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AFRICAN CENTRE OF EXCELLENCE IN INTERNET OF THINGS

Research Thesis Title: IoT Based Automated Mushroom Cultivation System

Case Study: Rwanda

A dissertation submitted in partial fulfilment of the requirements for the award of masters of science degree in internet of things: wireless intelligent sensor network

Submitted By

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August, 2024

Declaration

I GEBRREMEDHN Abrehet Gebregiorgis, Master ‘student from African Center of Excellence in internet of things, at University of Rwanda. I declare that this research thesis is my own original work and it has never been presented before anywhere in the world.

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Bonafide certificate

This is to certify that this submitted Research Thesis work report is a record of the original work done by GEBREMEDHN Abrehet Gebregiorgis (**Ref. Nu:** 215041434), MSc. IoT-WISNET Student at the University of Rwanda / College of Science and Technology / African Center of Excellence in Internet of Things, the Academic year 2023/2024.

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Abstract

Mushroom farming is one of the high-value innovative types of agriculture due to its nutrition and the big role it plays in food security and reducing malnutrition. Growing mushrooms is very economical and innovative. It grows by recycling agricultural waste products like wheat straw and cotton husk with limited resources like space area and water consumption. Oyster mushroom is the common type that grows in Rwanda due to its easy cultivation process and resistance to different weather conditions. Still, Rwandan mushroom farmers continue to experience unsatisfactory yields due to the traditional and manual type of farming they are using. This thesis aims to address the key environmental challenges that have a big role in growing mushrooms by using an IoT-based automated mushroom cultivation system. We will use sensors like DHT11 to monitor the temperature and humidity of the mushroom growing rooms and moisture sensors to control the soil moisture of the mushroom boxes. We will also use Oxygen and CO2 sensors to monitor the airflow in the growing room as proper ventilation has big effect on mushroom cultivation. The sensor data will be processed using ESP8266 microcontroller and send the data to the Blynk and Thingspeak cloud. The system will take an automatic action to irrigate, humidify, and ventilate when the sensor data is out of range or threshold level. Farmers will also be able to monitor their farms remotely using the Blynk app regardless of their location.

Keywords: IoT, mushroom cultivation, mycelium, productivity, cost efficiency, environmental monitoring, sustainable agriculture, Rwanda, food security, automated farming, resource optimization.

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List of Acronyms

Acronym	Full Form
IoT	Internet of Things
HTTP	Hypertext Transfer Protocol
API	Application Programming Interface
MINAGRI	Ministry of Agriculture and Animal Resources

Chapter 1

1.1 Introduction

Agriculture remains the backbone of many African countries including Rwanda. It is the major economic sector for the people of Rwanda, employing about 70% of the total population. The industry contributes about 31% to GDP, and it stands out as one of the most strategic sectors in Rwanda's development while 75% of the production comes from smallholder farmers [1]. As highlighted in 2015/16 BL JSR report of MINAGRI, [2] Mushroom was one of the four identified priorities for Fiscal Year 2017/2018 to contribute to the reduction of malnutrition through integrating an action plan, nutrition, and household food security as a subprogram strategy. The tearfund report [3] also highlights how mushroom has played a role in peacebuilding and livelihoods in the Rwandan community in addition to its economic contribution.

Mushrooms have emerged as a particularly important food source due to their high nutritional value in protein, vitamins, minerals, antioxidants, and carbohydrates, and their adaptability to various growing conditions. It is an innovative agricultural product that grows by recycling other agricultural waste products which is an environment-friendly circular economy supporting the SDGs. The fact that it grows indoors with a limited space area and small water for irrigation makes it possible to grow both in urban and rural areas by both men and women regardless of age and level of literacy ensuring its economic value in addition to its nutritional value.

Mushrooms are classified [4] into two categories poisonous and nonpoisonous. Those non-poisonous mushrooms can be edible or medicinal, and either grow naturally or grow by farming. In Rwanda, we have both wild mushrooms that grow in the forests and artificial mushrooms that grow in the farms. There have been around 20 varieties of mushrooms tested to grow in Rwanda, but oyster mushroom is the most common and preferable one which is adopted in the community due to its high nutrition and its ease of farming [5].

Oyster mushroom grows in a short period and with the system Rwandan Mushroom farmers use, it can be harvested every two weeks within the plantation cycle which is usually two to three months. This ensures healthy cash flow to the farmer proving the economic potential of mushrooms in the food system apart from their high role in tackling malnutrition and food insecurity. Besides, it can be cultivated all year round if there is a favorable environment. However, the traditional and manual way of farming is hindering the expected yield of mushroom making it hard to build sustainable mushroom farming for many farmers in

Rwanda. Hence, there is a need to develop a system that can monitor the mushroom growing conditions to optimize the productivity of the smallholder mushroom farmers in Rwanda and beyond.

1.2 Background and Motivation

In November 2020, a gruesome war started against the Tigray people in the north of Ethiopia, which led to manmade starvation and severe malnutrition [6], highlighting the urgent need for sustainable and nutritious food sources. Motivated by the plight of my people in Tigray and my observations in Rwanda, I founded a company called Tigrwa Mushroom Ltd blending the names of both Tigray and Rwanda to promote mushroom cultivation as a means to alleviate malnutrition. Because mushroom is a highly nutritious source of protein, vitamins, minerals, antioxidants, and carbohydrates which make it the best choice to have a healthy community and help maintain a malnourished body especially in regions affected by climate change, conflict, and food scarcity.

However, when started growing mushrooms traditionally like all the smallholder mushroom farmers do, I witnessed that it is not the easiest way to maintain a profitable business as the yield is always lower than the expected yield, and labor costs are also very high. With the manual farming system, many of the farmers are not even aware of which environmental parameter is affecting the production. However, considering the necessity of temperature, moisture, and ventilation for growing mushrooms, there are things most farmers consider by default for maintaining the mushroom growth manually. Mushroom growing rooms are built from grass, wood, or mud to create an ideal environment which is somehow cold and ventilated. Even sheeting is done with plastic and some agricultural wastes like grass, banana leaves or bamboo etc. With this manual system, farmers in cold areas like Musanze, the northern part of Rwanda are able to get comparatively better yields than those farm in hot areas. Despite all similar efforts, it is really hard to maintain a favorable environment for mushrooms manually especially in hot areas like Kigali. Thus, the yield is always below the expected harvest per tube per plantation cycle and it requires higher labor work to manage the farm. Especially during the dry season, most farmers don’t grow mushroom as the yield they get is very small and it requires too much labor work to maintain the moisture. Rwandan mushroom farmers also grow the mushroom in soil than hanging in plastic bags considering the moisture retention possibility of the soil. But still during the hot season, mushroom may be good and fresh in the morning, but later in the afternoon the heat causes the mushroom to dry. During this manual irrigation, if the farmer is not highly skilled, over-watering can also destroy the farm shortly after plantation before the expected plantation cycle and without even getting half of the expected yield from the farm. This will cause the farmer to end up in loss and dissatisfaction. Due to this, In the current scenario in Rwanda, many new mushroom farmers enter the sector believing the nutritional, economic, and environmental advantages they will get by growing mushrooms, but when they face the reality of these not yet-solved challenges, they get discouraged and quit the business. And this is highly affecting the sustainability of the sector despite its high need and advantage. Hence, it Is crucial to build a modern technology that will help the smallholder farmers to better manage their farm and improve their productivity. Figure 1 below shows the mushroom growth problems that were experienced in the environmentally unmonitored room I had in my farm located in Kigali by the time I started mushroom farming. As the arrow in the picture indicates, the wall of the mushroom growing house was fully covered by plastic which prohibited enough flow of oxygen and created a high level of CO_2. As a result, the mushroom that tried to grow was all burned. The study titled The Effect of Carbon Dioxide on the Quality of the Mushrooms [7] has also concluded their experiment that high CO_2 and deficiency of O_2 caused the death of individual cells, enzymatic browning, and a decrease in the fruit density of mushrooms. This is because the deficiency of oxygen leads to respiratory disorders and inhibits the biochemical processes of the mushrooms.

