APPLICATION OF INTERNET OF THINGS (IOT) ON CONTROLLED VERTICAL AGRICULTURE

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DECLARATION

I hereby declare that this degree dissertation entitled “Application of Internet of Things (IoT) on Controlled Vertical Agriculture”. I have submitted to the Office of School of Mechanical Engineering, Universiti Sains Malaysia, is entirely my original work prepared under the supervision of my supervisor. I have made due to acknowledgements to all ideas and information borrowed from different sources in the course of writing this dissertation. The results of this dissertation have not been presented or submitted anywhere else for the award of any degree or for any other purpose. There has no part of this dissertation has ever been published in any form before. I shall be solely responsible if any evidence is found against my declaration.

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Nazirul Asyraff Bin Rasidi

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Date: 28 May 2019

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LIST OF ABBREVIATIONS

IoT	Internet of Things
HHS	Horizontal Hydroponic System
VFS	Vertical Farming System
Wi-Fi	Wireless Fidelity
LED	Light Emitting Diode
GPIO	General Purpose Input Output
App	Application
SoC	System of Chip

ABSTRAK

Pada masa kini, terdapat banyak sensor yang telah diintegrasikan bersama rangkaian di pelbagai kawasan seperti peralatan rumah termasuk kawalan iklim, sistem kamera keselamatan dan juga kereta. Semua sistem ini memberikan banyak faedah kepada manusia untuk membantu dan memudahkan kehidupan mereka, namun majoriti sistem automasi/ kawalan di dalam konteks taman dan rumah tersebut samaada mahal, sukar untuk dilaksanakan atau semua alasan tersebut. Node MCU merupakan sumber pelantar terbuka Internet Pelbagai Benda (IPB) yang termasuk perisian di Wi-Fi ESP8266 sistem cip dan hanya memerlukan sedikit kuasa elektrik. Node MCU dilengkapi dengan pin antaramuka GPIO yang membolehkan input atau output berbeza yang diberikan kepada papan untuk mengendalikan pelbagai jenis fungsi seperti berkomunikasi dengan sensor atau menghidupkan litar. Menggunakan Node MCU, satu projek telah dibangunkan dengan rangkaian sensor tanpa wayar yang mampu dimiliki dalam sistem rumah hijau yang berkomunikasi dengan pelayan pusat di mana data sensor dikumpulkan. Data sensor akan dihantar ke aplikasi mudah alih untuk membantu manusia untuk memantau sensor melalui aplikasi mudah alih dan akan mengurangkan jumlah usaha manusia yang diperlukan dalam pertanian. Aplikasi mudah alih akan membolehkan orang ramai memantau kelembapan dan suhu di dalam rumah hijau. Selain itu, manusia juga boleh mengawal sistem pencahayaan dan penyiraman rumah hijau dengan menggunakan aplikasi mudah alih. Pengudaraan sistem juga dapat dikendalikan dengan menhidupkan atau mematikan kipas di dalam rumah hijau. Projek ini membolehkan orang lain yang berminat untuk membangunkan sistem ini lagi untuk membelanjakan lagi kefungsian dan kemungkinan pada masa hadapan sistem tersebut.

ABSTRACT

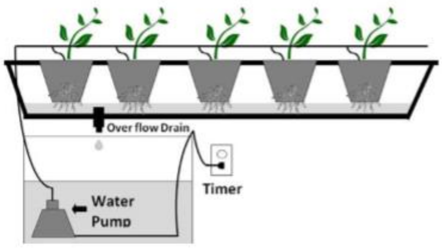
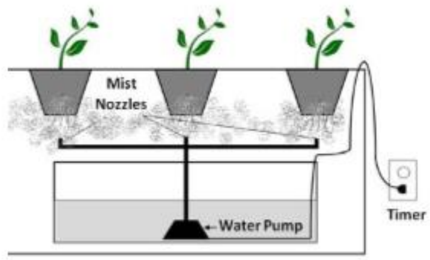
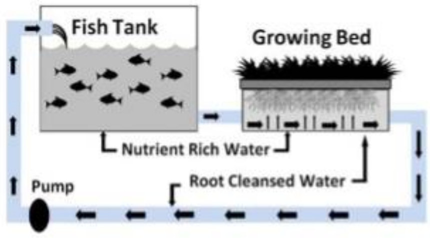
Nowadays, more sensors being integrated together in a network in many places such as home appliances including climate control, security camera system and automobiles. All of these systems give lot of benefits to the people which will help lives easier, however the majority of these automation/control systems in garden and home scenarios are either expensive, difficult to implement or all of those reasons. The Node MCU is an open source IoT platforms which includes firmware that runs on ESP8266 Wi-Fi SoC and only require a small amount of electrical power. The Node MCU equipped with GPIO interface pins which allow to have different inputs or outputs assigned to the board to handle various type of functions such as communicating with the sensors or turning on a circuit. Using Node MCU devices, a project has been developed with an affordable wireless sensor network in greenhouse system that communicates with a central server where the sensor data is collected. The sensor data will be sent to the mobile application to help people be easily monitor the sensors through the mobile application and will reduce the amount of human effort required in farming. The mobile application will allow the people to monitor the humidity and temperature inside the greenhouse. Besides that, people also can control the lightening and watering system of the greenhouse by using the mobile application. The ventilation also can be controlled by switching on or off the fan inside the greenhouse. This open source projects allows other interested people to develop the system further to expand the functionality and future possibilities of the system.

CHAPTER 1 INTRODUCTION

1.1 Overall Structure of The Project

Vertical agriculture are the practice of growing in vertically stacked layers which can use soil, aeroponic or hydroponic growing methods. It is more efficient because they grow 75 times more food per square foot then a traditional farm. Besides that, it's healthier and safer because no pesticides and no fungicides being used. Then, the water consumption of indoor farming is 90% less than outdoor farming. The most important factors for the quality and productivity of plant growth are temperature, humidity, and light. By monitoring these environmental parameters, the will provide valuable information on how each factor affects growth and how to maximize crop productiveness(Akkaş and Sokullu 2017).

Table 1.1: Types of Vertical Farming System[1]

i. Hydroponics The plant roots are submerged in the nutrient solution, which is frequently monitored and circulated to ensure that the correct chemical composition is maintained.	
ii. Aeroponics The most efficient vertical plant-growing system, using up to 90% less water than the hydroponic system. This system also takes more minerals and vitamins, making the plants healthier and potentially more nutritious.	
iii. Aquaponics The system is the same as the hydroponics system but combines the fish and plants in the same ecosystem. Fish are grown in indoor ponds, producing nutrient-rich waste that is used as a feed source for the plants in the vertical farm. The plants, in turn, filter and purify the wastewater, which is recycled to the fish ponds.	

