DEVELOPING A MINI AUTOMATED GREENHOUSE FOR INDOOR PLANTING

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A project report submitted in partial fulfilment of the requirements for the award of Bachelor of Engineering (Honours) Chemical Engineering

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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 **"DEVELOPING A MINI AUTOMATED GREENHOUSE FOR INDOOR PLANTING"** was prepared by **SIMON LEE YAN SHENG** has met the required standard for submission in partial fulfilment of the requirements for the award of Bachelor of ENGINEERINGS (Honours) CHEMICAL ENGINEERING at Universiti Tunku Abdul Rahman.

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ABSTRACT

The current studies of automated greenhouse systems are mainly focused on industrial scale projects. Hence, the operating conditions for irrigation system, ventilation system and artificial light source are require extensive studies in order to adapt the automation technology into the mini-greenhouse. The scope of this project is to develop an automated mini-greenhouse for indoor farming, which has the ability to control the greenhouse's environment such as temperature, air humidity, and soil moisture. Furthermore, the study also determines the effectiveness of artificial light (LED) on plant growth compared to natural sunlight. The utilisation of LED light in automated planting was able to promote the growth of *Allium fistulosum* (green onion), in terms of plant height and number of leaves, as well as natural sunlight applied in the traditional setup. The internal environment, in terms of temperature and air humidity of the automated greenhouse were well controlled compared with the traditional planting system, which depends on the weather. Furthermore, the study also found that a sprinkler system is a suitable irrigation system for small-scale planting and closely arranged plants such as green onions. The power consumption of the sprinkler system is lower for each irrigation circle (0.056 Wh compared to 0.167 Wh) and a shorter time is required per irrigation compared to a drip system (20 seconds compared to 30 minutes). Lastly, plant growth and development such as integrity, colour as well as the presence of pests are also included in the study. Based on the study, the specimens in automated mini-greenhouse show better results in terms of leaves' integrity, colour (greenish and bright) as well as the pests' control compared to traditional planting. Generally, the application of an automated mini-greenhouse, which has the ability to protect the plants from pests as well as weather conditions, provide better plant growth and development compared to traditional planting.

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C_i	*concentration of a medium inside the greenhouse*
G	*ventilation rate, m^3/s*
N	*air exchange rate, air change/h*
v_i	*air volume in greenhouse, m^3*
ρ	*density, kg/m^3*
P	*air specific humidity, kg/kg*
t	*time, s*
T	*temperature, ℃*

I.R	*Infrared*
CFD	*Computational Fluid Dynamics*
Covid-19	*Coronavirus disease 2019*

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CHAPTER 1

INTRODUCTION

1.1 General Introduction

In the past decade, automation technology has become a popular trend that has helped improve the work efficiency in many industries including the agriculture sectors. The implementation of automation in many sectors can assist people to control and perform works such as planting with reduced need of human workforce, especially for tasks such as irrigation and fertilising the crops. Furthermore, the spraying of chemicals throughout the planting area can be performed in a more effective manner, which minimises the cost stemming from wastage of chemical substances and crop losses. This can be done through round the clock inspection of plants to control diseases as well as defects (Mohd Saiful Azimi Mahmud, 2020).

In 2020, the recent Covid-19 pandemic has negatively affected many industries, which required ample manual labour including the food industry. Since Covid-19 is an infectious disease, it is common for frequent temporary closures of food production lines in the past two years to break the chain of infection. According to Malaysia's "MySejahtera" application, the R-value of Covid-19 in Malaysia has reached 1.04 with a total of 1.4 million confirmed cases as of 19 August 2021. Therefore, indoor planting can become a favourable option, which may help in reducing the frequency of leaving home to visit a grocery store for food or vegetables. However, since most Malaysians are practising work from home, manual indoor planting can be a troublesome daily chore to busy individuals. Hence, an automated design for a mini-greenhouse can make planting easier and time saving to encourage the public to adopt gardening at home. Along with the reduction of active human monitoring, the automated system can also be useful to grow plants indoors where there is limited access to land or space,

The studies on global population growth indicate that the total global population is expected to reach about 9.73 billion people in 2050. The number also revealed that the demand for food supplied by the agriculture sector would also increase. Furthermore, climate change is expected to become one of the main factors to the retardation of food production. According to the studies, climate changes that affect the production of food can lead to an additional 120 million people at the risk of malnourishment (FAO, 2017).

At present, urbanisation and industrialisation have continuously consumed available land for economic and living purposes. This situation has led to a reduction in agricultural land to produce the necessary products such as vegetables, fruits and medical plants. At the same time, the population is increasing year by year, which also constitutes a tremendous pressure on agricultural production due to the increase in demand (Anil, et al, 2006). Hence, the study of automated greenhouse planting is essential to increase the efficiency and productivity of the agricultural sector.

Greenhouse is a protection structure that is designed to protect the plants from the changing of weather or climate, which can cause the plants to wither due to the excessive cold or heat (Singh et al., 2008). In addition, the greenhouse planting associated with automated technologies are essential to monitor the planting parameters such as temperature and humidity to overcome the climate changes issues, where the temperature and the humidity can be controlled at certain levels via automated ventilation system to suit the plantation of several types of plants throughout the year. Furthermore, the greenhouse is usually designed to isolate the crops from the external environment. Hence, the internal environment that is suitable for different type of crops can be created inside the greenhouse. In the modern era, the greenhouse was further improved by the implementation of an automated system. The automated system is specialised in controlling the environment for plant growth by controlling the temperature of the planter's surroundings, which helps plants survive throughout the year especially in countries with four-seasons and during climate changes.

1.2 Importance of the Study

Currently, the world is facing an extremely grievous issue – the Covid-19 pandemic. The pandemic has brought many negative effects including health issues as well as economic issues. Many industries were forced to shut down temporarily or even permanently in order to survive or avoid further loss due to this deadly virus. Therefore, this situation has caused the losses of manpower especially on man plantation as well as harvesting in the agricultural industry. Hence, the indoor planting system is essentially to provide a continuous supply of vegetables or herbs as food. At the same time, the automated system that is able to simplify the daily tasks for planting activity is an important element for modern individuals to accept and start indoor planting. The simplification of manual works on plantation by automated technologies is suitable for current fast-paced society, where people are able to gain the reward from planting with minimum daily time consumption.

The global demand for agricultural products, especially food products, is expected to increase in the future due to the increase of population, and it has placed the agricultural sector under massive pressure. Hence, food production and supply are now one of the top issues that people must resolve in order to fulfil the demand in 2050. The recent study found that about 275 million hectares of land are being utilised for irrigated crops throughout the world. Meanwhile, this area has shown a growing trend at an average annual rate of 1.3 %, accounting for only 23 % of the cultivating land area. However, to fulfil the food demand in 2050, about 70 % increment of global food production has to be achieved associated with an increase of 38 % of farmed land globally (Aznar, et al., 2020).

Nowadays, greenhouse technology has already become a trend in global agriculture activities, where in the United State of America, around 4000 hectares of land were utilised as a greenhouse for floriculture with annual income of more than 2.8 billion USD. Furthermore, Spain and Italy have also utilised about 25,000 hectares and 18,000 hectares of land respectively for greenhouse and mainly use for planting the crops such as vegetables and fruits (Pandey and Pandey, 2015). Hence, the study on greenhouse associated with automated technologies are important to achieve the sustainability of food production.

1.3 Problem Statement

The current study of automated greenhouse mainly focuses on industrial scale, which involves large areas. To adapt the functions into the mini-greenhouse such as the irrigation system as well as the ventilation system, some study on the operating modes are required. For the irrigation method, the information for the usage of water, efficiency as well as feasibility of the method are still insufficient for small-scaled greenhouse. Although irrigation methods such as a sprinkler system and drip system are well adapted to commercial planting, further study for the information stated above is still required for a mini-greenhouse. Furthermore, the information in terms of operating mode for ventilation of the system, especially active ventilation system is also insufficient for small-scaled indoor greenhouse. Most of the ventilation fans for industrial greenhouse are operated continuously in order to maintain the temperature and humidity inside the greenhouse. Since, the mini-greenhouse is designed for indoor planting; the temperature and humidity are relatively constant. Therefore, the study for optimum operating mode for small scaled indoor greenhouse is required.

There are several parameters that will be focused on this project such as irrigation system, ventilation system and lighting system. Firstly, manual irrigation systems are the most simple but effective method to water the crops. However, this traditional irrigation method also posed with some critical drawbacks that could affect the efficiency in planting process such as high labour intensity, time consuming as well as the clogging of the equipment can occur if no proper maintenance is given to the equipment (SSWM. Info, n.d.). According to Patil, et al. (2018), automated dripping irrigation methods have the ability to reduce the water wastage up to 60 % compared to traditional and mud digging methods. Hence, the automated irrigation methods will be focused in this project to overcome the drawbacks of traditional irrigation methods.

Furthermore, a ventilation system is essential to maintain the optimum environment for the crops to grow at the same time improving the overall efficiency of the greenhouse. Ventilation system is also important in temperature and humidity regulating within the greenhouse (nsw. gov, n.d.). In our country Malaysia, the typical temperature range throughout the year is from 28 ℃ to 32 ℃ while the average rainfall is about 2500 mm at Peninsular Malaysia (Weather and Climate, n.d.). Hence, passive and active ventilation are important to avoid the excessive heat as well as humid build up in the greenhouse. According to Hatfield, et al. (2015), every plant species has their own temperature range for growing. When temperature exceeds the temperature range of the specific plant, irreversible effects to the plant can occur. For example, a maize plant has the optimum temperature range of 25 ℃ to 30 ℃. The study found that, if the temperature were increased to 35 ℃, the overall growth rate of the kernel was reduced and the effects were irreversible even though the temperature is lower down back to 30 ℃.

Nevertheless, light is the key element for growing the plants. However, for some four-seasoned countries, the light intensity reaches the minimum when it comes to winter. Low light intensity will significantly reduce the plant agronomic traits and inhibit photosynthesis process as well as carbon and nitrogen fixation. This condition can further lead to slow growth, reducing the weight of lead and buds. Moreover, the quality of the plants will also reduce in terms of starch and sugar levels of certain crops such as eggplants, grapes and rice (Zhu, et al., 2017).

