# AUTOMATED NUTRIENT DOSING SYSTEM FOR HYDROPONICS USING IOT TECHNOLOGY

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# Faculty of Mechanical Technology and Engineering

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**Bachelor of Mechanical Engineering Technology (Automotive) with Honours**

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TAJUK: **AUTOMATED NUTRIENT DOSING SYSTEM FOR HYDROPONICS USING IOT TECHNOLOGY**

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## DEDICATION

To my beloved parents,

whose constant love and encouragement have served as the foundation for my journey. Mom and Dad, your unwavering faith in my abilities and endless sacrifices have been my greatest motivators. Your constant reminders to strive for excellence, as well as your unconditional love, have strengthened my resolve to succeed. You have taught me the value of hard work, perseverance, and integrity, for which I am eternally grateful.

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Last but not least, I want to thank you for believing in me. I want to thank you for doing all this hard work. I want to thank you for having no days off. I want to thank you for never quitting. I want to thank you for always being a giver and trying to give more than I receive. I want to thank you for trying to do more right than wrong. I want to thank you for being me at all times.

# ABSTRACT

Hydroponics has become very popular for home plant growth due to its efficiency and space-saving nature. However, this method of cultivation has its drawbacks, such as limited real-time monitoring of nutrient concentrations and the inability to maintain optimal conditions because of evaporation and environmental changes. This research, therefore, is a design and implementation of a reliable and efficient automated nutrient dosing system in hydroponics using IoT technology. This shall monitor and control fertilizer concentration in the hydroponic tank. The system is also remotely accessible via a smartphone interface. Lactuca Sativa or lettuce was selected for the research study since it is one of the most widely cultivated plants by hydroponic farmers. Extensive literature review was done to identify the components required for developing the system: a peristaltic pump, ESP32 microcontroller, and TDS sensor. After the installation of hardware, calibration of sensors and integration with a smartphone application was done using Arduino IDE to ensure functionality and accurate data monitoring. During the experimental phase, the volume of nutrient solutions A and B was determined in order to reach a target concentration of 200 ppm in a 1-liter tank. By using a calibration equation, $y = 0.0102x + 0.4609$, it was found that 2.5 ml of fertilizers A and B gave the best dosing rate for 1-liter tanks. It also established that, for submersible pumps, this high flow rate of 33.25 ml/s is not suitable for the precise dosage of fertilizers. In such a case, peristaltic pumps were used and programmed with the volume they should dispense to the plants for their nutritional needs. This serves to greatly improve hydroponic fertilizer systems by significantly saving fertilizer costs while reducing environmental pollution from over-fertilization. The integration of IoT-based automation has huge potential to revolutionize hydroponic practices in a more efficient, cost-effective, and sustainable.

# ABSTRAK

Hidroponik telah menjadi kaedah yang digunakan secara meluas untuk menanam tumbuhan di rumah kerana kecekapan dan faedah penjimatan ruang. Walau bagaimanapun, teknik penanaman ini menghadapi cabaran seperti pemantauan masa nyata terhad kepekatan nutrien dan ketidakupayaan untuk mengekalkan keadaan optimum akibat penyejatan dan perubahan persekitaran. Untuk menangani isu ini, kajian ini bertujuan untuk mereka bentuk dan melaksanakan sistem dos nutrien automatik yang boleh dipercayai dan cekap untuk hidroponik menggunakan teknologi IoT. Sistem ini memantau dan mengawal kepekatan baja dalam tangki hidroponik dan boleh diakses dari jauh melalui antara muka telefon pintar. Kajian ini memberi tumpuan kepada penanaman Lactuca Sativa (salada), pilihan popular di kalangan penanam hidroponik. Kajian literatur yang komprehensif telah dijalankan untuk mengenal pasti komponen yang diperlukan untuk membangunkan sistem, termasuk pam peristaltik, mikropengawal ESP32, dan sensor TDS. Berikutan pemasangan perkakasan, penderia telah ditentukur dan disepadukan dengan aplikasi telefon pintar menggunakan Arduino IDE untuk memastikan kefungsian dan pemantauan data yang tepat. Dalam fasa eksperimen, isipadu larutan nutrien A dan B dianalisis untuk mencapai kepekatan sasaran 200 ppm dalam tangki 1 liter. Persamaan penentukuran yang diperolehi, $y=0.0102x+0.4609$, menentukan bahawa 2.5 ml baja A dan B adalah optimum untuk tangki 1 liter. Tambahan pula, kajian mengenal pasti bahawa pam tenggelam, dengan kadar aliran tinggi 33.25 ml/s, tidak sesuai untuk dos baja yang tepat. Pam peristaltik sebaliknya diprogramkan untuk menyampaikan isipadu yang diperlukan dengan tepat, memastikan penggunaan nutrien yang cekap. Penemuan ini meningkatkan sistem pembajaan hidroponik dengan ketara dengan mengurangkan kos baja dan meminimumkan pencemaran alam sekitar yang disebabkan oleh pembajaan berlebihan. Penyepaduan automasi berasaskan IoT menunjukkan potensi untuk merevolusikan amalan hidroponik, menjadikannya lebih cekap, kos efektif dan mampan.

