IOT BASED HUMIDITY AND TEMPERATURE CONTROL SYSTEM FOR VEGETABLES/FRUITS STORAGE WITH OZONE TREATMENT

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A project report submitted in partial fulfilment of the requirements for the award of the degree of Bachelor of Electronics Engineering with Honours

Faculty of Engineering and Green Technology
Universiti Tunku Abdul Rahman

MAY 2024

DECLARATION

I hereby declare that this project report is based on my original work except for citations and quotations which have been duly acknowledged. I also declare that it has not been previously and concurrently submitted for any other degree or award at UTAR or other institutions.

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APPROVAL FOR SUBMISSION

I certify that this project report entitled **"IOT BASED HUMIDITY AND TEMPERATURE CONTROL SYSTEM FOR VEGETABLES/FRUITS STORAGE WITH OZONE TREATMENT"** was prepared by **CHEW BOON KEE** has met the required standard for submission in partial fulfilment of the requirements for the award of Bachelor of Electronics Engineering with Honours at Universiti Tunku Abdul Rahman.

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Date : 22 April 2024

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ABSTRACT

Post-harvest storage is an important process in agriculture. However, the post-harvest process is usually done in conventional ways. IoT technology, as an emerging technology that is implemented in various fields, can be used to enhance the post-harvest process in agriculture. In other words, the shelf-life of the vegetables and fruits can be prolonged. A 15 days experiment has been conducted to investigate the effects of IoT cold storage chamber designed and ozone treatment in prolonging the shelf-life of vegetables in post-harvest process. In this experiment, two sets of cold storage chambers equipped with misting and cooling system controlled by Raspberry Pi were used to store butterhead lettuces. Monitoring and data collection of the internal environment have been done from time to time. One set of cold storage chamber used tap water for the misting system whereas the other was using ozonated water. The ozone treatment has been used to inhibit the growth of microorganisms to further improve the post-harvest storage process and it has been proven to be effectively prolong the shelf-life of the butterhead lettuces and also slowed down the quality deteriorations based on the appearance index measured. Thus, the design of the IoT cold storage chamber and ozone treatment were proven to be effective in the improvement of the post-harvest storage process. The practicality of the IoT cold storage chamber in agriculture has also been investigated during the project.

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LIST OF SYMBOLS / ABBREVIATIONS

g	gram
V	voltage
RWL	Relative Weight Loss
ARWL	Average Relative Weight Loss

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CHAPTER 1

INTRODUCTION

1.1 Background

IoT (Internet of Things) is an emerging global Internet-based technical architecture. It facilitates the exchanges of goods and services in global supply chain networks which results in significant impacts towards the security and privacy of the involved parties (Weber, 2010). IoT system is the network that provides connection between physical objects and digital devices by a three-layer architecture (Burhan *et al*., 2018). The three layers are the perception layer, network layer and application layer (Burhan *et al*., 2018). The system has been implemented in various fields that requires the digitization of physical data and information. Self-driving vehicles, smart agriculture equipment and smart home system are the examples of the5 technologies that involves the IoT system to monitor and analyze the surrounding physical conditions using sensors and computers and control the operation of embedded system based on the environmental factors (Al-Fuqaha, 2018). IoT system is applied in the different stages of agriculture process, including irrigations, pest control, sowing, harvesting, food processing and lastly storage and transportation (Ghutke and Agrawal, 2022). The storage of fresh produces is an important stage of agriculture especially for those high perishable vegetables and fruits. The extension of life of fresh produces using cold storage directly affect the supply chain and transportation of the fresh foods to the markets and customers. An ideal cold storage shall be stable enough throughout the process of storage and transportation in terms of the humidity and temperature inside the cold storage and at the same time, the stability can be achieved by a cheap and simple design to improve the efficiency and cost management. A cold storage system is built with temperature and carbon dioxide sensors to detect the changes in the cold storage. It is equipped with fans and misting to control the temperature and humidity and stabilize the inner environment by ensuring the parameters are always within the optimized range. The IoT system is applied in such a way that the information and data of the humidity, temperature and carbon dioxide density are detected, recorded, and analyzed using software applications to achieve remote monitoring and control via electronic devices. In this way, the inner conditions of the vegetables and fruits are guaranteed throughout the process of storage and transportation. The humidity and temperature can always be adjusted remotely, which results in a smarter management solution compared to conventional refrigerators and it uses lower costs and simpler design. The risk of stored produces being spoilt during the shipment will be highly reduced. Thus, it provides a more economical solution to cold chain logistics. The quality control is improved, thus the safety of food consumed by the customers is guaranteed. The implementation of IoT technologies in food storage reduces the wastage of produces due to the spoil and decay (Smith and Lance, 2021). However, the most important consideration is the cost of the storage, which differs it from conventional refrigeration that requires high power consumption and complicated designs and manufacturing process. It is more affordable and portable. In the future, IoT technologies will be commonly used in the cold chain logistics due to its higher efficiency and lower risk in food quality control. However, the cost and design will always be a main consideration in the business especially for the small and medium-sized enterprises, which accounts for 97.2% of total business establishments in Malaysia (OECD, 2022).

1.2 Problem Statements

From the previous literature studies, the waste of food is a global issue, and it leads to poverty especially in developing countries and undeveloped countries. One of the major causes is the lack of proper handling of the produces from farm due to poor storage skills and technologies (Magalhães *et al.*, 2018). It directly affects the logistics of supply chain and prices of the vegetables and fruits in the market. The produces rich in water are more perishable and has a shorter shelf life. They also decay faster in tropical countries like Malaysia due to the hot weather. In other words, the quality of vegetables and fruits are highly affected by the humidity and temperature of the surrounding environment (Nascimento Nunes, 2008). The quality loss of the produces is determined by the weight loss, appearance scoring, antioxidant contents, color, and others. The IoT cold storage is designed to precisely control the humidity and temperature of the inner environment to prolong the shelf life of produces for few days.

1.3 Aims and Objectives

The aim of the project is to design and build a IoT cold storage, which is able to conserve the freshness of vegetables and fruits for few days by utilizing the sensors and fans and misting system. The objectives of the project are shown as follow:

i. To design a smart IoT based cold storage chamber with ozone treatment.
ii. To develop/set up a lab-scale IoT-based cold storage control system with the humidity, temperature and carbon dioxide sensors and ozone generator using a Raspberry Pi.
iii. To evaluate the upscaled IoT-based cold storage control system (with ozone treatment) developed regarding its performance and its impact stored data quality compared to the same system using tap water.

CHAPTER 2

LITERATURE REVIEW

2.1 Internet of Thing

The Internet of Thing (IoT) describes an embedded system that uses network to connect physical objects, the "things" via sensors, software and other technologies to other devices and systems over the internet (Gillis, 2023). IoT will be more commonly adapted in the future to achieve advancement in various fields, especially when the 5G technology become common. Agriculture is one of field that requires IoT technologies to control and monitor the crops and domestic animals (Ghutke and Agrawal, 2022). An important part in agriculture is the transportation and storage of fresh vegetables and fruits, which shall be kept as simple and cheap as possible, but at the same time it must have adequate space to store the products and keep them fresh under a low temperature for a considerable duration.

2.1.1 Cold Storage Monitoring System using Raspberry Pi

A cold storage monitoring system has a huge advantage over a conventional refrigerator is the adaption of real-time operating system (RTOS) which enable the monitoring and control of the humidity and temperature anytime via electronic devices like smartphone (Afreen *et al.*, 2021). It prevents the error and minimizes the risk of spoiling the fresh products. It stabilizes the temperature and humidity of the cold storage. Whenever the sensors detect changes in the parameters, the misting and cooling fan will respond to the changes and kept the parameters within a desired range. The data of humidity and temperature is digitalized by the IoT system. Hence, it is easy to record and measure the freshness and condition of the vegetables and fruits from time to time. Besides that, long distant transportations are unavoidable in agriculture and food industry. A cold storage that can be monitored and controlled anytime is more suitable for long distance transportation as it guarantees the quality of the products throughout the process. A Thus, this project provides a cheaper and simpler method for the product transportation from the farms to food manufacturing factories and also to the markets. The project is helpful to the farmers and small and medium-sized enterprises (SME) to explore a wider market as they are able to send their fresh products to further markets. Hence, a system with low cost and simpler design is developed to improve the process of Cold Chain Logistics.

2.2 Literature Studies

2.2.1 IoT enabled Food Technologies: A systematic review approach by Nafrees *et al.* (2021)

This paper studied about the application of IoT on food technologies by reviewing relevant articles and publications. The data were collected and analyzed using qualitative research methods. It focused on the researching the types of IoT technologies, devices and applications to be implemented in food production, and how these technologies aid in improving these food technologies. It also deducted a brief content of security issues existing throughout the process of implementing the IoT technologies, devices and applications. An example of the usage of IoT in agriculture is via cloud-based to provide services to the farmers to monitor the cultivation time of crops and find the possible diseases and also the solutions to them. The soil conditions can be monitored based on the data of pH and soil moisture sensors. They are digitalized and analyzed using LoRa technology via mobile and computer interfaces. In this way, the soil can be analyzed whether it is suitable for certain types of plantations. Nonetheless, IoT systems are used in fresh agriculture products to monitor the freshness and security of foods. The supply chain integration level is increased by building management of those food products. On the other hand, the common issues in IoT systems includes forgery, location privacy, inability of server to impersonates resynchronization, data integrity, and etc. Data integrity is the major concern of IoT system. It happens when a set of data is transferred from one node to another node.

2.2.2 IoT Based Temperature and Humidity Controlling using Arduino and Raspberry Pi by Barik (2019)

The paper suggested that the combination of Arduino UNO with Raspberry Pi is a perfect method for electronic device monitoring, data collection, data saving. The temperature and humidity of particular surroundings are calculated using the DHT-11 Temperature Sensor, and graphically analysed by one ThingsPeak platform software and an ESP8266 Wi-Fi module. In Figure 2.1, the Arduino mega 2560 Raspberry Pi microcontroller is used for controlling the temperature, water level and the humidity levels. The system is capable of switching on and off the DC motor based on the soil water content level and the rainy season. It is also portable on the weather forecast. The humidity and temperature of particular surface area is carried out by the HTU-211D sensor. The data are all controlled and collected by the Arduino Uno with Raspberry Pi microcontroller. The system is beneficial for the farmers in non-power sector as the system is operating using solar panel instead of conventional power supply. IoT based temperature and humidity measurement system is economic and safe. It is highly suitable for the detection of agricultural-related parameters. Meanwhile, the system acts as a decision-making system performing corrective movement to stabilize the values of the parameters from time to time. This is achieved by controlling the DC fan, motor and water levels. The farmers can collect the data via their cell phones after the data are uploaded to the cloud and transferred to them through the GSM. They can decide to switch on or off the motor based on the collected data. They can also monitor the plants from other places. In addition, the studied system also prevents the overwatering. The paper concluded that IoT based systems will serve as a vital block in agricultural modernization.

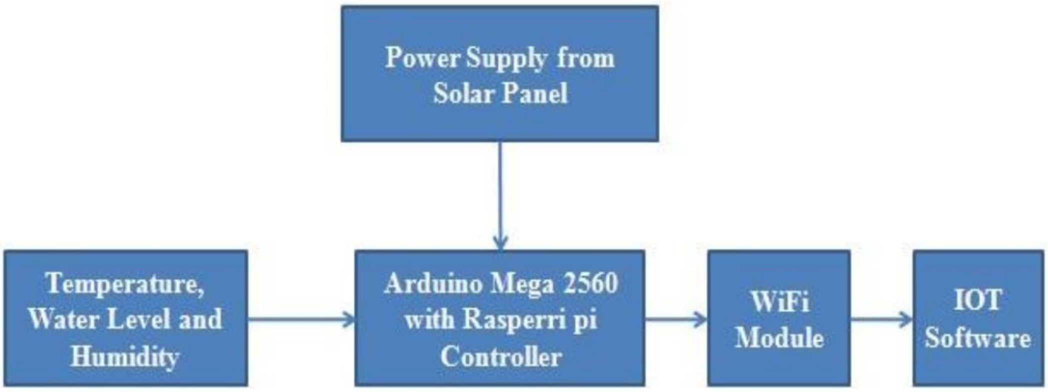

Figure 2.2: Overall Block Diagram (Barik, 2019).