Figure 1: *Mushroom burning due to high level of CO2 and low level of Oxygen*

Figure 2 shows substrate or mushroom tubes in the plantation box in the process of decomposition at an early stage of cultivation due to unmonitored over-irrigation. When the soil moisture level is too high, the substrate becomes very wet, increasing mold growth [8], and the mycelium loses its strength which leads the substrate to become a composite instead of growing mushroom.

These mushroom boxes started decomposition shortly after plantation because of too much water or manual overirrigation during the hot season where mushrooms dry quickly because of high temperature, and farmers irrigate 3-4 times a day resulting in extra moisture in the soil which speeds up the decomposition of the mushroom tubes.

Figure 2: Mushroom tubes are damaged due to much water irrigation

The mushrooms in Figure 3 are dried in the growing box before being harvested due to the high temperature of the day during the hot season. All these once show just a sample of the effect of traditional mushroom farming negatively impacting the quality and yield of mushrooms while requiring too much labor task.

Figure 3: Mushroom dried due to the high temperature of the day

The study on Oyster mushroom growing considering the weather conditions in India [9] stated that the mushrooms cultivated in the dry season of April and May where temperature goes up to 35ºC – 40ºC provided less yield and mushrooms were malformed and of low quality. The same is true in Rwanda. The mushroom yield and quality is great during the cold season, whereas the dry season stays challenging for mushroom farmers. There is enough production of mushrooms in November and December for example. Because most of the Rwandan mushroom farmers prefer to grow mushrooms when there is a favorable climate as there is no modern way, they can monitor the growing environment to grow throughout the year.

Hence, as an IoT Masters student and a mushroom farmer, I am proposing this IoT-based automated mushroom cultivation system to enable the farmers to remotely monitor and control their farm. The system uses sensors that will monitor the key environmental parameters, like temperature, humidity, soil moisture, CO2, and oxygen, which are critical for growing mushrooms. The favorable range of these parameters is programmed in the system with Arduino IDE and whenever the sensor data is out of the prescribed range, the system will automatically take action through the actuators like AC, humidifier, and irrigation pump. For example, when the Temperature is beyond 28ºC, the AC has to turn on to create a more ventilated cold environment. When the air humidity in the growing room is under the given threshold level, the humidifier (mist maker) will automatically turn on to humidify the growing room. Whereas, when the soil moisture in the growing boxes is under the given range, the water pump has to irrigate the growing boxes automatically in the form of spraying. The farmer can also monitor these actions manually through the Blynk mobile app or dashboard using the virtual button. The farmer will be able to visualize the Temperature, humidity, moisture, CO2, and Oxygen values on the Blynk app using virtual pins and can also download the datasheet from the Thingspeak dashboard to analyze the status of the farm.

The mushroom below in Figure 4 is grown traditionally, but during the rainy season in a favorable environment where there is optimal temperature, humidity, and moisture values for optimal yield of mushroom. From the picture, we can conclude that if we can create a favorable environment by monitoring and controlling the key parameters, growing mushroom can be very successful with optimal productivity and quality.

Figure 4: Mushrooms grown in a favorable environment during the rainy season

1.3 Problem Statement

Despite the potential of mushrooms, mushroom farmers in Rwanda face significant challenges due to the manual way of the cultivation process they are using. For optimal growth and yield of mushroom, it requires precise control of temperature, humidity, soil moisture, CO2, and Oxygen level. PH level is also one of the parameters to take into consideration. In Rwanda, soil-based mushroom farming involves placing the mushroom seed/tube in the soil and irrigating it manually to maintain moisture. However, this method often results in suboptimal yields, especially during hot seasons. To address these issues, this research aims to develop an IoT-based mushroom cultivation system that automates environmental controls, thereby improving productivity and cost efficiency.

1.4 Study Objectives

1.4.1 General Objective

The main objective of this thesis is to develop and implement an IoT-based automated mushroom cultivation system that enhances productivity and reduces costs for mushroom farmers in Rwanda by optimizing growing conditions through the use of sensors and automated environmental control.

1.4.2 Specific Objectives

i. To design and deploy an IoT-based system for real-time monitoring and control of critical environmental parameters, including temperature, humidity, soil moisture, oxygen, and CO2 levels, and send the data to Blynk and Thingspeak cloud

ii. To automate the regulation of humidity, temperature, soil moisture, and air condition to maintain optimal growing conditions for mushrooms

iii. To enable farmers to visualize their farm data on Blynk and Thingspeak, and control the environmental conditions remotely

1.4 Hypotheses

The implementation of an IoT-based mushroom cultivation system will significantly improve mushroom yield and cost-efficiency compared to traditional manual farming methods. Specifically, by automating the monitoring and control of environmental factors such as temperature, humidity, soil moisture, CO2 and oxygen levels. It will result in a measurable increase in productivity, a reduction in production costs, and enhanced consistency in mushroom quality. Furthermore, the system will facilitate year-round cultivation, overcoming seasonal challenges and contributing to improved food security and reduced malnutrition in Rwanda and potentially other regions.

1.5 Study Scope

This research focuses on the development and implementation of an IoT-based automated mushroom cultivation system for Mushroom farming in Rwanda which includes designing and integrating of environmental sensors for real-time monitoring of critical environment parameters such as temperature, humidity, soil moisture, oxygen, and CO2 level [10].

1.6 Significance of the study

It addresses the most common problems faced by mushroom farmers such as, the irregular yields, high production costs caused by labor-intensive processes for their cultivation. This project intends to introduce an IoT system to transform agriculture through its applications of advanced technology that has optimized growth and automated environmental conditions control. The project aims at improving farmer`s economic well-being by reducing their reliance on manual labor while enhancing the efficiency of mushroom farming. It is expected to use technology to improve food security by increasing mushroom yields, which are a crucial source of protein, vitamins, and minerals.

