer from the Raspberry Pi to YouTube. To optimize costs, the system avoids using the YouTube API, which incurs additional expenses. However, users just need to manually initiate the live stream by clicking a "create live" button on YouTube before starting the system.



Connect streaming software to go live

Viewers will be able to find your stream once you go live

Title: UTAR Ginger Live Stream

Category: People and blogs

Privacy: Public

Viewers waiting: 0

Likes: 0

Start sending us your video from your streaming software to go live

Stream key

Select stream key: Default stream key (RTMP, variable)

Stream key (paste in encoder): ••••••••••••••••••••••••

Stream URL: rtmp://a.rtmp.youtube.com/live2

Backup server URL: rtmp://b.rtmp.youtube.com/live2?backup=1

Additional settings

Enable DVR

360° video

Added delay: None

Closed captions

Figure 5.16. Screenshot of YouTube livestream setup.

A template node is implemented in Node-RED to display the YouTube livestream of the ginger plant on the dashboard. The embedded style uses a constant channel ID instead of the stream ID, eliminating the need to modify the template node configuration each time a new livestream is initiated.

Figure 5.17. Screenshot of YouTube livestream node.

MQTT-in nodes, switch nodes, button nodes, and MQTT-out nodes are created to facilitate automation control and provide status updates. These status updates reflect the system's automated actions or changes triggered by users via Telegram. As a result, the status of the light and fan switches is dynamically updated to reflect the current state of automation.

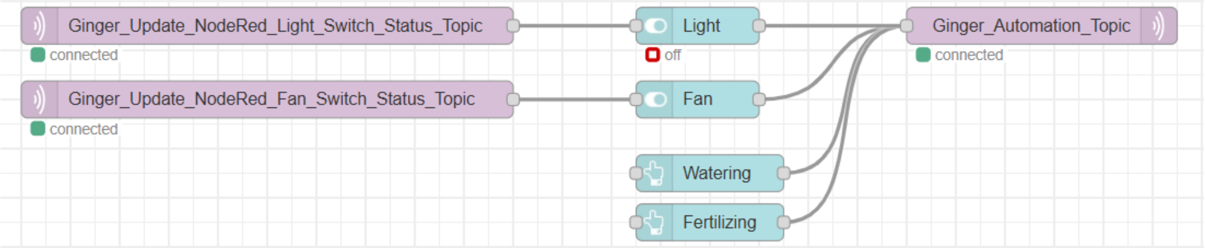


Figure 5.18. Screenshot of automation control node.

Inject nodes, AWS-simple-nodes, function nodes, MQTT-in nodes, and gauge nodes are integrated into Node-RED for displaying real-time environmental data on the dashboard. Upon opening the dashboard, the latest data is fetched from AWS DynamoDB. Subsequently, the dashboard updates the data every 5 minutes using values directly from the Raspberry Pi via MQTT.

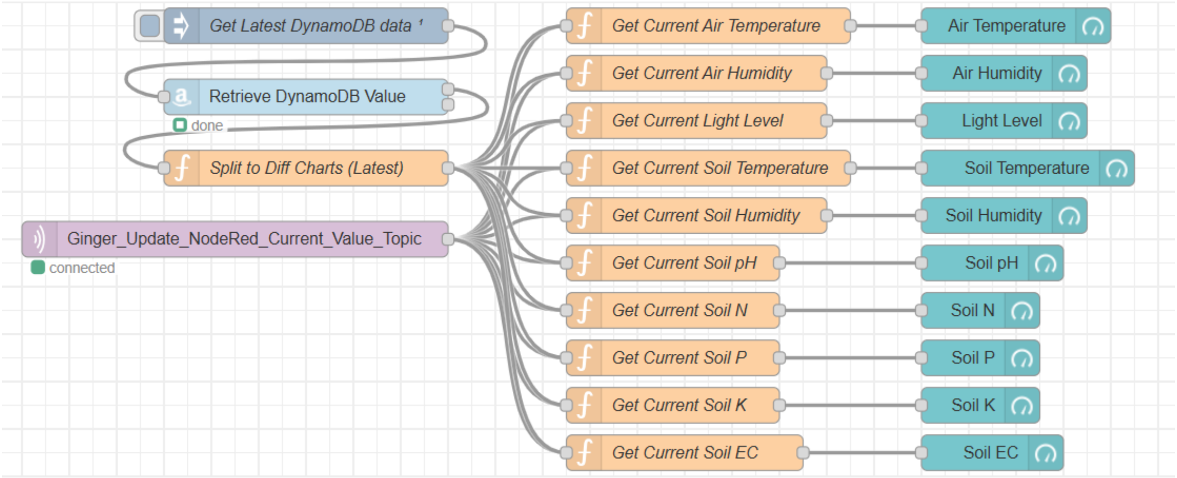


Figure 5.19. Screenshot of the current environmental value display node.

Inject nodes, AWS-simple-nodes, function nodes, and chart nodes are integrated into Node-RED for displaying line charts of historical data on the dashboard. Upon opening the dashboard, the latest 24-hour data is fetched from AWS DynamoDB. The dashboard then updates the charts every hour using values directly from the Raspberry Pi via MQTT.

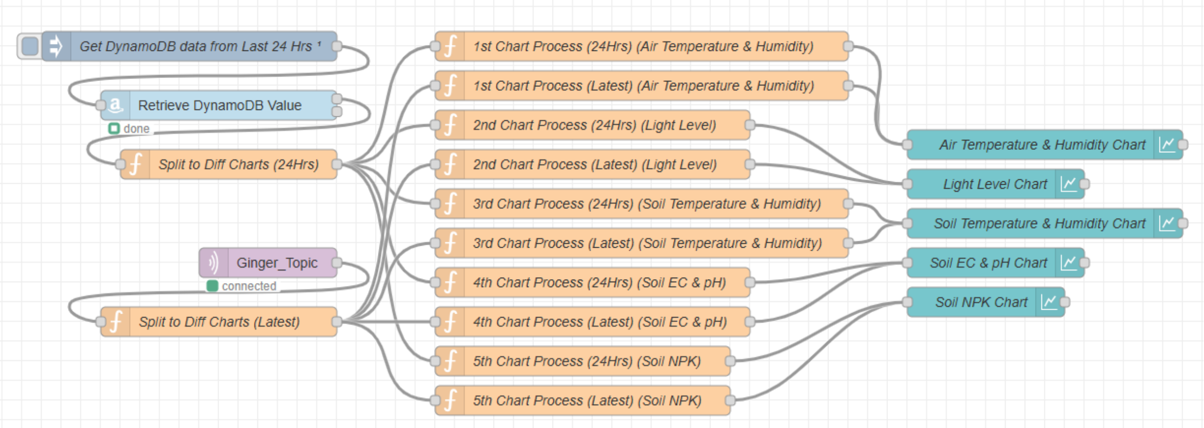


Figure 5.20. Screenshot of the charts displaying node.

The layout of the Node-RED dashboard is arranged in a preferred view by adjusting the width and height of each element group.

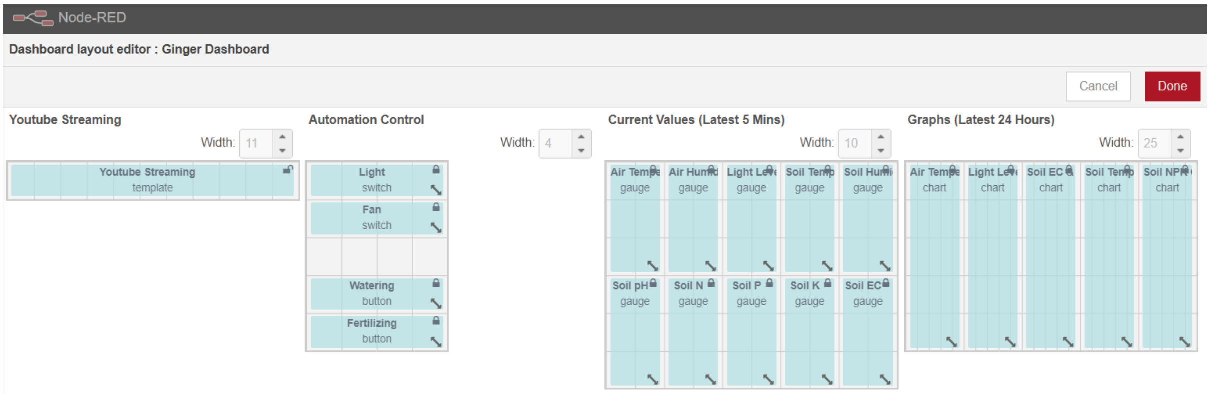
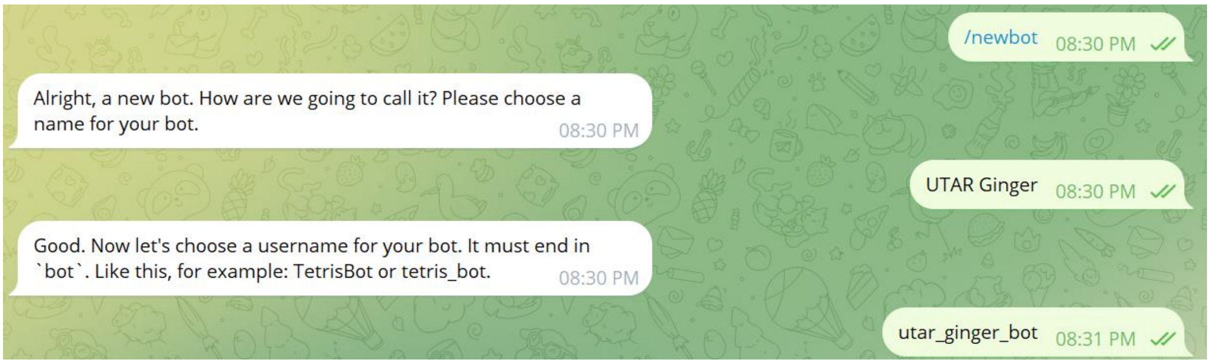


Figure 5.21. Screenshot of the Node-RED dashboard layout arrangement.

A Telegram bot named “UTAR Ginger” is created with the username “utar_ginger_bot” using Telegram Bot Father.