2.2.3 Monitoring food storage humidity and temperature data using IoT by Karim *et al.* (2018)

An internet based real time monitoring of temperature and humidity was developed using only DHT-11 sensor and ESP-8266 NodeMCU module in Figure 2.2. The module is used instead of Arduino UNO or Raspberry Pi which are widely used in similar projects. For the hardware setup, it is simple as it only requires connection between NodeMCU and DHT-11 sensor in order to function. On the other hand, the software is direct and simple, real-time data is sent to www.thingspeak.com, a free IoT web server to be analysed and results are generated which then being transferred to the cloud service. The flowchart of the circuit (Figure 2.3) is simple as the main operation is to transfer the real time data set. The parameters resulted from the ThingsPeak and the parameters obtained from the NodeMCU serial monitoring were being tabulated and compared in this project. As a result, the experiment is successful as only few variations have been detected on these data. This project has been done using simple steps and materials to create an automated system useful in cold storage for the users to evaluate and monitor the various data remotely using mobile phones or computers. It provides a picture of simple service layer designed to connect the physical layer of the system with the presentation layer on the mobile phones.

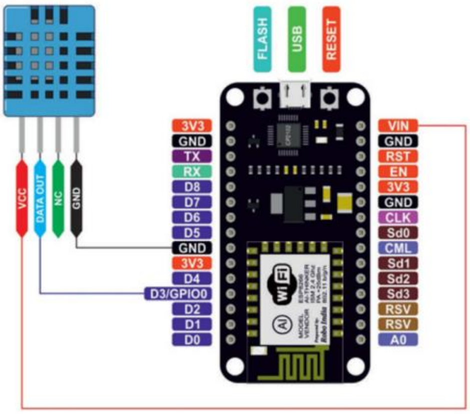

Figure 2.3: Connection between NodeMCU and DHT-11 Sensor (Karim *et al.*, 2018).

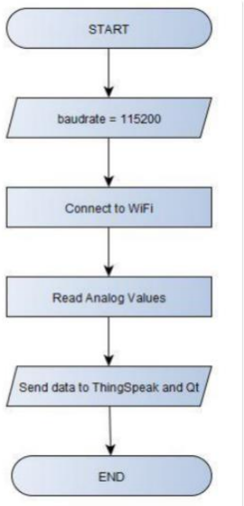

Figure 2.4: Flowchart of Operation (Karim *et al.*, 2018).

2.2.4 IoT in Agriculture: Nine Technology Use Cases for Smart Farming and Challenges to Consider by Shalimov (2023)

The application of IoT technology in agriculture is mostly denoted as smart agriculture. The IoT sensors are mainly used to collect environmental and machine data, for the farmers to improve every aspect of the farming process. There are six ways IoT can improve agriculture:

i. Tons of data collected by smart agriculture sensors to track the conditions and state of crops.
ii. Better control over the internal processes which leads to lower production risks.
iii. Cost management and waste reduction due to the monitor and control of storage.
iv. Increased business efficiency through process automation
v. Enhanced product quality and volumes
vi. Reduced environmental food print.

The usage of IoT system is involved in various aspects and stages, such as the monitoring of climate conditions, greenhouse automation, crop management, cattle monitoring and management, precision farming, agricultural drones, predictive analytics for smart farming, end-to-end farm management systems, robots, and autonomous machines.

2.2.5 IoT Elements, Layered Architectures and Security Issues: A Comprehensive Survey by Burhan *et al.* (2018)

There are six elements in an IoT system, which are identification, sensing, communication, computation, services, and semantics. Identification involves naming and addressing. Naming refers to the name of objects and components while addressing represents the unique address for each of them. Sensing is the process of collecting information from the objects. Communication is the process of sending and receiving messages, files, and data among different devices. Computation is performed on the received information to remove unnecessary information and processing the collected data. Services refers to the main action of the IoT system, which is what to do with the collected data or how should the system utilizes the collected information, such as making decisions based on the data collected, responds towards the data and so on. Lastly, semantics refers to the responsibilities of the IoT system itself, which in other words, to perform the tasks required by the users. The paper has mentioned three types of IoT architecture, which are three-layer, four-layer and five-layer architectures. The basic IoT architecture is a three-layer architecture consists of perception layer, network layer and application layer. Perception layer which also known as sensing layer is consists of sensors collecting the information and identify things from the real world. The network layer is the transmission layer acting like a bridge between perception layer and application layer. It carries and transmits the collected information from physical objects through sensors, via wireless or wired based. It also responsible from the connection between different devices and networks. Application layer defines all applications and services applied and provided by the IoT system based on the data collected by sensors. The fourth layer added to a four-layer architecture is the support layer for security purposes, to overcome the safety issues of data transmission in three-layer architecture. It involves anti-virus and to secure cloud computing. The information is sent from the perception layer to the support layer first instead of sending it directly to the network layer. It ensures that the information is send out by the specified authentic users and protects the information from threats. The five layer architecture consists of perception layer, transport layer, processing layer, application layer and business layer. Transport layer is similar to network layer. The newly introduced processing layer acts as a middleware layer. It processes the collected information from the transport layer and eliminate the meaningless information and extract the useful information, to avoid the issues caused by big amount of data that affects the IoT performance. Business layer, on the other hand, is responsible to manage and control applications, business, and profit models of IoT, and also the privacy of users.

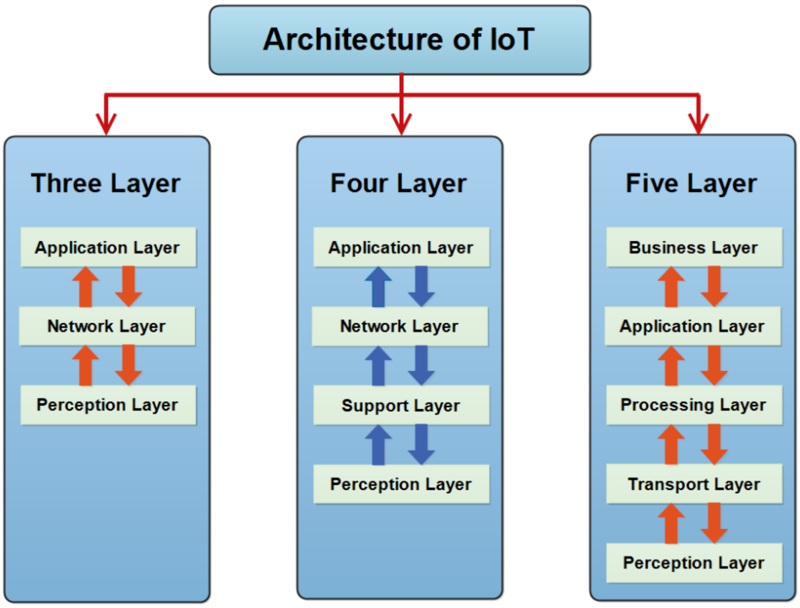

Figure 2.1: The Layered Architectures of IoT (Burhan *et al.*,2018).

2.2.6 Effect of Ozonated Water Treatment on Microbial Control and on Browning of Iceberg Lettuce (Lactuca sativa L.) by Koseki and Isobe (2005)

In this research, the effect of different concentration of ozonated water (3, 5, and 10 ppm) on microbial control and quality of cut iceberg lettuce (Lactuca Sativa L.) for 5 min at ambient temperature has been examined. The authors stated that ozone is a strong oxidant and strong antimicrobial agent with high reactivity. Because ozone decomposes spontaneously to oxygen, it leaves no toxic residue. Therefore, ozone has been proposed as an alternative sanitizer to chlorine that can produce toxic compounds such as trihalomethane. In other words, ozone is safer to use than chlorine in killing microorganisms. In this study, they examined the effects of ozonated water treatment on the quality of cut lettuce (PAL activity, browning, ascorbic acid content) and on microbial control. Ozonated water was generated with a flow-type electrolytic ozone generator (Do-30, Kobe Steel, Ltd., Kobe, Japan). This apparatus generated ozone via the electrolysis of water. The concentration of ozone was set between 0 and 20 ppm by adjusting the current passing through the electrode. Other than ozonated water, they also used hot water (50°C) together with the ozone treatment and investigate the effects. 350g of lettuce leaves were submerged in 5 litres of hot water (50°C) for 2.5 minutes. The lettuce leaves were subsequently taken out of hot water and immediately immersed in 5 liters of ozonated water with 5 ppm of concentration at ambient temperature for 2.5 minutes. In brief, the results of the experiment proven that the ozone treatment has bactericidal effect on the lettuce leaves. Besides that, the researchers discovered that the bactericidal effect of ozone increased with the concentration of the ozone in the water. Treatment with 5 ppm ozone would be appropriate for minimizing bacterial populations and the browning of lettuces. The browning of lettuce leaves was mentioned as ozone as a strong oxidant might damage the lettuce tissue during the treatment. Therefore, the researchers suggested to use hot water and ozonated water together for the practical use of ozonated water as this combination will kill the bacteria without causing any browning in the lettuce leaves. The authors acknowledged the bactericidal effects of ozone and proposed a solution when the browning of lettuce leaves during the treatment. Therefore, the ozone treatment is applicable in post-harvest storage and if browning of lettuce leaves is critical, hot water can be used as suggested by the authors.

CHAPTER 3

METHODOLOGY

3.1 Design Architecture

The Raspberry Pi III is used in this project as the microcontroller in Figure 3.1. The cold storage chamber is insulated from the outer environment by using insulated foil. In such way, the internal temperature and humidity can be controlled and measured precisely by the sensors and devices. The DHT22 temperature and humidity sensor is used together with the CCS811 carbon dioxide sensor, to measure the internal conditions of the chamber from time to time. The data is then being transmitted to the Raspberry Pi for further actions. The operation of Raspberry Pi is powered via the 12V power adapter and WiFi network connection for data transmission. The cooling operation in the storage is achieved by the Peltier cooler using 12V power adapter. This power adapter is also used for the water pump for the ozonated water. The ozonated water works together with the water misting system to preserve the produces' freshness. Blynk, a cloud platform that is useful for data collection, analysis and visualization is used to record the internal condition of chamber. It is a convenient platform as the data can be monitored on smartphone application anytime. The Raspberry Pi will receive the data and output a HIGH or LOW signal to the relay that is connected to the 4-channel 5V relay, when the sensors determine that the temperature inside the cooler box is higher than the predetermined threshold value. The water used for misting system is ozonated water for ozone treatment to inhibit the growth of microorganisms on the surface of the vegetables and fruits.

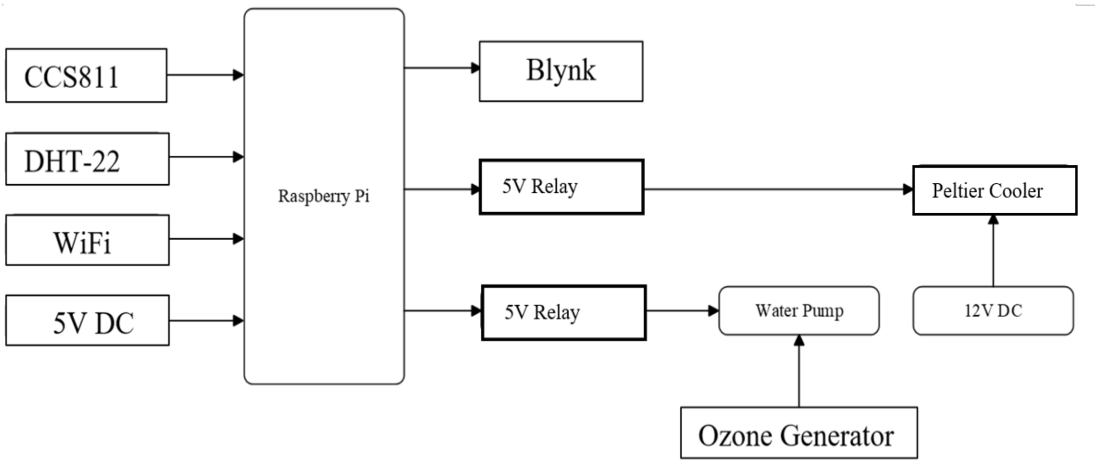

Figure 3.1: Block Diagram of the System.

3.2 Project Management

As we known that the function of a project Gantt chart's is to help complete all project activities/tasks on time. Table 3.1 shows the task schedules for FYP1. The progress of project title selection was carried out in Week 1 – 14. After the FYP title has been selected, the meeting with supervisor has been conducted from time to time. The first three chapters have been drafted during period of FYP1 and the first prototype has been designed and built before the FYP1 presentation at Week 14. However, during FYP1, the experiments has not been conducted yet on the prototypes built. The experiments have been carried out during the period of FYP2. In Table 3.2, the experiment taken place for 15 days and all the data has been analysed and tabulated for the next two weeks. The writing of the journal and report of the FYP in FYP2 was being done simultaneously in the following weeks. Lastly, the presentation and final printing and bounding has been done after the approval of supervisor.