1.7 Organization of the Study

The study paper discussed the introduction part in Chapter One and reviewed the existing literature in Chapter Two. In Chapter three and four, it discussed the research methodology, and system design and analysis of the proposed system respectively. Chapter 5 presents the result and analysis of the proposed project and is finalized with a Conclusion and Recommendation in Chapter Six.

Chapter 2

Literature Review:

Intelligent Management System for Agricultural Greenhouses [11] explains the necessity and compulsion of using technology to cope with the rapidly increasing food demand of the world population. IoT-based remote monitoring system for greenhouse [12] has used temperature and humidity sensor DHT11, BH1750 sensor to detect light intensity, and TDS sensor to measure dissolved solid content in the nutrient solution of hydroponic farming for plant cultivation. The paper [13] explains how Indonesia's mushroom-farming community struggled with the manual farming system despite their success in securing a good market. The IoT-based temperature and humidity monitoring system has enabled them to control their farm with real data and improve productivity. This paper [14] also explains the need of modern urban farming due to the need of food security and the availability of limited space for agricultural activities. It presents the role of IoT-based smart urban mushroom farming as a promising technology to enhance the production of mushroom which requires less maintenance, less manpower, and saves a lot of space. The system controls the temperature, humidity and light intensity of the growing room. [15] also discussed the implementation of IoT for controlling the temperature, humidity, CO2, and intensity of the grey oyster mushroom growing house using ATMEGA328. [16] Proved that the IoT-based mushroom growing kit they used to monitor the sensor data of the mushroom growing environment brought the cultivation period and yield of mushroom difference compared with the manual farming system. The system tested in Malaysia allows reading the sensor data like temperature, humidity, CO2, and light intensity and notifying the user to take action. By doing that, it has been stated that the mushroom was harvested in 5 days despite the manual farm which takes longer days. It also mentioned that the weight of the mushroom produced with the system was bigger than the mushroom grown manually. The IoT System for Mushroom Cultivation in Greenhouses of Mahasarakham Communities in Thailand [17] , mentioned that mushrooms can grow throughout the year by controlling the humidity and temperature of the growing rooms while it grows manually between March and October only. The system has resulted in an incredible increase in the yield of mushroom and the profit to the mushroom-growing community. productivity (per harvest) has increased from 1-3kg to 3-15kg and Profit - from 20 % manually to 60% with the system. The duration of harvest has also increased and it saved the time of the community. [18] Through real-time monitoring, precise control of environmental conditions, and automated humidity management, the IoT-based system improves mushroom yield, quality, and operational efficiency. This paper [19] presents an implementation of IoT monitoring and environmental control for indoor cultivation of Oyster Mushroom focusing on temperature, humidity and pH level parameters. The humidifier is set to activate every ten minutes and shuts off after five minutes to maintain the humidity of the area, and when the pH of the falls below 5, the system will automatically pump and inject an appropriate amount of liquid lime to adjust the pH level until it reaches the suitable pH level of 6. The experimental results revealed that optimal growth of Oyster Mushroom Pleurotus spp. was achieved when cultivated in a controlled environment with a temperature of 26˚C and a substrate pH level of 5.8 with average humidity at 89.67%, resulting in a remarkable mycelial growth rate of 0.8 cm per day.

All the above papers covered for mushrooms that grow in plastic while in Rwanda, we grow mushroom in soil and managing the soil moisture is the most sensitive and challenging scenario in our case. Hence, monitoring sensor data and notifying the user to take a manual action alone will not help too much as the action like irrigation requires skill. For this reason, we have proposed an automated mushroom cultivation system using IoT by enabling the sensors to read the key environmental parameters and let the system take an automatic action through the actuators using predefined values while allowing the farmer to intervene for follow-up and do even any arrangement if it is needed. The user will be able to visualize the system activity on LCD and the Blynk mobile App will enable him/her to remotely monitor and control the farm. Thingspeak will also add another function of data visualization, and data analytics and store historical data that can be used as backup and do predictive analysis.

Chapter 3

Research Methodology:

3.1 System Design and Prototyping Process

The proposed IoT based mushroom farming system is designed to provide a real-time monitoring and automated controlled environment of the mushroom growing sites. The development of the system started with initial prototyping focusing on the essential functionality of the environmental monitoring. The system consists sensors like DHT11 for temperature and humidity, soil moisture sensor, oxygen sensor (and CO2 level, and actuators with ESP8266 and Arduino UNO Microcontrollers. We select the components based on their compatibility with the system, cost effectiveness and their ease of integration to the IoT framework.

During the prototype development, we tried to do sensor calibration for data accuracy, and performed gradual improvement on the code and the whole system to ensure that it could meet the specific requirements of mushroom cultivation, such as maintaining optimal environmental conditions. Table 1 below presents the components we used for the prototype development and their individual functions.

Component	Role
DHT11 Sensor	Measures temperature and humidity. Provides accurate data crucial for maintaining optimal conditions for mushroom growth.
Soil Moisture Sensor	Monitors soil moisture levels to ensure consistent and optimal moisture content for the mycelium and mushrooms.
Grove VOC and eCO2 Gas Sensor (SGP30):	Measures CO2 concentration in the air, helping to maintain the optimal CO2 levels necessary for healthy mushroom growth.
Grove Oxygen Sensor	Measures the level of oxygen presence in the air
Esp82666 nodemcu	Microcontroller that serves as the central processing unit. Collects data from sensors, processes it, and controls actuators based on predefined thresholds.

Arduino UNO	As extension processor to read analog data as nodemcu has only one analog pin which is A0
Humidifiers	Increase humidity in the growing environment when levels fall below the optimal range, ensuring the necessary moisture for mushrooms.
Fans	Control temperature and CO2 levels by enhancing air circulation. Activated to cool the environment or disperse excess CO2.
Water Pumps	Irrigate the soil to maintain consistent moisture levels. Activated when soil moisture sensors detect levels below the optimal range.
LCD	It displays the real time values of the growing parameters like temperature, humidity, moisture, Oxygen and CO2 of the growing room
Wi-Fi/GSM Module	Provides internet connectivity for data transmission to the cloud and remote control via the Blynk app.
Power Supply	Ensures a stable and continuous power supply to all components, enabling uninterrupted operation of the system.

Table 1: Role of hardware Components of the System

Figure 5: Actuators used in the prototype:

As shown in the block diagram of Figure 6 below, the system is designed to collect data from the different sensors on the farm and transmit it to the microcontroller for processing. The processed data is then transmitted to Blynk and Thingspeak cloud for data storage and visualization. The system automatically activates the actuators according to the sensors reading data and the favorable optimal conditions of the mushroom growing environment. The Blynk app then enables real-time remote control and monitoring where the farmer can intervene to control the system manually and do any setting changes or updates. Thingspeak facilitates data visualization and analytics. Blynk app provides a user-friendly interface where the farmer can monitor and control the farm remotely. The system employs Wi-Fi communication, facilitated by the Nodemcu microcontroller, to transmit data to Blynk and Thingspeak cloud.