/newbot 08:30 PM

Alright, a new bot. How are we going to call it? Please choose a name for your bot. 08:30 PM

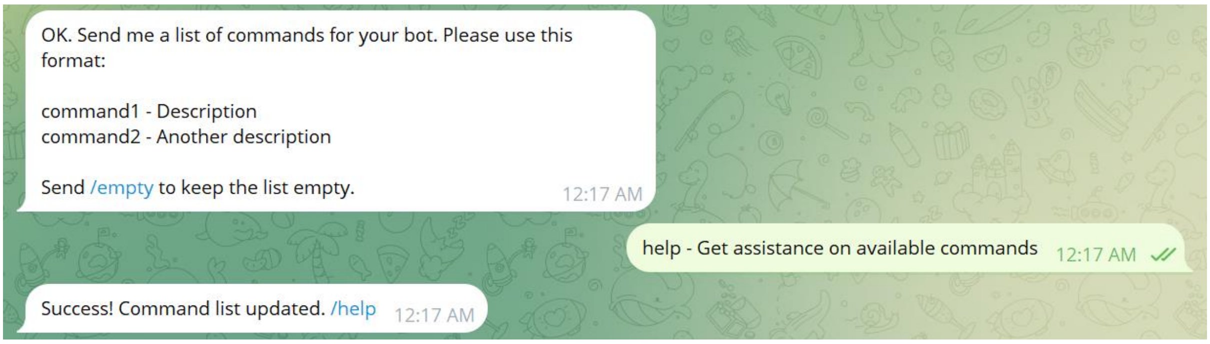
UTAR Ginger 08:30 PM

Good. Now let's choose a username for your bot. It must end in \`bot\`. Like this, for example: TetrisBot or tetris_bot. 08:30 PM

utar_ginger_bot 08:31 PM

Figure 5.22. Screenshot of the creation of Telegram bot.

A 'help' command is added to the Telegram bot menu, allowing users to view the available commands by simply clicking on the 'help' option.



OK. Send me a list of commands for your bot. Please use this format:

command1 - Description
command2 - Another description

Send /empty to keep the list empty. 12:17 AM

help - Get assistance on available commands 12:17 AM

Success! Command list updated. /help 12:17 AM

Figure 5.23. Screenshot of the help command setup of Telegram bot.

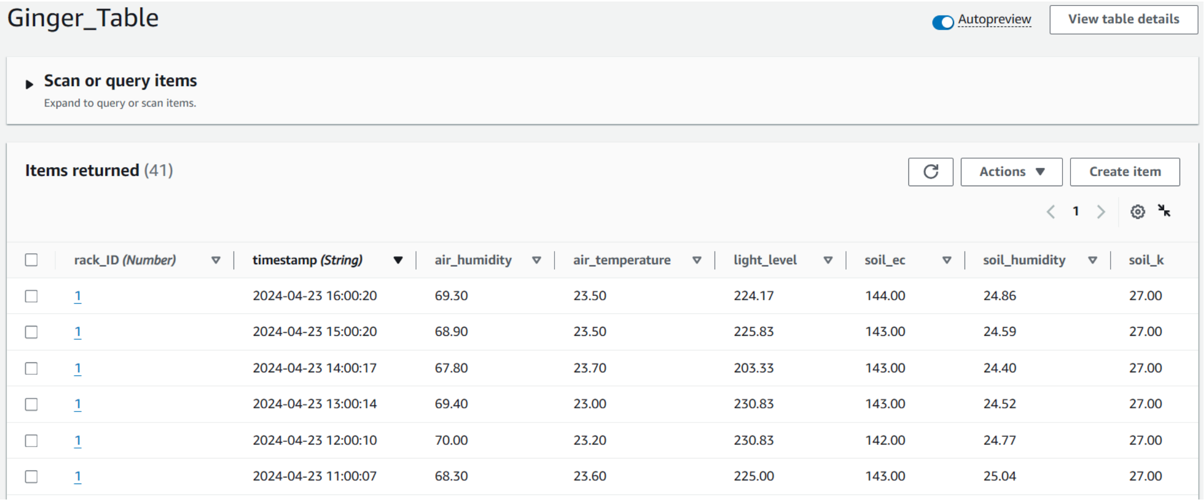
5.4 System Operation

As the project is planned to take place within a greenhouse, the testing of system operations is conducted directly within the greenhouse environment, providing a realistic assessment of the Raspberry Pi's reliability in its intended operational setting.

Figure 5.24. Inner view of UTAR greenhouse.

Data Collection

Environmental data such as air humidity, air temperature, light level, soil temperature, soil humidity, soil EC, soil pH, soil N, soil P, and soil K can be smoothly inserted into the Ginger_Table, along with the timestamp and rack_ID.

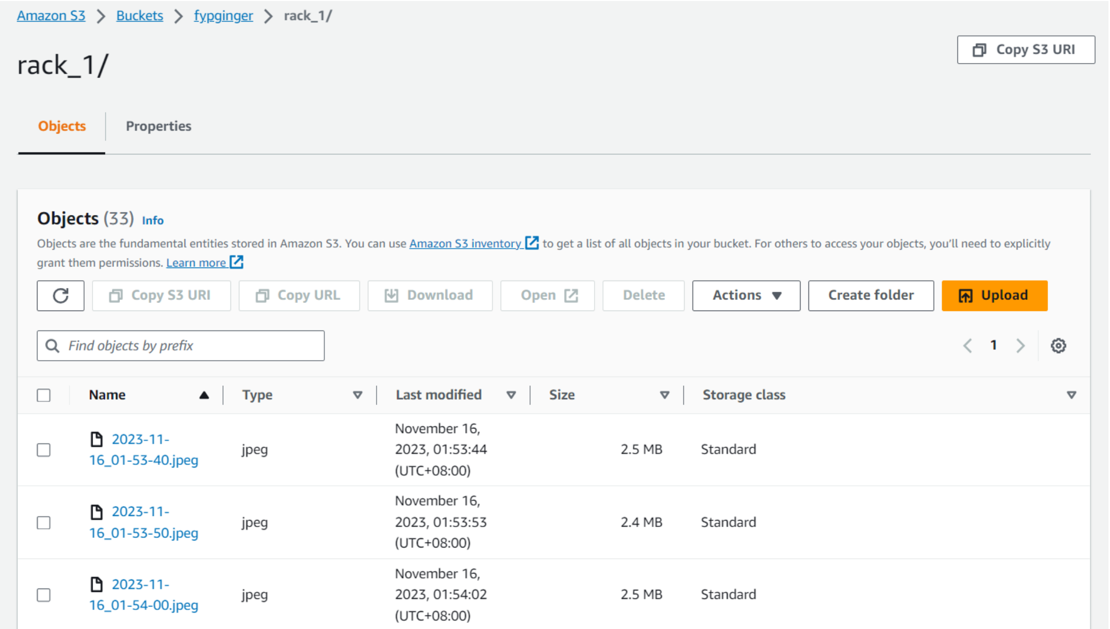


Items returned (41)

☐	rack_ID (Number)	timestamp (String)	air_humidity	air_temperature	light_level	soil_ec	soil_humidity	soil_k
☐	1	2024-04-23 16:00:20	69.30	23.50	224.17	144.00	24.86	27.00
☐	1	2024-04-23 15:00:20	68.90	23.50	225.83	143.00	24.59	27.00
☐	1	2024-04-23 14:00:17	67.80	23.70	203.33	143.00	24.40	27.00
☐	1	2024-04-23 13:00:14	69.40	23.00	230.83	143.00	24.52	27.00
☐	1	2024-04-23 12:00:10	70.00	23.20	230.83	142.00	24.77	27.00
☐	1	2024-04-23 11:00:07	68.30	23.60	225.00	143.00	25.04	27.00

Figure 5.25. Screenshot of data stored in Ginger_Table.

Plant images can be uploaded to S3 buckets, but they require more time to capture and upload than text data. The file's name is determined by the time of capture and inserted into the rack_ID folder accordingly.



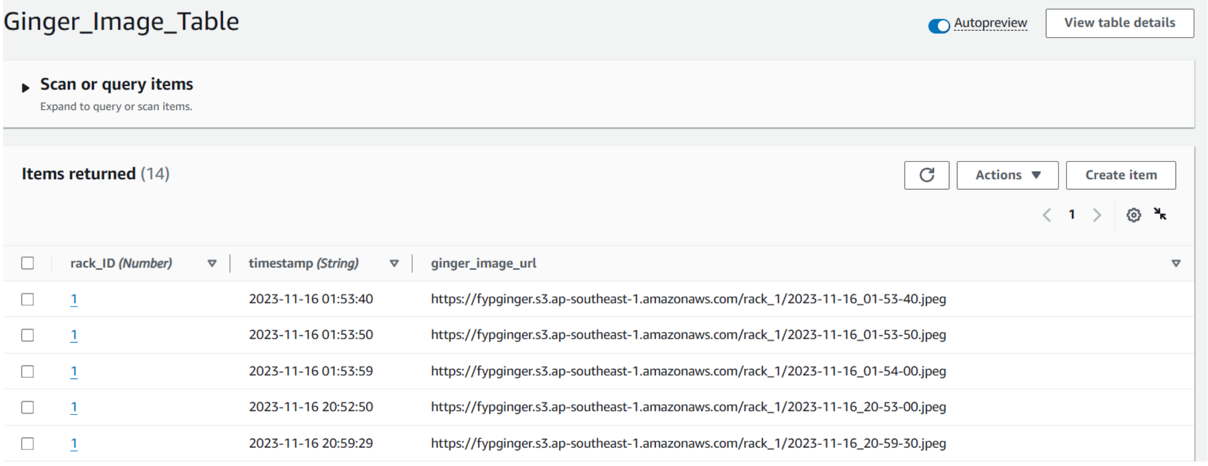
Objects (33)

Objects are the fundamental entities stored in Amazon S3. You can use Amazon S3 inventory to get a list of all objects in your bucket. For others to access your objects, you'll need to explicitly grant them permissions. Learn more

☐	Name	Type	Last modified	Size	Storage class
☐	2023-11-16_01-53-40.jpeg	jpeg	November 16, 2023, 01:53:44 (UTC+08:00)	2.5 MB	Standard
☐	2023-11-16_01-53-50.jpeg	jpeg	November 16, 2023, 01:53:53 (UTC+08:00)	2.4 MB	Standard
☐	2023-11-16_01-54-00.jpeg	jpeg	November 16, 2023, 01:54:02 (UTC+08:00)	2.5 MB	Standard

Figure 5.26. Screenshot of data stored in S3 buckets.

Once the ginger image has been successfully uploaded to the S3 bucket, the object URL and timestamp will be inserted into the Ginger_Image_Table.