Table 3.1: Final Year Project 1 Gantt Chart.

Task Name	**Week**													
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**
Project Title Selection	■	■												
Meeting with Supervisor			■	■					■					
Research	■	■	■	■	■	■	■			■	■			
Report Writing				■	■	■	■					■	■	■
Prototype Building										■	■		■	■
Presentation														■

Table 3.2: Final Year Project 2 Gantt Chart.

Task Name	**Week**													
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**
Experiment	■	■												
Data Tabulation			■	■										
Journal Writing									■	■	■			
Report Writing						■	■			■	■	■		
Presentation													■	
Checking and Printing														■

3.3 Hardware used in Cold Storage Chambers

3.3.1 Raspberry Pi 4 Model B

The Raspberry Pi’s versatility and affordability makes it suits for IoT project (Raspberry Pi, 2023). In Figure 3.2, the Raspberry Pi can interface with a various sensors and peripherals through its GPIO pins. Whether it's temperature sensors, motion detectors, or cameras, the Pi can connect to these devices, gather data, and process it. IoT generates enormous volumes of data, and processing this data is a critical aspect. Raspberry Pi's processing power, though modest compared to desktop computers, is more than sufficient for many IoT applications. It can process sensor data, run machine learning models, and perform real-time analytics. To be a part of the IoT, devices need connectivity. Raspberry Pi supports various connectivity options, including Wi-Fi, Ethernet, and Bluetooth. With these capabilities, it can communicate with other IoT devices, cloud services, or even smartphones. The Raspberry Pi has

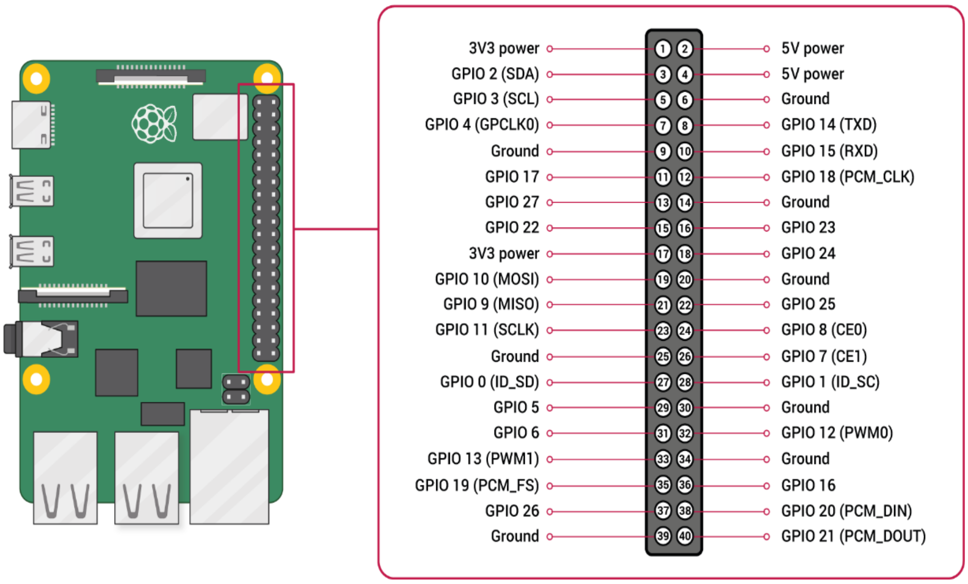

Figure 3.2: Pinout Labels of Raspberry Pi (Raspberry Pi, 2023).

fostered a vibrant and supportive community. A vast repository of open-source software, tutorials, and projects is available, making it easier for newcomers to dive into IoT development. The Raspberry Pi provides an affordable platform for prototyping and testing IoT concepts before scaling up. This dramatically lowers the barrier to entry for IoT development.

3.3.2 DHT22 Temperature and Humidity Sensor Module

The DHT22 sensor provides accurate measurements for temperature and humidity (Einstronic, 2023). It detects these parameters via capacitive sensing. It has a measurement range of temperature from 0°C to 50°C (32°F to 122°F) and humidity level between 20% and 80%. The pinout configuration of the DHT22 sensor module consists of three pins: VCC for power supply (3.3V to 5V), a data pin for communication, and ground (GND) for electrical grounding. Furthermore, the DHT22 sensor module carries out temperature and humidity readings every 1 to 2 seconds. It is considered energy-efficient as it consumes minimal power during operation. Therefore, excessive power drain has been avoided in the process of temperature and humidity measurement.

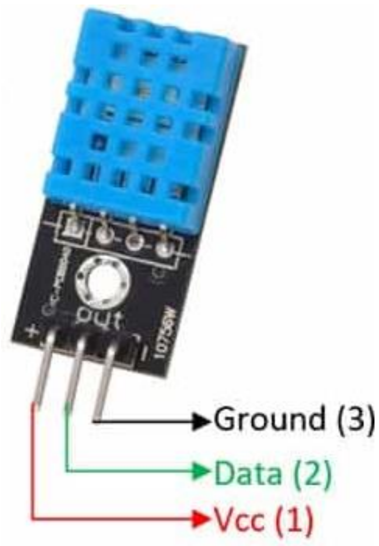

Figure 3.3: Pinout Labels of DHT22 Sensor Module (Einstronic, 2023).

3.3.3 CCS811 Air Quality Sensor

The CSS811 sensor module is able to detect a variety of gases, including carbon dioxide (CO_2), ammonia (NH_3), methane (CH_4), and various volatile organic compounds (VOCs) (Sainapse, n.d.). However, in the project, the concentration of carbon dioxide is the main focus. It is because carbon dioxide concentration could affect the growing condition for the microorganism. Fungi and Gram-negative bacteria are susceptible to carbon dioxide whereas anaerobic bacteria and yeast can adapt to the environment with high carbon dioxide content. The CSS811 sensor module uses a semiconductor-based gas sensing mechanism. It has a sensing element made of tin dioxide (SnO_2) that detects changes in electrical resistance during the contact with different gases. These resistance changes are very sensitive to the presence and concentration of specific gases, making the module a dependable tool for detecting gases.

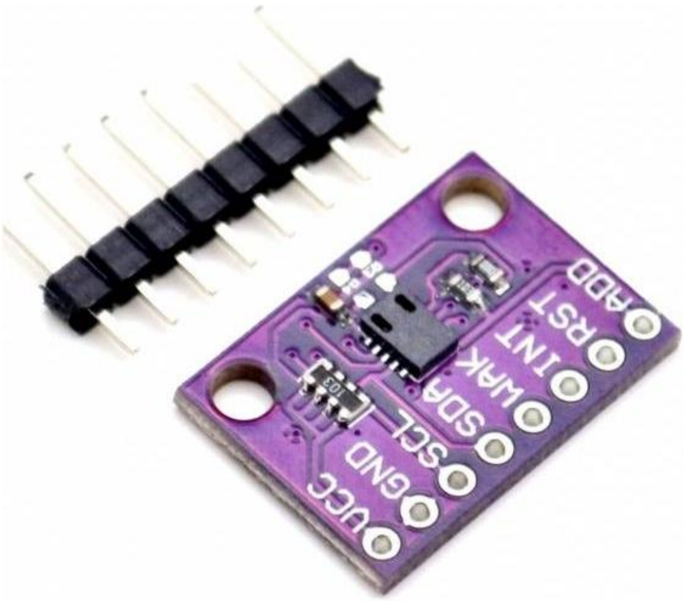

Figure 3.4: Pinout Labels of CSS811 Sensor Module (Sainapse, 2024).

3.3.4 Ozone Generator

Ozone treatment is carried out in the storage chamber by using the ozone generator to produce ozonated water that carry out misting and humidity regulation (Karaca and Velioglu, 2007). Ozone treatment can inhibit the growth of microorganism and pesticides to prolong the shelf life of fruits and vegetables. The O_3 disinfectant enables the preservation of polyphenols content in fruits and vegetables. In addition, washing the fruits and vegetables under 5 ppm concentration ozone water for 3 hours can significantly inhibit the growth of coliform, yeast and mould. In this experiment, the ozone generator was put into the water tank for 30 minutes to 1 hour per day to produce ozonated water that was used in the misting system of the IoT cold storage chamber.

Figure 3.5: Ozone Generator Used in N012 Lab.

3.3.5 150W DC-DC Boost Converter Module

The only part involving the boost converter was the connection to the Peltier cooler module. It was because the Peltier cooler module required relatively high current to optimize its function. However, the current flow was not stable and often dropped due to the sharing of the 12V power supply with other components. Therefore, the boost converter in Figure 3.6 was applied to boost up the voltage supplied to the Peltier cooler which also results in the increment of direct current flow into the Peltier cooler.

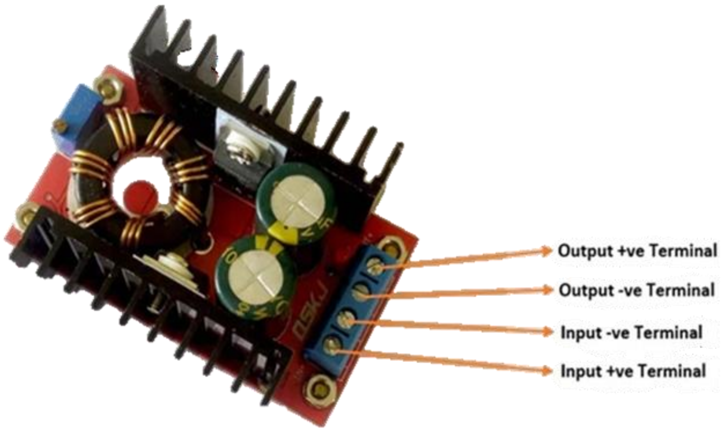

Figure 3.6: 150W Boost Converter Module (Quartz Components, n.d.).

3.3.6 4-channel 5V Relay Module

The 4-channel 5V relay is a crucial device to safely connect the sensors and devices to the Raspberry Pi. It plays a significant role in enabling remote or automated control of electrical circuits. This relay operates on the principle of electromagnetic induction, using a coil that receiving the output voltage from the boost converter to generate a magnetic field. This magnetic field then activates a mechanical switch mechanism. Essentially, the 5V relay acts as a high-power, low-voltage switch that can control circuits or devices that require voltage levels beyond what conventional control systems can handle. In this work, the 4 channels of the 4-channel 5V relay were connected to two water pumps, one pumped in and another pumped out the water from the chamber, and other two were connected to the module and the fan of the Peltier cooler assembly. The Python program of the Raspberry Pi will trigger the relay once the temperature or the humidity is above the threshold. However, to provide as low temperature as possible to prolong the shelf-life of the butterhead lettuces, the Peltier cooler was operating 99.9% of the time. Meanwhile, the misting system has regular schedule to operate. Besides the regular schedule, the misting system will operate as well if the humidity is too low. However, to avoid humidity inside the chamber from becoming too high, there was always a time interval of at least 1 hour in between the switching on of the misting system.

$$IF\ temperature\ higher\ than\ 15°C \rightarrow Peltier\ Cooler\ ON$$

$$(IF\ humidity\ lower\ than\ 70\%\ AND\ interval > 1\ hour)\ OR\ (Regular\ Schedule) \rightarrow Misting\ System\ ON$$

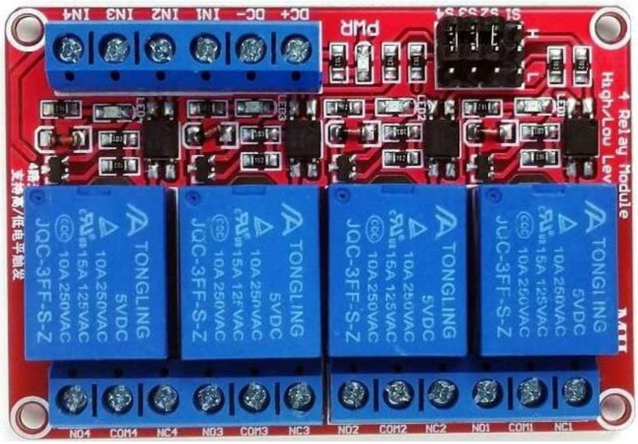

Figure 3.7: 4-Channel 5V Relay (Keim, 2024).