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In the Name of Allah, the Most Gracious, the Most Merciful

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Last but not least, from the bottom of my heart, I express my deepest gratitude to my beloved mother, who has always given me the motivation to continue my studies and has always understood the challenges I faced when starting this PSM project. Your unwavering support and compassion have been my guiding light during the toughest times. Your words of encouragement have been my anchor, keeping me steady and focused on my goals. Without your patience and understanding, I would not have had the strength to persevere. Thank you for believing in me even when I doubted myself, and for always being my biggest cheerleader.

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## LIST OF SYMBOLS AND ABBREVIATIONS

| | | |
|---|---|---|
| V | - | volt |
| mL | - | milliliter |
| L | - | Liter |
| s | - | second |
| ppm | - | parts per million |

# CHAPTER 1

# INTRODUCTION

## 1.1 Background

Nowadays, the total population of Malaysia in the third quarter of 2023 is estimated at 33.5 million, an increase of 1.8 percent compared to the third quarter of 2022 (32.9 million) (MalaysiaGazette, 2023). With the growing number causing the cost of living in Malaysia to increase, among the factors are reduced subsidies for various basic goods, price manipulation activities and the value of the ringgit currency is weakening. ("Keperluan Mendesak Bantu Rakyat Serap Kenaikan Kos Sara Hidup," 2024). This is also the reason why hydroponic was introduced as a method of cultivation to overcome the problem of the high cost of living in Malaysia. (Tan, K.H.Faculty of Technical and Vocational Education, UTHM,2018) .

A hydroponic system is a method of planting trees without using soil. The method uses materials such as mineral feathers, coconut hooks, sand, broken bricks, wood dust, and other soil replacements. Because of the conversion of soil to water, this system requires additional fertilizers to replace the soil, such as fertilizer A and B. fertilizer A and B are fertilizer consisting of minerals from the soil, like fertilizer A contains calcium nitrate and iron chelate, whereas fertilizer B contains potassium nitrates, monopotassium hydrogen, phosphate, magnesium sulphate, manganese sulphates, boric acid, zinc sulphate, copper sulphate, and natrium. (BAJA AB MEMBEKAL NUTRIEN LENGKAP KEPADA TANAMAN ANDA | PUSAT PERTANIAN PUTRA, n.d.)

The Internet of Things (IoT) describes devices with sensors that connect and exchange data with other devices and systems over the Internet or other communications networks. The Internet of Things encompasses electronics, communication, and computer engineering. "Internet of Things" only needs to be connected to a network and be individually addressable. IOT helps in terms of monitoring at all times, controlling the actuator over long distances, and changing the solution wherever it needs. The main aim of this research is to design and implement a reliable and efficient automated nutrient dosing system for hydroponics

## 1.2 Problem Statement

The use of electrical conductivity (EC) measurement to read the nutrient concentration in the solution does not give an accurate reading. This can lead to poor yields or excessive fertilizer use.(Fathidarehnijeh et al., 2024)

Another than that, Limited real-time monitoring to observe every moment the condition of nutrient concentration whether high or low such as nutrient concentration can increase in nutrient solution over time due to loss of water by evaporation.(Fathidarehnijeh et al., 2024)

Lastly, Limited of automatic dosing systems in hydroponics despite having a system that can read the concentration of the solution and provide fertilizer for the nutrient solution but it do not provide enough fertilizer to several plants due to variations in plant absorption rates and environmental conditions. (Maldonado et al., 2020)



## 1.3 Research Objective

The main aim of this research is to make an automated nutrient dosing system by monitoring and taking care of nutrients in plants automatically by using total dissolve sensor (TDS) and water PH sensors. Specifically, the objectives are as follows:

a) To design and implement a reliable and efficient automated nutrient dosing system for hydroponics

b) To Integrate total dissolve solid (TDS) into the system for control of nutrient concentration in the hydroponic solution

c) To create a mobile application interface that enables users to monitor TDS levels in real-time

## 1.4 Scope of Research

The following is the scope of this study:

a) Design and develop an automated nutrient dosing system using IoT for **Lactuca Sativa**.

b) Build an application for an automated nutrient dosing system to enable continuous monitoring of the system's condition.

c) Create a calibration of main sensor such as Total Dissolve solids (TDS) sensor for the accuracy of the solution value.

# CHAPTER 2

# LITERATURE REVIEW

## 2.1 Introduction

In today's modern society, hydroponic cultivation methods are increasingly used due to various factors such as infertile soil, limited land space and unstable air humidity. However, in this system there are difficulties in terms of fertilization that requires a certain amount so that the plants can grow, In this context, previous studies will be carried out on the components used, installation methods and problems found in previous studies so that these problems can be overcome well

## 2.2 Automated Hydroponic Systems

In the world of hydroponic systems, many have created automatic dosing systems that are used to help in providing fertilizer to plants. There are many types of hydroponics that have been used by farmers, among them are Ebb-Flow/Flood & Drain, Nutrient Film Technique (N.F.T), Water Culture and Aeroponics In the research from (Lei, 2020)The Nutrient Film Technique is the design that their use in this project. This is because the design of NFT system is easy to work and is more suited for home growing. From the another technique the differs between NFT and another types of hydroponic is water flows from one side to another plant by touching each plant in a sequential order and not all at once   This technique is that water flows from one side of a channel or tube to the other while touching the roots of all the plants.