Ginger_Image_Table

Items returned (14)

☐	rack_ID (Number)	timestamp (String)	ginger_image_url
☐	1	2023-11-16 01:53:40	https://fypginger.s3.ap-southeast-1.amazonaws.com/rack_1/2023-11-16_01-53-40.jpeg
☐	1	2023-11-16 01:53:50	https://fypginger.s3.ap-southeast-1.amazonaws.com/rack_1/2023-11-16_01-53-50.jpeg
☐	1	2023-11-16 01:53:59	https://fypginger.s3.ap-southeast-1.amazonaws.com/rack_1/2023-11-16_01-54-00.jpeg
☐	1	2023-11-16 20:52:50	https://fypginger.s3.ap-southeast-1.amazonaws.com/rack_1/2023-11-16_20-53-00.jpeg
☐	1	2023-11-16 20:59:29	https://fypginger.s3.ap-southeast-1.amazonaws.com/rack_1/2023-11-16_20-59-30.jpeg

Figure 5.27. Screenshot of data stored in Ginger_Image_Table.

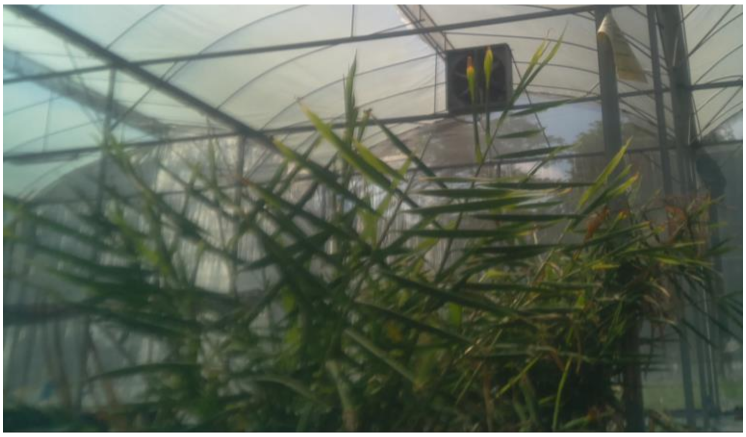


Figure 5.28. Example of a ginger image captured.

Automation Control

The system will perform checking on environmental data and automation control on the device to optimize the growth of Benting ginger every 5 minutes. The action performed is if either of the environmental data correspond to the device is below or exceed the threshold shown. During normal conditions, the automation device is usually off.

Table 5.1 Thresholds and actions for environmental data

Environmental Data	Threshold	Action
Air Temperature	> 30	Turn on fan
Air Humidity	> 70	
Light Level	< 10000	Turn on light
Soil Temperature	< 20	Watering
Soil Humidity	< 40	
Soil pH	< 6	Fertilizing
Soil N Value	< 10	
Soil P Value	< 10	
Soil K Value	< 10	
Soil EC	< 100	

To maintain the optimal range for plant growth, we'll implement a strategy of frequent, low-intensity watering and fertilizing. This approach helps prevent overshooting the preferred range for the plant. This strategy ensures consistent care for the plant while minimizing the risk of nutrient imbalance or overhydration. The execution time per action and volume of liquid pumped is shown the in the table below.

Table 5.2 Execution time and volume of liquid for watering and fertilizing action

Action	Execution Time (s)	Volume of Liquid Pumped (ml)
Watering	5	200
Fertilizing	5	200

Node-RED Dashboard

Users can directly view the YouTube livestream on the dashboard. Automation controls, including toggling the light and fan, as well as watering and fertilizing options, are available for user interaction. The dashboard provides real-time updates of the latest 5-minute environmental data, encompassing air condition, light intensity, and soil condition. At the bottom of the dashboard, five line charts display the latest 24-hour historical data attributes for detailed analysis and monitoring.

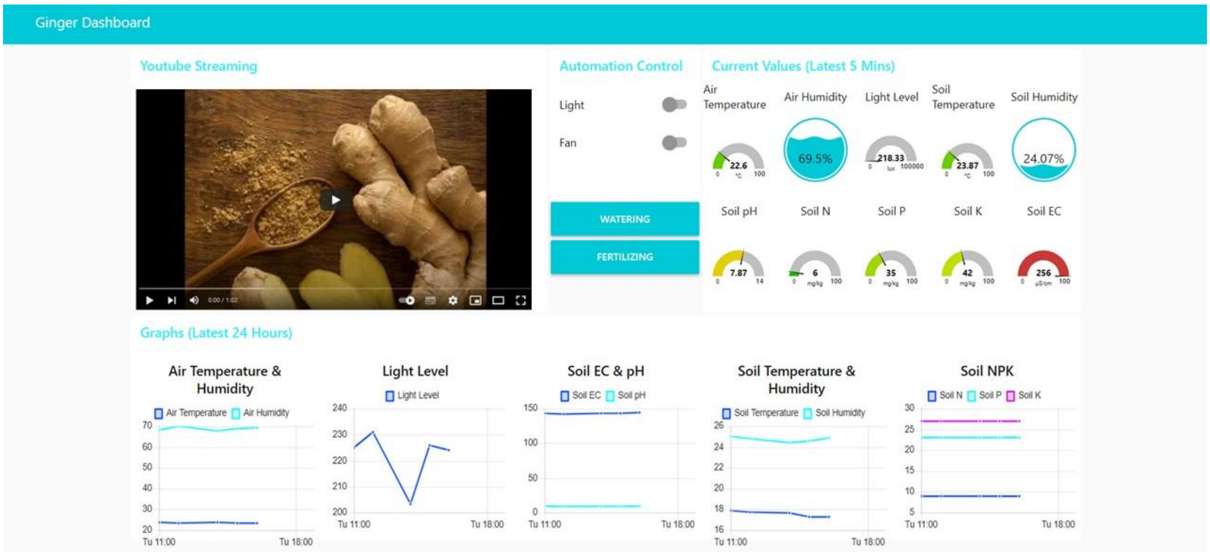
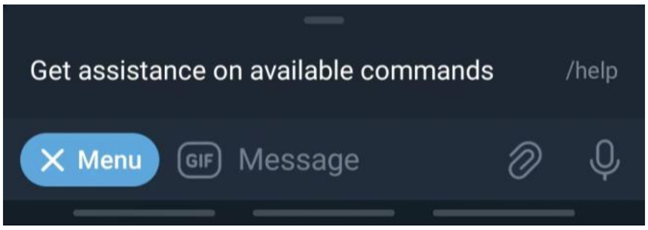


Figure 5.29. Screenshot of Node-RED Dashboard.

Telegram Bot

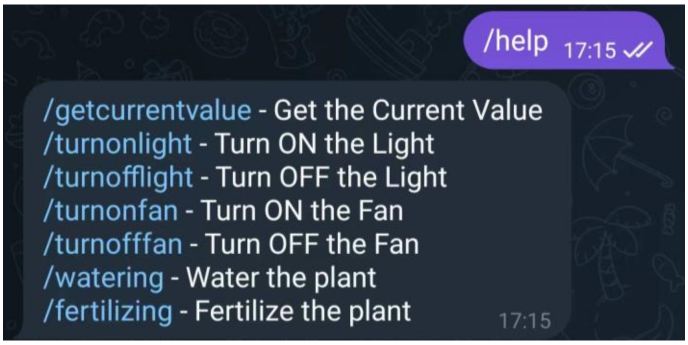
Users can simply click on the menu in the Telegram bot to display a "Help" command button, allowing them to access assistance on available commands.



Get assistance on available commands /help

Figure 5.30. Screenshot of help command in Telegram bot.

Users will be shown with a list of commands, including "getcurrentvalue," "turnonlight," "turnofflight," "turnonfan," "turnofffan," "watering," and "fertilizing," after clicking the help command.

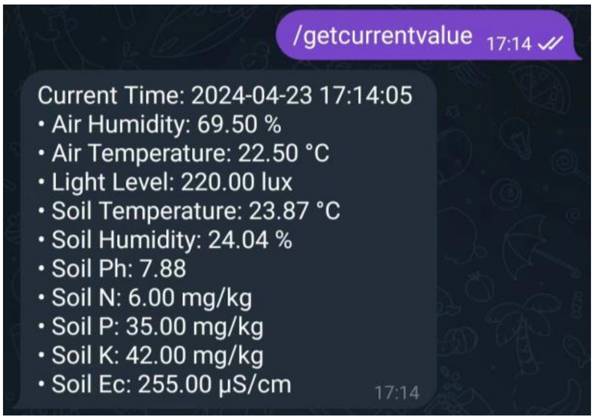


/help 17:15

/getcurrentvalue - Get the Current Value
/turnonlight - Turn ON the Light
/turnofflight - Turn OFF the Light
/turnonfan - Turn ON the Fan
/turnofffan - Turn OFF the Fan
/watering - Water the plant
/fertilizing - Fertilize the plant 17:15

Figure 5.31. Screenshot of available command list in Telegram bot.

Users will be provided with the current date and time along with all the environmental data values if they click the "getcurrentvalue" command.



/getcurrentvalue 17:14

Current Time: 2024-04-23 17:14:05
- Air Humidity: 69.50 %
- Air Temperature: 22.50 °C
- Light Level: 220.00 lux
- Soil Temperature: 23.87 °C
- Soil Humidity: 24.04 %
- Soil Ph: 7.88
- Soil N: 6.00 mg/kg
- Soil P: 35.00 mg/kg
- Soil K: 42.00 mg/kg
- Soil Ec: 255.00 µS/cm

17:14

Figure 5.32. Screenshot of current environmental value in Telegram bot.

Users can execute various automation controls by simply clicking on the available commands. Once the automation operation is completed, a feedback message will be sent back to the users.

/turnonlight 17:17

Light is now ON 17:17

/turnofflight 17:17

Light is now OFF 17:17

/turnonfan 17:17

Fan is now ON 17:17

/turnofffan 17:17

Fan is now OFF 17:17

/watering 17:17

Plant is Watered 17:17

/fertilizing 17:17

Plant is Fertilized 17:17

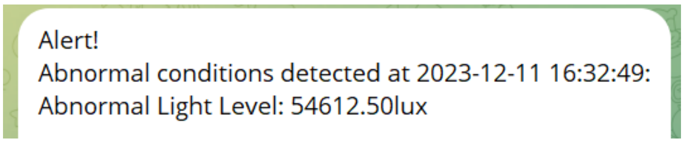
Figure 5.33. Screenshot of automation commands executed and feedback messages in the Telegram bot.