3.3.7 Peltier Cooler

In this experiment, Peltier cooler (Figure 3.8) is the main tool of the cooling system in the IoT cold storage chamber. It regulated the temperature inside the chamber within the range of slightly higher than 20°C, and also prevent the humidity to be too high after the operation of misting system. The Peltier cooler consisted of two parts, the cooling fan and the Peltier module. The Peltier module is the cooling device that interchange the heat inside and outside the chamber to produce cold air, whereas the fan blew the cold air produced by the Peltier module into the chamber. The Peltier cooler functions through the "Peltier effect" which refers to the generation of cooling effect on one side and heat on another side (KYOCERA Corporation, n.d.). Obviously, the cooling side was facing inside the IoT cold storage chambers for cooling purposes. The Peltier cooler was able to maintain the internal temperature of the chambers slightly above 20°C with the aids of aluminium foils and polystyrene layers that insulated the heats, and also the air exchanges between the internal and outer environments of the chambers.

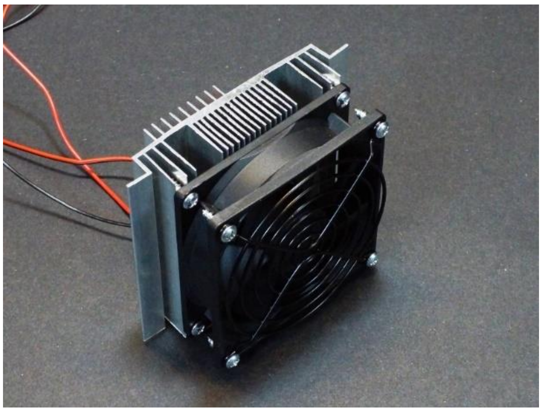

Figure 3.8: Peltier Cooler Module.

3.4 Python IDE

The configuration of Raspberry Pi is specifically done via Python IDE as it has been preinstalled on the Raspbian (Raspberrypi, 2023). It is selected by Raspberry Pi foundation as main language due to its power, versatility, and ease of use. The interface and configuration of devices and sensors have been done via Python IDE, programming the Raspberry Pi modules. Besides that, Python is a user-friendly programming language for beginners, and it is easy to learn.

3.4.1 Blynk

Blynk is a software company that provides infrastructure for the Internet of Things (Blynk, 2023). Blynk (in Figure 3.9) provides the IoT platform to receive the data from the sensors and acts as the application layer. In this work, Blynk monitored and recorded the internal environment of the chambers in real time. The real time data of

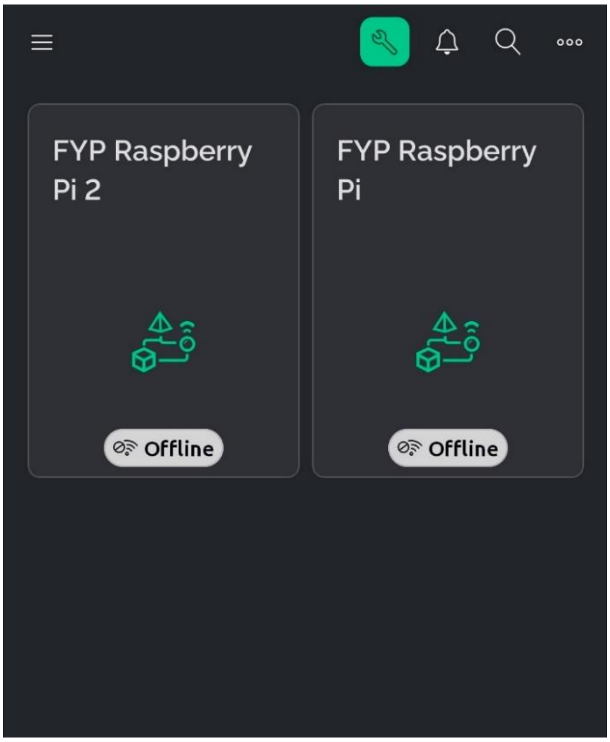

Figure 3.9: Blynk Mobile Application User Interface.

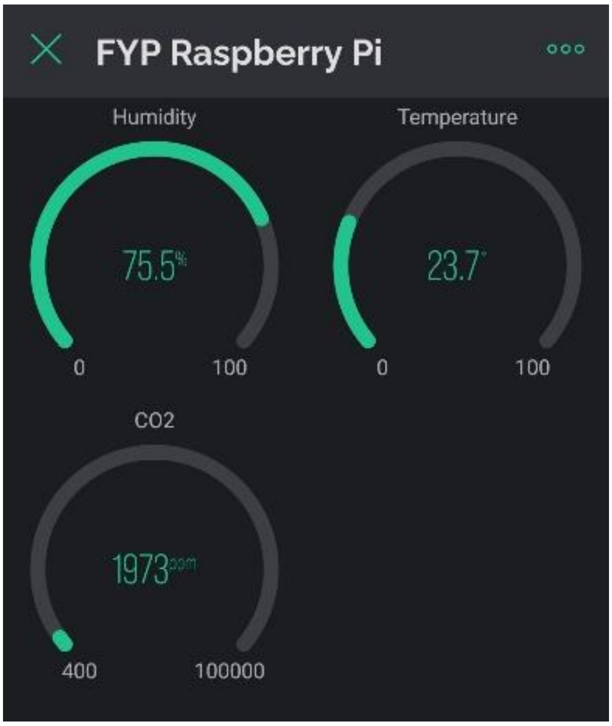

Figure 3.10: Blynk App Showing the Humidity, Temperature, and CO_2 Values Inside the Cold Storage Chamber in Real Time.

the chamber can be checked anytime via the mobile application as long as the Raspberry Pi was uploading data onto Blynk Cloud with a stable connection. Figure 3.10 shows the data presented by the Blynk mobile application.

3.5 Experimental Methodology

In order to investigate the effects of the ozone treatment and the storage of IoT cold storage chamber, the experiment has been conducted by placing two sets of *Lactuca Sativa* or butterhead lettuces each in two IoT cold storage chambers. Each of the two butterhead lettuces in any of the chamber were marked as Left or Right, or Sample 1 and Sample 2. The humidity and temperature provided for the two IoT cold storage chambers were kept at the same range. As a result, the differences in the changes of the butterhead lettuces such as the changes in appearance, the growth of moulds, and the differences in the shelf-life were due to the only manipulating variable in the experiment, which was the type of water used for the misting system, either tap water or ozonated water. If the IoT cold storage chamber with ozonated water shows better results than the one with tap water, it indicates that the ozone treatment is effective and useful in the post-harvest storage of vegetables. Meanwhile, the shelf-life of the IoT cold storage chamber with tap water shown the prolonged shelf-life of butterhead lettuces solely by the effects of IoT cold storage chamber itself. In this way, the experiment examined both the effects of IoT cold storage chamber and the ozone treatment in the post-harvest storage of vegetables and fruits.

3.5.1 Appearance Index

In order to evaluate the quality changes of the butterhead lettuces throughout the experiment, visual quality appearance has been used to examine the conditions of the butterhead lettuces for each of the day. The main aspects indicated by the appearance index are the marketability and whether the vegetables are consumable. It was determined by a 5 point-hedonic scale based on the wilting condition, turgidity and browning of the lettuce (Al Ubeed *et al.*, 2019). The 5-point hedonic scale was represented as following:

1 = Extremely defect,
2 = Slightly defect,
3 = Fair,
4 = Good, and
5 = Excellent

Table 3.3: The Rating and Description of the Appearance of *Lactuca Sativa* throughout Storage Duration (Belisle *et al.*, 2021).

Rating	Description of the appearance
5 (Excellent)	The lettuce is fresh, turgid with greenish bright colour, zero defect.
4 (Good)	The lettuce is well grounded and fresh, turgid and bright greenish colour. The leaves were slightly browning or defect with size less than 0.5 cm.
3 (Fair)	The lettuce is slightly wilt, lightly browning, and the lettuce leaves were dull greenish. The defect size is more than 0.5 cm. The lettuce was at the lower limit of the marketability.
2 (Slightly defect)	The lettuce is wilt, moderately browning of colours, the appearance is seriously defective with more than 1 cm. The lettuce is not marketable.
1 (Extremely defect)	The lettuce is seriously deteriorating, wilted and seriously browning and yellowing leaves. The lettuce is not marketable.

The appearance index was an important indication of effectiveness of the IoT cold storage chambers in prolonging the shelf-life of the butterhead lettuces. Furthermore, the chamber with ozonated water was estimated to have slower deterioration in the quality appearance index due to the inhibition of microorganisms’ growth. Therefore, the appearance index changes of the butterhead lettuces in the chamber with ozonated water shall be slower than those in the chamber with tap water.

3.5.2 Estimated Weight Loss from Butterhead Lettuces

The weight loss of the butterhead lettuces were caused by two main reasons, which are the loss in water content and the wilting of the lettuce leaves. The two causes usually happen starting from the surface or the outer leaves of the lettuces. The misting system which took care of the humidity inside the chambers was also keeping the moisture on the surface of the butterhead lettuces to slow down the water loss. As the misting system was equipped in both chambers, the weight losses in both of them were estimated to be slower than usual. Therefore, the weight losses of the butterhead lettuces in both chambers were estimated to be similar to each other as they were installed with same misting system. However, the microorganisms on the butterhead lettuces will increase the wilting rate of the leaves. Therefore, ozone treatment which inhibited the growth of microorganisms shall show effects in the weight losses. In other words, the weight loss of the butterhead lettuces in the IoT cold storage chamber with ozone treatment was estimated to be always slightly lower than those in chamber without ozone treatment.

3.5.3 Temperature and Humidity in the Cool Storage Chambers

The temperature and humidity of each day has been calculated by the formula as follows:

$$Humidty\ (day) = \frac{H_1 + H_2 + H_3 + H_4 + H_5 + \cdots + H_n}{n}$$

$$Temperature\ (day) = \frac{T_1 + T_2 + T_3 + T_4 + T_5 + \cdots + T_m}{m}$$

The temperature of both chambers was set to be slightly higher than $20°\mathrm{C}$ whereas the humidity was set to be around 70%. The temperature and humidity of the two chambers were kept at the same range by setting same program for both chambers including same control system and same threshold values of temperature and humidity for the operations of cooling system and misting system respectively. As a result, although fluctuations still present in the internal environment of the two chambers, they were maintained at the similar range for the experimental purposes with acceptable minor differences.

3.6 Materials and Components Used

Table 3.4 presents the materials and components used in this project. The table has 18 materials of components which were obtained from different sources. This FYP project was adapted as Undergraduate Research Scheme (URS) project. Therefore, some of the materials have been obtained by the funds of URS. For example, the water pump, Peltier cooler module, Storage Chamber and Ozone Generator were obtained under the URS funds.

Table 3.4: Materials and Components Used in the Cool Storage Chamber Project.

No	Materials and Components
1	Raspberry Pi with Raspberry Pi OS installed
2	4-Channel 5V Relay
3	12V DC Power Adapter
4	150W DC Boost Converter
5	12V DC Pneumatic Diaphragm Water Pump
6	DHT22 Temperature and Humidity Sensor
7	CCS811 eCO2 Gas Sensor
8	Peltier Cooler Assembly (Peltier Module & Heatsink Assembly)
9	Misting Nozzles and Rubber Tubing
10	Water Tank
11	90L Plastic Storage Chamber
12	PVC Net
13	Aluminium Foil Foam
14	Expanded Polystyrene (EPS) Rigid Foam
15	Misting Nozzles
16	Ozone Generator
17	Water Tank
18	Rubber Tube

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Fifteen-day Observation of Butterhead Lettuces

The experiment has been conducted for fifteen days for two IoT cold storage chambers, one of them was misted with tap water or plain water meanwhile another one was ozonated water. From the experiment results, the IoT cold storage chamber shown better effects in prolonging the shelf-life of the butterhead lettuces and slowing down the quality deterioration of them in terms of quality appearance index. Throughout the 15 days experiment, the temperature and humidity of the two IoT cold storage chambers were regulated at the same range by applying the cooling system (i.e. Peltier cooler) and the misting system. The humidity dan temperature sensors in the chambers measured and recorded the internal conditions for every two seconds. They were then averaged to obtain the average temperature and humidity for each day. On the other hand, the weight losses of the butterhead lettuces were recorded every day. In other words, there were three sets of important data that being measured and recorded throughout the experiment, which were the weight losses, the humidity and temperature and also the changes in appearance indexes every day.

4.1.1 Fifteen-day Observation of Butterhead Lettuces using Tap Water

Figures 4.1 – 4.15 present the changes in appearances and weights of the samples of

(a)

(b)

Figure 4.1: Two Lettuces were Selected to be Stored in the Tap Water Chamber for Day 1: (a) Sample 1 and (b) Sample 2.

(a)

(b)

Figure 4.2: Two Lettuces were Selected to be Stored in the Tap Water Chamber for Day 2: (a) Sample 1 and (b) Sample 2.