To maintain oxygenation, NFT uses air pumps to transfer water and nutrient solutions into sizable reservoirs. The canal is filled with water by a water pump that is timed. With its roots partially submerged, this gives the plant a thin layer of water and nutrients. Reusing the solution in the system, it goes back to the main reservoir.(Agrawal et al., 2023)

In a study using Arduino Uno as a microcontroller as a brain for the system, using a variety of sensors, including temperature sensors (DS18B20), water float sensors, DHT21 sensors, and TDS sensors, which are processed in order to display data in hydroponic installations, such as temperature, water limit, and total PPM (Part Per Million) . The advantages of the hydroponic system in terms of efficiency include the use of nutrition, water, and land more efficiently, leading to increased yield optimization. The system also allows for precise monitoring of plant conditions through automation, contributing to better precision in plant growth and nutrition distribution (LUTFI ARDHIANSYAH, 2021).



Another than that, the study on smart hydroponic systems emphasizes the importance of maintaining precise nutrient levels for the success of hydroponic systems. It delves into the relationship between environmental factors and plant growth patterns, showing that higher Total Dissolved Solids (TDS) values correlate with better plant growth. This research provides valuable insights into smart hydroponic systems, informing precision agriculture decisions and optimizing yields.(Vishram Kulkarni et al., 2024)

## 2.3 Hydroponics recirculation system

Hydroponics improves the productivity of water and fertilizer by managing the environment and water and nutrients more effectively by recirculating the nutrient solution. There is to type of recirculation system, which is the open loop and close loop system

In open hydroponic systems, the nutrient solution is not circulated back to the crop root zone after use; instead, it is drained after passing through the root zone.(Maboko et al., 2011). Reusing leachate in a closed-loop hydroponic system reduces negative aspects like nutrient solution disposal to the environment and is an efficient method of managing nutrient solutions.(Sanjuan-Delmás et al., 2020)

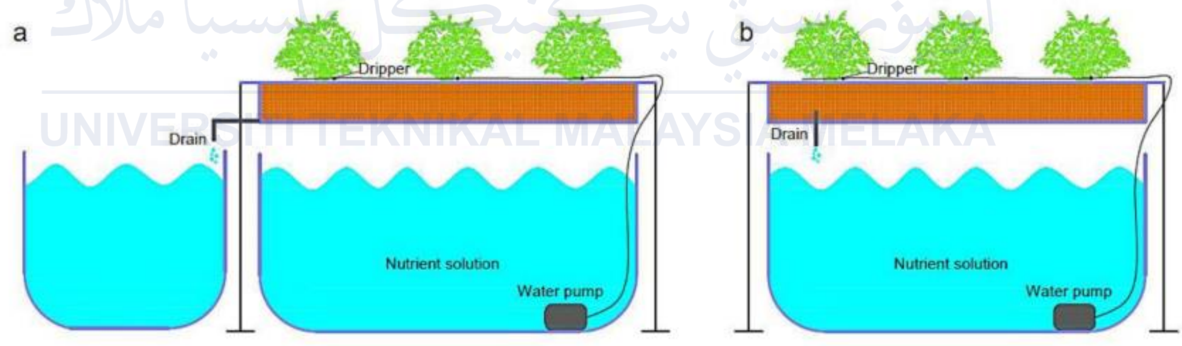


Figure 1 a)Open loop system & b) Closed loop system *(Fayezizadeh et al., 2021)*

Both of the System have a unique advantage, but in this project, closed loop is the appropriate system because it aims to reduce costs and the use of fertilizer. In one research from (Fayezizadeh et al., 2021) in open- and closed-loop drip hydroponic tomato production systems were compared. According to the scientists' findings, closed-loop systems produced 54.3% more water productivity than open systems. In addition, the closed-loop system used 2.53 kg of fertilizer less than the open system's 4.95 kg over the course of the crop cycle, a 96% reduction

## 2.4 Peristaltic Pump Applications in Agriculture

The purpose of the peristaltic pump is to achieve control and regulation of the water solution, both pH buffer and nutrient solution. When handling acidic materials, a peristaltic pump is thought to be ideal because of its capacity to maintain a steady flow and its resistance to corrosion. The peristaltic pump work by involves squeezing a hose or tube in a linear motion, resulting in fluid movement in the same direction.(Ortner & Ågren, 2019).

Peristaltic pumps play an important role in providing accurate and controlled dosing of nutrients in various agricultural practices such as aquaponics and hydroponics. Peristaltic pumps allow for very precise control over the amount of nutrients or other additives that are dosed into nutrient solutions or aquaculture tanks. This is because they can accurately control the speed at which the rollers turn and thereby regulate flow rates on a sub-milliliter level. This precision is important for maintaining optimal nutrient levels. The rolling motion of peristaltic pumps allows for nutrients to be dosed in preset, metered amounts according to a pre-programmed schedule. This ensures plants receive accurate doses of nutrients over time. The dosing can also be easily adjusted if monitoring indicates nutrient levels need to change. Since peristaltic pumps use tubes to transport liquids rather than coming into direct contact with them, they are well-suited for dosing diverse nutrient solutions into hydroponic systems without contamination. This closed system reduces risks of residue buildup or cross-contamination.(Kurian Oommen et al., 2019)

### 2.4.1 Development of a peristaltic pump for constant flow applications

In another research tell that the classical design peristaltic pumps is abrupt disengagement of the roller causes major oscillations in the flow rate in the classical peristaltic pump. When the roller is engaged, a fixed volume of fluid is isolated and moved in the direction of the discharge side with each rotation. The roller quickly separates from the tube, resulting in a sharp decrease in the volume the roller occupies within the brief disengagement arc. Sometimes a disengagement volume drop greater than an engaged volume produces negative flow rate values, indicating fluid backflow.(Ferretti et al., 2023)