The current monitoring system is by using the wired networks, the cables connected to the devices which need to be rearranged for every crop, so it is a waste of money and manpower(Pavithran 2016). Due to the wide growth of the greenhouse, a new intelligent monitoring system should be implemented by using the internet of things (IoT). By using IoT, a smart system can be built to control the climate, eliminating the need for manual intervention and monitor the temperature and humidity of the greenhouse with the help of sensors (light, humidity, temperature, soil moisture, etc.)

The cloud server can be created for remotely accessing the system after connected to the IoT. So, it will provide a new method for accessing the greenhouse information. The users can monitor the greenhouse conditions from anywhere. IoT-based smart agriculture is highly efficient when compared with the conventional approach.

1.2 Project Background

In this era, the world is preparing for the population explosion which reaches nearly 10 billion people according to the latest estimates. Thus, smart vertical agriculture with the help of the internet of things (IoT) is introduced in the agriculture field to diminish the land used which is more effective to grow plants. Besides that, this smart vertical agriculture also allows people to reduce and recycle the resources and automate processes with further cost reduction.

Most of the users would like to monitor and control the farming condition but with the limited knowledge of data management has forced them to investigate plant conditions with naked eyes. With the help of Internet of Thing (IoT), a smart vertical agriculture monitoring system can be implemented to collect the data and visualize it through a web-based application. Besides that, the system also will be used to control certain environmental parameters of the greenhouse. This method is more convenient to keep track of the vertical agriculture performance compared with the conventional approach. Therefore, a reliable environment for farming activities could be formed under controlled surroundings.

The monitoring system for the vertical agriculture greenhouse is made up of three major elements which are, numerous types of sensors works together with the system to collect a different kind of data such as temperature, humidity, soil moisture, etc. After that for the data transmission, sensors will communicate with the system wirelessly, through a microcontroller and a wireless module. A web-based application and also the mobile application will be implemented in monitoring the farming condition with an outstanding interface to deliver the information clearly with the aids of graph and figures(Shien Chin and Audah 2017). This application also will allow users to control some basic activities of the system; such as watering and lighting. Thus, users will be able to access all this information anytime, anywhere, with a computer or mobile device connected to the internet.

1.3 Problem Statement

In recent time, the farmers working in the farmlands are solely dependent on the rains for irrigation of their land. The farmers have been using irrigation technique through the manual control in which the farmers irrigate the land at regular intervals by turning the water-pump on or off when required. Most of the farmers would like to monitor and control the farming condition but with the limited knowledge of data management has forced them to investigate plant conditions with naked eyes. They may have to travel so far for switching on or off the motor. They may be suffering from hot Sun, rain and night time too. Besides that, the manual system also not efficient because time-consuming is higher and use lot of human power. Another disadvantage of the manual system is the farmer cannot monitor or control their farm when the farmers are at another place. Among the topics discussed above, there is very limited literature that only allows the user to monitor the temperature and humidity variations inside the greenhouse. Therefore, the main objectives of the present paper are to develop the temperature and humidity measuring system that can be remotely controlled using the mobile phone applications. This smart system will help the farmer by giving consistent data and increase efficiency. Then, human power and the time consuming will reduce.

1.4 Objectives

Throughout the project, a prototype of the vertical agriculture monitoring system will be developed, including all the hardware and software parts.

The objectives and goals of this project are:

a) To design a vertical agriculture system for indoor purpose.
b) To develop the temperature and humidity measuring system that can be monitored and controlled by using a mobile phone applications via Wi-Fi.
c) To remotely control the lighting, watering and ventilation system inside greenhouse using mobile phone applications via Wi-Fi.
d) To conduct experimental work to measure temperature and humidity variations inside the greenhouse.

1.5 Scope of The Project:

Generally, the main scope of this project is focussing on to design, fabricate and create a system of smart vertical agriculture with the help of the internet of things (IoT). The design and the fabrication structure of vertical farming are for the indoor purpose. This vertical agriculture is hydroponics. Then, a system also needs to create which it will measure and collect the temperature and humidity variations inside the greenhouse. Besides that, this system also will allow the user to switch on or off the LED, fan and water pump inside the greenhouse. Finally, the mobile application is used to monitor, display and control the temperature and humidity variations inside the greenhouse.

CHAPTER 2 LITERATURE REVIEW

2.1 Vertical farming system

Over the years, traditional farming for harvesting with the use of soil takes longer time to decompose making it prone to diseases and expensive. Vertical farming is a new method that is growing the crops in the controlled environments, with precise nutrients, temperatures, humidity, and light. The vertical farming is the solution for the people which is demand for space. There are many types of vertical farming that come in different shapes and sizes. The main thing about vertical farming is using a soil-free system(Birkby 2016).

Although a lot of studies have been made about crop production, there only a few comparisons between Vertical Farming System (VFS) and Horizontal Hydroponic System (HHS). Besides that, there only a little information which is available on whether VFS is a viable alternative to the HHS crop production system.

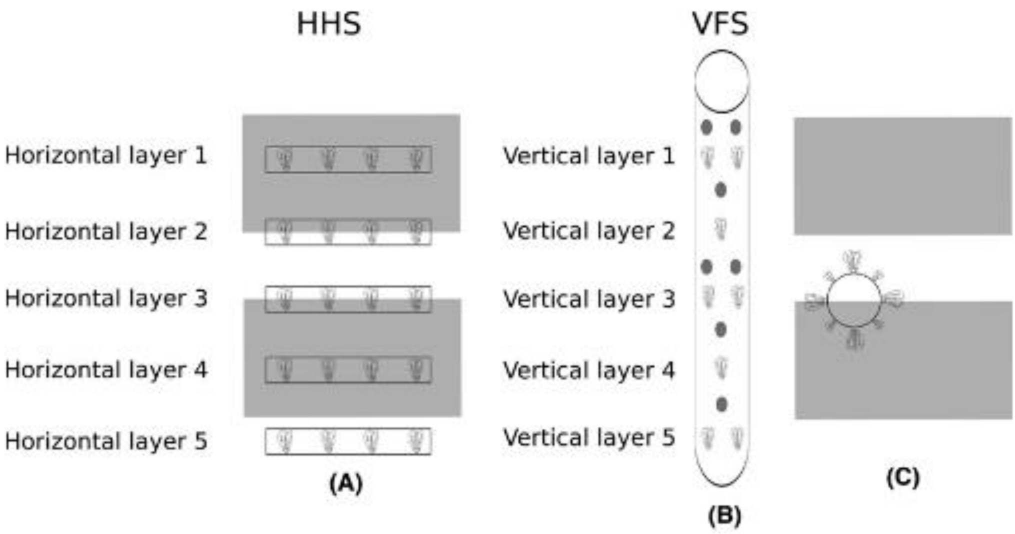


Figure 2.1: Comparison Between HHS and VFS[17]

An experiment has been made by (Touliatos, 2016 #23) to compare the productivity of the lettuce by using vertical farming system (VFS) and Horizontal Hydroponic System (HHS). The ***Figure 2.2*** shows that the VFS produced 13.8 times more crop per unit area compared to the HHS calculated as a ratio of yield (kg FW) to the occupied growing floor area (m^2).