(a) (b)

Figure 4.3: Two Lettuces were Selected to be Stored in the Tap Water Chamber for Day 3: (a) Sample 1 and (b) Sample 2.

(a) (b)

Figure 4.4: Two Lettuces were Selected to be Stored in the Tap Water Chamber for Day 4: (a) Sample 1 and (b) Sample 2.

(a) (b)

Figure 4.5: Two Lettuces were Selected to be Stored in the Tap Water Chamber for Day 5: (a) Sample 1 and (b) Sample 2.

(a) (b)

Figure 4.6: Two Lettuces were Selected to be Stored in the Tap Water Chamber for Day 6: (a) Sample 1 and (b) Sample 2.

(a) (b)

Figure 4.7: Two Lettuces were Selected to be Stored in the Tap Water Chamber for Day 7: (a) Sample 1 and (b) Sample 2.

(a) (b)

Figure 4.8: Two Lettuces were Selected to be Stored in the Tap Water Chamber for Day 8: (a) Sample 1 and (b) Sample 2.

(a) (b)

Figure 4.9: Two Lettuces were Selected to be Stored in the Tap Water Chamber for Day 9: (a) Sample 1 and (b) Sample 2.

(a) (b)

Figure 4.10: Two Lettuces were Selected to be Stored in the Tap Water Chamber for Day 10: (a) Sample 1 and (b) Sample 2.

(a) (b)

Figure 4.11: Two Lettuces were Selected to be Stored in the Tap Water Chamber for Day 11: (a) Sample 1 and (b) Sample 2.

(a) (b)

Figure 4.12: Two Lettuces were Selected to be Stored in the Tap Water Chamber for Day 12: (a) Sample 1 and (b) Sample 2.

Figure 4.13: One Lettuce was Selected to be Stored in the Tap Water Chamber for Day 13.

Figure 4.14: One Lettuce was Selected to be Stored in the Tap Water Chamber for Day 14.

Figure 4.15: One Lettuce was Selected to be Stored in the Tap Water Chamber for Day 15.

The weights of the butterhead lettuces have been measured and recorded every day. The figures shown that the weights have been decreased by day as well as the quality of appearances observed.

4.1.2 Fifteen-day Observation of Butterhead Lettuces using Ozonated Water Treatment

Figures 4.16 – 4.30 present the changes in appearances and weights of the samples of butterhead lettuces in the IoT cold storage chamber with ozonated water. The weights have been decreased by day as well as the quality of appearances observed.

(a) (b)

Figure 4.16: Two Lettuces were Selected to be Stored in the Ozonated Water Chamber for Day 1: (a) Sample 1 and (b) Sample 2.

(a) (b)

Figure 4.17: Two Lettuces were Selected to be Stored in the Ozonated Water Chamber for Day 2: (a) Sample 1 and (b) Sample 2.

(a) (b)

Figure 4.18: Two Lettuces were Selected to be Stored in the Ozonated Water Chamber for Day 3: (a) Sample 1 and (b) Sample 2.

(a) (b)

Figure 4.19: Two Lettuces were Selected to be Stored in the Ozonated Water Chamber for Day 4: (a) Sample 1 and (b) Sample 2.

(a) (b)

Figure 4.20: Two Lettuces were Selected to be Stored in the Ozonated Water Chamber for Day 5: (a) Sample 1 and (b) Sample 2.

(a) (b)

Figure 4.21: Two Lettuces were Selected to be Stored in the Ozonated Water Chamber for Day 6: (a) Sample 1 and (b) Sample 2.

(a) (b)

Figure 4.22: Two Lettuces were Selected to be Stored in the Ozonated Water Chamber for Day 7: (a) Sample 1 and (b) Sample 2.

(a) (b)

Figure 4.23: Two Lettuces were Selected to be Stored in the Ozonated Water Chamber for Day 8: (a) Sample 1 and (b) Sample 2.

(a) (b)

Figure 4.24: Two Lettuces were Selected to be Stored in the Ozonated Water Chamber for Day 9: (a) Sample 1 and (b) Sample 2.

(a) (b)

Figure 4.25: Two Lettuces were Selected to be Stored in the Ozonated Water Chamber for Day 10: (a) Sample 1 and (b) Sample 2.

(a) (b)

Figure 4.26: Two Lettuces were Selected to be Stored in the Ozonated Water Chamber for Day 11: (a) Sample 1 and (b) Sample 2.

(a) (b)

Figure 4.27: Two Lettuces were Selected to be Stored in the Ozonated Water Chamber for Day 12: (a) Sample 1 and (b) Sample 2.

(a) (b)

Figure 4.28: Two Lettuces were Selected to be Stored in the Ozonated Water Chamber for Day 13: (a) Sample 1 and (b) Sample 2.

(a) (b)

Figure 4.29: Two Lettuces were Selected to be Stored in the Ozonated Water Chamber for Day 14: (a) Sample 1 and (b) Sample 2.

(a)

(b)

Figure 4.30: Two Lettuces were Selected to be Stored in the Ozonated Water Chamber for Day 15: (a) Sample 1 and (b) Sample 2.

4.1.3 Analyses of Temperature and Humidity in the Cool Storage Chambers

The temperature and humidity of the two chambers (i.e. Tap Water and Ozonated Water) in the 15 days of experiment were recorded in Figures 4.31 and 4.32, respectively. In the case of Tap Water, the range of humidity of storage system falls in the range of 70% - 79%, whereas the measured temperature in the system is about 19°C - 25°C. With the ozone treatment, the measured temperature and humidity were in the range of about 17°C to 25°C and 68% to 76% respectively. The control system regulated the temperature and humidity around the optimized range as planned in the study. Table 4.1 illustrates the average temperature and humidity each day during the 15 days of data collection. It can be found that the average temperature of the IoT cold storage chambers without and with ozone treatment are at around 23°C and 22°C respectively, meanwhile their average humidity was at around 72.83% and 70.78%

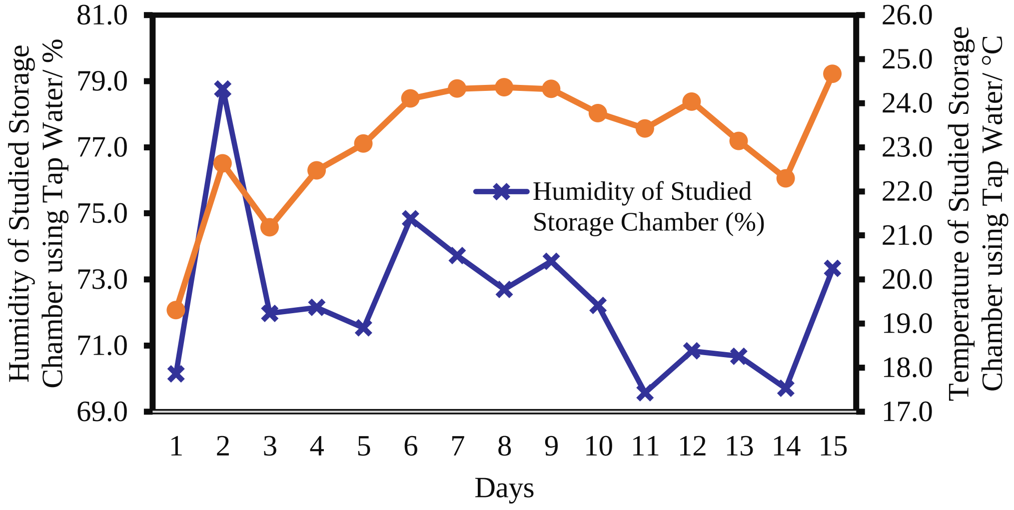

Figure 4.2: Average Temperature and Humidity of Studied Cold Storage Chamber using Tap Water by Day.

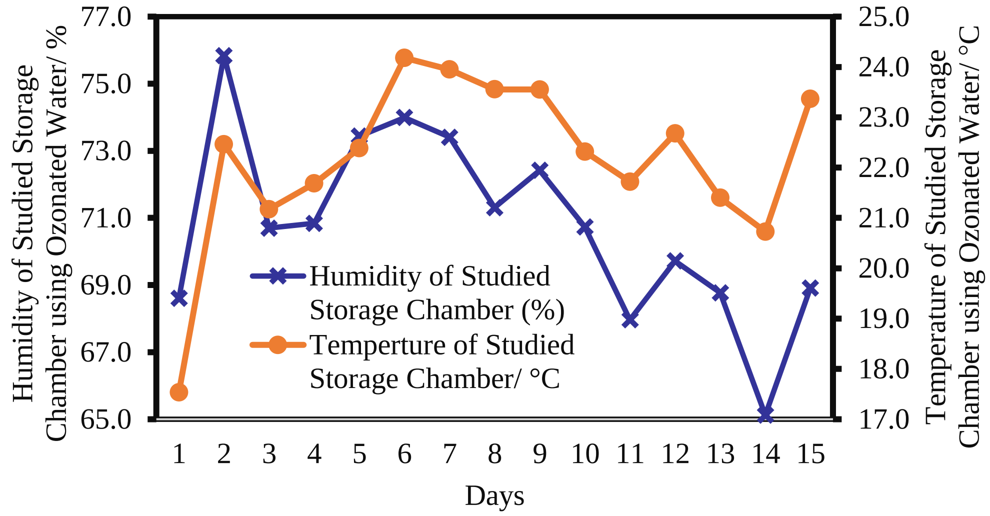

Figure 4.3: Average Temperature and Humidity of Studied Cold Storage Chamber using Ozonated Water by Day.

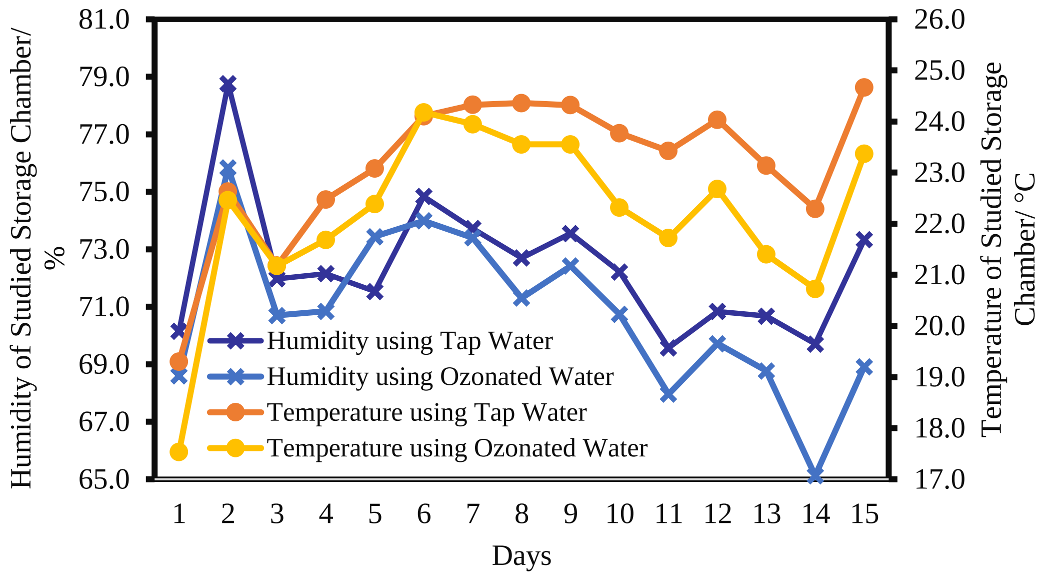

Figure 4.4: Comparison of Temperature and Humidity between Studied Cold Storage Chambers using Tap and Ozonated Water by Day.

Table 4.1: Average Temperature and Humidity of Tap and Ozonated Water Chambers.