When abnormal environmental conditions appear, a telegram bot will send messages to users. The notification will include the date and time, as well as the abnormal values. The environmental conditions is considered as abnormal either lower than the low-threshold or higher than the high-threshold below.

Table 5.3 High and low thresholds for environmental data

Environmental Data	**Low-threshold**	**High-threshold**
Air Temperature	10	60
Air Humidity	20	95
Light Level	-	50000
Soil Temperature	10	60
Soil Humidity	10	95
Soil pH	4	12
Soil N Value	-	1500
Soil P Value	-	1500
Soil K Value	-	1500
Soil EC	-	1500

Users will receive an alert message, including the date, time, and abnormal data value, if the environmental data is either lower than the low-threshold or higher than the high-threshold.



Alert!
Abnormal conditions detected at 2023-12-11 16:32:49:
Abnormal Light Level: 54612.50lux

Figure 5.34. Screenshot of Telegram alert notification**.**

5.5 Development of Conceptual Plant Growth Pattern Prediction Model

Dataset Preparation

To simulate a dataset for predicting ginger growth, a synthetic dataset was generated to emulate the environmental conditions and plant growth metrics. The dataset is organized into rows, each representing a day of observation for a specific ginger plant. The "ginger_id" column uniquely identifies each plant, and the "day" column signifies the day of observation. The generated dataset covers 365 days for each of the ten ginger plants. During the generation process, various parameters were considered to ensure a comprehensive representation of the conditions affecting ginger growth. The following ranges were applied for each environmental and growth metric:

Table 5.4 Ginger growth metrics

Column Name	**Description**	**Range**
avg_day_air_temp	Average Daytime Air Temperature	30°C - 35°C
avg_day_air_humidity	Average Daytime Air Humidity	70% - 80%
avg_day_light_level	Average Daytime Light Level	20,000 - 50,000 lux
avg_day_soil_temp	Average Daytime Soil Temperature	18°C - 35°C
avg_day_soil_moist	Average Daytime Soil Moisture	30% - 60%
avg_night_air_temp	Average Nighttime Air Temperature	25°C - 30°C
avg_night_air_humidity	Average Nighttime Air Humidity	80% - 95%
avg_night_light_level	Average Nighttime Light Level	0 - 3 lux
avg_night_soil_temp	Average Nighttime Soil Temperature	15°C - 25°C
avg_night_soil_moist	Average Nighttime Soil Moisture	30% - 60%
avg_EC	Average Electrical Conductivity	0.5 - 2.0 dS/m
avg_pH	Average pH	5.5 - 6.5
avg_N	Average Nitrogen Content	50 - 300 ppm
avg_P	Average Phosphorus Content	30 - 100 ppm
avg_K	Average Potassium Content	100 - 400 ppm
number_of_leaves	Number of Leaves (Remains stable before increasing)	1 - 200

number_of_shoots	Number of Shoots (Remains stable before increasing)	1 - 20
avg_gap_of_leaves	Average Gap of Leaves (Max diff 0.15 between days)	0.1 – 1.5 cm

Score Calculation

Because a synthetic dataset is being used, there is no need to deal with missing data, outliers, or noise in the data. The LSTM model utilizes a window size and perform growth score calculation excluding the initial (window size - 1) days for each ginger due to score calculation dependencies. The growth score is calculated for each day using a defined formula that considers multiple factors.

$$\boldsymbol{Growth\ Score = \frac{1}{2}(L - L_0) + \frac{1}{2}(S - S_0) - P} \tag{4}$$

where

L = leaves count on current day

L_0 = leaves count on day 1 of the window

S = shoots count on current day

S_0 = shoots count on day 1 of the window

P = penalty

$$\boldsymbol{P = \begin{cases} 0, & 0.25 \le G \le 1.00 \\ 0.25 - G, & G < 0.25 \\ G - 1.00, & G > 1.00 \end{cases}} \tag{5}$$

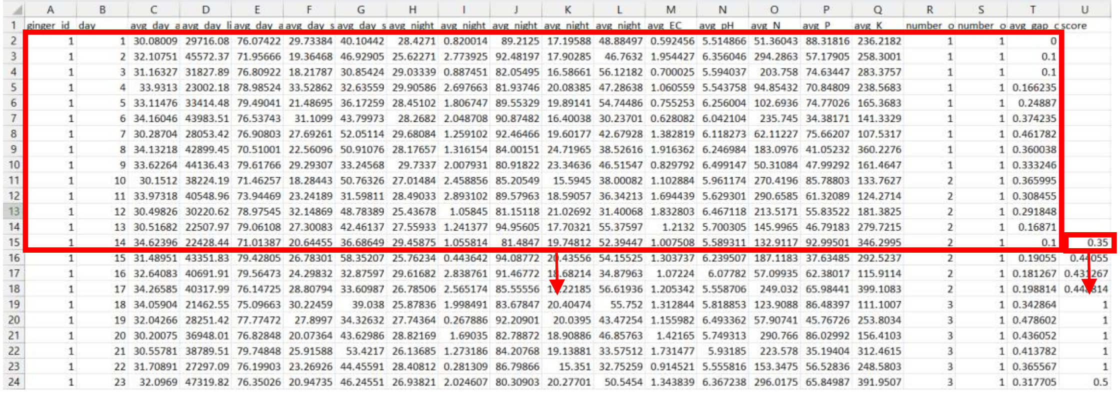
where

G = average gap of leaves on current day

In short, the score favors increase in leaves and shoots within the window, while penalizing deviations of the average leaf gap outside the optimum range of 0.25 to 1. The coefficients 0.5 can be adjusted to control the relative importance of leaves vs shoots in the score.

Sliding Window Implementation

The raw data is transformed into structured sequences and corresponding targets. This transformation is executed with a specified window size of 14 days, where each sequence only encapsulates the environmental data within this temporal frame, without including the growth parameters. The targets are designated as the growth scores observed on the 14th day. To ensure robust model evaluation, an 80-20 split is applied for training and testing sets. Importantly, this split is conducted with a temporal consideration, reserving the final 20% of each ginger's data exclusively for testing. This meticulous approach safeguards the chronological order of the data, enhancing the model's ability to generalize to unseen instances.



	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U
1	ginger id	day	avg day a	avg day li	avg day a	avg day s	avg day s	avg night	avg night	avg night	avg night	avg night	avg EC	avg pH	avg N	avg P	avg K	number o	number o	avg gap c	score
2	1	1	30.08009	29716.08	76.07422	29.73384	40.10442	28.4271	0.820014	89.2125	17.19588	48.88497	0.592456	5.514866	51.36043	88.31816	236.2182	1	1	0	
3	1	2	32.10751	45572.37	71.95666	19.36468	46.92905	25.62271	2.773925	92.48197	17.90285	46.7632	1.954427	6.356046	294.2863	57.17905	258.3001	1	1	0.1	
4	1	3	31.16327	31827.89	76.80922	18.21787	30.85424	29.03339	0.887451	82.05495	16.58661	56.12182	0.700025	5.594037	203.758	74.63447	283.3757	1	1	0.1	
5	1	4	33.9313	23002.18	78.98524	33.52862	32.63559	29.90586	2.697663	81.93746	20.08385	47.28638	1.060559	5.543758	94.85432	70.84809	238.5683	1	1	0.166235	
6	1	5	33.11476	33414.48	79.49041	21.48695	36.17259	28.45102	1.806747	89.55329	19.89141	54.74486	0.755253	6.256004	102.6936	74.77026	165.3683	1	1	0.24887	
7	1	6	34.16046	43983.51	76.53743	31.1099	43.79973	28.2682	2.048708	90.87482	16.40038	30.23701	0.628082	6.042104	235.745	34.38171	141.3329	1	1	0.374235	
8	1	7	30.28704	28053.42	76.90803	27.69261	52.05114	29.68084	1.259102	92.46466	19.60177	42.67928	1.382819	6.118273	62.11227	75.66207	107.5317	1	1	0.461782	
9	1	8	34.13218	42899.45	70.51001	22.56096	50.91076	28.17657	1.316154	84.00151	24.71965	38.52616	1.916362	6.246984	183.0976	41.05232	360.2276	1	1	0.360038	
10	1	9	33.62264	44136.43	79.61766	29.29307	33.24568	29.7337	2.007931	80.91822	23.34636	46.51547	0.829792	6.499147	50.31084	47.99292	161.4647	1	1	0.333246	
11	1	10	30.1512	38224.19	71.46257	18.28443	50.76326	27.01484	2.458856	85.20549	15.5945	38.00082	1.102884	5.961174	270.4196	85.78803	133.7627	2	1	0.365995	
12	1	11	33.97318	40548.96	73.94469	23.24189	31.59811	28.49033	2.893102	89.57963	18.59057	36.34213	1.694439	5.629301	290.6585	61.32089	124.2714	2	1	0.308455	
13	1	12	30.49826	30220.62	78.97545	32.14869	48.78389	25.43678	1.05845	81.15118	21.02692	31.40068	1.832803	6.467118	213.5171	55.83522	181.3825	2	1	0.291848	
14	1	13	30.51682	22507.97	79.06108	27.30083	42.46137	27.55933	1.241377	94.95605	17.70321	55.37597	1.2132	5.700305	145.9965	46.79183	279.7215	2	1	0.16871	
15	1	14	34.62396	22428.44	71.01387	20.64455	36.68649	29.45875	1.055814	81.4847	19.74812	52.39447	1.007508	5.589311	132.9117	92.99501	346.2995	2	1	0.1	0.35
16	1	15	31.48951	43351.83	79.42805	26.78301	58.35207	25.76234	0.443642	94.08772	20.43556	54.15525	1.303737	6.239507	187.1183	37.63485	292.5237	2	1	0.19055	0.44055
17	1	16	32.64083	40691.91	79.56473	24.29832	32.87597	29.61682	2.838761	91.46772	1[illegible].68214	34.87963	1.07224	6.07782	57.09935	62.38017	115.9114	2	1	0.181267	0.43[illegible]267
18	1	17	34.26585	40317.99	76.14725	28.80794	33.60987	26.78506	2.565174	85.55556	1[illegible].22185	56.61936	1.205342	5.558706	249.032	65.98441	399.1083	2	1	0.198814	0.44[illegible]814
19	1	18	34.05904	21462.55	75.09663	30.22459	39.038	25.87836	1.998491	83.67847	20.40474	55.752	1.312844	5.818853	123.9088	86.48397	111.1007	3	1	0.342864	1
20	1	19	32.04266	28251.42	77.77472	27.8997	34.32632	27.74364	0.267886	92.20901	20.0395	43.47254	1.155982	6.493362	57.90741	45.76726	253.8034	3	1	0.478602	1
21	1	20	30.20075	36948.01	76.82848	20.07364	43.62986	28.82169	1.69035	82.78872	18.90886	46.85763	1.42165	5.749313	290.766	86.02992	156.4103	3	1	0.436052	1
22	1	21	30.55781	38789.51	79.74848	25.91588	53.4217	26.13685	1.273186	84.20768	19.13881	33.57512	1.731477	5.93185	223.578	35.19404	312.4615	3	1	0.413782	1
23	1	22	31.70891	27297.09	76.19903	23.26926	44.45591	28.40812	0.281309	86.79866	15.351	32.75259	0.914521	5.555816	153.3475	56.52836	248.5803	3	1	0.365567	1
24	1	23	32.0969	47319.82	76.35026	20.94735	46.24551	26.93821	2.024607	80.30903	20.27701	50.5454	1.343839	6.367238	296.0175	65.84987	391.9507	3	1	0.317705	0.5

Figure 5.35. Visualization of the sliding window.