Table 1. Comparison of the productivity of the vertical farming system (VFS) and horizontal hydroponic system (HHS).

Parameter	HHS	VFS	Result
Shoot fresh weight (g) Mean ± SE (n = 40)	138 ± 6	95 ± 6	$P < 0.001$*
Yield per occupied growing floor area[1] (kg $FW \cdot m^{-2}$)	6.9	95	VFS/HHS = 13.8
Number of plants per occupied growing floor area[1] (plant number m^{-2})	50	1000	VFS/HHS = 20

[1]HHS growing floor area: 0.4 m^2, VFS growing floor area: 0.02 m^2.
*Student's t-test on square root transformed data, t (78) = 5.656.

Figure 2.2: Comparison of the Productivity Between HHS and VFS[17]

2.2 Hydroponics system

Hydroponics is the method of growing plants using water and the essential nutrients required without soil instead the root system is supported by using an inert medium such as rock wool, clay pellets, peat moss, perlite or vermiculite[18]. This growing method is from the hanging gardens of Babylon, the floating gardens of the Aztecs of Mexico, and in older Chinese cultures (Resh, 1995). William Gericke of the University of California Berkley began promoting the growt of plants in a soil-less medium and coined the term hydroponics in 1929.

The hydroponics system gives a lot of advantages such as the system will be increased rate of growth of the plant. The plants will mature 25% faster and capable to produce 30% crop production compared to the soil system. Besides that, less water been used in this system because the system is enclosed thus less evaporation occurs[18].

Despite the fact that this system gives more advantages, a few disadvantages could be addressed as well. First, this hydroponics system will cost more than the soil system. Besides that, a lot of time is needed to set up the large scale of the hydroponics systems. Finally, the biggest risk with this system is to control and balance the pH and nutrient levels of the plants. The plants can die quickly if the pump failure because the growing medium cannot store water like the soil system[18].

2.3 Types of Hydroponics System

According to this journal(Tembe, Khan et al. 2018), the type of hydroponics system can be classified into six systems which is listed below:

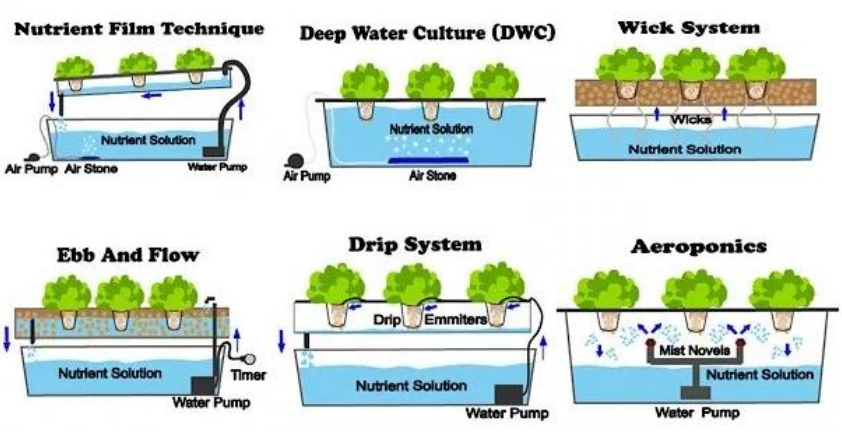


Figure 2.3: Types of Hydroponics System [7]

1. Nutrient Film Technique (NFT)

   The nutrient solution is pumped into slightly sloped channels that can hold a varied amount of plants. So, the nutrient solution flows through the channel, over the plant's root and back into the hydroponic reservoir. This system doesn't often use grow medium and foam net pot inserts are typically used to secure the plant. The NFT system is the most scalable because of the simple concept which makes it easy to set up the system. The NFT system work best for plants that have a small root system

Pros	Cons
Little to none growing medium used	Susceptible to pump failure and power outages
Recirculating, water saving	Not suitable for large heavy plants

2. Deep Water Culture (DWC)

   The plant's roots are suspended in the nutrient solution and the air is provided directly to the roots with an air stone or diffuser. Plants are placed in net pots with growing medium to help secure them. The DWC system works great for large plants with a big root systems or ones that grow an abundance of fruit.

Pros	Cons
Inexpensive, easy to build	Not suitable for large plants

Recirculating, water saving	Not suitable for plants with a long growing period.

3. Wick Hydroponics

The most simplistic system because requiring no electricity (passive system), pumps, or aerators. This system doesn't supply the plant with a lot of nutrient solution, this system only works well for small houseplants and herbs.

Pros	Cons
Very easy to set up	Not suitable for large plants
Great start for beginners	Not efficient in nutrient use

4. EBB & Flow/Flood & Drain System

Plants are placed in large grow beds filled with growing medium. The grow bed is flooded with nutrient solution until it reaches a certain point. A drain allows the water to only get a few inches below the top of the growing medium. This system also can be set up to drain with an automatic drain, removing the need for the pump to be set up with a timer. The EBB system works great for almost all types of plants.

Pros	Cons
Good for water craving plants	Susceptible to pump or timer failure, power outages
Easy to build	Require lots of growing media

5. Drip Hydroponics

The nutrient solution is pumped through tubes directly to the base of the plant. The drip emitters at the end of the tubes allow the nutrient solution to drip at an adjustable flow, saturating the growing medium. This system works great for a variety of different plants.

Pros	Cons
Simple to build and use	pH and nutrients fluctuations
More control of nutrient amounts and water schedule	More suited to larger gardens

6. Aeroponics

Plants are suspended in the air and nutrient solution is sprayed over the plant's root system. The nutrient solution is pumped into piping that's fitted with mist nozzles. As the pressure builds the misters spray the plant's roots and the solution falls back into the reservoir. The difficulty of this system is to make sure the mist nozzles able to spray the entire root system.

Pros	Cons
Plenty of oxygen for plant roots	More expensive than other types

Little to none growing medium and efficient water use	More vulnerable to dryness caused by power outages

2.4 Monitoring and Control System Using IoT

According to this paper by (Palande, Zaheer et al. 2018) called 'Titan Smartponics', a fully automated hydroponic system for indoor plant growth has been made. The system is using Arduino and Raspberry Pi microcontrollers. Two Arduino is used to take the data from sensors and send it to the third Arduino which is acts as a gateway in the IoT network. While the gateway is connected to the Raspberry Pi running a local server which makes the data available on the web interface. The system uses Arduino which is programmed to operate the sensors and light. While the system uses a Raspberry Pi is running a local server to automatically monitor the state of the server and restart it if necessary. A web-interface is used called Domiticz which will allow the user to monitor the data and control it.