1.4 Aim and Objectives

Greenhouse technology is a technique to create an optimum environment for planting. The aim of this project is to develop a simple, automated and affordable mini-greenhouse prototype for indoor planting of herbs. To achieve the aim, the objectives of this project are to:

i. Design an automated mini-greenhouse for indoor farming using a microcontroller (Arduino MEGA 2560) to control temperature, humidity and soil moisture.

ii. Determine a suitable setup in an automated mini-greenhouse (irrigation method and light source) for indoor planting of culinary herbs such as *Allium fistulosum* (green onion) based on overall plant health and development (number of leaves, plant height, colour and presence of pests).

iii. Determine the performance of indoor planting using the automated mini-greenhouse compared to traditional planting of *Allium fistulosum* (green onion).

1.5 Scope and Limitation of the Study

The scope of this study was limited to a few important parameters such as irrigation system, ventilation system and lighting system. Firstly, the temperature and humidity of the greenhouse were controlled by a proper ventilation system. The ventilation system such as passive ventilation and active ventilation were included in this study to identify the stability in terms of temperature and air humidity of mini-greenhouse compared to natural planting setup.

Since watering is one of the major tasks in the planting routine, the irrigation system for the greenhouse was designed to be automated. In addition, there are a few types of irrigation methods such as spraying and dripping methods. The efficiency and performance of both methods were focused in the study. Next, the soil moisture was detected by using a soil moisture sensor and coordinated with the irrigation system to control the water flow to the plants.

There are a few limitations in this study. Firstly, the mini-green house was assembled manually by using acrylic sheets. Hence, the air tightness is not perfect. Furthermore, for the drip system, the study was conducted with limited professional equipment and apparatus. Hence, the water output of each irrigation circle was fixed to be the same as the sprinkler system and only the working period of the pump was compared. Moreover, in order to avoid the effecting of different amounts of fertiliser affect the growth of specimens, the study was conducted without providing fertilisers in both setup.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Greenhouse automation has become a popular trend adopted in growing plants or crops. The investment of automated systems can significantly increase the efficiency and reduce the dependency on manpower. Since the Covid-19 pandemic is still ongoing, the food supply chain, which supplies vegetables and herbs were affected. Therefore, personal indoor plantations can help the community to grow and manage their own food source such as vegetables or herbs to fulfil the requirement of a balanced diet (Sharma, et al., 2020). An automated indoor planting system can simplify the daily routine on the planting with only the minor tasks required per week to grow plants.

However, further study is required to integrate automated technologies with a mini-greenhouse to fit indoor planting. The topics of interest to help develop an automated mini-greenhouse prototype include background knowledge on irrigation system, lighting system, ventilation system, soil moisture as well as the temperature and humidity of the environment for indoor plant growth.

2.2 Irrigation System

Irrigation system is the process where the water is supplied to watering the plants or crops in agricultural activities. The process can be done by using pipes, sprinkles and water pumps (Conservation Energy Future, n.d.). Since water is one of the basic requirements for living organisms including plants. Therefore, the efficiency of the irrigation system is important to ensure that the water that supplies to the plants is on point. Furthermore, compared to outdoor planting, indoor plantings do not experience weather changes, where there will be no rain water as an external water supply. Hence, the water supply for the indoor planting has to be fully artificial with the implementation of an automated system. There are a few common irrigation systems available to fulfil the requirement for different types of plant and crops. In this project, two methods will be investigated, which are the dripping method and spraying method.

2.2.1 Drip System

Dripping irrigation method is one of the advanced watering systems. This method has the function to supply water and fertiliser mixture at critical areas (near the root of the plant) only. The water does not spray randomly; instead, the right amount of water and fertiliser will be distributed to each plant drip by drip in order to keep the soil in moist status. Furthermore, the dripping method has the ability to supply the water and fertiliser to the plant or crop according to the daily needs and concentrate to the critical zone of each plant (Shareef and Ma, 2019). **Figure 2.1** illustrates the dripping irrigation system that applies for commercial planting.

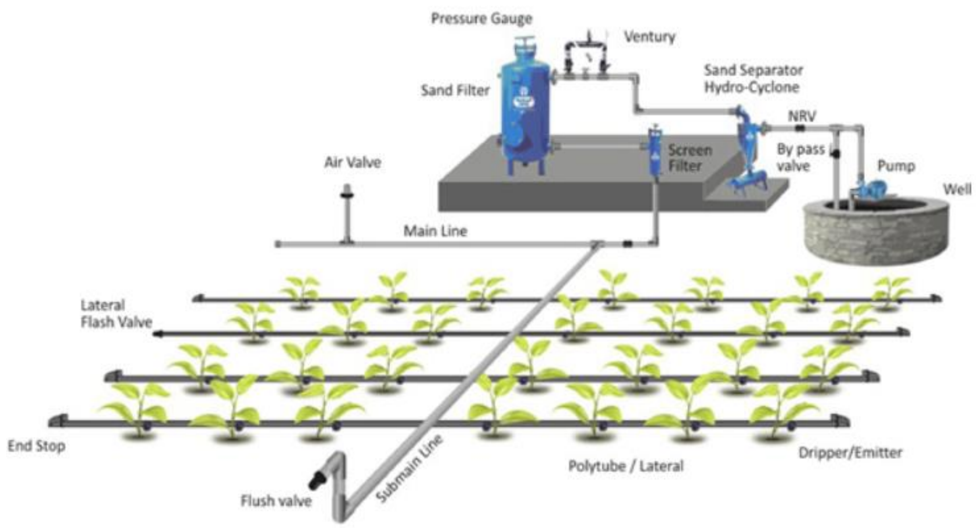

Figure 2.1: A Professional Dripping Irrigation System.

(Plantations International, n.d.)

The advantage of dripping irrigation method is the high efficiency of water utilisation. There are two factors that contributed to the high efficiency of water use. The primary factor that contributed to this advantage is the ability of drip system that able to distribute the water directly to the root zone of each plant. Therefore, it minimises the evaporation and also reduces the water reach to the non-benefits zone, where the water cannot be utilised by the plants. Secondly, the cost for the watering process can be reduced. Since the water is supplied drip by drip to the plant, a specific amount of water per day that is needed by the plant can be achieved on point by controlling the amount of water. The controlling is much easier compared to other methods due to the water flow being relatively slow. Furthermore, the effectiveness of water usage for the dripping method is highest (85 % to 95 %) compared to the sprinkler method and surface method, which has the maximum effectiveness at 80 % and 70 % respectively (Shareef and Ma, 2019).

However, this method has some drawbacks in terms of cost as well as skills. The drawbacks are:

- High initial cost in developing and installing. Since this method requires several technologies to control the flow of the water to meet the daily requirement for different types of plant, a few automated systems are required.
- Since the method involves numerous technologies, therefore, the users must possess some professional knowledge and skills to carry out the project.
- Furthermore, clogging and damages on the equipment especially for pipes are more likely to happen compared to spraying methods. It is because the dripping method always performs together with fertilising. The small particles inside the water could accumulate at each outlet (small holes for water dripping) of the pipes, which can lead to pipe clogging. (Shareef and Ma, 2019).

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2.2.2 Sprinkler System

Sprinkler irrigation methods perform the watering process by mimicking rainfall. This method is able to spray water with large area coverage to the plants or crops. The water will be pumped to the plants though the pipes and sprayed into the air via multiple sprinklers to create small water drops similar to natural rainfall (FAO, n.d.). **Figure 2.2** illustrates the sprinkler irrigation method.

Figure 2.2: Sprinkler Irrigation Method

(SSWM. Info, n.d.)

The advantages of the sprinkler irrigation method are:

- The equipment and overall setup of this method is affordable and requires minimum professional skills compared to dripping methods.
- Since this method involves less equipment, it is actually easier in terms of mechanisation as well as automation.
- This method also does not consume large space and relatively less in terms of land losses.

However, this method also faces some drawbacks such as:

- High operating cost due to high water pressure is required to supply the water evenly throughout every sprinkler at the farm.
- The water that is sprayed to the air will be affected by the winds, which can lead to water losses.
- Water with high amounts of impurities such as salt and sand can cause problems with the sprinkler for example clogging.

(Khanam, n.d.)

2.3 Light System (Artificial Light)

Among the basic requirements for plants to grow, light source is the primary factor that triggers the photosynthesis process in all the green leaf plants. Therefore, the quality and quantity of light are important factors, which impact plant growth in terms of morphogenesis and differentiation of plant cells, tissues and organs. The growth of plants is strongly dependent on the light wavelength that reaches the surface of the plant. The light quality refers to the red and blue lights that give the most impact on the growth, as they are the primary energy source for the photosynthetic CO_2 assimilation in plants. However, the studies also prove that green light has an effect on the plant growth as well (Chen, et al., 2014).

The two most common light sources, which are fluorescent and LED light that are usually applied in plant cultivation. Therefore, it is important to study these light sources to identify the advantages and drawbacks, which can affect the plant cultivation for indoor plant cultivation.

2.3.1 Fluorescent Light

Fluorescent light is a type of artificial light source that contains gases inside the lamp tube such as mercury and noble gases (argon, xenon, neon and krypton). The gas pressure inside the lamp tube is relatively low, about 0.3 % of atmospheric pressure. By being connected to the electricity, the electrons of these gases inside the lamp tube will get excited and produce a mixture of visible and ultraviolet light emissions. The typical wavelength of fluorescent lamps is around 400 to 700 nm. According to Cristopher, et al. (2010), the major emission lines of fluorescent lamps occurred at 544 nm and 611 nm, which correspond to the green and orange colour zones. However, the emission of the infrared zone (about 700 nm) shows a very low intensity. **Figure 2.3** shows the schematic diagram for a fluorescent lamp.

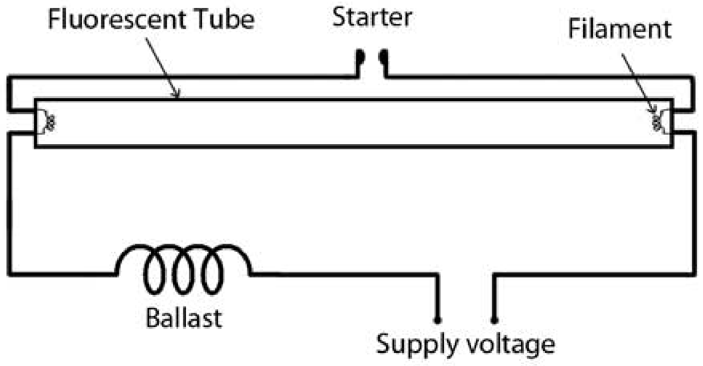


Figure 2.3: Schematic Diagram for Fluorescent Lamp

(Circuits Tune, n.d.)