Day	Date (2024)	Tap Water		Ozonated Water	
		Temperature (°C)	Humidity (%)	Temperature (°C)	Humidity (%)
1	**21-Feb**	19.29806396	70.14572682	17.53193246	68.60300588
2	**22-Feb**	22.6292802	78.76031924	22.46290216	75.83262280
3	**23-Feb**	21.18090308	71.97297508	21.17245509	70.69564717
4	**24-Feb**	22.47532228	72.15326493	21.68383760	70.84138052
5	**25-Feb**	23.07921319	71.5329187	22.38558607	73.43960856
6	**26-Feb**	24.10374332	74.83950825	24.18017929	73.99256587
7	**27-Feb**	24.32567552	73.72231465	23.94859885	73.40317083
8	**28-Feb**	24.36063667	72.69928613	23.55345369	71.30801342
9	**29-Feb**	24.31919332	73.55267235	23.55222895	72.41973032
10	**1-Mar**	23.77216316	72.21181053	22.31839752	70.73570604
11	**2-Mar**	23.42321863	69.57098465	21.71931162	67.96309414

12	**3-Mar**	24.03392672	70.83577417	22.67703518	69.71968413
13	**4-Mar**	23.13770983	70.67606263	21.39925296	68.77103133
14	**5-Mar**	22.29103989	69.70383337	20.72689423	65.12213500
15	**6-Mar**	24.66566717	73.33103448	23.36757123	68.91370421
	Average	**23.13971713**	**72.38056573**	**22.17864246**	**70.78407335**

respectively. Both results of temperature and humidity for the cool storage system with the ozone treatment are slightly lower than that of tap water, but they were being regulated in the same range throughout the 15 days of experiment. For the first day, both of the chambers have lower temperature at the first day because the Peltier Cooler has been operated while the chambers were empty for a few days. The Peltier coolers were able to maintain a lower internal temperature when the chamber is empty. However, after the first day storing the butterhead lettuces, the internal temperature slowly increased and were slightly higher than 20°C for the rest of the experiment. Figure 4.33 shows that both the temperature and humidity of the two chambers were maintained in the same range. The differences between the internal environment of the two chambers were small although they fluctuate from time to time providing similar environments in terms of humidity and temperature as plan. The percentage differences of the humidity and the temperature of the two chambers were calculated as follows:

$$Percentage\ Difference = \frac{\left|V_{tap\ water} - V_{ozonated\ water}\right|}{(V_{tap\ water} + V_{ozonated\ water})/2} \times 100\%$$

Based on the results obtained in Table 4.2, the percentage differences of temperature and humidity of two chambers indicated that the internal environment of them were maintained at similar ranges. The largest difference occurred in Day 1 which the temperatures of the two chambers had a percentage difference of around $\mathbf{9.59}\%$. However, even the largest difference recorded throughout the experiment was within $\mathbf{10}\%$ of percentage difference. On the other hand, the largest difference that was recorded for humidity was on Day 14 which was $\mathbf{6.796}\%$. Most of the days, the percentage differences for both temperature and humidity were less than $\mathbf{3}\%$. The temperature percentage difference on Day 3 was even smaller than $\mathbf{0.04\%}$. In other words, the internal environment has been regulated as planned to be as similar as possible for both chambers. In this case, the differences between weight losses and changes in appearance index of the butterhead lettuces in two chambers can be deducted as the results of the presence or absence of ozone treatment in the chambers.

Table 4.2: Percentage Difference of Temperature and Humidity of Tap and Ozonated Water Chambers.

Day	**Date (2024)**	**Percentage Difference (%)**	
		Temperature	**Humidity**
1	**21-Feb**	9.5907200	2.2237600
2	**22-Feb**	0.7379460	3.7876200
3	**23-Feb**	0.0398929	1.7906200
4	**24-Feb**	3.5849600	1.8348700
5	**25-Feb**	3.0512700	2.6304200
6	**26-Feb**	0.3166100	1.1381200
7	**27-Feb**	1.5622300	0.4338390
8	**28-Feb**	3.3692900	1.9322300
9	**29-Feb**	3.2042700	1.5522700
10	**1-Mar**	6.3083000	2.0652400
11	**2-Mar**	7.5490100	2.3381700
12	**3-Mar**	5.8097300	1.5881100
13	**4-Mar**	7.8068000	2.7322600
14	**5-Mar**	7.2720600	6.7964600
15	**6-Mar**	5.4049900	6.2108900
	Average	**4.3738719**	**2.6031973**

4.1.4 Analyses of Weight Loss from Butterhead Lettuces

The weight losses (*WL*) of the samples throughout the 15 days of experiment were tabulated in Table 4.3. The initial weights of the samples were different, therefore, instead of analysing the weight loss of the samples in gram directly, the data recorded and tabulated in Table 4.3 has been further analysed after the calculation of the relative weight loss which were tabulated in Table 4.4. Due to the differences in the initial weight of the butterhead lettuces, instead of deducting observations directly from the weights changed day by day in gram, a better approach was relative weight loss (*RWL*)

Table 4.3: Weight Loss (g) of the Samples in the Tap and Ozonated Water Chambers.

Day	Tap Water			Ozonated Water		
	Sample 1	Sample 2	Average	Sample 1	Sample 2	Average
1	106.86	150.55	128.705	142.63	157.89	150.260
2	102.62	137.51	120.065	137.1	157.09	147.095
3	96.92	124.07	110.495	124.38	143.12	133.750
4	94.69	113.21	103.950	117.66	137.18	127.420
5	89.65	103.07	96.360	113.94	129.86	121.900
6	86.12	94.32	90.220	104.64	120.42	112.530
7	81.98	86.43	84.205	96.01	108.6	102.305
8	78.52	79.23	78.875	89.08	101.1	95.090
9	72.86	73.83	73.345	84.65	93.87	89.250
10	68.18	69.18	68.680	79.56	91.93	85.745
11	63.36	64.82	64.090	72.50	85.30	78.900
12	60.50	61.12	60.810	64.72	79.14	71.930
13	46.95	57.12	52.035	57.32	73.07	65.195
14	-	53.76	53.760	50.18	68.62	59.400
15	-	49.46	49.460	41.92	61.34	51.630

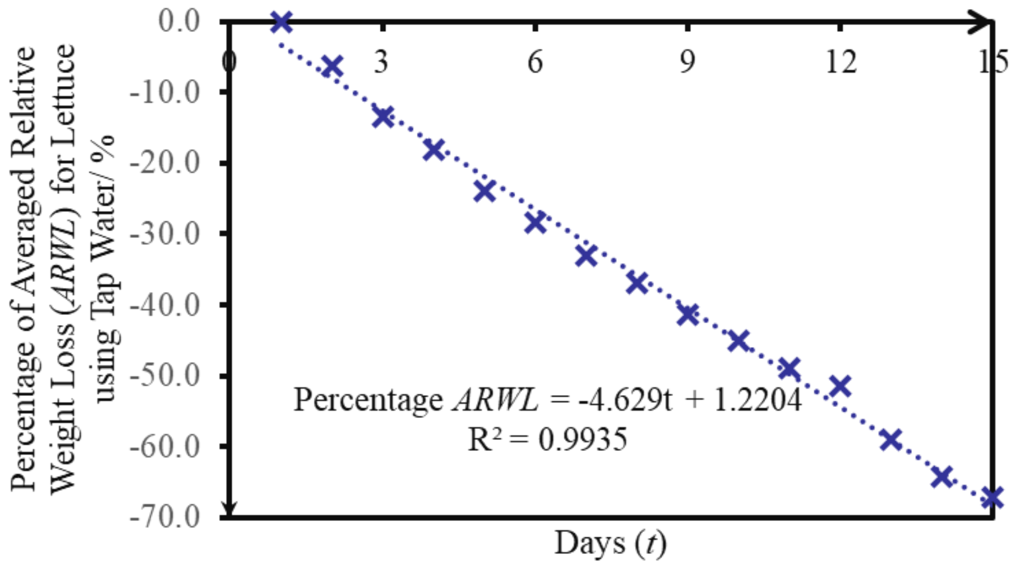

Figure 4.5: Averaged *RWL* of Sample 1 and Sample 2 in Studied Cold Storage Chamber using Tap Water in 15 Days.

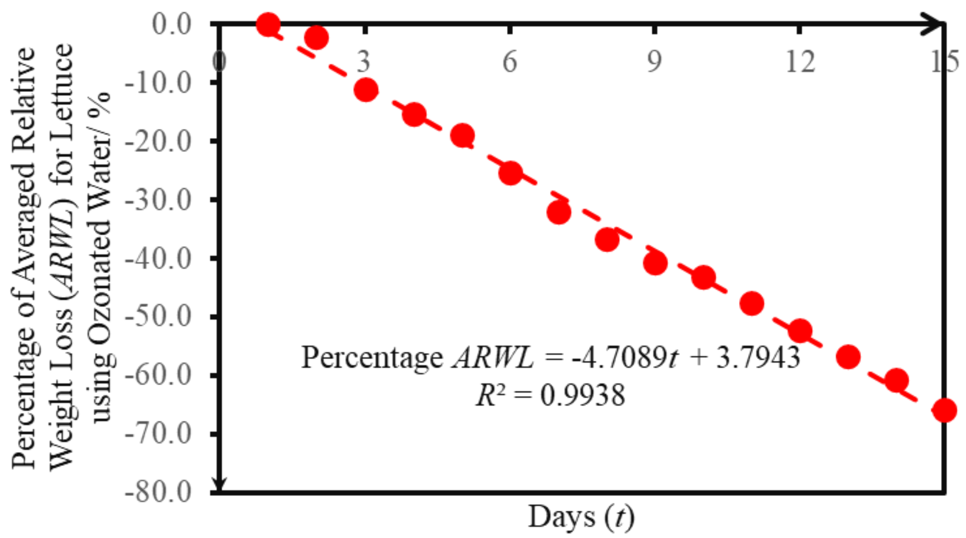

Figure 4.6: Averaged *RWL* of Sample 1 and Sample 2 in Studied Cold Storage Chamber using Ozonated Water in 15 Days.

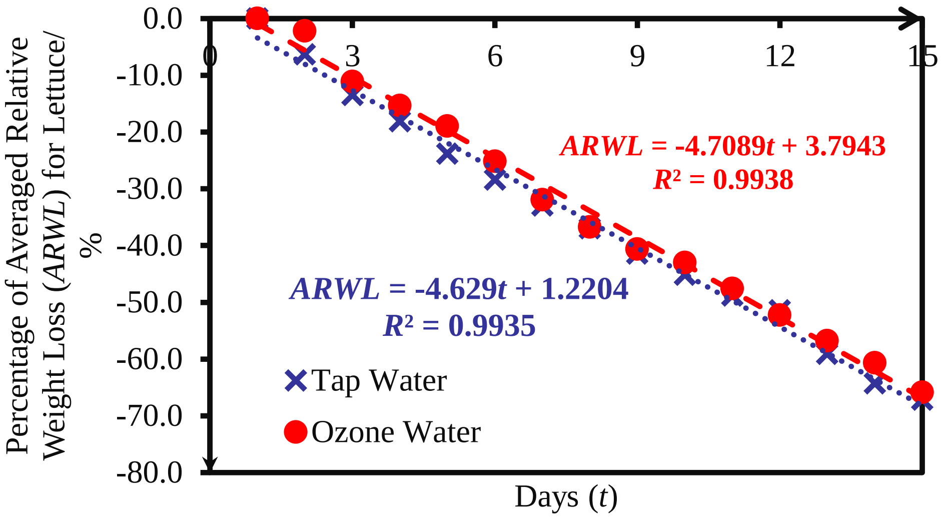

Figure 4.7: Comparison of Averaged *RWL* of Samples in Studied Cold Storage Chambers using Tap and Ozonated Water in 15 Days.

Table 4.4: Percentage of Average Relative Weight Loss (%) for the Tap and Ozonated Water Chambers.