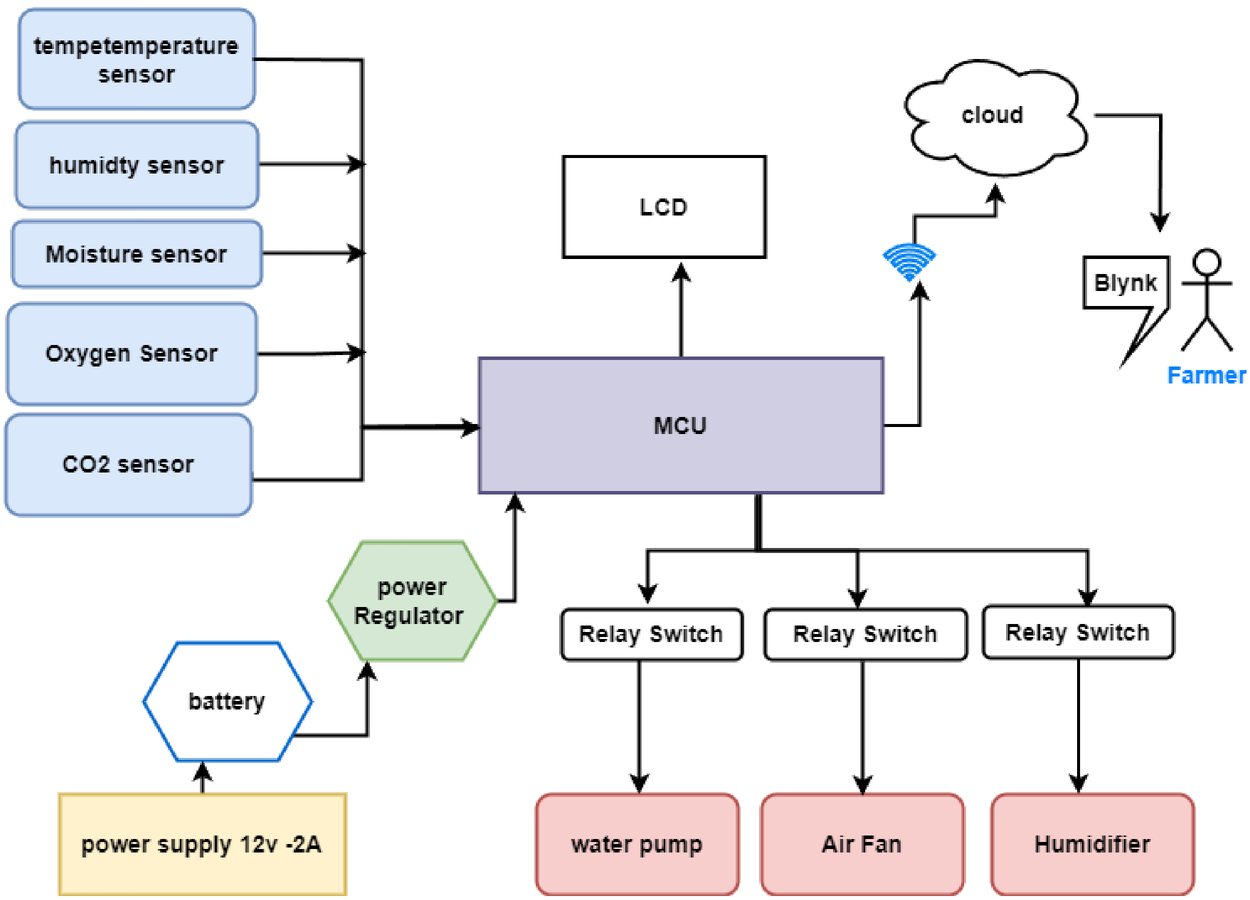

Figure 6: System Block diagram

3.2 Implementation of the Prototype

3.2.1 Hardware Integration

The selected sensors were interfaced with the microcontrollers to ensure accurate data collection, while actuators like AC, humidifier (Mist Maker), and water pump were connected to control the environmental conditions. Detailed schematics as shown in Figure 7 below were developed to guide the connections between components, ensuring smooth data flow from sensors to the ESP8266, and then to the actuators and Blynk and Thingspeak clod. Arduino UNO microcontroller was used as an additional board to enable us to read analog moisture and oxygen data as ESP8266 has only one analog pin.

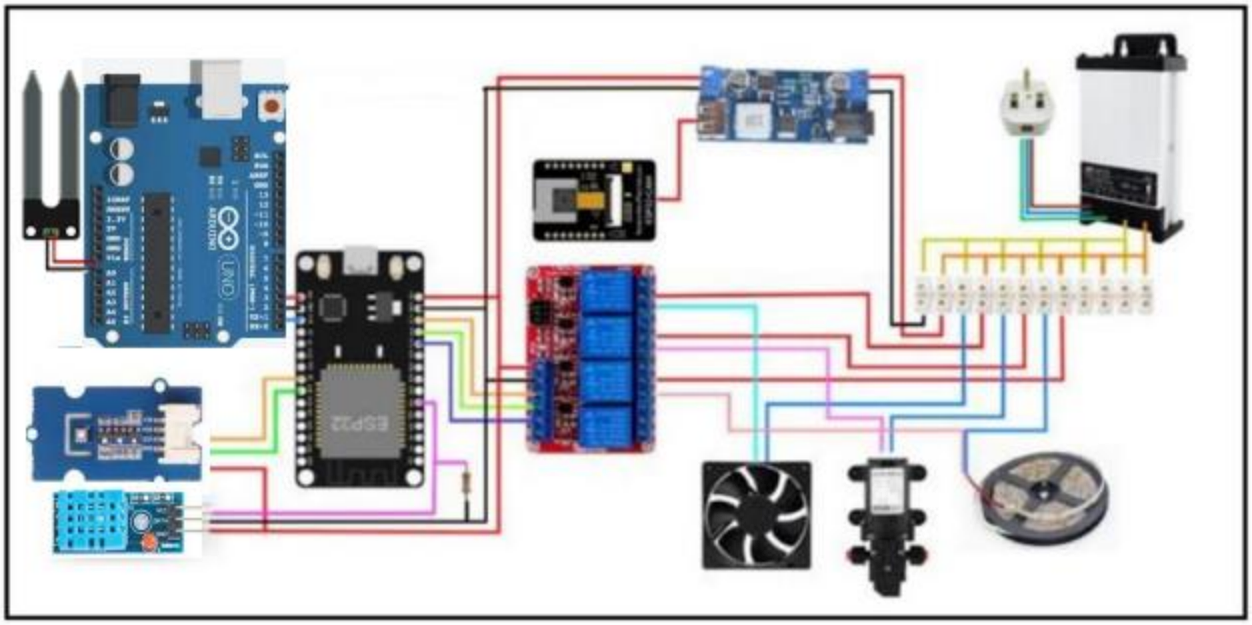

Figure 7: Circuit Diagram of the Proposed System

3.2.2 Software Development

Arduino IDE is used to develop the firmware for the microcontroller by utilizing specific libraries for each sensor and actuator. The software development process involved writing code to handle sensor data readings, Control (activate or deactivate) the actuators based on the sensor data, and communication protocols for data transmission. The coding includes the implementation of decision-making logic which automatically adjusts the environment based on real-time sensor readings. To enable the automation of the mushroom cultivation process.