Besides that, another project also has been made by(Nalwade and Mote 2017) which is a hydroponic system for tomatoes. The basic need for tomatoes hydroponic farming is shown in the table below. A control system is required to monitor and control those parameters. This system is by using Arduino Uno as a microcontroller, sensors, LED for lighting, motor for watering the plant and fan for cooling. Then, this system will automatically water the plant, maintenance of farm temperature at the required level, maintenance of nutrients pH level and electrical conductivity of nutrient solution at the required level and will provide required light for the farm. Besides that, this system also will automatically display all the parameter value on the panel and will send to the owner's mobile through SMS.

Next, (Tembe, Khan et al. 2018) also perform IoT based automated hydroponic system by using Arduino Mega as a controller to suffice the requirement of interfacing all the parameters together to perform in synchronization with the help of sensors. This system is automatically watering the plant to control the temperature and humidity of the system. This system also uses sprinklers to sprinkle the pH solution/nutrient solution/water in response to the humidity, pH and electrical conductivity sensors but this system has an extra system to control the pest inside the system by sprinkle organic pesticides. The sprinkles will activate when detecting pests on the plant. Then, the data will store and monitored on the cloud.

2.5 Conclusion

By referring to the (Palande, Zaheer et al. 2018), the system only allows the user to monitor and control the system by using the web-based interface called Domiticz. Then, a project from (Nalwade and Mote 2017) also a hydroponics system but it was designed not for indoor purpose. Besides that, the system also will display the data and only allow the user to monitor it through SMS. The users cannot control the parameters of the system. Lastly, (Tembe, Khan et al. 2018) was a great project which it's control solution/nutrient, water, humidity and pH of the plant. The system also can control the pest inside the system, but the problem is the system is automated. Thus, for this project, a mobile phone application will be developed to allow the user to measure and monitor the temperature and humidity variations inside the greenhouse. Then, the mobile application also will allow the user to control the LED, fan and water pump inside the greenhouse.

CHAPTER 3 RESEARCH METHODOLOGY

3.1 Introduction

A prototype for vertical agriculture is based on hydroponics used to grow plants. The structure is design for the indoor vertical agriculture purpose which vertically stacked as shown in ***Figure 3.1***. The light source from the LED light and water that was pump from the water tank need to be supplied to the plant. The fan is needed as a ventilation for the proper air circulation.

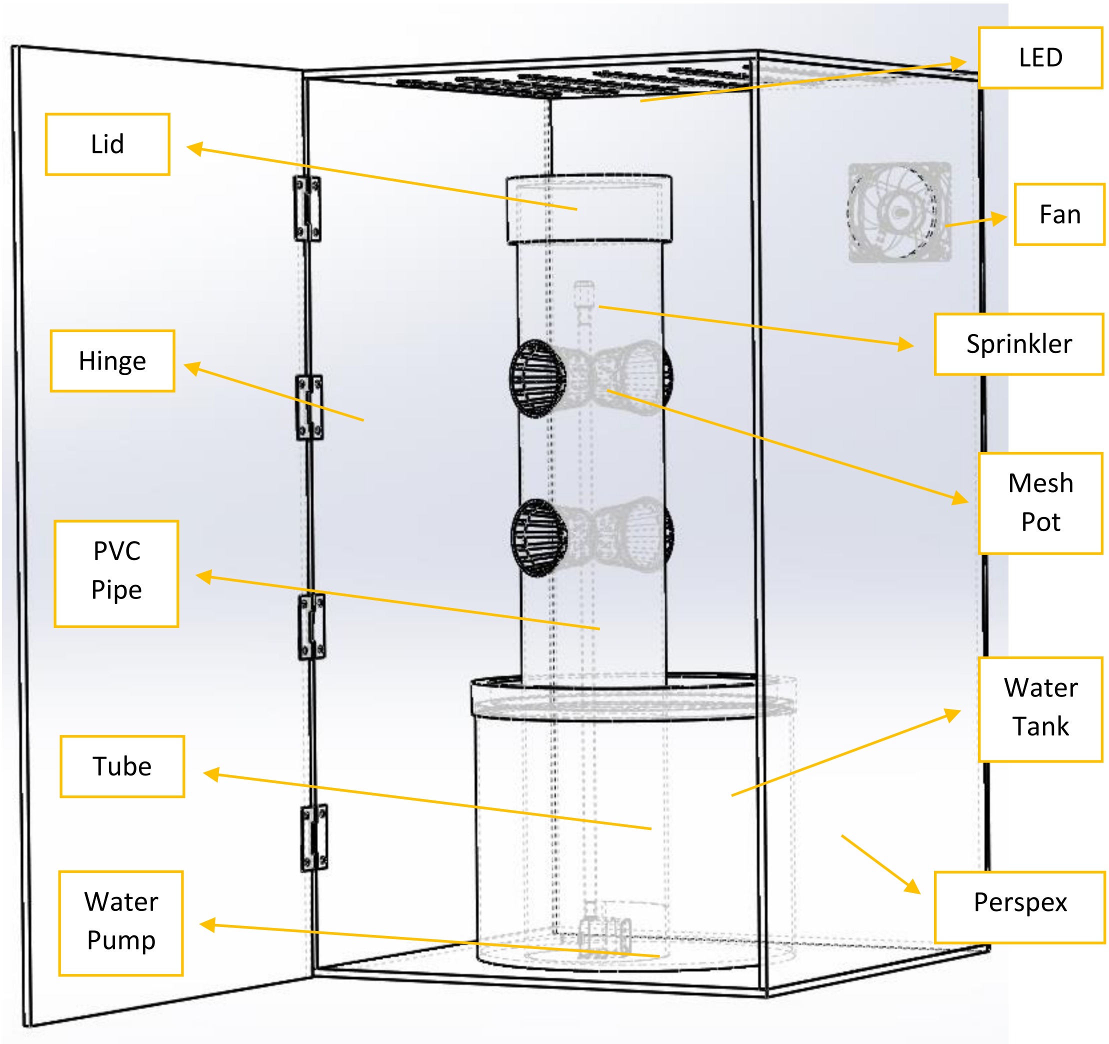


Figure 3.1: Vertical Agriculture System

The ***Table 3.1*** shows the list of the hardware components and its functions that being used in this project.