Day	**Tap Water**			**Ozonated Water**		
	Sample 1	**Sample 2**	**Average**	**Sample 1**	**Sample 2**	**Average**
1	0.00	0.00	0.000	0.00	0.00	0.000
2	-3.97	-8.66	-6.315	-3.88	-0.51	-2.195
3	-9.30	-17.59	-13.445	-12.80	-9.35	-11.075
4	-11.39	-24.80	-18.095	-17.51	-13.12	-15.315
5	-16.11	-31.54	-23.825	-20.11	-17.75	-18.930
6	-19.41	-37.35	-28.380	-26.64	-23.73	-25.185
7	-23.28	-42.59	-32.935	-32.69	-31.22	-31.955
8	-26.52	-47.37	-36.945	-37.54	-35.97	-36.755
9	-31.82	-50.96	-41.39	-40.65	-40.55	-40.600
10	-36.20	-54.05	-45.125	-44.22	-41.78	-43.000
11	-40.71	-56.94	-48.825	-49.17	-45.98	-47.575
12	-43.38	-59.40	-51.390	-54.62	-49.88	-52.250
13	-56.06	-62.06	-59.060	-59.81	-53.72	-56.765

14	-	-64.29	-64.290	-64.82	-56.54	-60.680
15	-	-67.15	-67.150	-70.61	-61.15	-65.880

which compared the changes in weights of butterhead lettuces and their initial weights. The RWL calculated for the two samples in each chamber were averaged to obtain the averaged relative weight loss which has been plotted in the following graphs. The formula of relative weight loss is as follows:

$$\text{Relative Weight Loss}, RWL\ (\%) = \frac{\text{current weight} - \text{initial weight}}{\text{initial weight}} \times 100\%$$

In Figure 4.36, the results show that the R^2 of averaged RWL of samples in cold storage chambers using tap and ozonated water treatment were determined to be about 0.9938 and 0.9935, respectively. These values of R^2 indicate that both studied cool storage chambers perfectly to control the weight loss of butterhead lettuces in this study. However, the averaged RWL in cold storage chamber using ozonated water was observed to be slightly lower than that in the chamber using tap water. For both chambers, the detail analysis for averaged RWLs of the samples for each day are summarized in Table 4.4. The averaged RWLs of the samples in chamber using ozonated water for each day were always lower than the averaged weight losses of the samples in chamber using tap water. However, the weight losses of both samples were similar to each other. As can be seem from data in Table 4.4, both of the averaged RWLs of the samples in chambers using tap water and ozonated water were exceeded 25% and 50% of their initial weights at Day 6 and Day 12. From Day 1 to Day 15, the averaged RWLs of each day for the butterhead lettuces in the ozonated water chamber were lower than those in the tap water chamber, except for Day 12. However, the differences were not big because both of the chambers were equipped with misting systems that were activated from time to time based on the real-time humidity inside the chamber. In other words, the misting system regulates the humidity inside the chamber and hydrated the butterhead lettuces in a suitable frequency to reduce the weight loss. As the humidity of the two cold storage chambers were maintained at the same range, which is around 70%, the average weight loss of the butterhead lettuces in both chambers were similar. However, the average weight loss of the butterhead lettuces inside the ozonated water chamber were always slightly lower than those inside the tap water chamber. It was due to the wilting of the lettuces' leaves. When the leaves shrunk and wilted, which usually started with the outermost layer, the weight of the butterhead lettuces decreased as the leaves can no longer hold the water content. The leaves eventually drop once they were wilted, also results in the weight loss of the butterhead lettuces. When the misting system sprayed the water onto the surface of the butterhead lettuces, it slowed down the wilting of the leaves. However, the leaves wilt faster when the microorganisms grow. Therefore, the misting of ozonated water onto the surface of the butterhead lettuces inhibited the growth of the microorganisms, and also the wilting of the leaves. Therefore, the average relative weight loss of butterhead lettuces with the ozone treatment were always lower throughout the experiment. The reason that the Sample 1 in the IoT cold storage chamber with tap water was removed on Day 14 was because it has been observed that molds was grown on the lettuce's leaves. Therefore, it has been removed from the experiment as the condition of that sample was too bad and even worse than 1 (extremely defect). There was no reason to continue the experiment with a butterhead lettuce with molds.

4.1.5 Appearance Index

Table 4.5 reports the changes in appearance index recorded in the 15 days of experiment. The quality deterioration of the butterhead lettuces in chamber with ozone treatment is much slower than that another chamber. Based on the data in the able, the appearance indexes of the both sets of butterhead lettuces in the chamber misted with tap water decreased from 4 to 3 on the 6th day and from 3 to 2 at the 10th day. Meanwhile, the appearance indexes of the two sets of butterhead lettuces with ozone treatment remained at 4 until day 8 and day 9 respectively and both at 3 until the 12th day. One of the reasons causing the deterioration in the appearance is the growth of microorganisms. On the other hand, the butterhead lettuces were removed from the experiment once their appearance index was lower than 3 (fair), as they were defect and no longer marketable. Therefore, the shelf-life of the butterhead lettuces in this experiment is defined by the number of days of the butterhead lettuces to maintain at appearance index above 3 (fair). In this case, the shelf-life of the two butterhead lettuce in the tap water chamber were 10 days. Meanwhile, the shelf-life of the two butterhead lettuce in the ozonated water chamber were 12 days. The difference in the shelf-life of the butterhead lettuces in two cold storage chambers has been observed despite the same range of humidity and temperature has been provided and maintained in the two

Table 4.5: Quality Appearance Difference in the Tap and Ozonated Water Chambers.

Day	**Tap Water**		**Ozonated Water**	
	Sample 1	**Sample 2**	**Sample 1**	**Sample 2**
1	5	5	5	5
2	5	5	5	5
3	5	5	5	5
4	4	4	4	4
5	4	4	4	4
6	4	4	4	4
7	3	3	4	4
8	3	3	4	4
9	3	3	3	3
10	3	3	3	3
11	2	2	3	3
12	1	2	3	3
13	1	2	1	2
14	-	2	1	2
15	-	1	1	1
Shelf-life (days)	**10**	**10**	**12**	**12**

chambers. Moreover, the butterhead lettuces in the chamber with ozone treatment deteriorate slower in terms of appearance index. The only difference between the two chambers is the type of water used in the misting system. As a result, the butterhead lettuces in the chamber with ozone treatment have longer shelf-life and slower quality deterioration. Based on the changes in the appearance indexes which indicate the deterioration in the vegetables' quality, the ozone treatment has been proven to be an effective inhibitor of microorganism growths.

4.2 URS Project

In addition, this FYP project has also been adapted as Undergraduate Research Scheme Project. As compared to the FYP project, the URS project was more scientific and research based. It involved more sample sets of chambers than the FYP project itself for research purposes. In fact, it involved 4 sets of chambers with different specifications in Table 4.6. Besides the 15 days experiment conducted in this FYP, there were few experiments conducted that involved all the four chambers. The main purposes of these experiments were to inspect the effects or functionality of each system in the IoT cold storage chamber such as the misting system and the cooling system. Therefore, the systems were removed from the storage one by one from Chamber 1 to Chamber 4. During the experiments, there were unexpected results happened. For example, the diagram in Figure 4.37 illustrates the butterhead lettuces observed after only 4 days stored in Chamber 4 (negative control). The moulds have grown all around on the lettuce. Leaves within only 4 days. In other words, the butterhead lettuces have shelf-life less than 4 days. It was unexpected that the conditions of the butterhead lettuces was worse than extremely defect after only 4 days considering the shelf-lives of 10 days and 12 days in the previous experiment. The leaves of the butterhead lettuces were full with moulds and definitely unconsumable. When the cover of Chamber 4 was opened, an extremely pungent smell immediately flows out from the chamber and the scent of moulds was extremely unpleasant. The main acquisition from this result was the comparison often made between storing the vegetables in a chamber and storing it in room condition or in refrigerator. However, it is also important to consider the space or area provided to be the same when the

Table 4.6: Involvement of Different Chambers in URS and FYP Projects.

Chamber	Specifications	Involved in FYP?	Involved in URS?
1	IoT Cold Storage Chamber with cooling system and misting system and ozone treatment	YES	YES
2	IoT Cold Storage Chamber with cooling system and misting system	YES	YES
3	IoT Cold Storage Chamber with cooling system (positive control)	NO	YES
4	Chamber without any system, only sensors to record the internal changes (negative control)	NO	YES

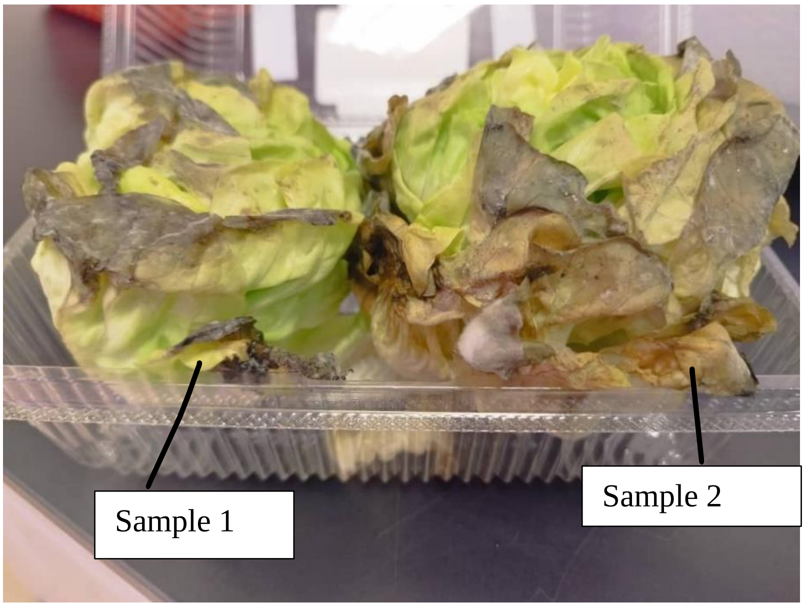

Figure 4.8: Samples 1 and 2 in Chamber 4 (Day 4).

comparison is made. In this experiment, the effects of the cooling system, misting system and ozone treatment has been further proven as in the same volume of storage, the butterhead lettuces defect in short time as there were no action taken to prolong the shelf-life. The isolated chamber without any treatment or system accelerated the quality deterioration of the butterhead lettuces and become a perfect environment for the growth of fungi and bacteria. In other words, it was impressive that with or without the cooling system, misting system and ozone treatment resulted in totally different outcomes as Chamber 1 and Chamber 2 in the FYP were also isolated chamber but they did not face the same issues as Chamber 4. On the other hand, they prolonged the shelf-life of the butterhead lettuces. The temperature and humidity in Chamber 4 were around $30°C$ and almost 100% respectively due to no control system applied to it. It was proven that the differences in temperature and humidity even only by $5°\mathrm{C}$ and 30% can result in entirely different outcomes. Chamber 1 and Chamber 2 were functioning well as cold storage chamber, meanwhile Chamber 4 became a unhygienic environment that exhibited the growth of microorganisms. There was nothing unexpected happened in the Chamber 3. As Chamber 3 was lack with misting system, the butterhead lettuces dried faster and weight loss was higher in it.

4.3 Practicality of IoT Cold Storage Chamber in Post-Harvest Storage

Although the experiment conducted has proven the ozone treatment and IoT cold storage chamber designed were useful in post-harvest storage of vegetables and fruits, it was still doubted whether it was applicable or suitable to be used in agriculture. In order to investigate the capability and usefulness of the IoT cold storage chamber in agriculture, a trip to a farm in Teluk Intan, Perak. The farm is named as “Ah Peng Orchard” and the owner of the farm is Mr. Tan Chao Chin, who has inherited the farm from his father. The farm consists of different sections with various plantation and domestication. For example, the main plantation in the farm is bell-fruit, also known as Java Apple (*Syzygium Samarangense*). Moreover, there are also other important fruits such as Durian, Guava, Passion Fruits, Longan, Banana, Jackfruit, Sapodilla and etc. The animals domesticated are chickens, ducks, honey bees and so on. Mr. Tan generously shared his knowledges and experiences in fruit farming and cultivation

Figure 4.9: The orchard visited in Kampung Sungai Suli, Teluk Intan, Perak, Malaysia.

Figure 4.10: The Orchard Uses Newspapers and Polystyrene Boxes to Store Fruits Temporarily.

such as the dilemmas of managing a small orchard in Malaysia, the post-harvest processes of fruits, the considerations, concerns and necessities of automations and technical upgrades in farming systems as well as some successful examples of farm automations and digitalization.

4.3.1 Dilemma of Local Farmers

Mr. Tan as a small orchard owner in Malaysia stated that the main dilemma of small farmers like him is the lack of pricing power of both upstream and downstream in agriculture. He had mentioned that the for prices for the pesticides and fertilizers were set by the suppliers whereas the prices of fruits produced from the farms were determined by the middlemen or brokers before the fruits reaches the markets and consumers. In order words, the farmers are not able to control neither the budgets nor the profits made in the supply chain due to the lack of fair system. The prices of pesticides and fertilizers increased gradually over the past 30 years due to inflation meanwhile the offered prices by the brokers are not constant and fluctuated from time to time depends on the seasons and variance of production volume. The price of fruits might be multiplied by more than 5 times when they reach the consumers as compared to the selling price of the fruits of farmers to brokers as the logistic and transportations of the fruits in post-harvest process also contribute a significant amount of costs in the supply chains. Consequently, the profits made by the farmers are not fixed and sometimes hard to predict. They fall into a dilemma that they have to accept the prices offered by both upstream and downstream as they have to depends on the fertilizers and pesticides for pest control and yield of fruits and to depends on the brokers to save the time for transportation and post-harvest storage.