There are a few types of fluorescent light, such as compact fluorescent lights (CFLs) and cool white fluorescent tubes. According to Kommareddy and Anderson (2003), cool white fluorescence has the emission of light with a significant wavelength from 400 nm to 700 nm. However, the range of 400 nm – 500 nm shows a significant value in terms of irradiance, which is 1.47 W/ m^2 or 25 % of overall emission. Furthermore, the light emission from this type of fluorescent lamp is stronger in the blue region, which benefits plant growth. Furthermore, this type of lamp is inexpensive and easy to apply for a mini-greenhouse.

2.3.2 LEDs Light

Light-Emitting Diodes (LEDs) are solid-state semiconductor diodes that are able to release the energy in the form of photons after receiving a certain amount of voltage. It is also an ideal lighting system for plant cultivation, which artificial light system is required (Paucek, et al., 2020). Furthermore, LED lights can achieve the spectral control, which allows the wavelength of the light to be synchronised to the plants requirement. The peak of the wavelength of the LED lights is about to vary from 250 to 1000 nm. **Figure 2.4** shows the schematic diagram of the LED bulb.

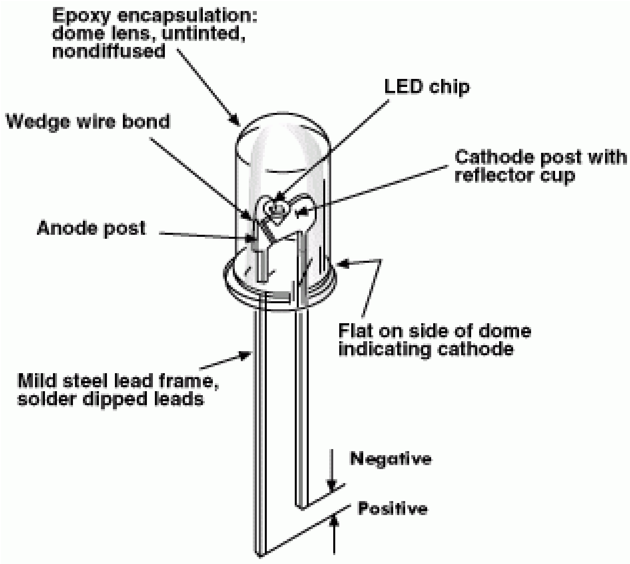


Figure 2.4: A Single LED Light Bulb

(Marian, n.d.)

According to Olle and Viršilė (2013), the wavelength and light quantity applied on green vegetables will directly affect photosynthesis, growth as well as nutrition value. For example, when far-red light (700 - 740 nm) were used to cultivate baby leaf lettuce, the overall chlorophyll concentration for the plant is lower by 14 % compared to white fluorescent lamps. Furthermore, the concentration of anthocyanin and carotenoids in lettuce plants under far-red light also shows a value, which is lower by 40 % compared to the same species of plant under white fluorescent lamp. However, if the wavelength applied to the lettuce plant is lowered to between 625 and 700 nm, which falls under red light condition, the phenolic concentration is able to achieve an increment of 6 % (Olle and Viršilė, 2013).

The major advantages of applying LED light in a mini-greenhouse are as follows:

- LED lighting is more energy efficient compared to other types of lighting systems. The luminous efficacies of phosphor-converted LED can achieve as high as 200 lm/W with the standard operating current density of 35 A/cm^2 compared to incandescent light and fluorescent tube at 20 lm/W and 104 lm/W respectively.

- LED light has the ability to distribute the light uniformly. This ability encourages uniform illumination over an area so that each of the plants in the mini-greenhouse can receive a similar amount of light for better growing.
- Furthermore, LED light is excellent in product life. A typical LED light has a lifetime of between 30 000 h to 60 000 h compared to fluorescent light, which has only about 8000 h to 10 000 h (Lighting Manufacturer, n.d.).

However,the application of LED light also has a few drawbacks such as:

- LEDs do not produce heat to the surrounding. However, the heat does build up at the semiconductor of the LED device. Furthermore, the wall-plug efficiency of LEDs falls in between the range of 5 % to 40 %, which means the remaining energy (60 % to 95 %) is lost as heat. Moreover, overheating in semiconductors will also reduce the lifetime of LEDs.
- The initiating cost of a mini-greenhouse with LED light system will be high due to LEDs being usually more expensive compared to other light systems (LEDs Magazine, 2005).

2.4 Ventilation System

The ventilation system in a greenhouse is an open channel that allows air exchange between the outer atmosphere and internal space of a greenhouse. Furthermore, the ventilation system is also important when it comes to greenhouse temperature and humidity regulation. The open channel allows air circulation and brings excessive heat as well as moisture, which have built up inside the greenhouse to the outer atmosphere. Moreover, a good ventilation system can help in preventing crop mineral depletion as well as diseases caused by fungi (Flores, eat al., 2014).

There are various types of ventilation systems available to fulfil different climate and atmospheric conditions. Among numerous ventilation modes, natural ventilation and fan-induced ventilation are the most common. Natural ventilation is a type of passive ventilation system that works by allowing air movement to keep the indoor temperature as low as possible compared to the outside temperature of a greenhouse. On the other hand, fan-induced ventilation, which can be considered as forced ventilation encourages the air flow by using mechanical equipment such as fans to regulate the temperature and humidity of the greenhouse (Mohd. Akrami et al., 2020).

2.4.1 Natural Ventilation

Natural ventilation normally required an opening at the top of a greenhouse. The basic principle for natural ventilation is based on the pressure differences that are created by the wind and temperature gradient between the inside of a greenhouse and its outer atmosphere. The experiment will be carried out separately in order to identify the effect of ventilation for each parameter such as wind-induced force and thermal buoyancy effect (Wang and Deltour, 1998).

Boulard and Draoui (1995) conducted an experiment, in order to identify the air exchange rate of natural ventilation of a greenhouse. The methods, which are used to identify air exchange in the greenhouse are decay rate method, continuous enrichment and water vapour balance. The results were shown in **Table 2.1**.

Table 2.1: Air Exchange Rate Data set for each Measurement Method (Boulard and Draoui 1995)**.**

Method	**Medium**	**Number of Measurements**	**Crop in the Greenhouse**	**Min and Max Angle of Opened Vent, θ^o**	**Min and Max Air Exchange Rate, h^{-1}**	**Min and Max in Temperature Different, $T_i - T_o$, K**	**Min and Max Wind Velocity, ms^{-1}**
Decay Rate	N_2O	90	Tomato	0 ~ 48	1.86 ~ 48	-2 ~ 12	0 ~ 8.2
Continuous Enrichment	CO_2	90	-	0 ~ 30	0 ~ 30	1 ~ 10	0.1 ~ 7
Water vapour Balance	Water Vapour	281	Tomato	0 ~ 20	0.5 ~ 20	0.7 ~ 12	0 ~ 10

From **Table 2.1**, continuous enrichment methods do not apply to any crop in the greenhouse, due to carbon dioxide being consumed by the plants and affecting the results. Therefore, an empty greenhouse was used to conduct the measurement. For decay rate method, the equation that use to identify the air exchange rate is:

$$C_i(t) = C_i(t_o)e^{-(N(t-t_o))} \tag{2.1}$$

Where $C_i(t)$ is the concentration of medium inside the greenhouse at time t and N is the air exchange rate or can be represented by the equation:

$$N = \frac{3600G}{v_i} \tag{2.2}$$

Where G is ventilation rate, m^3/s and v_i is the air volume of the greenhouse. For the water vapour balance method, the measurement is conducted by measuring the air specific humidity inside and outside of the greenhouse. The equation can be represented by:

$$\rho v_i \frac{dp_i}{dt} = \rho G(t)\big(p_o(t) - p_i(t)\big) + T_i(t) \tag{2.3}$$

Where $p_i(t)$ is the inside greenhouse air specific humidity, kg/kg and $p_o(t)$ is the outside greenhouse air specific humidity, kg/kg.

For continuous enrichment methods, the carbon dioxide concentration measurement for inside and outside of the greenhouse were assisted by I.R. analyser BINOS with 0-1000 ppm scale (Boulard and Draoui 1995).

From the experiment, the normalised air exchange rate showed a linear relationship with the opening angle of the vent. However, the experiment also shows a minimum effect of wind velocity to the ventilation due to low airflow we are usually facing at the experimental area. Furthermore, the wind direction also shows an independent relationship with air exchange rate in the greenhouse, where the direction of air flow does not affect the ventilation efficiency.

2.4.2 Fan Induced Ventilation

Fan-induced ventilation is an artificial ventilation system made possible through the implementation of exhaust fans or blowers to encourage air exchange. The fan that is installed at one end of a greenhouse will withdraw the heated air from a greenhouse and create a slight vacuum to encourage the cooler air from the atmosphere to flow into the greenhouse though the louvre at the opposite end of the greenhouse (UMassAmherst, n.d.).

An experiment conducted by Flores, et al. (2014), in order to determine the effect of mechanical ventilation systems on the air exchange of the greenhouse. The experiment was carried out with a closed roof top vent and opened roof top vent. The results of the experiment were listed in **Table 2.2**

Table 2.2: Condition and Result of the Ventilation rate of the Greenhouse Sample (Flores, et al. 2014)**.**

Natural Ventilation Vent	Initial Temperature (CFD Model), K	Wind Speed (CFD Model), m/s^{-1}	Average Ventilation rate, h^{-1}
Fully Closed	297	2.5	20.8
Partially Opened, 30 %	298.5	1.7	26.6
Fully Opened	295	3.5	24.9

The ventilation rate for fully closed roof top vent was 20.8 h^{-1} due to the ventilation being fully dependent on the mechanical fan. However, the result for fully open vent at 24.9 h^{-1} is unexpected, which is lower than partially opened vent at 26.6 h^{-1}. This situation can be explained as the low wind speed condition encouraged thermal driven ventilation, a form of natural ventilation, which occurred as the major effect in air exchange, especially for partially opened and fully opened vents.

However, fan induced and natural ventilation systems should work together to increase the ventilation rate, instead of involving only the mechanical ventilation system.