Table 3.1: List of Components and Functions

Component	Description
Node MCU	It's an open source IoT platform that includes firmware which runs on the ESP8266 Wi-Fi SoC and hardware which is based on the ESP-12 module.
Water Pump	12V DC waterproof pump is used to lift the water from the tank for watering the plant inside the greenhouse.
LED Strip	Provide light a source for the plant to carried out photosynthesis because the vertical agriculture is placed indoor.
Power Supply	Converts mains AC to low voltage regulator DC power for the use of the water pump and led lights.
Relay Module	To control the water pump and led light.
Temperature & Humidity Sensor (DHT22)	This sensor takes input from the surroundings and gives a digital signal as output.
Resistor	Resistors are used to reduce current flow, adjust signal levels, to divide voltages, bias active elements, and terminate transmission lines, among other uses.
AB Fertilizer	AB fertilizer is for drip irrigation, NFT and all type of hydroponic system that contains all primary, secondary nutrients and traces element.
Mesh Pot	Small plant pots made of plastic that are perforated all over to allow plant roots to grow through and into the hydroponic environment.
Rockwool & Cocopeat	The substrate to germinate the seeds.
Sprinkler Nozzle	Device to make the rainfall for watering the plants.
Tube	To transfer the water from the water tank.
PVC Pipe	The PVC pipe that consists of holes to holds the mesh pots.
Fan	As a ventilation for proper air circulation.

The monitor and control system for this project is modeled by using Node MCU which connects to the environment temperature/humidity sensor for getting the temperature and humidity level in the surrounding. The LED, fan and water pump also being connected to the Node MCU by using relay module because this using 12V. This system can be used to continuously analyze and monitor the temperature, humidity which is vital for the greenhouse system by using the mobile application which is Blynk via Wi-Fi. This application also allows the user to remotely control the LED, fan and water pump.