4.3.2 Importance of IoT Technology in Automations in Agriculture

IoT technology can be helpful to automize the various stages in agriculture to reduce the dependence of the farmers towards the upstream and downstream and also the cost of labour. For example, the automated machines that are able to identify and capture the pests are cheaper and safer than the pesticides. The automated misting system, automated collecting system and central monitoring system in the farm can reduce the labour cost and also increase the yield of the farm. For the post-harvest process, the IoT control system that regulates and monitors the temperature and humidity of the fruits and vegetables are able to prolong the shelf-life and also provides a alternative to the farmers in the post-harvest transportation than relying on the brokers and also explore a wider market as the fruits and vegetables can be transported to farther locations. Therefore, Mr. Tan also agreed that IoT technology and automation are the future of agriculture. In fact, it is becoming more and more common in foreign countries. However, there are considerations that has to be taken in the advancement of IoT system in agricultural processes.

4.3.3 Important Factors to be Considered in applying IoT system into Agriculture

First of all, the costing of IoT system is the main consideration including the instalment and maintenance of microcontrollers, sensors, and machines. For example, the IoT cold storage chamber designed in this FYP involved the usage of Raspberry Pi which is an relatively expensive microcontroller. For the agricultural practice, it might not be the best choice depends on the applications and situations. If the tasks and automations are not wide and complicated, a simpler and cheaper microcontroller such as ESP32 might be a good choice. Secondly, the environment, area and type of farms highly affect the practicality of the IoT technology as central control system. Mr. Tan gave a successful example of a greenhouse-type ginger farm in Teluk Intan which also used IoT technology as central control system for the automation and monitoring of the farm. He stated that the differences between the ginger farm and his farm is his farm is an open area, and the fruits are distributed in a wider area whereas the ginger farm were managed in a greenhouse which is a closed area, and the gingers are more concentrated in the same region. Besides that, his farm has a larger variety of fruits as compared to the ginger farm that focuses on the ginger plantation. The implementation of IoT technology will be more challenging and expensive in his farm. Thirdly, different fruits have different shelf-life, yield rate and difficulty to maintain the freshness throughout the transportation process. Fruits with higher water content such as java fruit harder to maintain the freshness meanwhile banana are easier. The fruits that can only be collected when they are ripe are also harder to maintain the freshness as compared to bananas that can be collected even they are not ripe yet. Therefore, the IoT cold storage chambers or related technology in post-harvest storage are more useful and vital to fruits with higher difficulty to store and with shorter shelf-life. However, Mr. Tan highlighted that it is only practical if the costs can be saved and yield can be increased with these IoT technologies. If not, the conventional ways that are cheaper such as merely using newspapers will still be the best solutions for now. Based on the interview with Mr. Tan, it can be concluded that even though IoT technology is the future trend of agriculture, there are still many factors and issues to be considered and solved and now is still the early stage of this long path. The IoT cold storage chamber with ozone treatment has a large potential in agriculture application and the concepts and experiences in this project and research will become the foundation of the future research and advancement. Therefore, even though the IoT cold storage chamber are still not practical for now due to various aspects, it is still valuable for the future applications of IoT technology in agriculture.

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

In conclusion, the IoT cold storage chamber system with ozone treatment has been designed and built successfully with the control system of humidity and temperature. The experiment has proven the functionality of the IoT cold storage chamber and the ozone treatment in prolonging the shelf-life of vegetables in post-harvest storage. The experiment has further proven that the ozone treatment is useful to inhibit the growth of microorganisms of the vegetables. The IoT cold storage chamber with ozone treatment has shown better results such as slower quality deterioration and longer shelf-life in storage of butterhead lettuces than chamber using tap water. The similar range of temperature and humidity in both chambers throughout the experiment has proven the stability of the misting system and cooling system in regulating the internal environment of the IoT cold storage chamber. The sensors functioned well throughout the experiment as they successfully recorded more than 50 thousand sets of data into the Excel file in Raspberry Pi and Blynk Cloud system. Thus, the project has been completed successfully. Ozone treatment is in fact useful in prolonging shelf-life of vegetables.

5.2 Recommendation

Image processing can be applied to ease the observations on the changes of the appearance and quality of the vegetables. A camera can be installed into the chamber and captures about 100 to 1,000 images per day. A large database can be built based on the changes in the appearance of the vegetables. The chamber slows down the deterioration of quality helps to capture slow and minor changes in the appearance. The changes in the appearance of vegetables can be studied more deeply and in detailed. The image processing shall focus on the feature extraction and evaluation of the appearance quality index of the vegetables and fruits. For example, the 5-point hedonic scale used currently was evaluated manually by the human's observation. A more accurate and automated evaluation by computer can be done by applying image processing and machine learning. Instead of using 5-point hedonic scale, a scale with higher accuracy and more points can be applied to have a more detailed evaluation of the appearance quality of the vegetables and fruits. Besides that, various experiments can be made for different vegetables and fruits and the image processing for each of them will be different from each other as they have different features and standards of evaluations. On the other hand, the circuit of the IoT cold storage chamber can be improved such as printing customized PCB boards for the circuit instead of using jumper wires.

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APPENDICES

APPENDIX A: Python Program Used in the IoT Control System

```
import time
import board
import busio
import adafruit_dht
import adafruit_ccs811
import RPi.GPIO as GPIO
import BlynkLib
from time import sleep
from BlynkTimer import BlynkTimer
import datetime
import signal
from BlynkLib import Blynk
import csv
import openpyxl
from openpyxl import Workbook
import requests

# ThingSpeak parameters
#THINGSPEAK_API_KEY = '95KIA374O56MRB04'
#THINGSPEAK_CHANNEL_ID = '2391727'

# Prepare the ThingSpeak URL with your API key
#thingspeak_url =
'https://api.thingspeak.com/update?api_key=95KIA374O56MRB04'
```

```
BLYNK_AUTH_TOKEN = '_M4c8G0JexbOYOp-W9gkpzec_ku4mMbQ'

# Initialize Blynk
blynk = BlynkLib.Blynk(BLYNK_AUTH_TOKEN)

# Create BlynkTimer Instance
timer = BlynkTimer()

current_time = datetime.datetime.now()

# function to sync the data from virtual pins
dhtDevice = adafruit_dht.DHT22(board.D4, use_pulseio=False)
i2c = busio.I2C(board.SCL, board.SDA)
ccs = adafruit_ccs811.CCS811(i2c)

RELAY_GPIO = [17, 27, 22, 24]
GPIO.setwarnings(False)
GPIO.setmode(GPIO.BCM)
for relay_pin in RELAY_GPIO:
        GPIO.setup(relay_pin, GPIO.OUT)

@blynk.on("connected")
def connected():
        print("Connected to Blynk2.0")
        print("......................................................")

while not ccs.data_ready:
    pass
```

```
def myData():
	interval = 0
	set_interval = 900
	pump = 0
	routine = 0
	pcount = 0
	set_pcount = 900
	filewrite = 1800
	starter = 0
	while True:
		try:
			temperature_c = dhtDevice.temperature
			humidity = dhtDevice.humidity
			current_time = datetime.datetime.now()


			if filewrite >= 1800:
				filewrite = 0

				#Create a new Excel workbook
				workbook = Workbook()

				# Create a new Excel sheet
				sheet = workbook.active
				excelname = str(current_time)
				excelname = excelname.replace(':','')
				excelname = excelname.replace('.','')
				excel_file_path = "/home/raspberry1/blynk-library-
python/excel/data"+excelname+".xls"

				sheet.cell(row=1,column=1,value="Date & Time")
```

```
sheet.cell(row=1,column=2,value="CO2(ppm)")
sheet.cell(row=1,column=3,value="TVOC(pbb)")

sheet.cell(row=1,column=4,value="temperature(Celsius)")
sheet.cell(row=1,column=5,value="Humidity(%)")
sheet.cell(row=1,column=7,value="FileWrite")
sheet.cell(row=1,column=8,value="new file opened")
print("new excel file opened.")
row =2



filewrite += 1
if starter == 0 and humidity is not None and humidity <70:
    GPIO.output(27,1)
    time.sleep(0.4)
    GPIO.output(27,0)
    starter = 1
    sheet.cell(row=row,column=6,value="water pump
activated")

if temperature_c is not None and temperature_c > 15:
    #If temperature is above 30 degrees, activate the relays
    for relay_pin in [24, 22]:
        GPIO.output(relay_pin, 1)
else:
    #If temperature is 30 degrees or below, deactivate the
relays
    for relay_pin in [24, 22]:
        GPIO.output(relay_pin, 0)

#Check humidity and cooldown timer for pump control
#BLYNK_WRITE
```

```
if humidity is not None and humidity < 85 and interval == set_interval:
    #If humidity is below 80 and cooldown interval has passed, trigger the water pump
    GPIO.output(27, 1)
    time.sleep(0.4)
    GPIO.output(27, 0)
    interval = 0
    pump = 1
    sheet.cell(row=row,column=6,value="water pump activated")

if routine == 3600:
    GPIO.output(27,1)
    time.sleep(0.4)
    GPIO.output(27,0)
    interval = 0
    pump = 1
    routine = 0
    sheet.cell(row=row,column=6,value="water pump activated")

if pump == 1 and pcount == 900:
    GPIO.output(17,1)
    time.sleep(0.5)
    GPIO.output(17,0)

    pump = 0

if interval != set_interval:
    interval = interval + 1
```

```
else:
    interval = set_interval

if pcount != set_pcount:
    pcount = pcount + 1
else:
    pcount = set_pcount

routine = routine + 1

if ccs.data_ready:
    temp = temperature_c
    print("Date & Time: {},CO2: {} ppm, TVOC: {} ppb, 
Temp: {} C, Humidity: {} %".format(current_time, ccs.eco2, ccs.tvoc, temp, 
humidity))
    print("filewrite=",filewrite)
    blynk.virtual_write(0, humidity)
    blynk.virtual_write(1, temp)
    blynk.virtual_write(2, ccs.eco2)
    data = [current_time,ccs.eco2,ccs.tvoc,temp,humidity]

    # Prepare the data to send to ThingSpeak
    #thingspeak_data = {
    #'field1': temperature_c,  # Assuming temperature_c is 
in Celsius
    #'field2': humidity,
    #'field3': ccs.eco2,}

    # Send data to ThingSpeak
    #response = requests.post(thingspeak_url, 
data=thingspeak_data)
```

```
                                        # Check if the request was successful (HTTP status code 200)
                                        #if response.status_code == 200:
                                                #print('Data sent to ThingSpeak successfully!')
                                        #else:
                                                #print(f'Error sending data to ThingSpeak. Status code: {response.status_code}')
                                        #thingspeak causes extra problem to the coding
                                        # Write data to the Excel sheet
                                        current_time = datetime.datetime.now()
                                        sheet.cell(row=row,column=1,value=current_time)
                                        sheet.cell(row=row,column=2,value=ccs.eco2)
                                        sheet.cell(row=row,column=3,value=ccs.tvoc)
                                        sheet.cell(row=row,column=4,value=temp)
                                        sheet.cell(row=row,column=5,value=humidity)
                                        sheet.cell(row=row,column=7,value=filewrite)
                                        row+=1

                                        # Save the workbook to an Excel file
                                        workbook.save(excel_file_path)

                                        print("Values sent to Blynk Server!")
                                        time.sleep(2)
                                #else:
                                #       print("Error: Data not ready")



                        except RuntimeError as e:
                                print("Error reading DHT22:", e,"filewrite=",filewrite)
                                if interval != set_interval:
                                        interval = interval + 1
```

```
else:
    interval = set_interval

filewrite+=1

if pcount != set_pcount:
    pcount = pcount + 1
else:
    pcount = set_pcount

routine = routine + 1
# Write data to the Excel sheet

current_time = datetime.datetime.now()
sheet.cell(row=row,column=1,value=current_time)
sheet.cell(row=row,column=2,value="DHT22 Error")
sheet.cell(row=row,column=3,value="-")
sheet.cell(row=row,column=4,value="-")
sheet.cell(row=row,column=5,value="-")
sheet.cell(row=row,column=7,value=filewrite)
row+=1

# Save the workbook to an Excel file
workbook.save(excel_file_path)

time.sleep(2)

except OSError as e:
    print("OSError:", e)
    print("Restarting the loop...")
```

```
                continue

            except KeyboardInterrupt:
                GPIO.output(17,0)
                GPIO.output(27,0)
                GPIO.output(24,0)
                GPIO.output(22,0)
                GPIO.cleanup()
                sheet.cell(row=row,column=1,value=current_time)
                sheet.cell(row=row,column=2,value="keyboard interrupt")
                sheet.cell(row=row,column=3,value="-")
                sheet.cell(row=row,column=4,value="-")
                sheet.cell(row=row,column=5,value="-")
                sheet.cell(row=row,column=7,value=filewrite)
                row+=1

                # Save the workbook to an Excel file
                workbook.save(excel_file_path)
                exit(0)

timer.set_interval(2, myData)

while True:
    blynk.run()
    timer.run()
```