2.5 *Allium Fistulosum* (Green Onion)

Allium fistulosum or known as green onion is a popular vegetable-herb that is usually found in tropical regions. Most of the time, green onion is used to enhance the flavour of soups, steamed-boils and salads. Furthermore, the popularity of green onions is contributed by its nutritional composition. The researchers found that the leaves of the green onion contain β-carotene, vitamin B1, vitamin B2 and vitamin C. Although the vitamins that contain in the green onion is lower compared to other vitamin-rich vegetable, the green onion plant is still important due to the potential benefits such has anti-inflammatory responses, risk reduction in cardiovascular diseases, anti-cancer due to the presence of anti prostanoid and potential ability in decrease the rate of DNA degradation (Singh and Ramakrishna, 2017).

According to Western Institute for Food Safety and Security (n.d.), the production of green onions is currently led by China and followed by India, United Stated, Turkey and Pakistan. Furthermore, the popularity of the green onion has shown an increasing trend in the United State market, due to the mild flavour of this vegetable. However, according to the Organisation for Economic Co-operation and Development (2020), farm production around the world, especially in the vegetable and fruit industry, is facing bottlenecks for inputs due to the Covid-19 pandemic. The important inputs such as labour, pesticides, fertiliser, and seeds were significantly decreased due to limited mobility of the transports as well as labour forces when most of the countries were practising lock downs as well as social distancing. Furthermore, the Covid-19 pandemic also affected the food processing industries. The fruits and vegetables that produced from the farm required further processing such as cleaning and packaging were affected due to the limited labour forces and companies also facing the risks of being temporarily shut down due to detection of positive cases within the workers. Therefore, an indoor mini-greenhouse for green onion planting can supply fresh green onion for personal needs as well as reduce the impact of shortage of green onion production due to Covid-19 pandemic.

In order to grow the green onion, the temperature range for the leaves to grow in optimum growth rate is from 20 °C to 25 °C. However, the overall growth rate of the green onion will also depend on the amount of light, which is the day lengths. Furthermore, green onions can grow under a wide range of soil types. However, the best soil for green onions to grow is well-drained soil such as sandy loam, loam and clay loams. Next, the green onion is very sensitive to the salinity of the soil during the germination stage. However, high levels of soil salinity is tolerable when the green onion is established. Moreover, in commercial farms, the sprinkler system for green onion irrigation is more common compared to drip systems due to the packed arrangement of each plant. In addition, the amount of water and frequency of irrigation is very dependent on the soil types and weather conditions (Smith, et al., 2011).

In terms of common pests and diseases, maggots are the most common pests that can be found around green onions. The pests favours conditions such as cool, moist soils with high levels of non-decomposed organic substances. However, pre-treatment on the soil to allow the organic matter to completely decompose before planting is not possible. Hence, insecticide is required to prevent product losses (Smith, et al., 2011).

2.6 Automation of Indoor Greenhouse

The automated greenhouse for indoor planting has been in development for the past few years. Hence, there are a few parameters, which are essential to control the environment inside the greenhouse. According to Saha, et al. (2017) the main automated components applied by the project were Arduino UNO, AT mega 328. The data collected by each sensor was transferred into a microcontroller to generate an output to the specific equipment according to the coding applied in the microcontroller. In the project, factors such as temperature and humidity were controlled to regulate the greenhouse environment. Since moisture exists in the air, therefore, the sensors, which are applied to obtain the temperature and humidity level in a greenhouse, are important to keep the parameters at desired levels. Usually, action taken by the system is always linked with a ventilation system such as a fan.

Furthermore, soil moisture sensors were also introduced in the project to maintain the sufficient water contained in the soil for the plants. The moisture sensors are working similarly to the other type of sensor, which is a loop that continuously obtains the moisture data from the soil and transfers back to the microcontroller to decide the necessity to take any action on the moisture regulation. The moisture sensor is always cooperated with a water pump or motor to deliver the water to the greenhouse. Next, the project also included the light system. In the project that states above, the major light source was by natural light. Therefore, a light dependent resistor is implemented and cooperated with a light intensity sensor. Since, the sunlight will not be consistent at all times. For example, the intensity of sunlight is significantly low when it is raining. Therefore, when the sensor detects the low intensity of light, the resistance of the light dependent resistor will automatically be reduced by the microcontroller and allow the artificial light to work as a temporary light source.

The specific trigger condition for each equipment that applied in the project that was conducted by Saha, et al. (2017) is shown in **Table 2.3**. From the condition stated in Table 2.3, the action level of high indicates the reaction of the microcontroller to regulate the greenhouse environment if certain conditions have exceeded or insufficient. For example, if the humidity sensor detects the humidity inside the greenhouse is higher than 75 %, the ventilation system such as the fan will trigger to work actively in order to bring the humidity inside the greenhouse back to the desired range. If the humidity inside the greenhouse is detected within the desired range, the ventilation system will work at normal rate or even stop working, depending on the requirement of the greenhouse.

However, the operating mode of this ventilation system is limited to a greenhouse that requires continuous cooling or ventilation due to the heat building up rapidly. For example, a greenhouse that is located outdoors and in contact with sunlight. Therefore, for indoor automated mini-greenhouse, additional control feature such as timer setting is required to optimise the utilising of energy for active ventilation.

Table 2.3: Critical Condition of each Parameter to Trigger the Action from Microcontroller (Saha, et al. 2017)**.**

Observation	Humidity, %	Action level from AT mega 328	Temperature, °C	Action level from AT mega 328	Light intensity Value	Action level from AT mega 328	Soil Moisture Value	Action level from AT mega 328
1	< 30	High	< 20	High	< 400	High	High	Low
2	> 75	High	> 35	High	> 400	Low	Low	High
3	30 >Hum > 75	Low	20 > Temp > 30	Low	-	-	-	-

2.7 Summary

The automated greenhouse has become a popular trend for planting activities. Therefore, modification of the greenhouse that was established for commercial purpose into an automated mini-greenhouse for indoor planting would bring multiple benefits to the individuals especially during the Covid-19 pandemic. Generally, the performance of a mini-greenhouse is highly dependent on a few major parameters, such as the artificial lighting system, irrigation method as well as the ventilation system. Therefore, to improve the ability and the planting environment of the mini-greenhouse, the microcontroller such as Arduino is needed to automate the equipment such as water sprinklers, ventilation fan and artificial lights in order to keep the optimum planting condition for the plant to thrive.

CHAPTER 3

METHODOLOGY AND WORK PLAN

3.1 Introduction

The study as well as the design of this automated mini-greenhouse are divided into three main stages, which are (1) initiation of project, (2) planning and design as well as (3) experiments and studies.

3.2 Initiation of Project

In this stage, the required equipment and apparatus to were identified and determined. In addition, the initiation cost for the construction of a greenhouse was determined as well. Furthermore, the cost for materials, which require customisation (size and dimension was determined according to the latest price from the supplier. The general material and equipment is listed in **Table 3.1**.

Table 3.1: The General Equipment and Material List for the Project.

Item	Quantity	Price per Piece/Set (RM)	Sub Total (RM)
Arduino MEGA 2560 R3	1	36.70	36.70
Breadboard	1	3.90	3.90
Jumper wire	1 set	4.50	4.50
5V Relay Module	4	3.80	15.20
Water pipe (silicon pipe)	1	1.50	1.50
Water pump (5 V / 12 V)	1	15.00	15.00
Soil Moisture Sensor	1	2.50	2.50
Humidity and Temperature Sensor DHT22	2	14.90	29.80
Fluorescent Lamp 32 cm	1	8.90	8.90
Buzzer Alarm	1	2.90	2.90
Acrylic Sheet	2 × (59.4 cm × 84.1cm)	60.0	120
Hot Glue Gun	1	17.00	17.00
*external power supply 12V 20A 240 W	1	38.50	38.50
LCD Display	1	19.90	19.90
Total (RM)			316.30

3.3 Planning and Design

In the planning stage, the type of plant to cultivate in the automated greenhouse was chosen by considering several parameters such as difficulty in cultivation, size of a fully-grown plant and the duration for the plant to grow. Since the greenhouse was constructed and applied indoors, the size of the plant should not be too big or too high. Hence, herbs are suitable candidates for the planting activity. Among the types of vegetable and herb available in the market, green onion was chosen because of the weather in Malaysia, which is suitable for the plant. Furthermore, planting green onion plants in Malaysia does not require huge temperature and humidity modification as well as requires relatively short time to grow by using bulb regrow method. Usually, the green onion can be regrow about one week (Huffstetler, 2021)

Furthermore, green onion plants have a typical height of 1 ft to 3 ft (30.48 cm to 91.44 cm) (Iannotti, 2021). Therefore, the height of the plant is suitable to plant in the indoor greenhouse, which is relatively small and easy to harvest. Next, the duration for the green onion plant to start regrowing from bulb is around seven days after the first planting and allow it to harvest at around two to three weeks. Hence, the time taken for the plant to grow is relatively short, which is suitable for our studies (Huffstetler, 2021.).

In the designing stage, the automated control parameters for the mini-greenhouse was predetermined. Firstly, since the mini-greenhouse was designed for indoor planting. Therefore, it is not possible for the greenhouse to contact with natural sunlight. However, light sources are one of the fundamentals for a plant to grow. Hence, the implementation of an artificial light system is essential for the indoor automated greenhouse. The artificial light were designed to be automated and controlled by using timer device.

Next, the irrigation systems were also designed to supply the water automatically. The water pump will only start to work when the microcontroller receives the digital signal from the soil moisture sensor. The minimum value of the moisture percentage for the soil will be set into the microcontroller by C++ language input. Hence, if the moisture percentage received by the microcontroller is lower than the setting value, the water pump will turn on and deliver the water into the greenhouse. Both the sprinkler method and drip method will be tested out to identify the most suitable irrigation method for the mini-automated greenhouse. **Figure 3.1** illustrates the control flow chart of the water pump.