Sensor calibration and system and unit testing was performed to assure the accuracy of data and the effectiveness of the system. It is very challenging to get real-time data without calibrating the sensors. Example Figure 8 below shows moisture sensor data before calibration followed by calibrated data.

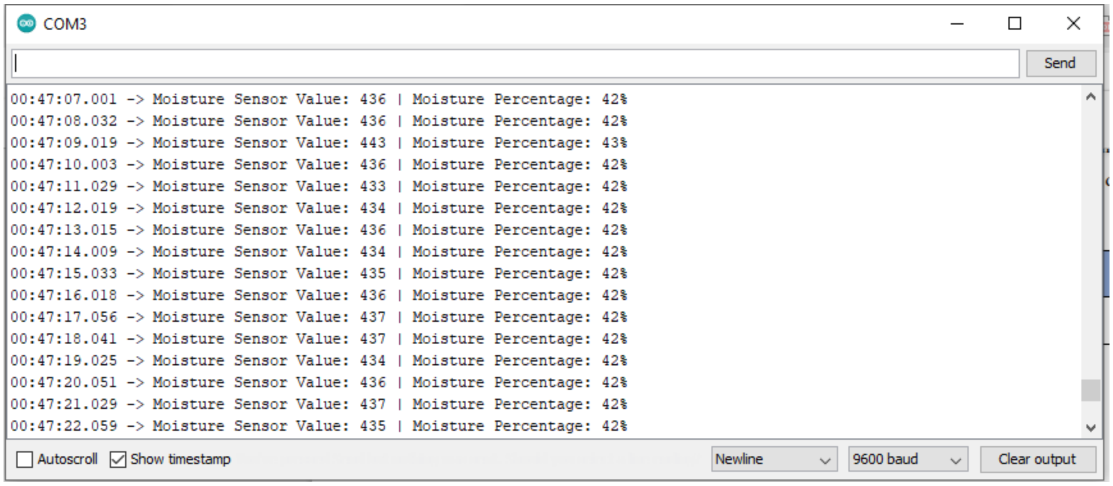

Figure 8: Moisture data before Calibration

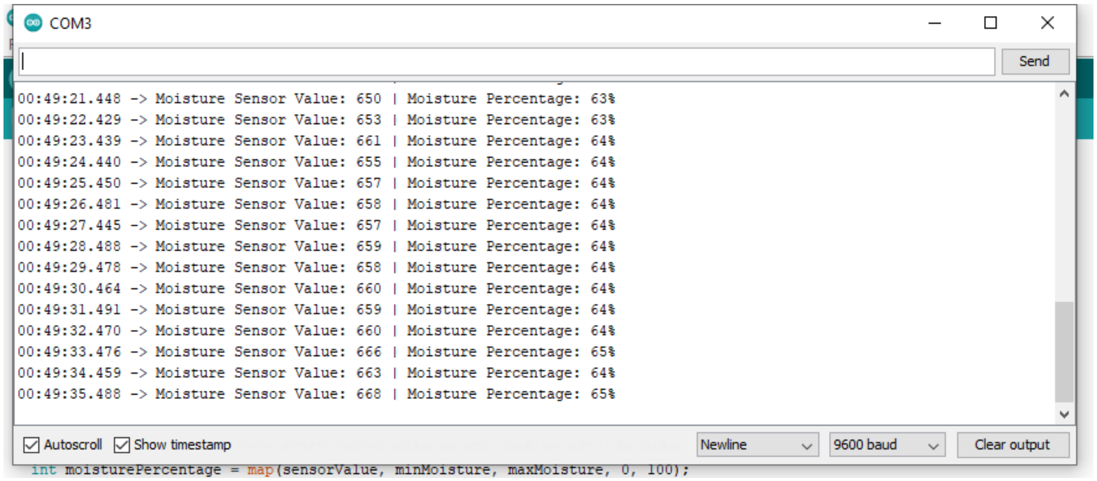

Figure 9: Moisture data after calibration

Chapter 4

System Analysis and Design:

Similar to the challenges we faced on my farm, after visiting and conducting an interview with mushroom farmers in Rwanda mostly those around Kigali, we have learned that the main problems they are facing are keeping the growing room cold and well-ventilated, and the growing boxes with the correct water amount or moisture level. They control everything manually and this hinders their productivity.

As Figure 10 below shows about the existing manual system which is commonly used by Rwandan farmers, everything is handled manually without understanding and monitoring the level of the environmental parameters which damages the farm shortly before the expected plantation cycle.

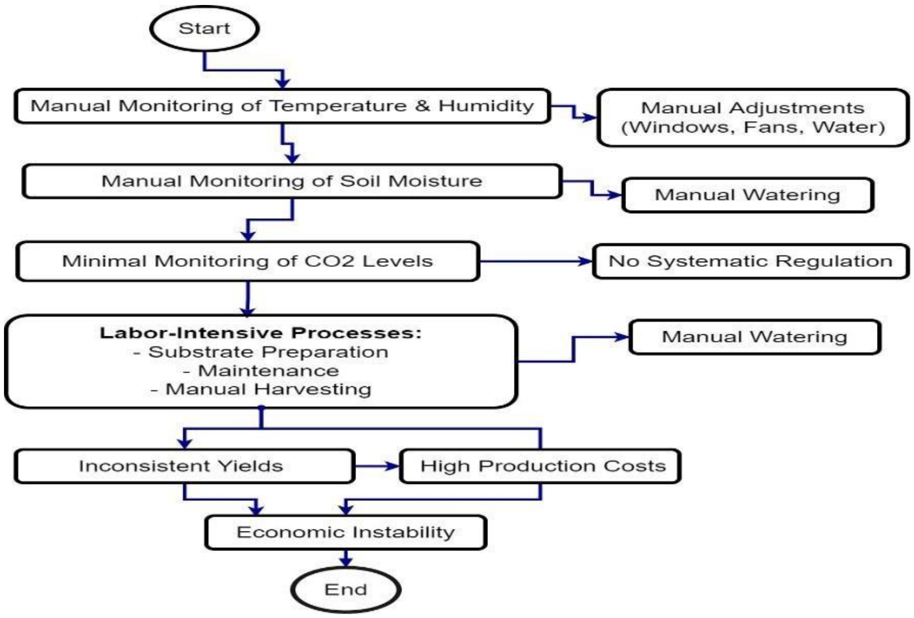

Figure 10: Existing Traditional System Working Principles

4.1 System Requirement

To optimize the mushroom production of the farmers it is very critical to monitor the key environmental parameters like temperature, humidity, soil moisture, and air quality mainly for oxygen and CO2. As most of the mushroom farmers are young people who are already familiar with the use of smartphones, they will be able to manage the remote control of the system with the necessary training. The widgets in Blynk App are built in a way that is easy to interact with. Table 2 below describes the optimal environmental conditions for oyster mushrooms. To monitor these parameters, we need the sensors, actuators, data storage and communication protocols we have discussed in chapter three.