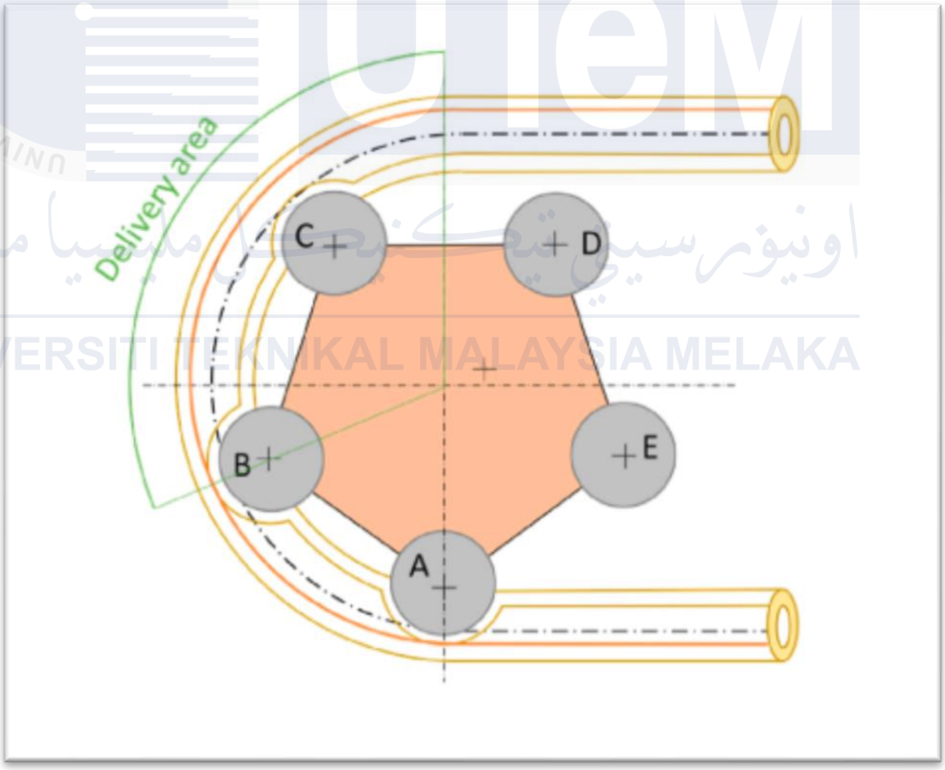


Figure 2 Diagram of roller disengagement in the rotor rotation stages(Ferretti et al., 2023)

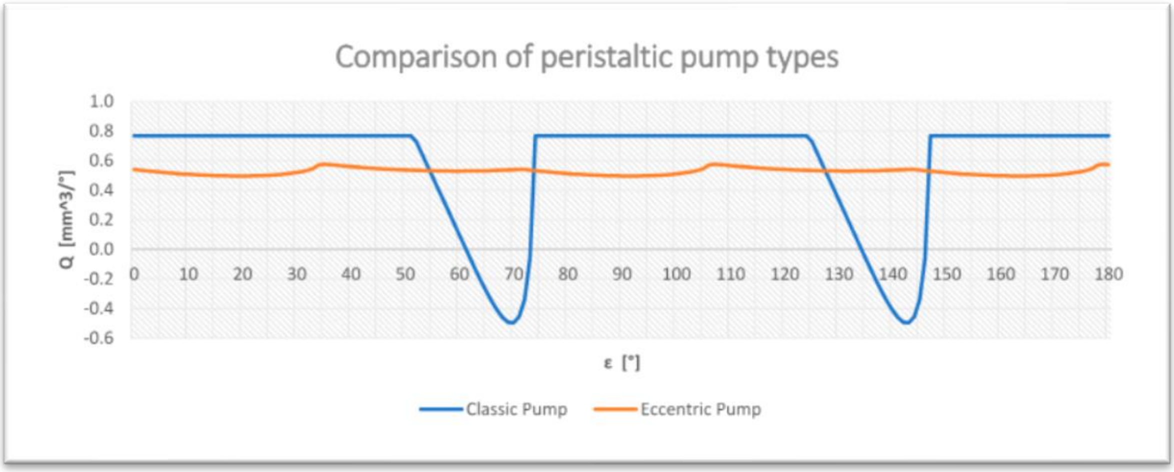


Figure 3 The flowrate between the classic pump and the eccentric pump(Ferretti et al., 2023)

The research suggests a new eccentric peristaltic pump geometry as a means of solving the problem. Over a greater angular distance (between α and 180-α degrees),.In addition, replacing each large roller with two to three smaller ones around the circumference will improve the flow rate. The abruptness is decreased by the smaller rollers disengaging gradually. (Ferretti et al., 2023)

## 2.5 IoT Applications in Agriculture

The use of IoT in agriculture has been widely used, mainly used to monitor the current state of hydroponics by using sensors attached to plants. This makes hydroponic cultivation more efficient by controlling the pump anywhere if there is any problem with the hydroponic system.

### 2.5.1 Automated monitoring and control systems using IoT

The reviewed literature demonstrates how Internet of Things (IoT) technologies works. After the sensor gets data on the hydroponic system then the data will go to the ESP32 microcontroller to be processed whether the fan, lamp or pump needs to be turned on, the ESP32.The ESP32 Wi-Fi chip is analyzed as an alternative CSI measurement tool. It can act as both transmitter and receiver, device-free Wi-Fi sensing (DFWS) uses Wi-Fi signals to enable passive sensing and monitoring without requiring devices to be installed on the objects being sensed.(Atif et al., 2020) .