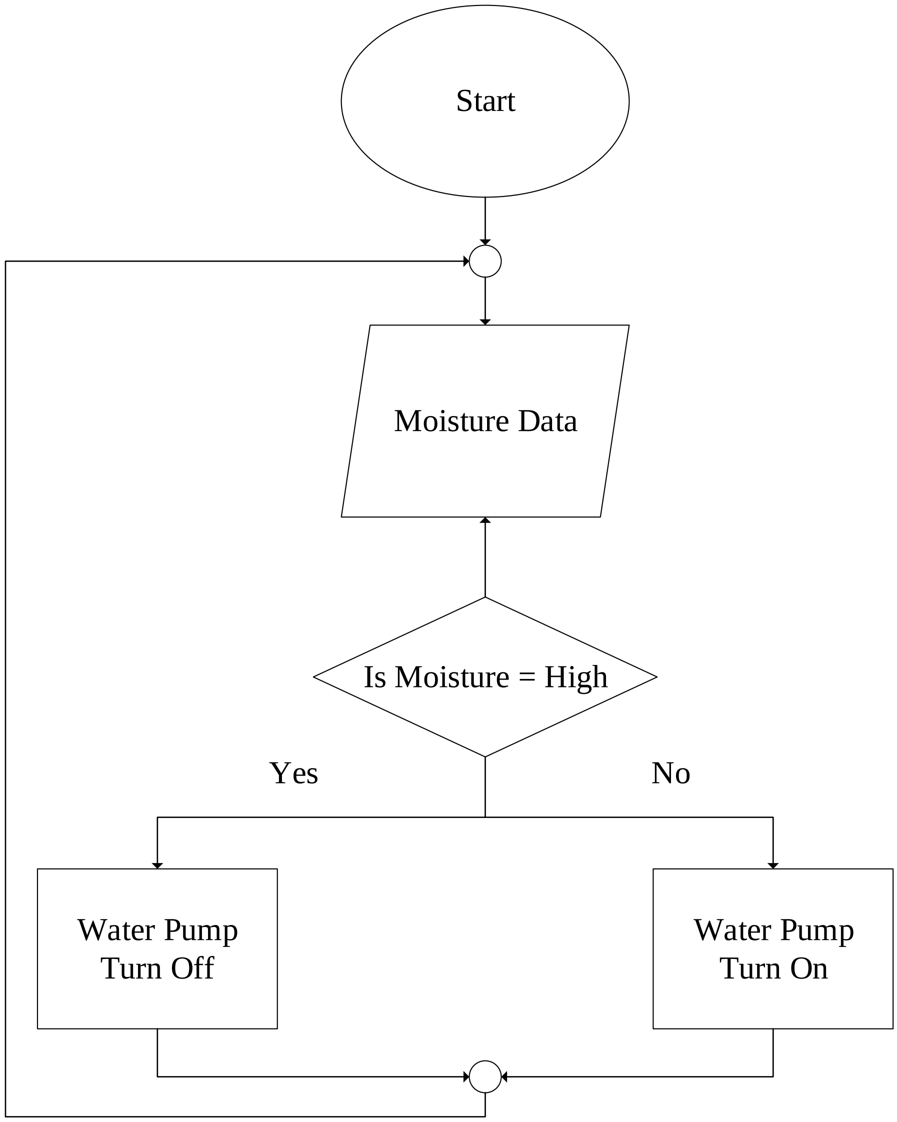


Figure 3.1: Simple Flow Chart of Water Pump Controlling

For the ventilation system of the mini-greenhouse, both passive and active ventilation were included in the design. For passive ventilation, the position of the opened louvre will be located at the side end of the greenhouse to remove the heated air via temperature difference in between the inner and outer environment of the mini-greenhouse. For an active ventilation system, a mini electric fan will be installed at one end of the greenhouse, which the louvre will be installed at the opposite end of the electrical fan. The fan is installed to withdraw the heater air and create a slightly vacuum condition inside the greenhouse and enhance the air exchange via the louvre. The electrical fan will be triggered to function when the microcontroller has received the signal, where either the temperature or the humidity condition inside the greenhouse does not fall at the optimum condition. The purpose of turning on the fan when the temperature is higher than the set point is to encourage the exchange of air inside the greenhouse so that there is an air circulation to prevent overheated conditions and also to prevent the growing of fungi and other diseases that can affect the plant. . **Figure 3.2** illustrates the control flow chart of electric fans.

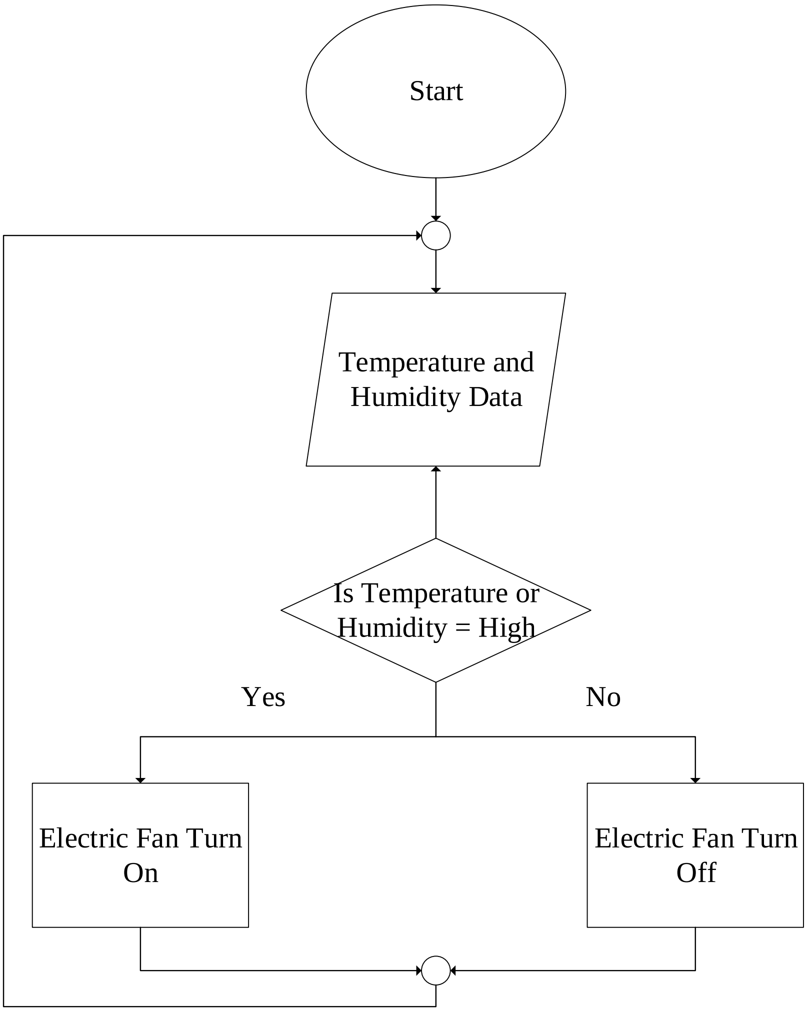


Figure 3.2: Simple Flow Chart of Active Ventilation

In addition, the bottom part of the planting pot will be designed with multiple holes to allow the circulation of water. This function is important to avoid the growing of fungi as well as pests invasion. Furthermore, a removable water collector will also be installed at the bottom of the planting pot to collect the water drops.

3.4 Experimental Study on Plant Growth and Studies

In this project, parameters such as temperature and humidity, irrigation methods as well as the ventilation systems are the focus of study in order to identify suitable operating conditions, which will maintain the environment of an automated mini-greenhouse at optimum levels.

3.4.1 Irrigation Method

There were two types of irrigation systems, which were sprinkler systems and drip systems. Each method was operate for two weeks to identify the amount of water used per week as well as the feasibility of the method to apply in the mini-greenhouse such as operating duration of the pump, difficulty of operating as well as the availability of techniques and technologies. The water was supplied by using a 5V water pump for both methods. For the sprinkler system, the pump was designed to work for 20 seconds to deliver the water to the greenhouse once the moisture sensor detects the moisture level of the soil was equal or above the analogy set point of 650. For the drip system, the water was supplied by pump when the soil moisture sensor detects an analog signal, which was larger or equal to 650. Furthermore, the pump was designed to work for 60 seconds per loop, in order to let the water accumulate in the pipe for the dripping process. The moisture sensor was allocated to detect the soil moisture level once per 30 minute in order to let the water that accumulated inside the pipe, slowly discharge into the soil. Therefore, the data for pump working period and water usage for both system were recorded and compared.

3.4.2 Temperature and Humidity Control

For traditional planting, no external temperature and humidity controller were allocated and the data for these parameters were recorded based on the daily weather forecast at 12 p.m.. On the other hand, a temperature and humidity sensor was installed in the automated mini-greenhouse to obtain the data of these parameters. The digital data obtained by the sensor will be further sent to the microcontroller, Arduino Mega 2560 and the result will be displayed through the computer. The data were recorded daily at 12 p.m. as well and compared with the temperature and air humidity data of traditional planting.

Furthermore, the ventilation fan was designed to trigger and remove the heated air inside the greenhouse, when the temperature of the automated mini-greenhouse was detected higher than the set point,

3.4.3 Planting of *Allium Fistulosum* (Green Onion)

In this study, alternative planting was carried out simultaneously. However, the alternative planting was carried out manually using a traditional way of planting, which was outdoor planting. The soil and the source of water for each planting method were the same. The height of the plant as well as the number of the leaves were measured and compared after 16 days of the planting. Furthermore, the developments of each specimen from traditional planting as well as automated mini-greenhouse was observed. The parameters such as colour, integrity of leaves and presence of pests were considered.

3.5 Summary

In this project, the cut off period of the study of each parameters was set for 16 days. The purpose of longer testing duration is to collect sufficient data in order to determine the optimum operating conditions and the irrigation method. The overall growth efficiency of the automated mini-greenhouse will be tested by comparing it with outdoor traditional planting. The test is to identify the differences in terms of growth rate as well as quality of the plant that is planted indoors with automated technologies compared to traditional planting.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 The Overall Setup of Automated Indoor Mini-Greenhouse

The automated indoor mini-greenhouse was assembled with a few major component, such as Arduino, breadboard for wires connection, artificial sunlight (LED light), temperature and humidity sensor, water tank with pump, water pipe, sprinkler (for sprinkler irrigation method), soil moisture sensor, ventilation fan and louvre. **Figure 4.1** shows the exact layout for the automated indoor mini-greenhouse for the study. The general coding for the automated mini-greenhouse was shown in **Appendix A**.