Sensor	Range	unit
Temperature	18-25	°C
Humidity	85-90	%

Soil Moisture	60-70%	%
CO2 Levels:	< 800	ppm
Oxygen	20-22	%

Table 2: Optimal conditions for oyster mushroom cultivation

This new system will enable continuous monitoring of environmental conditions within the mushroom cultivation system. Whenever the sensor data is out of range, the system will automate the actuators to irrigate, ventilate or humidify the farm. The farmer will be able to monitor the real time data of the farm using the user friendly Blynk App User interface which shows the sensor readings and the control mechanisms.

4.2 System Design

4.2.1 System Architecture

The system is an integration of four layers namely sensors and actuators layer, Processing layer, communication layer, and cloud and user interface layer. This architecture facilitates seamless interaction among the sensors, actuators, and the microcontroller, ensuring real-time monitoring and control of the cultivation environment. The temperature and humidity sensor, moisture sensor, CO2 sensor and Oxygen sensors continuously monitor the mushroom growing environment and send the data they read to the central microprocessor unit nodemcu for processing. Nedelcu ESP8266 acts as the brain of the system, receiving data from these sensors and issuing commands to actuators. It processes sensor inputs using the predefined conditions or threshold values to maintain the mushroom's optimal growing conditions. It then transmits the collected and processed data to Blynk and Thingspeak cloud using Wi-Fi for further remote monitoring and analysis. Thingspeak enables better visualization and download history data. Using the Blynk User Interface, the farmer can instruct the actuators by using switch buttons on Blynk app and can also set the threshold level of the parameters. We have used Wi-Fi for connectivity and HTTP/API protocol has facilitated the communication between the microcontroller and the software platforms for efficient and reliable data transmission. Figure 11 below summarizes the system architecture.

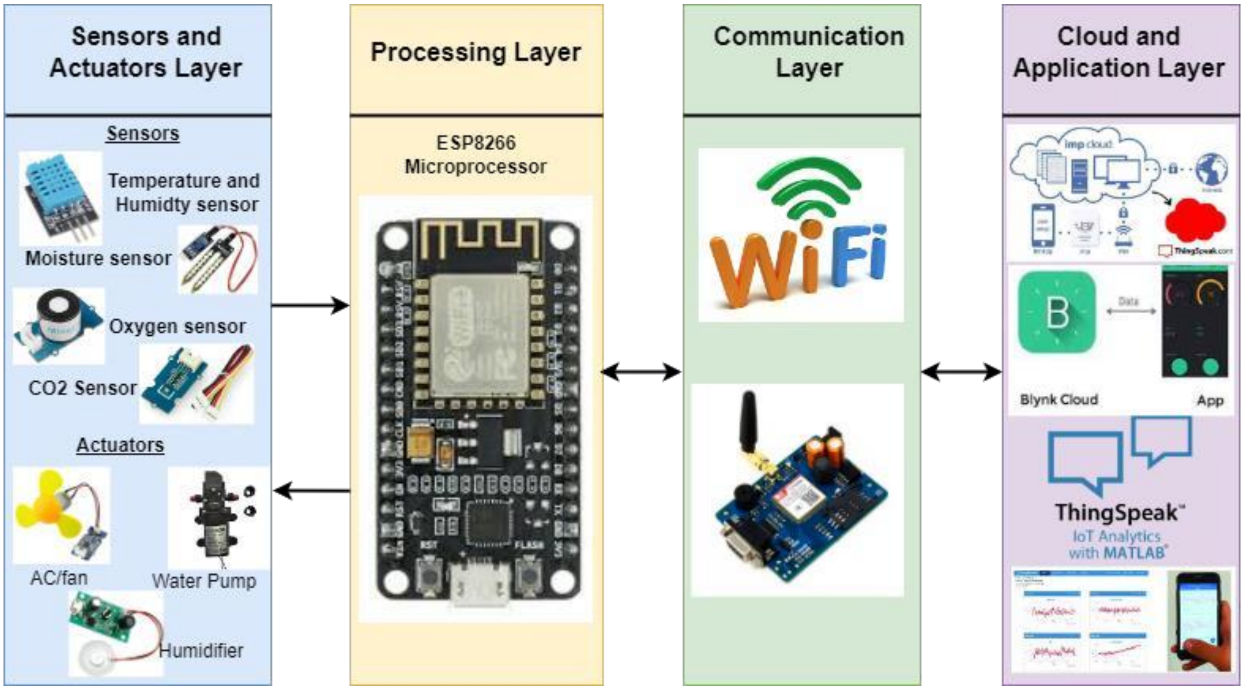

Figure 11: System Architecture

4.2.2 Data Flow Communication

In this Automated Mushroom Cultivation system, sensors are initialized to read the key environmental data like temperature, humidity, soil moisture, Oxygen, and CO2 level of the mushroom growing room. When this data is sent to the microprocessor, the system does comparison of these sensor data readings with the predefined favorable conditions or threshold levels. When any of the sensor data is out of the range, it takes an automated action and simultaneously, it sends an alert or notification to the farmer on the Blynk App so that he/she can control the farm remotely. Besides, all the data will be sent to both Blynk and Thingspeak for real-time monitoring and analysis.

As shown in the flow chart diagram in Figure 12, the system is automatic, but the user here is meant to monitor the system through the Blynk app and receive alerts so that s/he will have to manually interfere if needed to change the settings of the system. Because human supervision is very important [20] as the system can trigger the automation at any time when the data is out of range even when there is wrong data due to sensor failure etc. This work will help in the optimal growing of mushrooms, enhancing yield and quality.