Moreover, ESP8266 with Arduino Mega 2560, the ESP8266 Wi-Fi also used as a microprocessor for hydroponic cultivation. The ESP8266 is a Wi-Fi module that allows microcontrollers like Arduino to connect to Wi-Fi networks. ESP8266 is used to connect the Arduino Mega 2560 to the internet through a Wi-Fi network, enabling it to send sensor data to the Blynk cloud platform over the internet. The Arduino Mega 2560 acts as the main microcontroller to read sensors like temperature, humidity, water level etc. and control actuators like pumps and fans through relays. (Li et al., 2022)

### 2.5.2 IoT devices enhance the precision and efficiency of nutrient management in plant cultivation

IoT devices allow continuous monitoring of the nutrient solution quality. IoT enables maintaining the optimal pH and nutrient concentration very precisely. Another than that, IoT also can control automated nutrient dosage, actuators like pumps can be automatically controlled based on sensor readings to maintain the right nutrient levels. For example, if pH drops, a pH pump can be switched on via IoT to raise it back precisely(Mulla & Sakthi, 2021).There are three main components to remote the hydroponic monitoring system, system data retrieval, server and Android applications by using Hydroeyes apps Arduino. (Hidayanti et al., 2020)

The nutrient solution's temperature has an impact on the plants' capacity to absorb water and nutrients, which makes the temperature sensor crucial. A plant's ability to absorb oxygen is directly correlated with temperature, while the amount of oxygen dissolved in the nutrient solution is inversely correlated with temperature. (Almaqtari et al., 2020)

## 2.6 TDS and pH Sensor Technologies:

TDS sensor and pH sensor are important components in the automatic nutrient dosing system. This is because this sensor is used to read the concentration of the fertilizer solution and get the pH data of the water in the system to determine whether pump fertilizer needs to be used or not.

In hydroponics, the pH is carefully monitored and controlled, usually between 5.5-6.5. This pH sensor allows the system to automatically control the pH adjustment of the water. Correct pH control can help maximize nutrient uptake and photosynthesis and plant productivity. Sensors guide targeted and timely pH changes to optimize conditions.(Ansari et al., 2021)

However, the TDS sensors assist in the monitoring and maintenance of the ideal nutrient concentrations in solution in hydroponics. Plants may become stressed by overly high or low of nutrient. TDS sensors allow dosing systems to automatically add nutrients when necessary to maintain TDS levels within predetermined ranges. Crop yield and plant growth are enhanced by this precision. In soil-based agriculture, TDS monitoring is also utilized to accurately deliver fertilizers via irrigation based on real-time readings.(Ansari et al., 2021)

The pH scale, which ranges from 0 to 14, indicates how alkaline or acidic a solution is. An acidic value is zero, a neutral value is seven, and a alkaline is fourteen. Using two electrodes the reference electrode and the glass electrode, which is sensitive to hydrogen ions, the sensor can measure the potential difference between them to determine the solution. The PH sensor's probe, consisting of two electrodes. (Ansari et al., 2021)

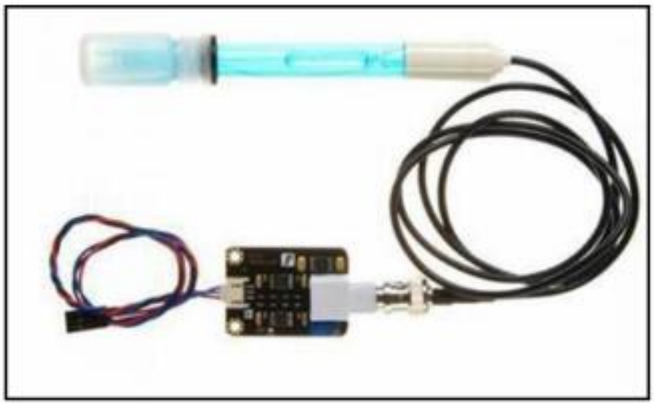

Figure 4 pH sensor*(Ansari et al., 2021)*

Two stainless steel probes are part of a conductivity sensor system used by the Total Dissolved Solids (TDS) sensor in water. This sensor makes the direct current flow into the liquid extremely vulnerable to ion polarity shifts and electrolysis. For the solution to flow current and convert the conductance value into volts, a constant AC voltage source is used on the probe. (Ansari et al., 2021)



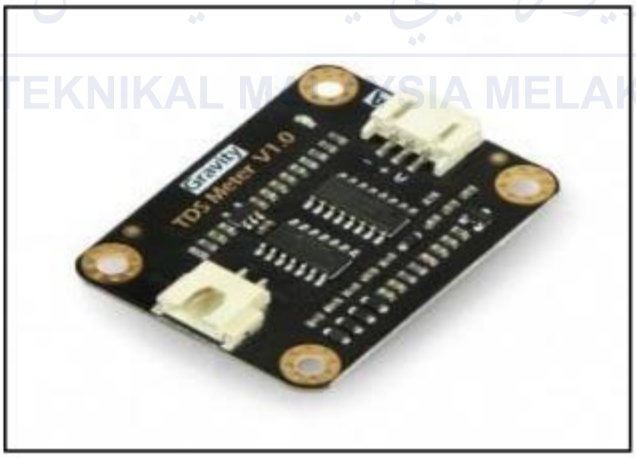


Figure 5 Total Dissolved Solids (TDS) Sensor*(Ansari et al., 2021)*

## 2.7 Blynk App and similar IoT platforms Integration for Agricultural Monitoring

In hydroponic there are several studies that have similar IoT platform. Firstly after sensor give the signal to ESP32 Microcontroller. Then, it will send the data to the cloud server. A cloud server will house the data. The owner can control the hardware additives with his or her cell phone and the facts can be verified at the display by using a cell utility. Furthermore, every sensor's data is stored inside the Thing speak cloud.(Mulla & Sakthi, 2021).