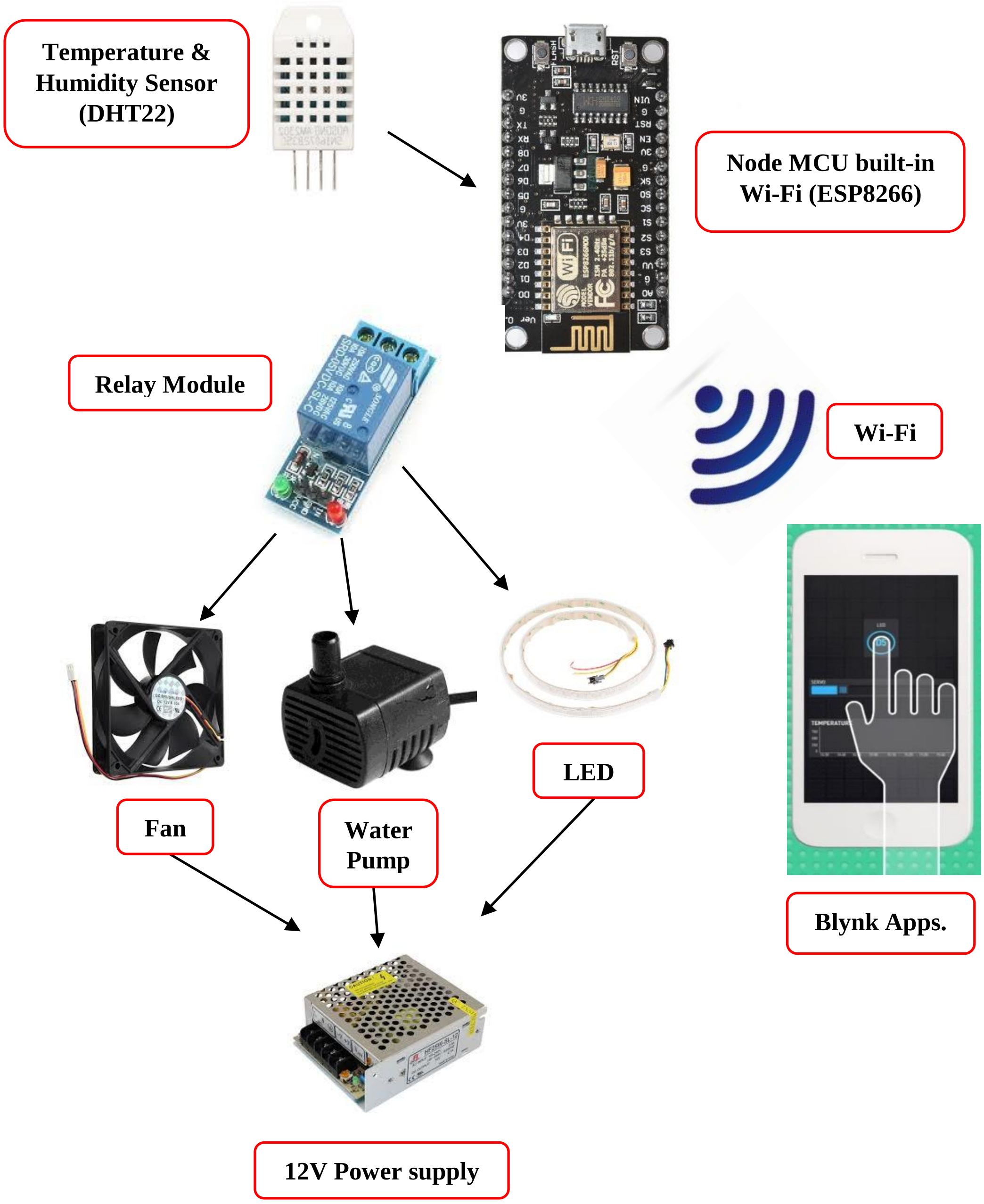


Figure 3.2: Block Diagram of the System

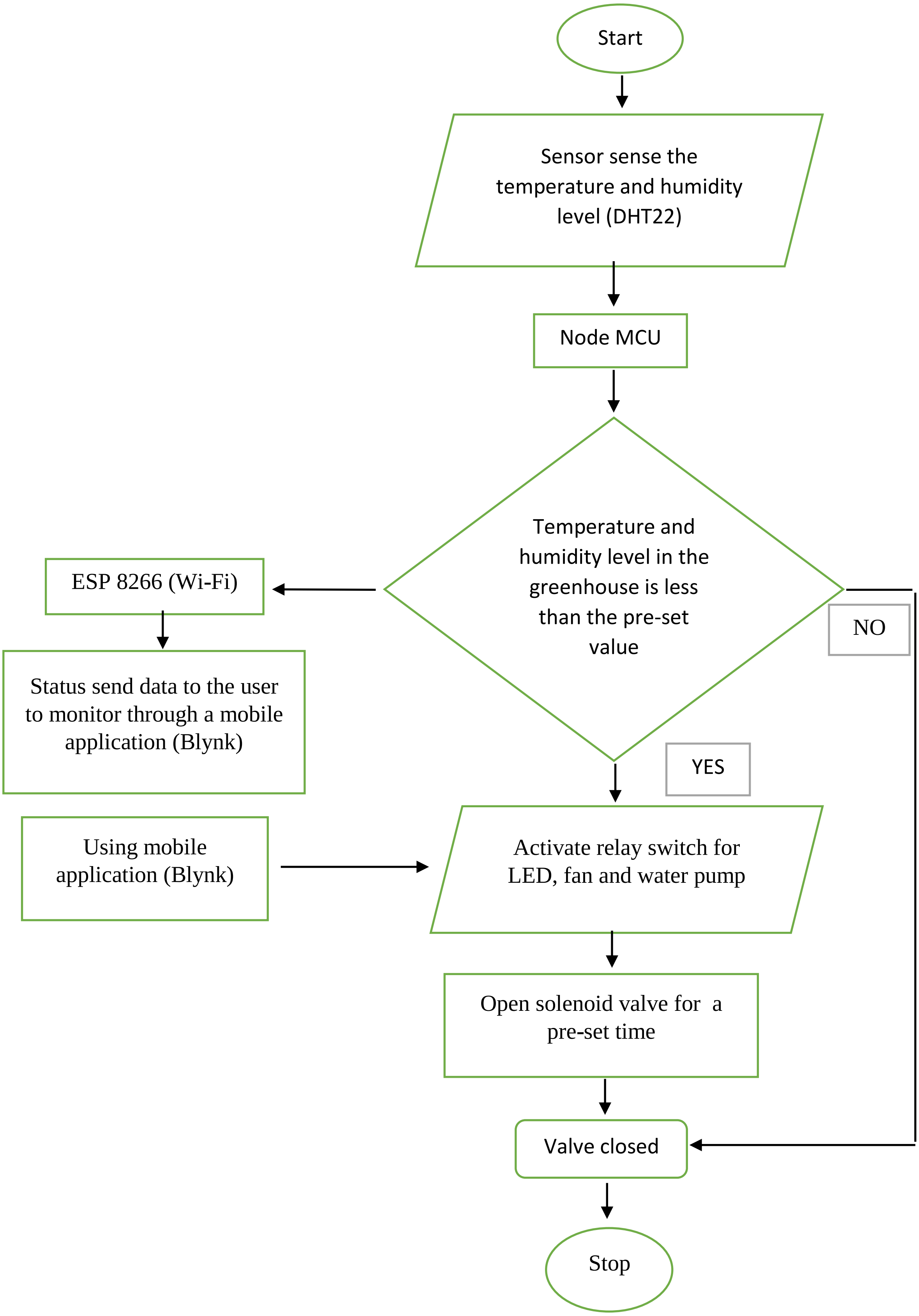


Figure 3.3: Flow Chart of the System

3.2 Design of The Vertical Agriculture

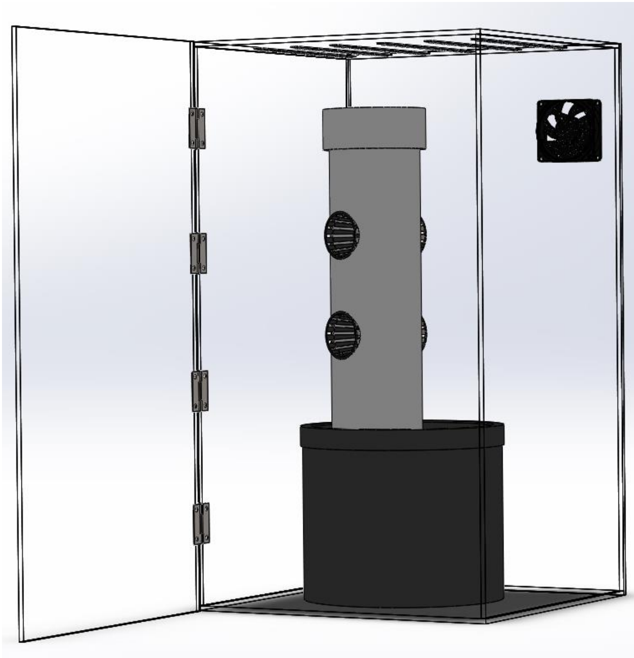


Figure 3.4: Design of the Vertical Agriculture

From ***Figure 3.4***, this design was chosen because of its less complex and ergonomics. The idea is to use a tube system with a pump to get water to the top layers. From there, with the assistance of gravity, the water will flow down back to the water tank. The size of the design is suitable for the indoor purpose because of less space required. The material being used is a single PVC pipe and a single tube to deliver water to the top level. Several holes are made around the PVC pipe to house the individual plants. The plants are housed in mesh pot to allow the water to flow through the root systems and the plants are grown at an angle of 45°. The water pump is used to suck the water in the tank and push upward. As the water is pushed upward, it will become rain and be watering the plants. After that, the water will fall back into the water tank.

The fast-growing plants and herbs are the best options for this design such as:

Table 3.2: Best Plants for Vertical Agriculture Design

Lettuce	Flowers	Tomatoes
Kale	Cabbage	Cucumbers
Chard	Basil	Eggplants
Mustard Greens	Cilantro	Peppers
Collard Greens	Mint	Strawberries
Spinach	Chives	Broccoli

Traditionally, the greenhouse is built with glass, but this comes with several disadvantages. The glass is heavy and required better frame construction than perspex. Besides that, the glass is easily broken and will give risk in a garden to the people. The glass is inexpensive if compared with the perspex, but extra precaution steps required to carry the glass.

Nowadays, the glass has been replaced with the perspex due to several advantages. The perspex is transparent as the final optical glass. Besides that, the perspex has a huge decrease in weight compared to the glass. The perspex is extremely strong with an impact resistance 6-17 times greater than glass. Another than that, the perspex is completely durable in all weathers and has excellent UV stability. This material was capable to look spectacular for 15-20 years because of non-yellowing material and also chemical resistance.

Table 3.3: Properties of Perspex

Property	Test Method	Unit	Value
General			
Density	ISO 1183	g cm^{-3}	1.19
Rockwell Hardness	ISO 2039-2	M scale	102
Water Absorption	ISO 62	%	0.2
Flammability	BS 476 Part 7	Class	3
	DIN 4102	-	B2
	NFP 92-507	-	M4
	UL94	-	HB
	ISO 11925-2	-	E
Optical Properties			
Light Transmission	ASTM D1003	% (3 mm)	> 92
Refractive Index	ISO 489 A	-	1.49
Thermal Properties			
Vicat Softening Point	ISO 306 A	°C	> 110
Coefficient of Thermal Expansion (Linear)	ASTM D696	x 10^{-5}. K^{-1}	7.7
Mechanical Properties			
Tensile Strength	ISO 527 (5 mm/min)	MPa	75
Elongation at Break	ISO 527 (5 mm/min)	%	4
Flexural Strength	ISO 178 (2 mm/min)	MPa	116
Flexural Modulus	ISO 178 (2 mm/min)	MPa	3210
Impact Strength – Charpy (unnotched)	ISO 179	kJ M^{-2}	12
Poisson's Ratio	ISO 179	kJ M^{-2}	0.38
Electrical Properties			
Surface Resistivity	IEC 93	Ω.m-2	> 10^{14}
Electrical Strength	IEC 243	kV.mm-1	15

The design consists of LED as a source for the plants to carry out photosynthesis. The PVC pipes or thicker drainage pipes being used as a central tower that consists of several holes at the interval to house the individual plants. The plants are housed in mesh pot which has the rockwool which acts as a substrate to allows the water to flow through the root system.