Data Standardization

A Standard Scaler is employed to achieve uniformity in data representation. This scaler plays a pivotal role in normalizing the feature values, ensuring that they have a consistent scale and distribution. The scaler is fitted exclusively on the training data, learning the mean and standard deviation of each feature within this set. Subsequently, the trained scaler is applied to transform not only the training dataset but also the testing dataset. This ensures that both the training and testing datasets are brought to a common scale, promoting consistent and unbiased model training and evaluation.

$$\boldsymbol{x_{scaled}} = \frac{\boldsymbol{x-\mu}}{\boldsymbol{\sigma}} \tag{6}$$

$$\boldsymbol{\mu} = \frac{\boldsymbol{1}}{\boldsymbol{n}}\sum_{i=1}^{n}(\boldsymbol{x_i}) \tag{7}$$

$$\boldsymbol{\sigma} = \sqrt{\frac{\boldsymbol{1}}{\boldsymbol{n}}\sum_{i=1}^{n}(\boldsymbol{x_i} - \boldsymbol{\mu})^{\boldsymbol{2}}} \tag{8}$$

where

x_{scaled} = standardized data

x = raw data

μ = mean

σ = standard deviation

LSTM Model Architecture

In the construction of the LSTM model architecture, a singular LSTM layer has been meticulously designed with 50 neurons, strategically implemented to adeptly capture intricate temporal dependencies within the dataset. To address the potential challenge of overfitting, a prudent integration of a dropout layer has been executed, featuring a dropout rate set at 0.7. This dropout layer introduces a stochastic element during training, thereby preventing the model from overly relying on specific neurons and enhancing its generalization capacity.

Furthermore, the output layer is architecturally poised as a densely connected layer, housing a solitary unit. To best cater to the requirements of the regression task at hand, the activation function chosen for this layer is the hyperbolic tangent (tanh). The tanh activation function is expressed by the formula:

$$\tanh(x) = \frac{2}{1 + e^{-2x}} - 1$$

This activation function, being particularly suited for regression problems, ensures that the output is continuous and falls within the range of (-1, 1). The carefully selected architectural elements collectively contribute to the model's efficacy in capturing temporal intricacies and addressing overfitting concerns, making it a robust framework for regression tasks within the specified context.

Model Compilation and Training

The model is compiled using the Adam optimizer and mean squared error loss function for regression. Training spans 10 epochs with a batch size of 32, optimizing computational efficiency. A 20% validation split monitors model performance on unseen data, aiding in preventing overfitting and ensuring robust generalization.

Post-training evaluation yields a test loss of 0.1399, indicating the model's performance on unseen data. This meticulous training and evaluation regimen ensures the model's effectiveness in capturing temporal dependencies while avoiding overfitting, validating its utility for the specified regression task.

Model Evaluation

The trained model has undergone evaluation on the test set, resulting in a MSE of 0.1399. However, it's important to note that the validity of this evaluation is limited. The model was trained using a dummy synthetic dataset, and hyperparameter tuning was not performed. Hyperparameter tuning is considered unnecessary for the dummy dataset as the synthetic growth patterns may not accurately represent real-world scenarios. Consequently, while the MSE provides insight into the model's performance on the synthetic data, caution should be exercised in generalizing these results to real-world applications.

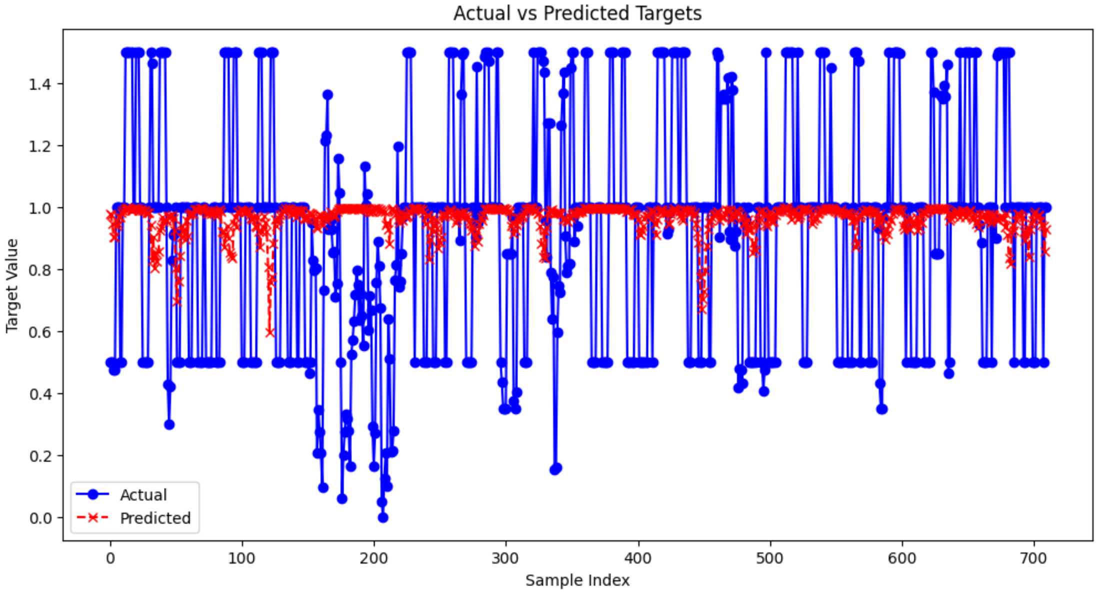


Figure 5.36. Visual representation of LSTM Model predictions.

5.6 Implementation Issues and Challenges

Network Connectivity: Ensuring consistent and reliable network connectivity is crucial for real-time data transmission and remote monitoring. Challenges may arise due to network interruptions, signal interference, or bandwidth limitations, impacting the system's responsiveness and data accuracy.

Unstable Camera: Managing an unstable camera can lead to inconsistent image capture quality, image distortion, or frequent camera failures. Addressing these issues requires optimizing camera settings, enhancing hardware stability, and implementing error-handling mechanisms to ensure reliable and high-quality image capture.

Limited Usage of Computing Cores: Utilizing Python as the programming language introduces certain limitations due to its interpreted nature. Unlike compiled languages, Python code is executed line-by-line by the Python interpreter, which can lead to inefficient utilization of computing cores. This process cause high context switching between threads, where the system frequently switches between different tasks, resulting in increased overhead and reduced efficiency. As a result, this lead to instability and potential disconnection of the livestream.

5.7 Concluding Remark

The chapter provides a clear description of the hardware and software setup procedures, along with detailed configurations and settings. The operational aspects of the system are illustrated through various perspectives, including views from AWS, the Node-RED dashboard, and Telegram. Additionally, a conceptual LSTM model is presented as a potential direction for future work, indicating possibilities for integration once a complete dataset becomes available to further augment the project's utility. Various implementation issues and challenges are also discussed to provide a comprehensive understanding of the project's complexities and considerations.

Chapter 6

System Evaluation

In this chapter, we will cover system testing, project challenges, SWOT analysis of the system, and evaluation of the objectives.

6.1 System Testing

The system reliability testing involves removing certain components to assess system functionality without them. Accuracy tests are conducted on measurable data attributes using high-end sensor devices to validate data precision. Additionally, the response time for automation control triggers to execution is measured to evaluate system efficiency.

System Reliability

Table 6.1 System continuity overview

Component Removed	System Continuity
LED Grow Light	Continues to work, but loses control on it
Cooling Fan	Continues to work, but loses control on it
Water Pump	Continues to work, but loses control on it
Fertilizer Pump	Continues to work, but loses control on it
Dashboard	Continues to work, but loses visualization and automation control through dashboard
YouTube Livestream	Continues to work, but no live observation on dashboard
Soil Sensor	Continues to work, uses previous soil data for updates
DHT22 Air Humidity and Temperature Sensor	Continues to work, uses previous air data for updates
BH1750 Sensor	Continues to work, uses previous light data for updates
Additional Power Supply	Continues to work, loses control on automation devices and soil sensor
Camera	System down
Internet Connectivity	System down
Raspberry Pi Power Supply	System down

After conducting several component removal tests, it was observed that only the removal of the camera, internet connectivity, and Raspberry Pi power supply resulted in the entire system going down. All other components continued to function, albeit with limited control or data updates as described in the table above.

Sensors Accuracy

The accuracy of air temperature and humidity measurements obtained from the DHT22 sensor is compared with data collected by the Mi Temperature and Humidity Monitor 2 (XiaoMi sensor).

Table 6.2 Comparison between the air temperatures collected by the DHT22 and Mi sensors

Test No.	**DHT22 Air Temperature and Humidity Sensor**	**Mi Temperature and Humidity Monitor 2**	**APE (%)**
	Air Temperature (°C)	**Air Temperature (°C)**	
1	22.60	22.60	0.00
2	22.60	22.70	0.44
3	23.50	23.50	0.00
4	23.50	23.60	0.43
5	23.70	23.80	0.42
6	23.00	22.80	0.87
7	23.20	23.20	0.00
8	23.60	23.60	0.00
9	23.00	23.10	0.43
10	22.50	22.40	0.44

The MAPE of the collected air temperature is 0.303%, which is well within the expected performance of a MAPE of 5%.