Looking at other studies, Blynk Platform is used for the implementation of mobile application functions by using C programming language and Microsoft excel for displaying data from the Thing Speak platform.(Paul et al., 2022)

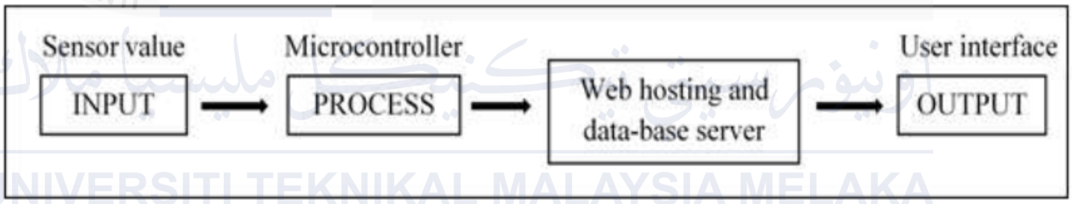


Figure 6 The block diagram of monitoring hydroponic system*(Paul et al., 2022)*

From the figure 5, The proposed control block diagram is designed as an open-loop control system. This is to continuously provide real-time measurements from all sensors. The microcontroller gathers and processes the sensor data, which is then sent to a web hosting and database server via Wi-Fi. Users can monitor the sensor measurements in real-time through a smartphone application but cannot control the output, but user doesn’t have the capability to influence the system's output.(Azimi et al., 2020)

Through the use of internet-connected devices and mobile apps, farmers can remotely monitor cultivation parameters such as pH, EC, temperature, and moisture levels from any place. As a result, decisions can be made quickly. The cultivation system's sensors send data to cloud servers via Wi-Fi or other wireless protocols. Because of their flexible APIs and SDKs, platforms like Blynk , ThingSpeak, Microsoft Azure, and Amazon AWS are frequently used to develop agricultural IoT monitoring apps. Apps can be modified to meet the needs of the user. (Azimi et al., 2020)

## 2.8 Nutrient Management in Hydroponics

Among the research related to nutrient management is from (Vishram Kulkarni et al., 2024) in this research using 2 macronutrients, the first Macronutrients are Nitrogen, Phosphorus, Potassium and in addition, are Magnesium, Calcium, Sulphur, Manganese, Iron, Zinc, Copper, Molybdenum, Boron.

Table 1 Essential parameters for Leafy Greens

| No | Vegetable | Ph | EC | TDS |
|---|---|---|---|---|
| 1 | Spinach | 6-7 | 1.8-2.3 | 1260-1600 |
| 2 | Lettuce | 5.5-6.5 | 0.8-1.2 | 560-840 |
| 3 | Cilantro | 5.8-6.4 | 1.2-1.8 | 800-1000 |
| 4 | Basil | 5.5-6.0 | 1.0-1.6 | 700-1120 |



In the same research, Experiments are conducted related to pH, TDS and temperature to study their effect on **Spinach** growth. The purpose of experiment 1 is to see the effect for the plant if the plant doesn't enough pH in water. Usually, the pH of water will be dropped around 2.8 to 3 just after the growth. This plant grows about 4-5 inches tall and then causes the plant to start showing drying and spots

In experiment 2 &3 show that, Results show higher TDS values between 1000-1200 ppm support better plant growth and quality and temperature is also found to influence pH levels which slightly drop during evenings but no major impact on plants is observed. (Vishram Kulkarni et al., 2024)

## 2.9 Challenges and Solutions in Automated Hydroponics

There are several challenges encountered in the development, which is Power requirements. A dependable power source is necessary for continuously operating sensors, pumps, and fans. Another than that, for remote monitoring and control, reliable Wi-Fi/internet connectivity needs to be established within greenhouses. Signal strength issues could interfere with system operation.(Li et al., 2022).

We can solve this problem by using the solar system to be used as a power source for the hydroponic system, this is because solar energy is easy for us to get because our country has a high rate of exposure to the sun. The problem of Wi-Fi signal strength can also be overcome by using a Star-link device that can get a signal in areas that do not have internet coverage

## 2.10 Hydroponic system of Lactuca Sativa

Lettuce is a crucial leafy vegetable known for its wide range of shapes and genetic diversity. lettuce is from Egypt and Iran. This plant has a rosette of leaves and yellow flowers. this plant also have variable genetic diversity is a result of its complex domestication such as green coral, red coral (Lolla Rossa) and butterhead (Boston).(E. Křístková, 2008)

According to other studies, this plant needs nutrients around 560-840 ppm through TDS sensor.(Vishram Kulkarni et al., 2024) This value needs to be calibrated because this reading is not specific to the type of lectue itself. So a research to get the correct reading value and the type of plant should be done to get the optimal plant growth results.