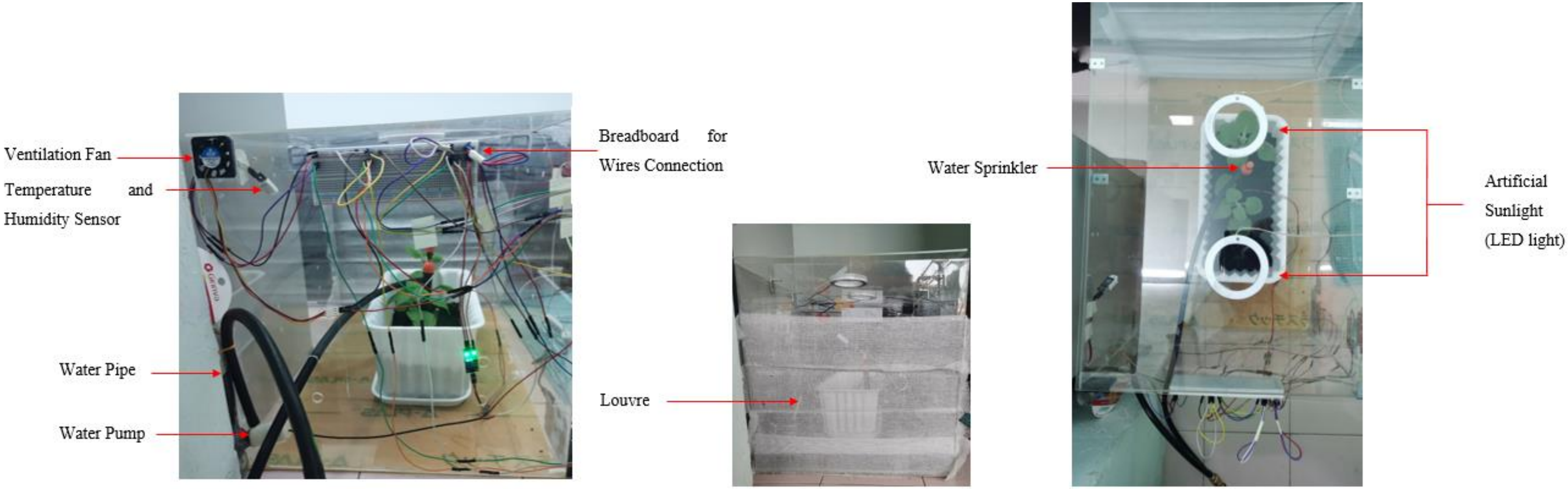


Figure 4.1: Setup of Automated Indoor Mini-greenhouse

4.2 Effects of Irrigation Method for Automated Mini-Greenhouse on Power-Saving Potential.

The irrigation systems, studied for the design of the automated mini-greenhouse include a sprinkler system and drip system. Before the test was started, the amount of water to achieve a similar soil moisture level was identified. The soil moisture level for the mini-greenhouse was determined by using a soil moisture sensor. The sensor will generate an analog signal, which has the range from 0 to 1025. In order to define a suitable set point for dry condition, initially, a specific amount of water was supplied to the dry soil and the soil moisture sensor was inserted to identify the analog reading. Next, the analog reading from the soil moisture sensor was compared with the observer's tactile sense and naked eye observation. The maximum and minimum range for the analog reading and the corresponding observation is tabulated in **Table 4.1**.

Table 4.1: Analog Reading from Soil Moisture Sensor and the Corresponding Observation.

Analog Reading Range	Observation	Amount of Water Supplied (ml), $\pm$ 10 ml	Observation Period (min)
950 to 1025	Completely dry	0	2
864 to 944	dry	20	2
680 to 759	Slightly dry	40	2
500 to 673	Slightly wet	60	2
430 to 543	Wet	80	2
380 <	Completely Wet	100	2

From the observation above, the water that was supplied to the greenhouse was set at 100 ml per irrigation for both methods The analog set point for dry status was 650, where the pump will start to deliver the water if the analog reading generated from the sensor has reached 650 or above. The required pump-working period per irrigation for both methods is shown in **Figure 4.**.

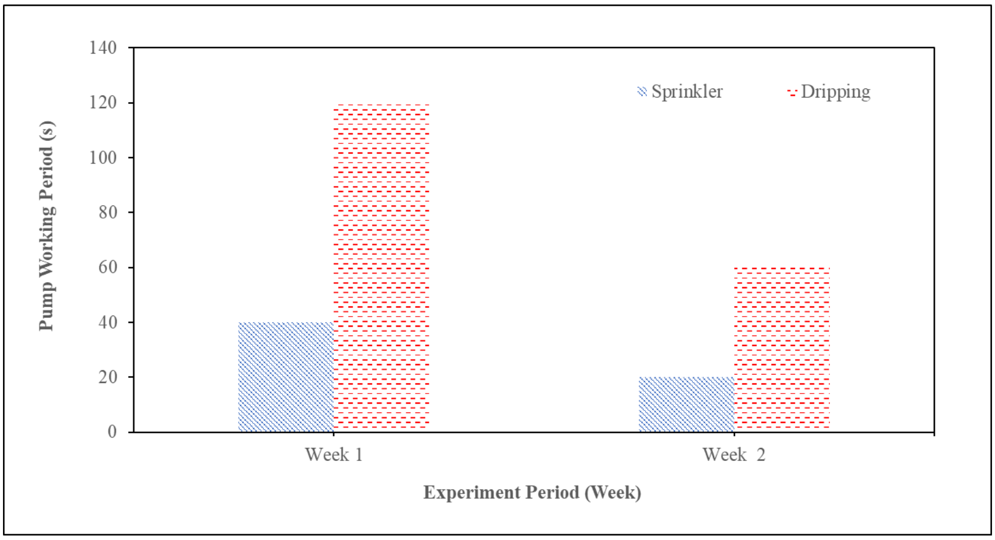


Figure 4.2: Pump-working Period for Sprinkler and Drip System

Based on **Figure 4.2**, the pump-working period for the drip system is significantly longer compared to the sprinkler system. This is because the water outlet flow rate for the drip system is relatively small compared to the sprinkler system. Hence, the pump has to work for a longer period in order to supply the required amount of water.

The drip system consist of a water pipe with several small holes across the length which acts as the water outlet while one of the pipe ends was closed water accumulation inside the pipe. At the same time, the loop of the sensor to read the soil moisture level was set as 30 min per loop to let the water that accumulated inside the pump flow into the soil. The whole process of irrigation requires about 30 to 45 min. Furthermore, the variance of the water that was supplied by using the drip system was $\pm$ 10 ml as excess water may accumulate inside the pipe, after previous irrigation circles.

On the other hand, for the sprinkler system, the sprinkler was allocated at the planting area. Furthermore, the irrigation area was fixed by adjusting the cap of the sprinkler, to ensure every plant specimen in the planter receives proper water coverage. At each irrigation circle, the water was delivered from the pump to the sprinkler and the water was sprayed to the soil. Each irrigation circle required only a pump-working period of 20 s to supply 100 ml of water to the soil. Since the working period for the pump with the sprinkler method was shorter than the dripping method, in terms of power consumption, the sprinkler system has better power-saving potential compared to the drip system.

The power consumption of each irrigation system was calculated as shown below.

$$Power, P = IV \tag{4.2}$$

where,

I = Current of the pump, A

V = Voltage of the pump, V

Since the pump that used in this study is 5.0 V and 2.0 A, the power rating of the pump is:

$$Power, P = 2.0\text{ A} \times 5.0\text{ V} = 10\ W$$

Hence, by multiplying the working period of the pump in hour for sprinkler system,

$$Power\ Consumption = 10\text{ W} \times 20\text{ s} \times \frac{1\text{ h}}{3600\text{ s}} = 0.0556\text{ Wh}$$

Similar calculation was applied to the drip systems with 60 s pump working period and the pump consumption is 0.167 Wh, Therefore, the power consumption of the sprinkler system is lower compared to drip systems.

In **Section 2.2.1**, according to Shareef and Ma (2019), the effectiveness of water usage in drip systems can achieve 85 % to 95 % compared to sprinkler systems with only 70 % to 80 %. However, the study conducted in this automated mini-greenhouse did not show enough evidence to prove this statement. It is because the planting area in the mini-greenhouse is significantly smaller compared to the commercial planting area. Since the planting area is small, the non-beneficial zone is insignificant, where most of the water supply to the greenhouse can reach the plants even though the method that was used was the sprinkler method. Hence, for automated mini-greenhouse, the sprinkler system is more adequate compared to the drip system.

4.3 Water-Saving Potential of Automated Mini-Greenhouse.

The study of the water usage for automated indoor mini-greenhouse planting as well as the traditional planting was conducted for 16 days (2 weeks and 2 days). The irrigation method applied for automated indoor mini-greenhouse in the investigation was the sprinkler system, while manual watering was used for the traditional planting. Furthermore, the amount of water for both settings was fixed at 100 ml per irrigation circle. In addition, the irrigation system for the automated mini-greenhouse was fully controlled by the microcontroller, Arduino Mega 2560. The soil moisture level for automated indoor planting was determined by a soil moisture sensor. The analog data that was detected by the sensor was sent to the microcontroller and further compared with the set point, which has been saved in the Arduino in advance. Therefore, when the signal generated from the soil moisture sensor is considered as dry condition by the Arduino, it will take the action and trigger the pump to deliver the water and supply to the plant inside the greenhouse. On the other hand, soil moisture for traditional planting was fully measured by the observer with naked eye observation as well as hand feeling. The summary for each irrigation system was tabulated in **Table 4.2**.

Table 4.2: The Summary of Irrigation System for both Planting

Parameter	Automated Planting	Traditional Planting
Irrigation System	Automated sprinkler irrigation	Traditional irrigation (pouring)
Amount of Water Per Irrigation Circle (ml)	100 ± 3 ml	100 ± 5 ml
Irrigation Control	Measured by soil moisture sensor and controlled by Arduino	Measured and controlled by an observer.

The water usage of both planting systems is illustrated in **Figure 4.3**. From **Figure 4.3**, the water usage for automated planting in the first week of the study was 200 ml and 100 ml for Week 2 as well as Week 3. The total water usage across the study period for automated planting was 400 ml. On the other hand, the water usage for traditional planting reached 300 ml in the first week of study and required 200 ml as well as 100 ml for Week 2 and Week 3 respectively. The total water usage for traditional planting across the study period was 600 ml. Therefore, the percentage difference between water usage for automated and traditional planting was calculated using **Equation 4.1**.

$$Percentage\ Difference\ (\%) = \frac{W_{Traditional} - W_{Automated}}{W_{Traditional}} \times 100\ \% \quad (4.1)$$

where,

$W_{Traditional}$ = Total water usage of traditional planting, ml

$W_{Automated}$ = Total water usage of automated planting, ml

Therefore, the percentage difference in between water usage for automated and traditional planting is:

$$Percentage\ Difference\ (\%) = \frac{600 - 400}{600} \times 100\% = 33.33\ \%$$

Hence, from the calculation, the total water saving by using automated planting across the study period is 33.33 % compared with the water usage of traditional planting..