A single tube is connected to the pump for the watering purpose. The water is pump to the top layers and the water coming out from the sprinkler will become rain, thus will watering the plant. Then, with the assistance of gravity, the water will fall back to the water tank.

Then, a fan being used as ventilation to circulate the air by allowing the user to control temperature and humidity inside the greenhouse. The proper air circulation is needed inside the greenhouse to create uniformity in oxygen, carbon dioxide, temperature and humidity within the environment. This is to ensure each plant within the greenhouse receives the same atmospheric conditions as the environment. Besides that, the air movement is to simulate the wind in an enclosed environment. The wind serves to strengthens the cell walls of a plant's stem and directly influences the architectural integrity of plant growth.

a) Fabrication Process

Figure 3.5: Length of PVC Pipe

The PVC pipe is required to create a vertical agriculture system. The PVC pipe was cut to 61 cm with a diameter of 11.43 cm. The PVC pipe was cut by using hacksaw until the blade underneath the pipe. Then, by using a hot gun, heat the PVC pipe around one minute. A wood with a diameter 5 cm was pushed into the pipe at the heating region to make a hole for the housing individual plant.

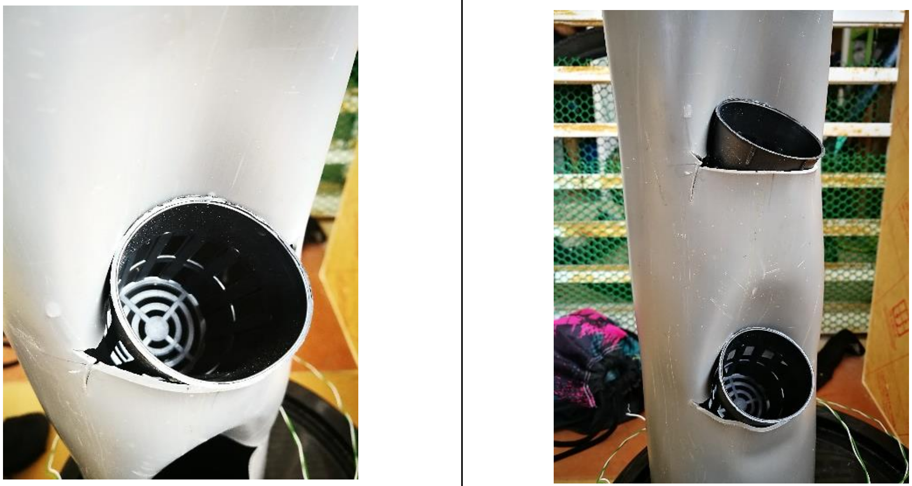


Figure 3.6: Diameter of Holes at the PVC Pipe

Four holes with diameter 5 cm were made with 12.5 cm distance separation. ¾ of the mesh pots were inserted into the hole. The lettuce seeds need to germinate first in the rockwool before transferred into this mesh pot.

Figure 3.7: Diameter of Hole at the Lid Water Tank

A hole was made with a diameter 11.43 cm on the lid of the beaker (water tank). The PVC pipe was inserted through the hole. This water tank also will hold this PVC pipe to keep stand vertically.

Figure 3.8: Sprinkler and Water Pump Attached to the Tube

A sprinkler nozzle was attached to the tube and the tube is inserted in the PVC pipe. At another end, the tube is attached to the water pump. The water pump will pump the water inside the water tank and will push the water upward. As the water is pushed upward, the water will become rain and watering the plants. After that, the water will fall back into the water tank.

Figure 3.9: Germinate Lettuce and Lemon in Rockwool and Cocopeat

The rockwool is needed as a substrate for the hydroponic system to absorb the nutrients. The lettuce seeds need to germinate first in the rockwool before transfer into the mesh pot. The tap water is used to germinate the seeds around 1-2 weeks. As the seeds start germinates, the fertilizer is provided as a nutrient to the plant.

Figure 3.10: Fan Installation for Ventilation

A hole with diameter 7.75cm was made at the back of the perspex and a fan was attached to the perspex. The purpose of this fan is as ventilation to circulate the air within the greenhouse and environment.

Figure 3.11: Dimension of the perspex

The perspex was cut into four pieces with the dimension of (70cm x 40cm) and two pieces with dimension (40cm x 40cm) by using a jigsaw. Then, the perspex was combined by using glue. Four hinges were attached to the front perspex as a door. On the top of the perspex, an LED strip was attached for the lighting purpose. This perspex is act as a greenhouse for indoor purpose.

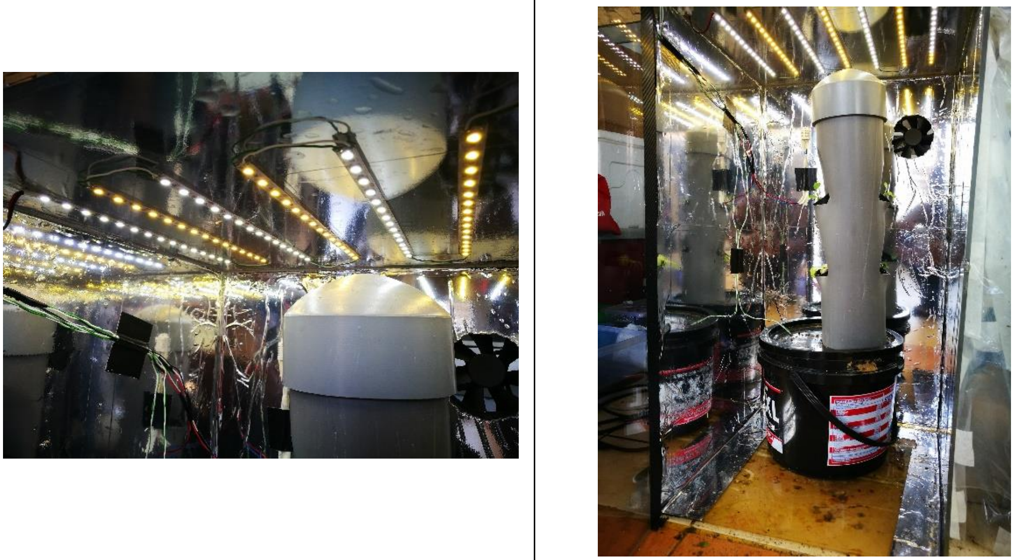


Figure 3.12: Complete Vertical Agriculture System

The ***Figure 3.12*** above shows the complete design and system of the vertical agriculture system. The system was completed fully functioning. The system consists of LED, fan, water pump, and temperature and humidity sensor.

b) Calculation

The ***Table 3.4*** and ***Table 3.5*** below shows that the characteristics of the tube and pump. The ***Table 3.6*** shows that the properties of water.