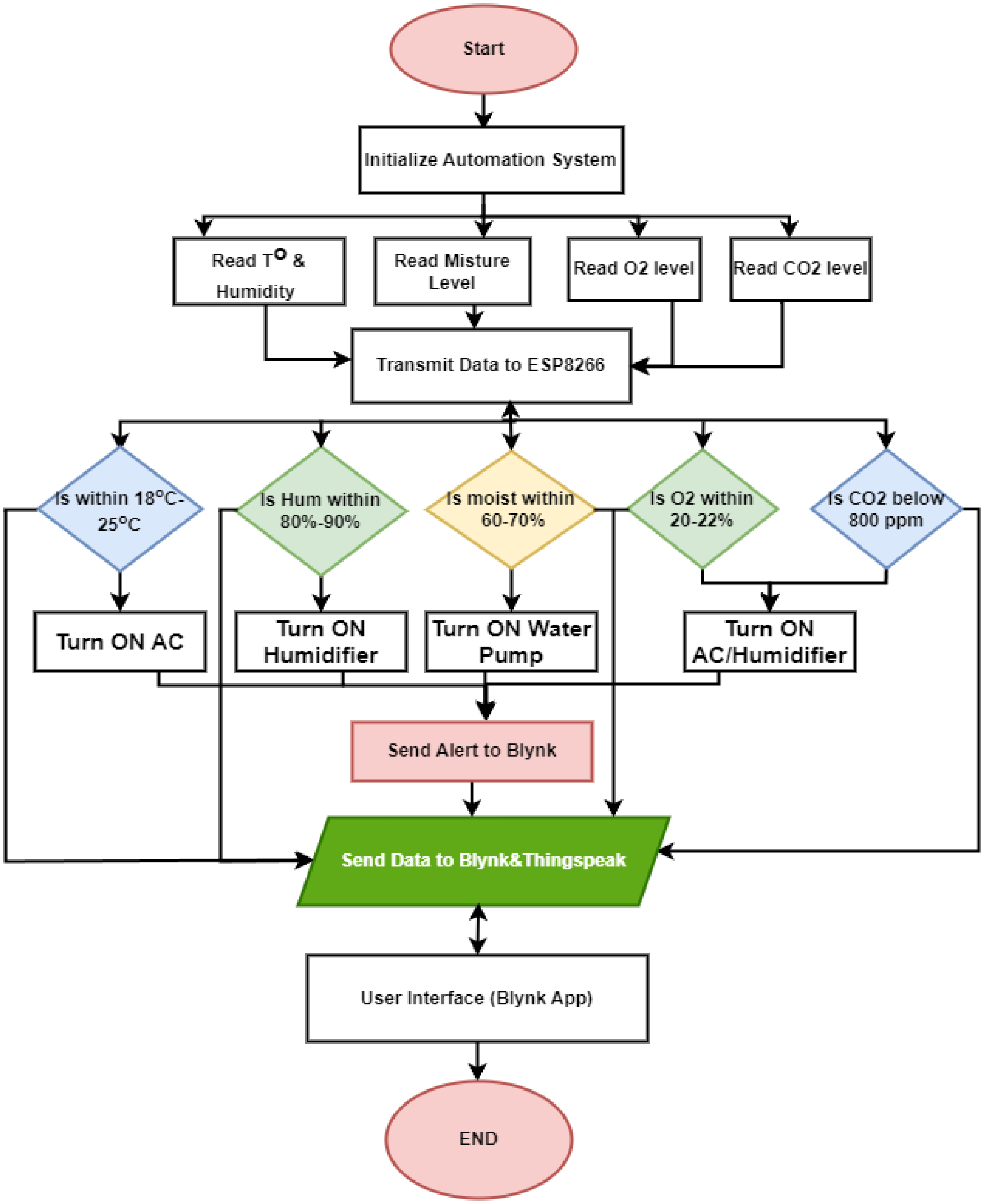

Figure 12: System Flow Chart Diagram

4.2.3 User Interface

Blynk App and Thingspeak design the prototype's user interface for data visualization and analysis. The Blynk mobile app offers real-time monitoring and control capacities of the farm remotely to the farmer. This will grant the farmer hassle-free interaction with the system, and thus efficient mushroom-growing management. The sensor data like temperature, humidity, moisture, CO2 and Oxygen is displayed in the blink App through the virtual pins. Each sensor has dedicated widgets displaying current readings and historical data.

Besides the farmer can set threshold value of these environmental parameters in the Blynk App and can manually control the actuators like fan, humidifier and the mist maker. Each actuator has switch or slider widget for an easy control like by turning ON/OFF control or adjustment. The App uses Wi-Fi to communicate with the system ensuring that the farmer can monitor and control the farm remotely, and it is integrated with the Thingspeak cloud for data backup and additional analytics capabilities. Figure 13 below shows how the Blynk app displays the sensor data.

Figure 13: Sensor data on Blynk App

Chapter 5

Results and Analysis

Real-time data is collected from DHT11 (Temperature, Humidity), Soil Moisture Sensor, CO2, and Oxygen Sensors and sent to the cloud. The data has been extrapolated on the attached graphs showing trends over time. The actuators like the fan, water pump, and humidifier or mist maker have successfully monitored the mushroom growing conditions with less human intervention. Real-time notifications and alerts were effectively sent to the farmer. The farmer was able to control the system remotely using the Blynk app and visualize, download the history data of the farm from Thingspeak. Hence, the prototype met its objectives by keeping optimal conditions and reducing manual intervention. As the system has successfully monitored to keep the key environmental parameters at optimal levels, it is expected that this project will improve the mushroom productivity and reduce the manual operational costs. By using this system mushroom farmers in Rwan, communities in Tigray, and beyond can effectively grow mushroom both for home consumption and business all year round without depending on seasons.

Figure 14 below shows the different sensor data monitored in the mushroom farm before applying the automation system.