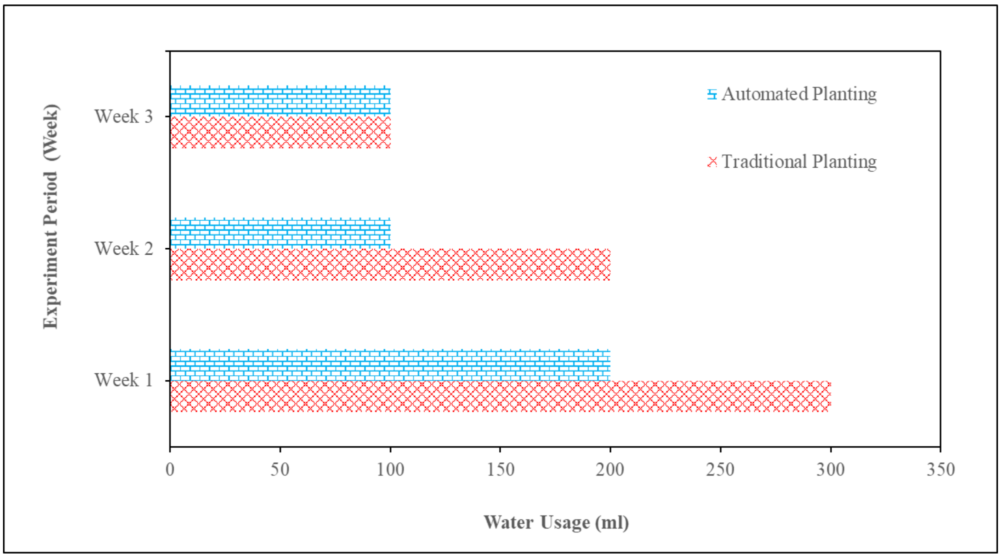


Figure 4.3: Water Usage for Automated and Traditional Planting

According to Western Institute for Food Safety and Security, the optimal growing temperature for green onions is at about 68 ºF to 77 ºF (20 °C to 25 °C). However, the daily average temperature across Malaysia is between 21 °C to 32 °C (My Government, 2016). Usually, the temperature during the daytime will be higher than 30 °C. Therefore, the traditional planting for green onion specimens was conducted with slightly shaded to prevent high temperature conditions. Furthermore, the surrounding air humidity does not affect the growth of green onions. On the other hand, an effective drainage system for soil was applied to prevent water logging, which may cause several diseases on plants' root (Iannotti, 2021). The temperature of the automated mini-greenhouse was identified by using the temperature and moisture sensor, DHT22, which function together with the Arduino. On the other hand, the temperature for traditional planting was recorded based on the highest temperature at 12:00 p.m. by the weather forecast for Kajang, Selangor area (time and date, 2022). The temperature and air humidity for automated mini-greenhouse and traditional planting are illustrated in **Figure 4.4** and **Figure 4.5**.

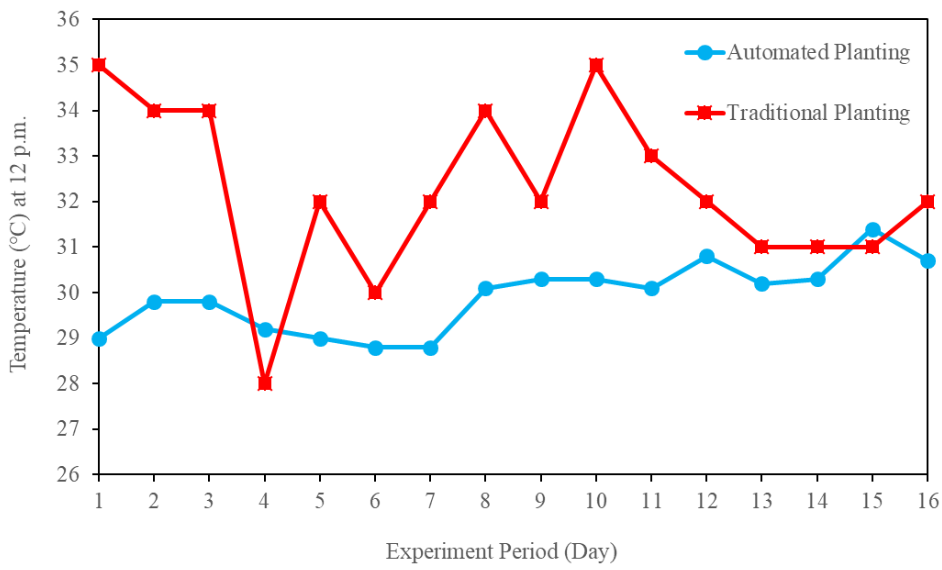


Figure 4.4: Temperature for Automated and Traditional Planting

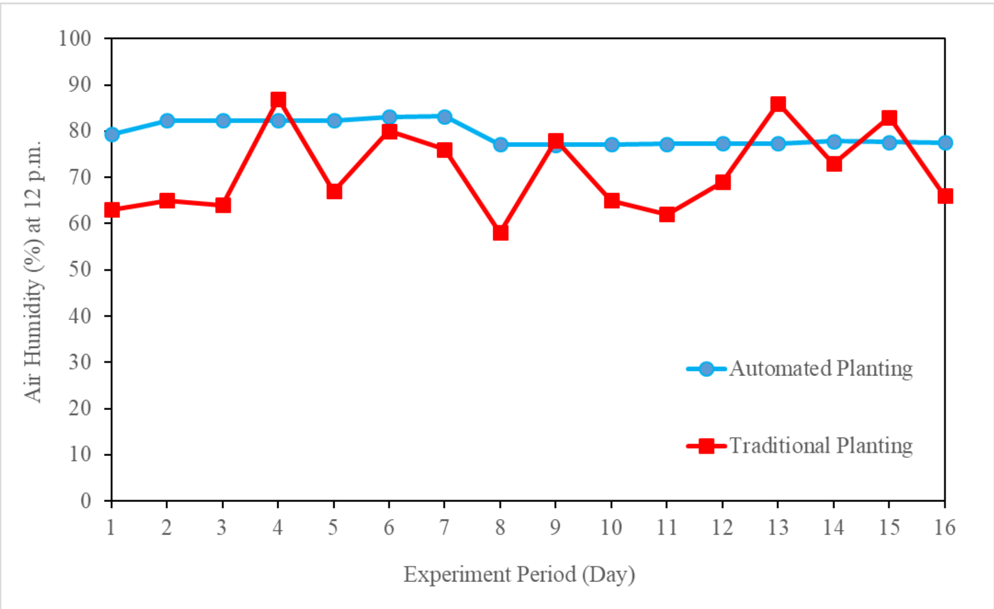


Figure 4.5: Air Humidity for Automated and Traditional Planting

According to the temperature data in **Figure 4.4**, both automated indoor mini-greenhouse as well as traditional planting has exceeded the optimum growing temperature for green onions. However, the excess temperature was not too high, which can still be tolerated by the green onions. Hence, there were no significant symptoms to show that the high temperature has affected the growth and status of green onions. On the other hand, by comparing the consistency of the temperature and humidity for automated greenhouse as well as traditional planting, the automated indoor mini-greenhouse shows smaller temperature and humidity fluctuation across the study period. The highest temperature for the automated indoor mini-greenhouse was 31.4 ℃ and the lowest was 28.8 ℃. On the other hand, based on **Figure 4.5**, the highest air humidity percentage for the automated planting was 83.17 % and the lowest was 77.02 %. In contrast, the fluctuation of temperature and humidity for traditional planting was larger compared to automated planting. The highest temperature and humidity for traditional planting reached 35 ℃ and 87.0 % respectively, while the lowest temperature and humidity were 28.0 ℃ and 58.0 % respectively.

Based on the study on temperature and humidity, the automated indoor mini-greenhouse has the ability to regulate or control the temperature as well as air humidity inside the planting environment. Therefore, the automated mini-greenhouse is possible to develop into a planting system that is suitable for the plant, which is sensitive to the fluctuation of temperature and humidity. Furthermore, since the air humidity and temperature of automated greenhouse is more consistent compared to traditional planting, the water evaporation due to temperature and air humidity in automated greenhouse is much lower compared to traditional planting, where the water evaporation will be affected by the changes of hot temperature as well as low air humidity.

4.4 Growth Development in Automated versus Traditional Planting

The growth of the plant specimen was observed daily from the day of planting. The onion bulbs chosen for planting for both automated and traditional were pre germinated. Next, the experiment cut off period was set as 16 days of the planting. The average plant height as well as average number of leaves of each specimen for automated indoor mini-greenhouse planting are shown in **Figure 4.6** and **Figure 4.7** respectively.