Table 3.4: Characteristics of Tube

Length	1 m
Inner Diameter	0.8 cm
Outer Diameter	1 cm

Table 3.5: Characteristics of Water Pump

Power Consumption	4.2 W
Rated Voltage	12 V
Rated Current	350 mA
Flow Rate, Q	6.6667e-5 m^3/s

Table 3.6: Properties of Water

Table C-1
Physical properties of water (SI units)

Temperature T (°C)	Specific Weight γ (kN/m³)	Density[a] ρ (kg/m³)	Dynamic Viscosity[b] μ (× 10⁻³ kg/m·s)	Kinematic Viscosity ν (× 10⁻⁶ m²/s)	Surface Tension[c] σ (N/m)	Modulus of Elasticity[a] E (× 10⁹ N/m²)	Vapor Pressure P_v (kN/m²)
0	9.805	999.8	1.781	1.785	0.0765	1.98	0.61
5	9.807	1000.0	1.518	1.519	0.0749	2.05	0.87
10	9.804	999.7	1.307	1.306	0.0742	2.10	1.23
15	9.798	999.1	1.139	1.139	0.0735	2.15	1.70
20	9.789	998.2	1.002	1.003	0.0728	2.17	2.34
25	9.777	997.0	0.890	0.893	0.0720	2.22	3.17

At the temperature of the water, T_{water} at 25°C

- Specific weight, γ = 9.777 kN/m^3
- Density, ρ = 997.0 kg/m^3
- Dynamic viscosity, μ = $0.890 \times 10^{-3}\ kg/m.s$
- Kinematic viscosity, υ = $0.893 \times 10^{-6}\ m^2/s$

The velocity of the tube, V is not uniform across section area. Therefore a mean velocity is used and was calculated by the continuity equation for the steady flow.

$$V = \frac{Q}{A} = \frac{4Q}{D^2\pi}$$

$$V = \frac{4 \times 6.6667 \times 10^{-5}}{(0.8 \times 10^{-2})^2 \times \pi}$$

$$V = 1.3263\, m/s$$

Where:

V = Fluid velocity m/s
Q = Flow rate m^3/s
A = Tube area m^2

The nature of flow in the tube by Reynold Number, Re is depending on the tube diameter, density, viscosity of the flowing fluid and the velocity of the flow.

$$Re = \frac{V \times D}{\upsilon} = \frac{D \times V \times \rho}{\mu}$$

$$Re = \frac{0.008 \times 1.3263 \times 997.0}{0.890 \times 10^{-3}}$$

$$Re = 11886.0324$$

Where:

D = Tube diameter m

V = Fluid velocity m/s
ρ = Density kg/m^3
μ = Dynamic Viscosity $kg/m.s$

The Reynold Number, Re is 11886.0324. Therefore the flow is turbulent since the Re≥4000.

The friction factor, f in fully developed turbulent tube flow depends on the Reynolds number and the relative roughness ε/D, which is the ratio of the mean height of the tube diameter.

Commercially available tubes or pipes differ from those used in the experiments in that the roughness of pipes in the market is not uniform and it is difficult to give a precise description. Equivalent roughness values for some commercial pipes are given in the ***Table 3.7*** as well on the Moody chart.

Table 3.7: Equivalent Roughness Values for Pipes

Equivalent roughness values for new commercial pipes*

	Roughness, ε	
Material	ft	mm
Glass, plastic	0 (smooth)	
Concrete	0.003–0.03	0.9–9
Wood stave	0.0016	0.5
Rubber, smoothed	0.000033	0.01
Copper or brass tubing	0.000005	0.0015
Cast iron	0.00085	0.26
Galvanized iron	0.0005	0.15
Wrought iron	0.00015	0.046
Stainless steel	0.000007	0.002
Commercial steel	0.00015	0.045

The material of the tube being used is plastic, therefore the equivalent roughness values of the tube are 0mm (smooth).

From the Colebrook equation, the friction factor, f is

$$\frac{1}{\sqrt{f}} = -2.0 log\left(\frac{\varepsilon/D}{3.7} + \frac{2.51}{Re\sqrt{f}}\right)$$

$$\frac{1}{\sqrt{f}} = -1.8log\left(\frac{6.9}{Re} + \left(\frac{\varepsilon/D}{3.7}\right)^{1.11}\right)$$

$$\frac{1}{\sqrt{f}} = -1.8log\left(\frac{6.9}{11886.0324} + \left(\frac{0/0.008}{3.7}\right)^{1.11}\right)$$

$$f = 0.0295$$

Therefore the friction factor, f is 0.0295.

While from the Moody chart, when

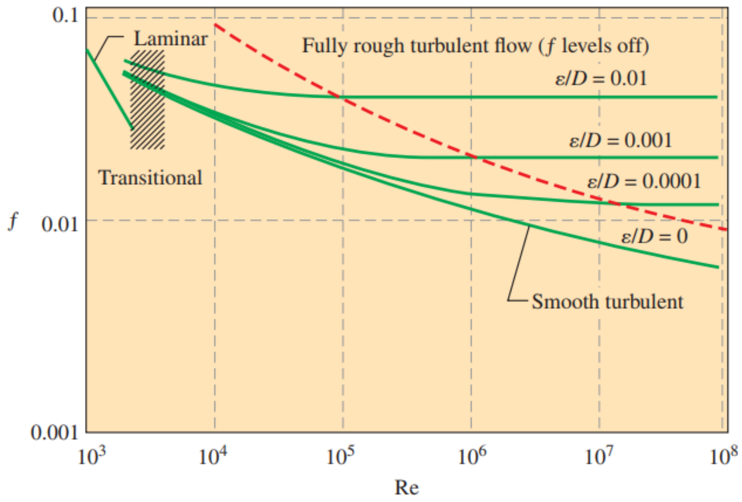


Figure 3.13: Moody Chart

- Relative roughness, ε/D : 0
- Reynolds number, Re : 11886.0324

Therefore the Darcy friction factor, f is 0.029.

The general equation for pressure drop, known as Darcy's formula expressed

$$\Delta P_L = \frac{\rho f L V^2}{2D} = \frac{8\rho f L Q^2}{\pi^2 D^3}$$

$$\Delta P_L = \frac{997.0 \times 0.0295 \times 1 \times 1.3263^2}{2 \times 0.008}$$

$$\Delta P_L = 3233.5586\ Pa$$

Where:

- Δp = pressure drop due to friction in the tube
- ρ = density