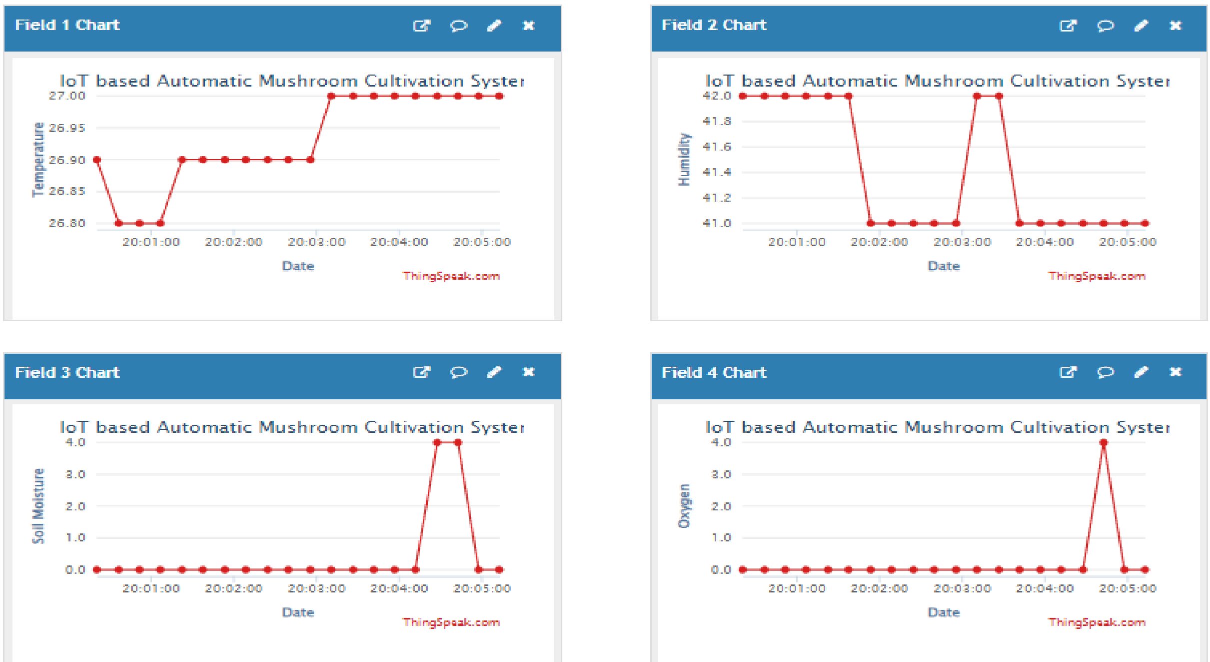

Figure 14: Environmental data of Uncontrolled Mushroom House

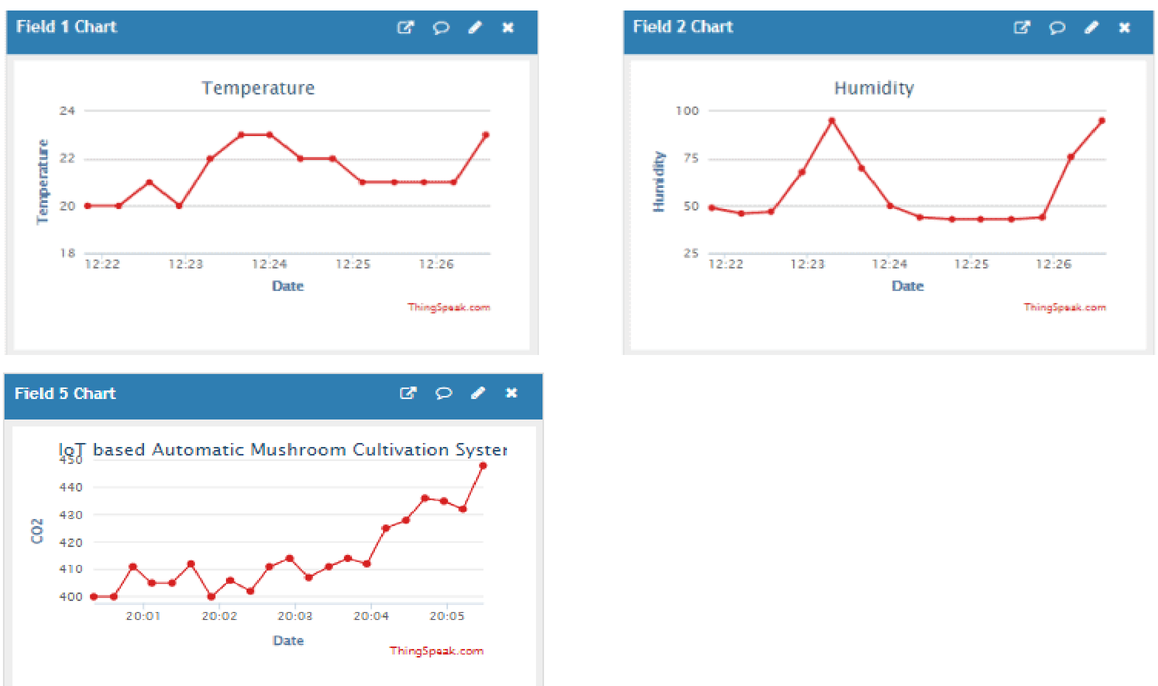

Figure 15: Temperature, humidity, and CO2 data of controlled environment on Thingspeak data

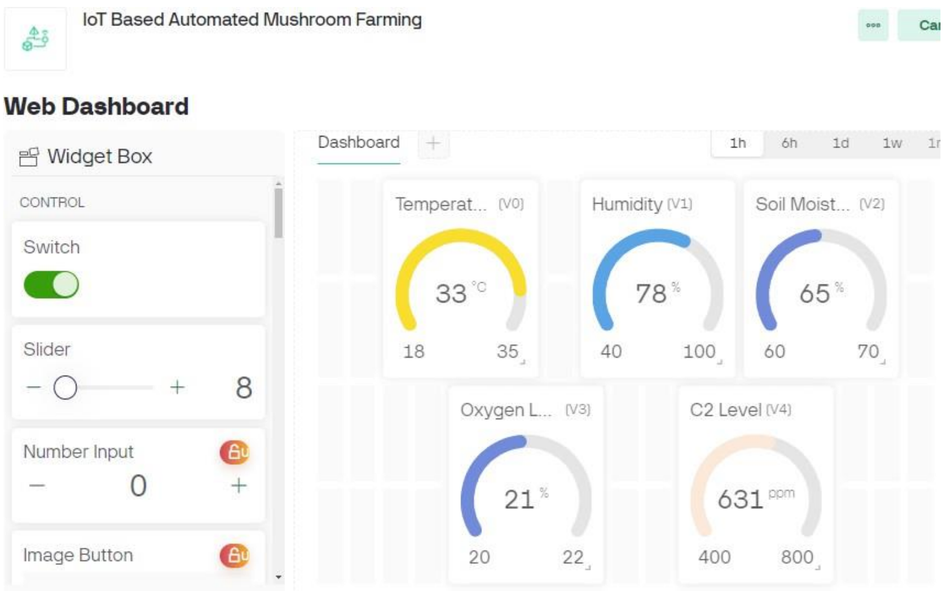

Figure 16: Sensors data on Blynk

Chapter 6

Conclusion and Recommendation

The proposed IoT-based mushroom cultivation system successfully validated the monitoring and maintenance capacity of environmental conditions which are critical for the optimal growth of oyster mushroom. Real-time data collection, together with automatic temperature, humidity, CO2, oxygen, and soil moisture data control, allows the system to achieve a success in maintaining parameters within the desired range. With the controlled system, the quality and productivity of mushroom is expected to be improved with a mushroom being freshly harvested in a good environment. The prototype proved to be a viable and efficient solution for modern mushroom farming, offering substantial improvements over traditional methods.

We recommend performing more sensor calibration for better accuracy of the sensor data and refining machine learning for predictive analysis. Besides, for farmers who don't have Wi-Fi access, we suggest the use of GSM with MQTT protocol [21] using ESP32 to enhance reliable data transfer with efficient power consumption.

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