Table 6.3 Comparison between the air humidities collected by the DHT22 and Mi sensors

Test No.	**DHT22 Air Temperature and Humidity Sensor**	**Mi Temperature and Humidity Monitor 2**	**APE (%)**
	Air Humidity (%)	**Air Humidity (%)**	
1	70.60	69.60	1.42
2	69.60	69.50	0.14
3	69.30	69.50	0.29
4	68.90	68.80	0.15
5	67.80	68.00	0.29
6	69.40	70.00	0.86
7	70.00	70.00	0.00
8	68.30	68.30	0.00
9	64.10	64.00	0.16
10	68.10	67.90	0.29

The MAPE of the collected air humidity is 0.36 %, which is well within the expected performance of a MAPE of 5%.

Response Time

Table 6.4 Response time for Telegram automation commands

Test No.	**Telegram Automation Command Response Time (s)**
1	≤ 1
2	≤ 1
3	≤ 1
4	≈ 2
5	≤ 1
6	≈ 4
7	≤ 1
8	≤ 1
9	≤ 1
10	≈ 2

The response time for executing Telegram automation commands is almost immediate with smooth internet connectivity, except for occasional delays due to internet connectivity issues.

Table 6.5 Response time for YouTube livestream

Test No.	Time Taken to Show YouTube Livestream (s)
1	20
2	17
3	15
4	22
5	23

After conducting several experiments, the time taken to display the YouTube livestream on the dashboard is typically below 30 seconds. The mean average time taken is 19.4 seconds, which falls within an acceptable startup time. Therefore, the other working threads are set to run after a 30-second delay to ensure the livestream stabilizes first.

Other Findings

The BH1750 light intensity sensor frequently encounters a cold start issue where readings often stabilize around zero during initial operation. However, this issue occasionally occurs only once during the cold start, after which the sensor's readings normalize and operate as expected. Thus, while this initial anomaly may pose a minor inconvenience, it generally does not significantly impact the overall functionality and reliability of the sensor in subsequent operations.

6.2 Project Challenges

Limited Agricultural Expertise: A lack of specialized agricultural knowledge can pose challenges in interpreting environmental data accurately and optimizing growth conditions for the Bentong ginger plants. Understanding plant physiology, growth patterns, and specific requirements is essential for tailoring the automation controls and ensuring optimal cultivation practices. This gap in expertise may lead to suboptimal resource allocation, reduced growth efficiency, and potential risks to plant health.

Delay in Soil Sensor Procurement: The delay in obtaining the soil sensor and the absence of an official user manual hinder the progress of the project. This delay result in extended project timelines, increased development costs, and challenges in sensor integration and calibration.

Integration Complexity: Integrating multiple hardware components, software libraries, and cloud services introduce complexities in system configuration, compatibility issues, and interoperability challenges. Managing these integrations effectively requires meticulous planning, testing, and troubleshooting to ensure seamless operation and data flow across the system.

Lack of Sufficient Dataset for AI Modeling: The absence of a comprehensive dataset hinder the development and training of AI models to predict and optimize growth conditions for Bentong ginger cultivation. A limited dataset restrict the accuracy and reliability of predictive algorithms, affecting the system's ability to adapt and respond effectively to changing environmental conditions. This limitation underscores the importance of continuous data collection and analysis to enhance the system's predictive capabilities and support informed decision-making in ginger cultivation.

6.3 SWOT Analysis

Strengths:

The system offers a cost-effective solution with high automation capabilities, leveraging Python and Node-RED to streamline data collection, analysis, and control processes. This automation ensures efficient monitoring and management of environmental conditions, contributing to improved plant growth and health.

Weaknesses:

One of the system's vulnerabilities is its dependency on WiFi connectivity. In the absence of a stable WiFi connection, the system's functionality may be compromised, leading to potential data loss or interruptions in monitoring and control operations.

Opportunities:

The system presents an opportunity for scalability, allowing for the integration and monitoring of multiple Bentong ginger plants simultaneously. This scalability can facilitate broader environmental monitoring, enabling more comprehensive insights and adaptive control strategies to optimize plant growth and yield.

Threats:

The placement of the Raspberry Pi in the greenhouse exposes it to the surrounding environment's humidity levels. Elevated humidity levels can potentially impact the Raspberry Pi's performance and longevity, leading to hardware issues or malfunctions. Ensuring proper environmental protection and monitoring can mitigate these risks and enhance the system's reliability and durability.

6.4 Objectives Evaluation

I. Develop a Specialized IoT Framework for Bentong Ginger

Successfully Achieved: The development of a specialized IoT framework for Bentong ginger involved the integration of various hardware components, such as sensors and actuators, with cloud services and software platforms. The system's architecture was meticulously designed to facilitate real-time data collection, processing, and automation, ensuring seamless monitoring and management of environmental conditions for optimal Bentong Ginger cultivation.

II. Create a Comprehensive Bentong Ginger Growth Dataset

Successfully Achieved: Despite facing challenges, including delayed delivery of the soil sensor and issues with the soil sensor manual, the project successfully established a foundational dataset for Bentong ginger growth. The late arrival of the soil sensor and the difficulties in accessing its manual resulted in a delayed start to data collection, commencing only in week 6 of the FYP2 trimester. However, despite these setbacks, the completed system has been operational over an period, providing consistent data on Bentong ginger growth patterns and environmental conditions. The dataset, though limited, offers valuable insights into the growth trends and requirements of Bentong ginger cultivation, laying a robust foundation for future dataset expansion and analysis.

III. Establish an Adaptive Resource Optimization Framework

Successfully Achieved: The establishment of an adaptive resource optimization framework involved the development automation processes to dynamically adjust environmental conditions based on real-time data insights. Through the implementation of predefined thresholds and small-volume-high-frequency resource allocation strategies, the system effectively optimized resource allocation for lighting, ventilation, watering, and fertilizing. This approach ensured optimal growth conditions for Bentong ginger by providing resources only when needed, thereby conserving resources during inactive periods and preventing overshooting of optimal ranges.

6.5 Concluding Remark

In this chapter, we discuss system testing in terms of data accuracy and software response time. We also address the challenges encountered during the project timeline, conduct a SWOT analysis to evaluate the project, and provide an assessment of the project's objectives.

Chapter 7

Conclusion and Recommendations

7.1 Conclusion

The Bentong ginger precision agriculture project stands as a testament to the successful integration of innovative technologies and methodologies in revolutionizing ginger cultivation practices. The project's core achievement lies in the robust data collection mechanism that gathered real-time environmental data essential for optimal Bentong ginger growth. This meticulous data collection was underpinned by automation capabilities that dynamically adjusted environmental conditions, ensuring the plants received the precise levels of lighting, ventilation, watering, and fertilization tailored to their needs.

Despite facing challenges, including delayed delivery of the soil sensor and issues with the soil sensor manual, the project successfully establishes a foundational dataset for Bentong ginger growth. This dataset captures a comprehensive range of environmental parameters critical for optimal growth, including air temperature, humidity, light intensity, soil moisture, pH levels, electrical conductivity, nitrogen, phosphorus, and potassium concentrations. In addition, high-resolution images were collected at key growth stages to visually track and analyze the ginger plants' development. While initially limited, the dataset offers valuable insights into Bentong ginger growth trends and requirements, laying a robust foundation for future dataset expansion and analysis.

The establishment of an adaptive resource optimization framework involved the development of automation processes to dynamically adjust environmental conditions based on real-time data insights. Through the implementation of predefined thresholds and a low-intensity-high-frequency resource allocation strategy, the system effectively optimized resource allocation for lighting, ventilation, watering, and fertilizing. This approach ensured optimal growth conditions for Bentong ginger by providing resources only when needed, conserving resources during inactive periods, and preventing overshooting of optimal growth ranges.

The project's intuitive visualization tools, including dashboards and graphs, provide users with a clear and comprehensive overview of the collected environmental data and growth patterns. These visualizations empower users with actionable insights for informed decision-making, aiding in monitoring the growth trends and ensuring efficient management of ginger cultivation processes. Additionally, the system's remote control and monitoring capabilities enable users to oversee and adjust environmental conditions in real-time, enhancing operational flexibility and responsiveness.

The project embarked on an ambitious journey to revolutionize ginger cultivation through innovative technologies and methodologies. The project set the stage by outlining the problem statement, motivations, objectives, and scope, emphasizing the need for enhancing ginger cultivation practices. A comprehensive literature review synthesized existing systems and deep learning models relevant to precision agriculture, which informed the project's direction and design choices.

The methodology established a structured framework that guided the project's development, including hardware and software selection, functional requirements, and expected challenges. The system design presented a comprehensive overview of the system's architecture, hardware connections, functional modules, and database and GUI design, laying the foundation for the project's implementation.

The practical implementation detailed the hardware setup, software configuration, system operation, and the development of a conceptual LSTM model. This phase showcased the integration of innovative technologies and highlighted the challenges encountered during the development process. The critical assessment of the project's performance evaluated system testing, project challenges, SWOT analysis, and objectives evaluation.

In conclusion, the Bentong ginger precision agriculture project has made significant strides in advancing ginger cultivation practices through the integration of cutting-edge technologies and methodologies. While achieving notable successes in system design, implementation, and evaluation, there remain opportunities for future enhancements and refinements. The holistic approach to precision agriculture serves as a testament to the potential of leveraging technology to optimize agricultural practices, ensuring sustainable and efficient ginger cultivation for the future.

7.2 Recommendations

Development of an Actual LSTM Model: Implementing a full-fledged LSTM model could greatly enhance the accuracy and predictive capabilities of the system. By leveraging time-series data from sensors, the LSTM model can provide more nuanced insights into Bentong ginger growth patterns, enabling more precise resource allocation and automation adjustments.

Scaling Up to Handle More Ginger Plants: As the system's capacity grows, it's essential to ensure scalability. This involves optimizing hardware resources, refining data processing algorithms, and possibly integrating cloud-based solutions to handle larger datasets and increased computational demands effectively.

Automating Image Processing for Plant Growth Analysis: Incorporating image processing techniques can automate the analysis of plant growth, reducing the need for manual measurements and enhancing efficiency. This automation can provide real-time visual assessments, allowing for quicker decision-making and timely interventions to optimize growth conditions.