Table 2 AB mix-nutrient dose for lettuce*(Li et al., 2022)*

| Week | First | Second | Third | Fourth | Fifth | Following weeks |
|---|---|---|---|---|---|---|
| TDS(ppm) | 0 | 200 | 400 | 600 | 800 | 800 |
| pH | 5.5-6.5 | 5.5-6.5 | 5.5-6.5 | 5.5-6.5 | 5.5-6.5 | 5.5-6.5 |

At another side, from (Li et al., 2022) said that for growing Lettuce plants hydroponically in the first week he did not put any fertilizer and used distilled water to make the TDS value reading more accurate. starting from the 2nd week to the next it increases as much as 200 ppm up to 800 ppm and the pH level is from 5.5-6.5 pH but this research gives recommendations to build a green house and add adequate lighting so that this plant can live well

### 2.10.1 Optimum flow rate enhances the performance of lettuce (Lactuca sativa L.) in hydroponic

In this research, explain that the optimal flow rate for higher yields for lettuce grown hydroponically, this is because there is still no study that sets the water flow rate for this plant so that it can absorb nutrients optimally. This study uses two types of lectuce, namely Boston and Lollo Rossa, and used four different flow rates (0.5, 1.0, 1.5, and 2.0 L $min^{-1}$) in the hydroponic system. The results showed that Lollo Rossa outperformed Boston in terms of roots, number of leaves, length and several other aspects. This parameter improves with increasing flow rate up to 1.5 L $min^{-1}$ but decreases beyond that. Therefore, for a higher production of this salad variety, the optimal flow rate should be maintained at 1.5 L $min^{-1}$ in the Nutrient Film Technique (NFT) hydroponic system under the specified environmental conditions, as this flow rate supports root and shoot growth, nutrients.(Abbas et al., 2024)

## 2.11 Summary

The previous chapter covered different facets of hydroponic systems, highlighting Nutrient Film Technique (NFT) as the method we find the best match for our DIY home garden because of its simplicity and trickle watering. We-conduct a review of closed-loop recirculation systems to teach horticultural industry professionals how to use closed-loop recirculation to optimize water and fertilizer use through energy-efficient and benefit the environment.. The use of Arduino Uno and IoT technologies, including ESP32 and ESP8266, was discussed for their roles in automating and monitoring hydroponic systems, ensuring precise nutrient management and environmental control. Additionally, the integration of peristaltic pumps for accurate nutrient dosing and the importance of TDS and pH sensors for maintaining optimal growing conditions were emphasized. Lastly, specific case studies on the nutrient requirements and optimal conditions for growing lettuce hydroponically were reviewed, underscoring the significance of precise flow rates and environmental parameters in maximizing crop yield

# CHAPTER 3

# METHODOLOGY

## 3.1 Introduction

This section describes the project's methods and processes. Project methodology is crucial for ensuring accurate workflow and efficient execution. The methodology aimed to achieve project objectives through research, data collection, and experimental procedures. This project includes flow charts to illustrate and explain the workflow. Flow charts are crucial for describing and clarifying project steps, visualizing the process, and understanding its structure and dependencies. By following the methodology and using flow charts, the project can efficiently plan, execute, and monitor its progress to stay on track and achieve desired goals.



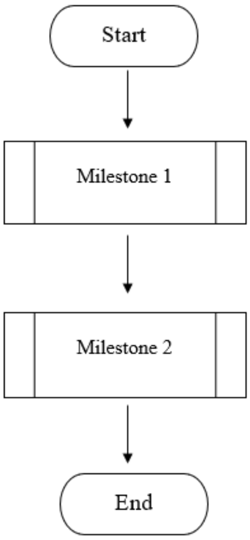


Figure 7 Flow chart of overall methodology

## 3.2 First Milestone

Firstly, this section will discuss the development of the automatic dosing system, the working procedure begins with research and idea generation, followed by the hardware design stage. If the design is feasible, we proceed to Milestone 2 (software Development). However, if the design is not feasible, we will go back to the hardware design phase

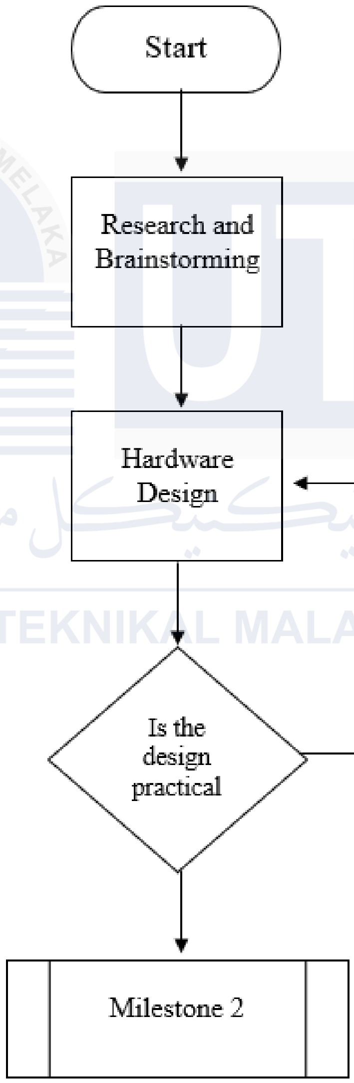




Figure 8 Flowchart of Milestone 1

### 3.2.1 Wiring Diagram

In our automatic dosing project, various components are connected to the ESP32 to create an efficient and user-friendly waste sorting system. Figure 9 illustrates the wiring setup of the automatic waste sorting machine. The system integrates a TDS sensor for measuring water quality, a peristaltic pump for precise liquid transfer, and a relay to control the dosing system. By combining these components, the system ensures accuracy and efficiency in waste sorting and dosing processes.