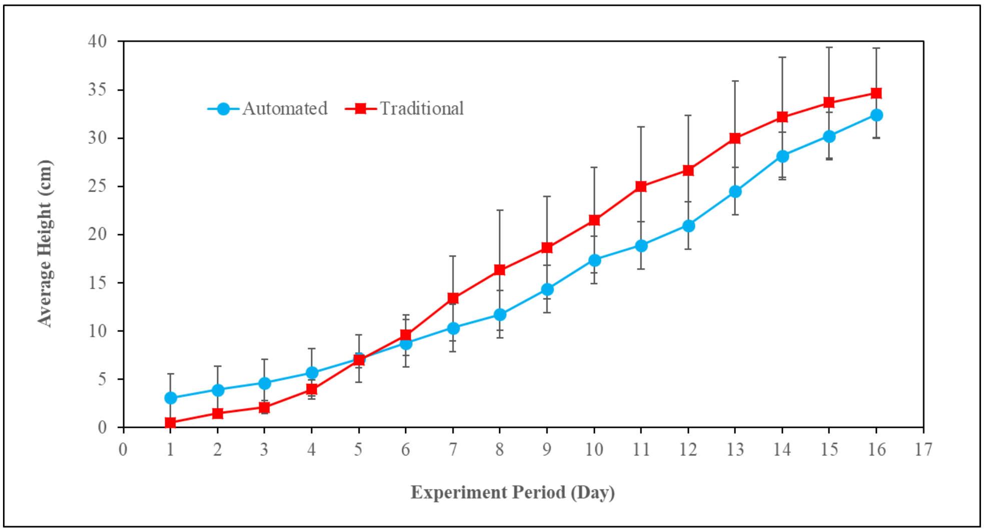


Figure 4.6: Average Plant Height (cm) for Automated and Traditional Planting

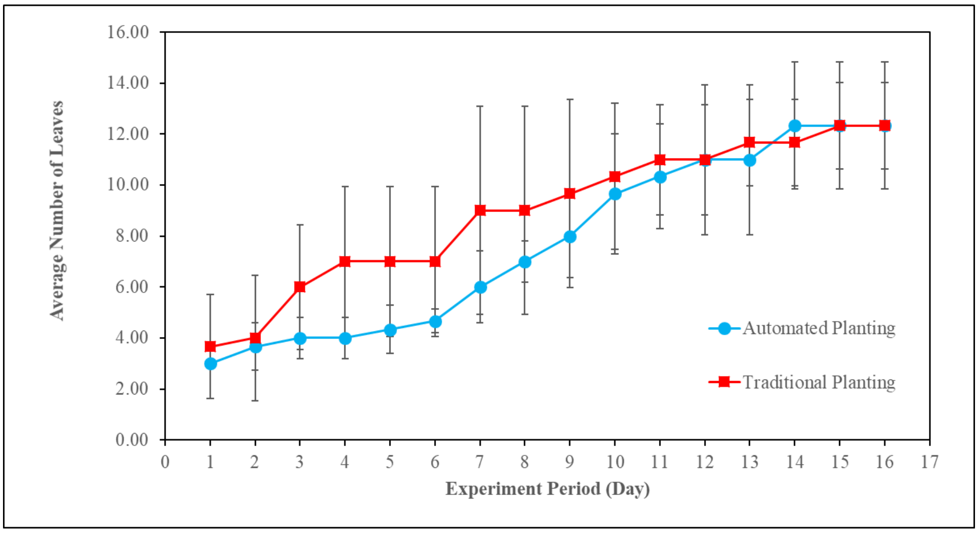


Figure 4.7: Average Number of Leaves for Automated and Traditional Planting

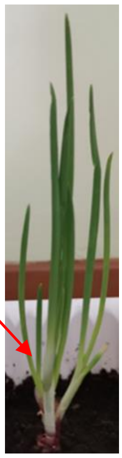
Since the study did not apply fertiliser for both automated and traditional planting, therefore, light source is the most significant parameter that affected the growth of the plant. For traditional planting, the light source will be the natural sunlight, while for automated indoor mini-greenhouse; the light source is artificial light. According to **Section 2.3**, by comparing between fluorescent light and LED light, the parameters such as wavelength, efficiency of light, light distribution and product shelf life were considered. Therefore, since LED light has wider wavelength, higher efficiency, better distribution of light and longer product shelf life compared to fluorescent light, LED light is chosen.

According to **Figure 4.6**, the traditional planting has achieved higher average plant height (34.67 cm) compared to automated mini-greenhouse planting (32.43 cm). However, in terms of average number of leaves, automated planting shows slightly higher value (13.0) compared to traditional planting (12.33). Although the average height of automated planting shows lower value compared to traditional planting, the standard deviation of both setup is overlapped each other throughout the experiment period. Furthermore, the difference in terms of number of leaves also showed similar results between automated and traditional planting. Therefore, the LED light is suitable and able to produce the plant with similar quality compared to natural light as there was no significant difference in plant height and number of leaves.

In addition, the similar growth between automated and traditional planting also contributed by the effect of sunlight intensity. Since the weather during the experiment period was impossible to control, the intensity of sunlight will be significantly lower when the weather is cloudy or rainy. This situation will also affect the growth of the plant. In contrast, for the automated mini-greenhouse, there will be no four season or weather changes. Therefore, the intensity of the light source will remain constant for all day and the growth of the plant will be enhanced.

Next, the development of the plant specimens such as the colour of the leaves, presence of bugs or parasites and integrity of leaves in the automated indoor mini-greenhouse and traditional planting were observed. **Table 4.3** shows the development of each specimen in the automated and traditional planting.

Table 4.3: Growth Status of Each Specimen in Automated Mini-greenhouse and Traditional Planting.

Day	Automated	Traditional
7		
Greenish and bright 16		 Yellowish and dull

Based on the images shown in **Table 4.3**, the yellowish leaves condition was found in traditional planting on day 16. Compared to the specimens for automated mini-greenhouse, the leaves of the specimens were greenish and bright. The yellowish condition of the specimens in traditional planting were mainly due to the existence of pests such as onion maggots. The pests' larvae will tunnel into the bulb of green onion and damage the bulb, which will cause the onion leaves to become yellowish (Delahaut, 2001). On the other hand, the pests were absent for the automated greenhouse planting. This is because the planting was carried out in indoor mode and the specimen was protected in the confined greenhouse. Hence, it is less possible for the pest to attack the plant from outside of the greenhouse. **Figure 4.8** illustrates the pest, which is onion maggot.

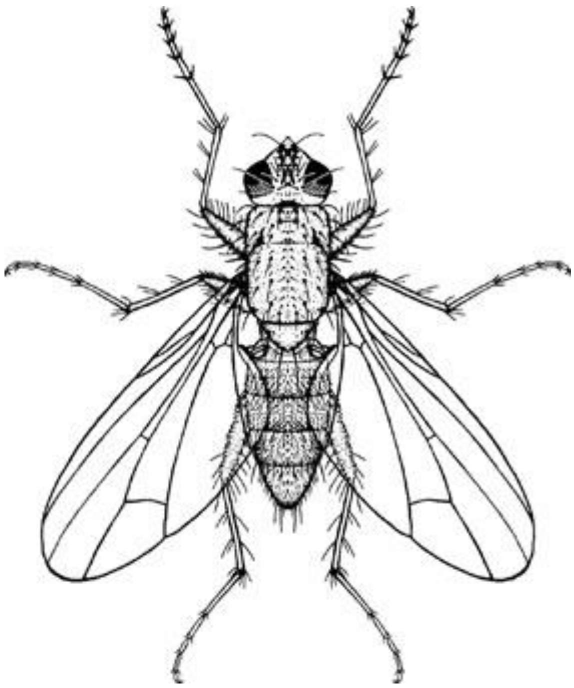


Figure 4.8: Delia Antique (Onion Maggot)

(Capinera, John, 2008)

Furthermore, in terms of integrity of the leaves, the specimens for traditional planting show significant creases or folds on the leaves compared to the specimens in the automated greenhouse. The major reason, which caused the leaves in the traditional planting to collapse, was the windy condition especially on rainy days. When the leaves of the specimens reach a certain height (about 20 cm), it is susceptible to instability when attacked by strong wind, causing the leaves to bend and fold. In contrast, the specimen inside the greenhouse does not experience weather change or windy conditions. The plantation was set indoors with the protection of a confined greenhouse. Therefore, bad weather will not directly affect the plant specimens which are protected inside the greenhouse.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

At this point of this project, the first objective has been achieved, in which an automated mini-greenhouse for indoor farming by using Arduino Mega 2560 was developed with the ability to control the mini-greenhouse's internal temperature and air humidity as well as the planter's soil moisture. Furthermore, the second objective, which is the suitable setup for automated mini-greenhouse such as irrigation method and light source, are successfully determined. From the results of studies, the optimum choice for the irrigation system is the sprinkler system due to lower power consumption as well as shorter time required for each irrigation circle compared to the drip method. In addition, the sprinkler system is more suitable for closely arranged plants, such as *allium fistulosum* (green onions). Moreover, in terms of status of plant, the automated planting shows better condition (integrity, colour and presence of pests) compared to traditional planting due to the automated mini-greenhouse has the ability to provide consistent light source and protect the plant from harmed by pests as well as weather condition (windy and rainy). Lastly, the third objective in this project has also been achieved. Based on the results, the effectiveness of automated planting is similar to traditional planting. Therefore, it shows that the automated greenhouse has the ability to grow plants while ensuring healthy plant growth and product quality in terms of plant height as well as number of leaves.

5.2 Recommendations for future work

In order to improve the study, firstly, professional equipment such as control valves as well as drip nozzles should be included for the setup of drip irrigation system. The equipment can help the irrigation system to control the water flow rate properly as well as perform the watering circle effectively. Furthermore, the measurement tool such as auxanometer is considered to be included in the study to obtain accurate height of each specimen. Next, temperature and humidity measurement tools are considered to be included for traditional planting in order to obtain accurate local data for these parameters instead of referring to the average data from the forecast.

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APPENDICES

Appendix A: C++ Coding for Arduino Mega 2560

```
#include <DHT.h>; // Include libraries
const int dry = 650; // Declare set point for low soil moisture
const int hot = 33; // Declare set point for high temperature
const int fanPin = 3;
const int pumpPin = 12;
const int soilSensor = A4;
#define DHTPIN 7
#define DHTTYPE DHT22
DHT dht(DHTPIN, DHTTYPE);

float hum;
float temp;
void setup() {
  pinMode(pumpPin, OUTPUT);
  pinMode(fanPin, OUTPUT);
  pinMode(soilSensor, INPUT);
  Serial.begin(9600);
  digitalWrite(pumpPin, HIGH);
  digitalWrite(fanPin, HIGH);
  delay(5000); // Interval time(5 seconds) for arduino to read another data)
  {
  Serial.begin(9600);
  dht.begin();
  }
}
```

Figure A.1: First Part of Coding

```
void loop()
{
  int moisture = analogRead(soilSensor);
  Serial.println(moisture);
  delay(5000); // Interval time(5 seconds) for arduino to read another data)

  if (moisture >= dry)
  {
    Serial.println("Watering starts now..moisture is " + String(moisture));
    digitalWrite(pumpPin, LOW);

    delay(20000); // Let the pump work for 20 seconds

    digitalWrite(pumpPin, HIGH);
    Serial.println("Done watering.");
  }
  else
  {
    Serial.println("Moisture is adequate. No watering needed " + String(moisture));
  }
```

Figure A.2: Second Part of Coding

```
  if (temp >= hot)
  {
    Serial.println("Ventilation starts now..Temperature is " + String(temp));
    digitalWrite(fanPin, LOW);

    delay(10000); // Let the Fan work for 10 seconds

    digitalWrite(fanPin, HIGH);
    Serial.println("Done.");
    }
    else
    {
    Serial.println("Temperature is adequate. No Ventilation needed " + String(temp));
    }
  {
    hum = dht.readHumidity();
    temp= dht.readTemperature();
    Serial.print("Humidity: ");
    Serial.print(hum);
    Serial.print(" %, Temp: ");
    Serial.print(temp);
    Serial.println(" Celsius");
    delay(5000); // Interval time(2 seconds) for arduino to read another data)
  }
}
```

Figure A.3: Third Part of Coding