Enhancing System Robustness: To ensure reliable and uninterrupted operation, it's crucial to enhance the system's robustness. This can be achieved by implementing fault-tolerant mechanisms, improving error handling, and conducting rigorous testing under various conditions to identify and address potential vulnerabilities or bottlenecks

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FINAL YEAR PROJECT WEEKLY REPORT

(Project II)

Trimester, Year: Year 3 Trimester 3	**Study week no.: 2**
Student Name & ID: Lim Xuan (20ACB01673)	
Supervisor: Ts. Dr. Goh Hock Guan	
Project Title: Implementing IoT System in Growth Monitoring of Bentong Ginger	

1. WORK DONE Integrate soil sensor into the project.
2. WORK TO BE DONE Automation on control devices.
3. PROBLEMS ENCOUNTERED The use of RS485 to TTL converter doesn't work for this soil sensor, maybe due to non-compatibility issue but solved using USB to RS485 converter.
4. SELF EVALUATION OF THE PROGRESS The progress of the project is on schedule.

Supervisor's signature

Student's signature

FINAL YEAR PROJECT WEEKLY REPORT

(Project II)

Trimester, Year: Year 3 Trimester 3	**Study week no.: 4**
Student Name & ID: Lim Xuan (20ACB01673)	
Supervisor: Ts. Dr. Goh Hock Guan	
Project Title: Implementing IoT System in Growth Monitoring of Bentong Ginger	

1. WORK DONE

Implemented light and fan control automation.

2. WORK TO BE DONE

Automation on watering, fertilizing automation and YouTube streaming.

3. PROBLEMS ENCOUNTERED

No problems encounterd.

4. SELF EVALUATION OF THE PROGRESS

The progress of the project is on schedule.

Supervisor’s signature

Student’s signature

FINAL YEAR PROJECT WEEKLY REPORT

(Project II)

Trimester, Year: Year 3 Trimester 3	**Study week no.: 6**
Student Name & ID: Lim Xuan (20ACB01673)	
Supervisor: Ts. Dr. Goh Hock Guan	
Project Title: Implementing IoT System in Growth Monitoring of Bentong Ginger	

1. WORK DONE Successfully implement watering, fertilizing automation and YouTube streaming.
2. WORK TO BE DONE Build a NODE-Red Dashboard for visualization and control.
3. PROBLEMS ENCOUNTERED YouTube streaming API cost much so change to manually click live button in YouTube Creator Studio for cost optimization.
4. SELF EVALUATION OF THE PROGRESS The progress of the project is on schedule.

Supervisor's signature

Student's signature

FINAL YEAR PROJECT WEEKLY REPORT

(Project II)

Trimester, Year: Year 3 Trimester 3	**Study week no.: 8**
Student Name & ID: Lim Xuan (20ACB01673)	
Supervisor: Ts. Dr. Goh Hock Guan	
Project Title: Implementing IoT System in Growth Monitoring of Bentong Ginger	

1. WORK DONE Successful building of NODE-Red Dashboard.
2. WORK TO BE DONE Improve system in terms of integration.
3. PROBLEMS ENCOUNTERED Many depreciated node in NODE-red for fetching data from AWS DynamoDB, but solved after many trial and error.
4. SELF EVALUATION OF THE PROGRESS The progress of the project is on schedule.

Supervisor's signature

Student's signature

FINAL YEAR PROJECT WEEKLY REPORT

(Project II)

Trimester, Year: Year 3 Trimester 3	**Study week no.: 10**
Student Name & ID: Lim Xuan (20ACB01673)	
Supervisor: Ts. Dr. Goh Hock Guan	
Project Title: Implementing IoT System in Growth Monitoring of Bentong Ginger	

1. WORK DONE Code the system in a more dynamic way for robustness.
2. WORK TO BE DONE Finish report writing.
3. PROBLEMS ENCOUNTERED No problems encountered.
4. SELF EVALUATION OF THE PROGRESS The progress of the project is on schedule.

Supervisor's signature

Student's signature

FINAL YEAR PROJECT WEEKLY REPORT

(Project II)

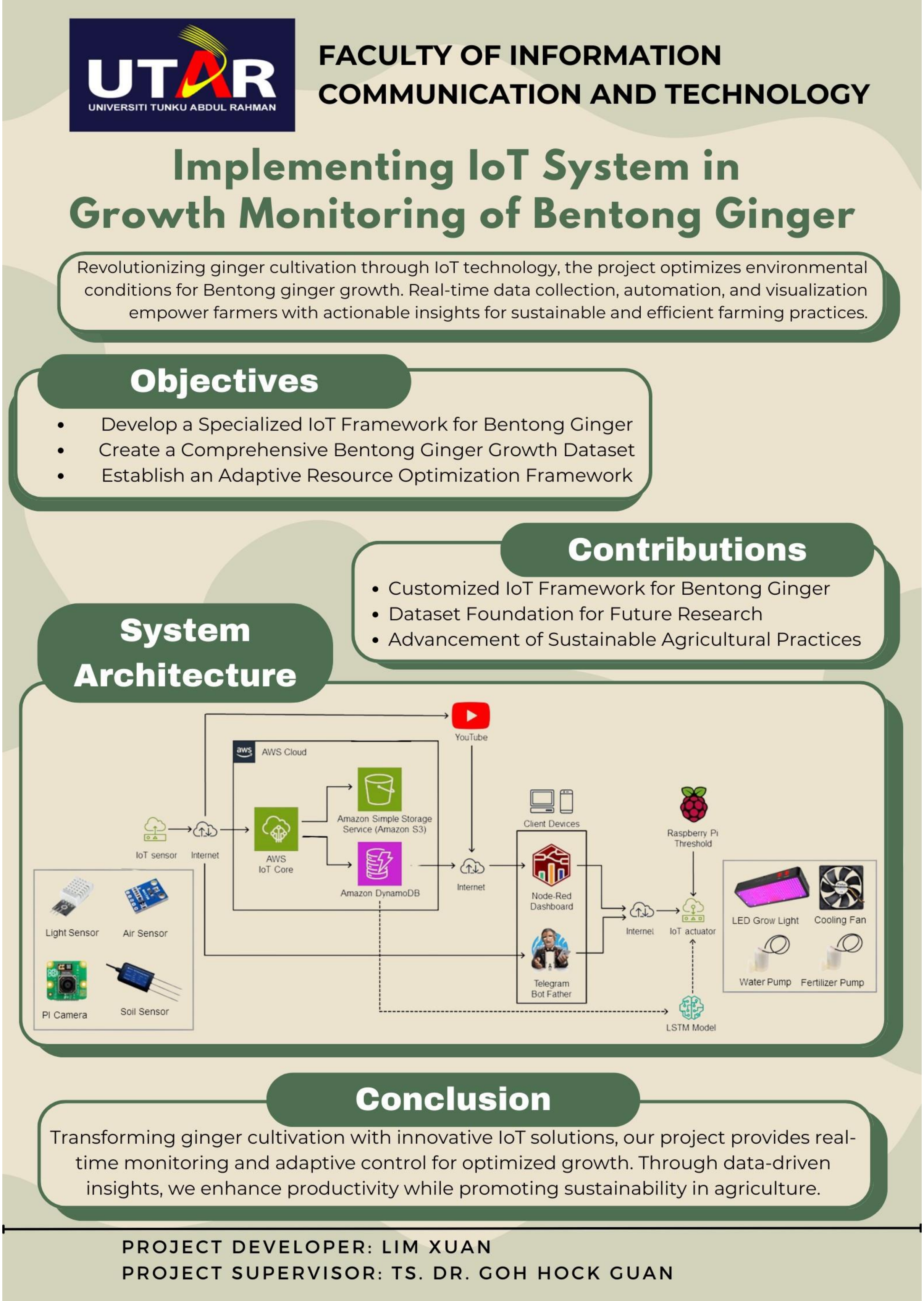
Trimester, Year: Year 3 Trimester 3	**Study week no.: 12**
Student Name & ID: Lim Xuan (20ACB01673)	
Supervisor: Ts. Dr. Goh Hock Guan	
Project Title: Implementing IoT System in Growth Monitoring of Bentong Ginger	

1. WORK DONE Half way in finishing report.
2. WORK TO BE DONE Complete report writing.
3. PROBLEMS ENCOUNTERED No problems encountered.
4. SELF EVALUATION OF THE PROGRESS The progress of the project is on schedule.

Supervisor's signature

Student's signature

POSTER



UNIVERSITI TUNKU ABDUL RAHMAN

FACULTY OF INFORMATION COMMUNICATION AND TECHNOLOGY

Implementing IoT System in Growth Monitoring of Bentong Ginger

Revolutionizing ginger cultivation through IoT technology, the project optimizes environmental conditions for Bentong ginger growth. Real-time data collection, automation, and visualization empower farmers with actionable insights for sustainable and efficient farming practices.

Objectives

- Develop a Specialized IoT Framework for Bentong Ginger
- Create a Comprehensive Bentong Ginger Growth Dataset
- Establish an Adaptive Resource Optimization Framework

Contributions

- Customized IoT Framework for Bentong Ginger
- Dataset Foundation for Future Research
- Advancement of Sustainable Agricultural Practices

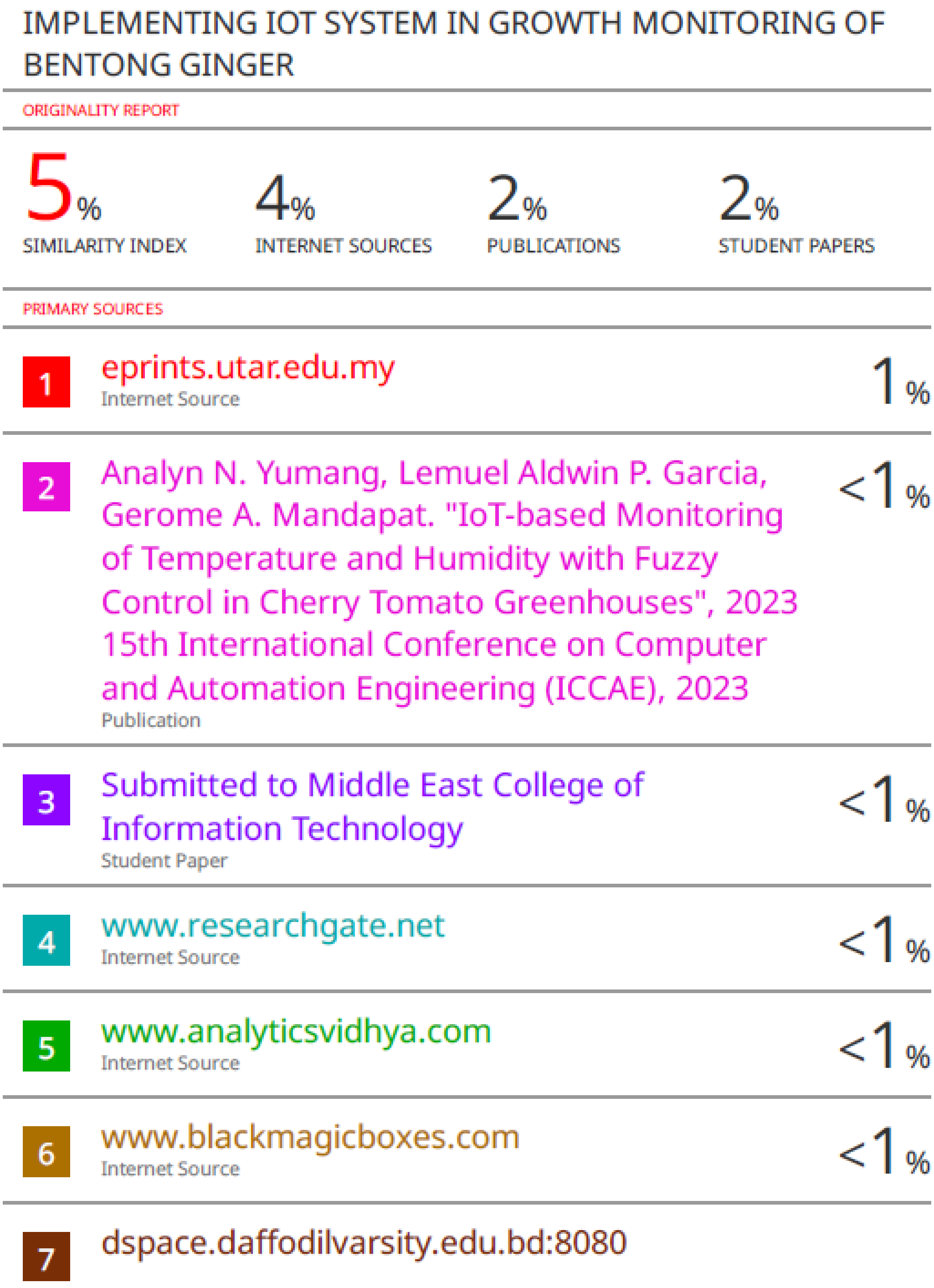
System Architecture

Conclusion

Transforming ginger cultivation with innovative IoT solutions, our project provides real-time monitoring and adaptive control for optimized growth. Through data-driven insights, we enhance productivity while promoting sustainability in agriculture.

PROJECT DEVELOPER: LIM XUAN
PROJECT SUPERVISOR: TS. DR. GOH HOCK GUAN

PLAGIARISM CHECK RESULT



IMPLEMENTING IOT SYSTEM IN GROWTH MONITORING OF BENTONG GINGER

ORIGINALITY REPORT

5%	4%	2%	2%
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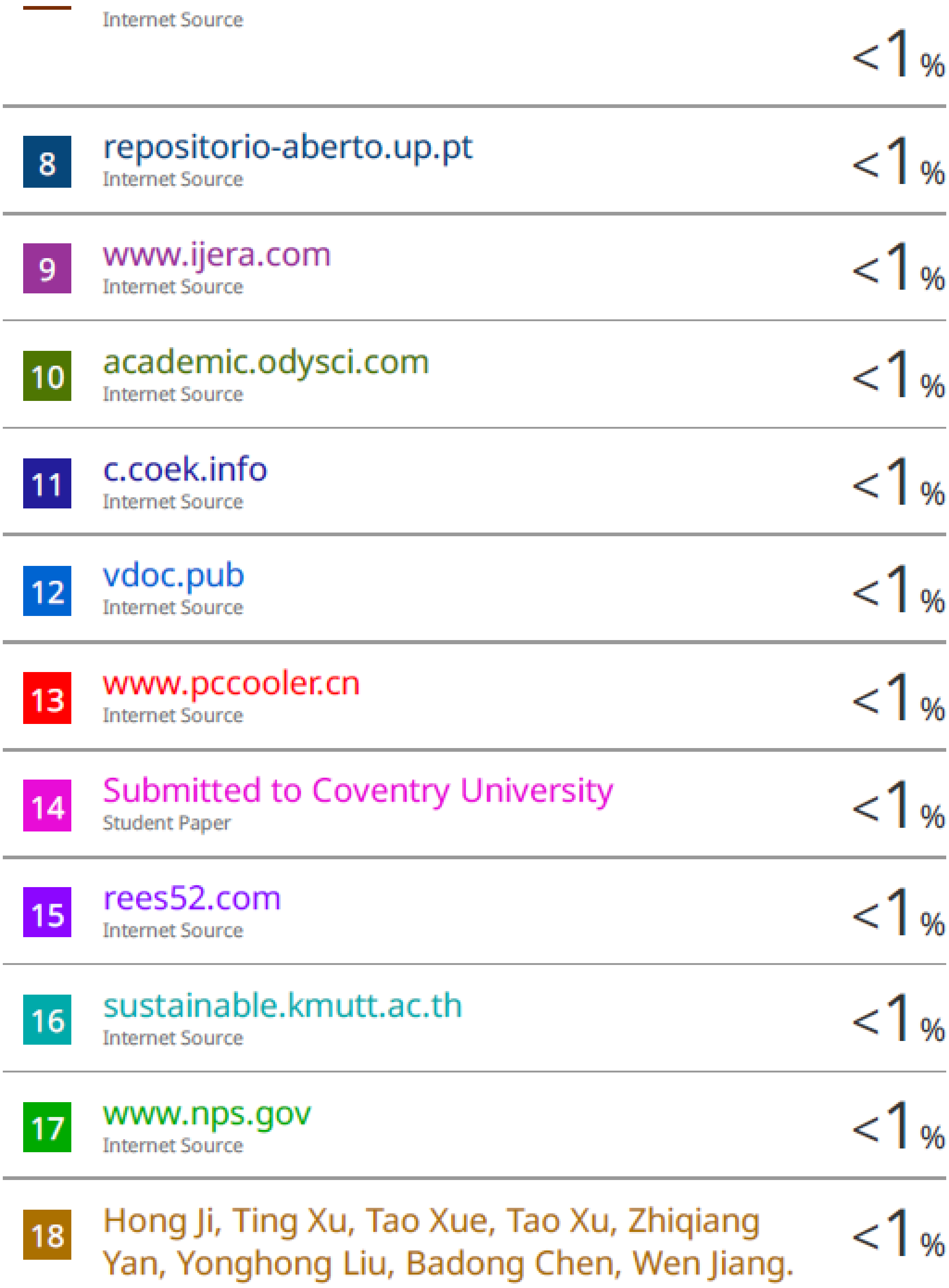

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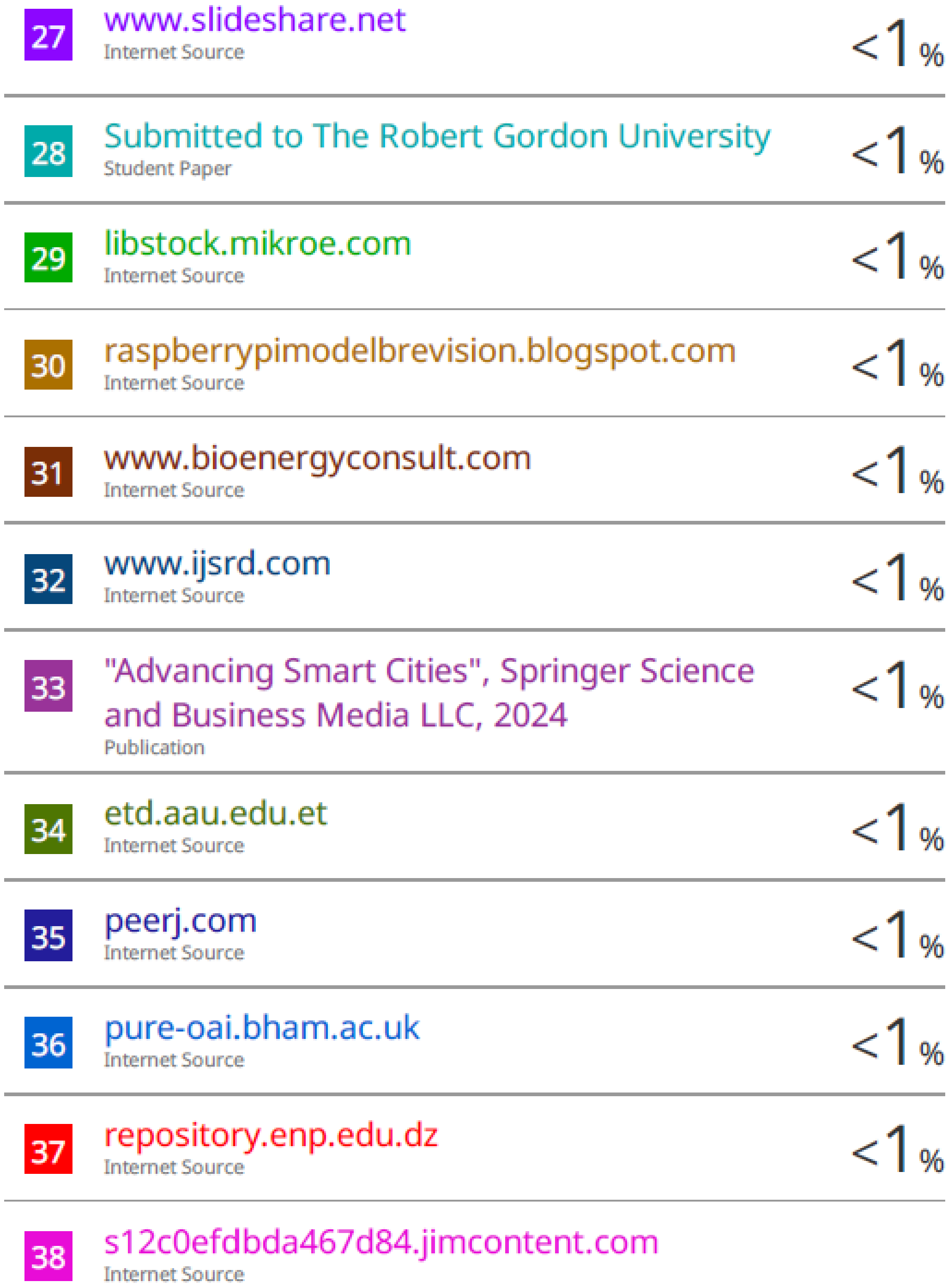

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