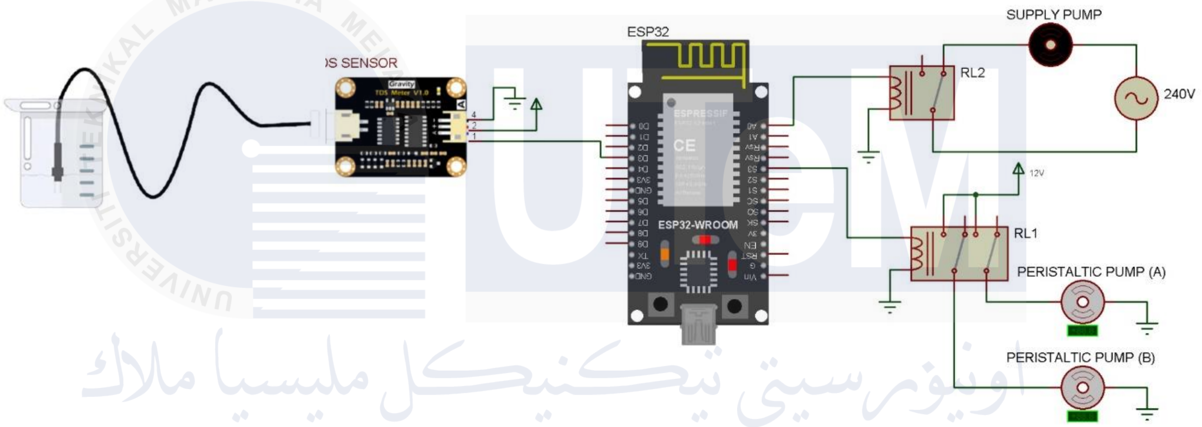




Figure 9 Wiring diagram

### 3.2.2 Equipment

Table 3 List of equipment used for system

| Product Type | Quantity |
|---|---|
| Peristaltic pump | 2 |
| Relay | 2 |
| Capacitors | 2 |
| TDS sensor | 1 |
| ESP32 | 1 |
| Power supply | 1 |
| Lactuca sativa | 8 |
| Nutrient solution A | 1 |
| Nutrient solution B | 1 |
| 12L plastic container | 1 |
| Hydroponic System | 1 |

Components of automated hydroponic dosing systems are listed in the Table 3 which includes the inclusion of peristaltic pump for precise dispensing of nutritional dosage, relay for the switching on/off mechanisms of the electrically powered mechanism, automation microcontroller of ESP32 type, a TDS sensor ensuring appropriateness of concentration and power supply which energizes all components in action. This setup comprises a 12L plastic container for nutrient storage, capacitors for stability in voltage, and a hydroponic mechanism for growing Lactuca sativa, commonly known as lettuce. It also tests nutrient solution A and B in several proportions for optimum plant growth. The system here combines mechanical with electronic for efficient automated plant cultivation.

### 3.2.2.1 ESP32

The ESP32 is a low-cost, low-power system on a chip (SoC) with built-in Wi-Fi and Bluetooth, developed by Expressive Systems. It features a dual-core processor, integrated sensors, and various peripherals, making it ideal for IoT devices and automation systems due to its versatility and energy efficiency.

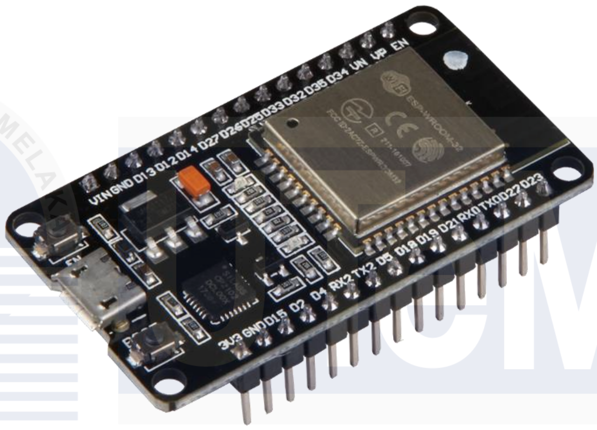

Figure 10 ESP32 (NodeMCU ESP32 | Joy-IT, n.d.)



Table 4 Specification of ESP32

| No | Specifications | Esp32 |
|---|---|---|
| 1 | Model | Nodemcu ESP32 |
| 2 | Processor | Tensilica LX6 Dual-Core |
| 3 | Clock Frequency | 240 Mhz |
| 4 | Memory | 4 MB |
| 5 | Wireless Standard | 802.11 B/G/N |

### 3.2.2.2 TDS Sensor

The amount of dissolved materials in a liquid, usually water, is measured by a TDS (Total Dissolved Solids) sensor. It functions by measuring the water's electrical conductivity, which is correlated with the concentration of dissolved ions in the solution. To guarantee the safety and purity of the water, TDS sensors are widely used in hydroponics, aquariums, and other industrial processes. By giving a numerical measurement of all the inorganic and organic materials dissolved in the water, they aid in determining the general quality of the water.

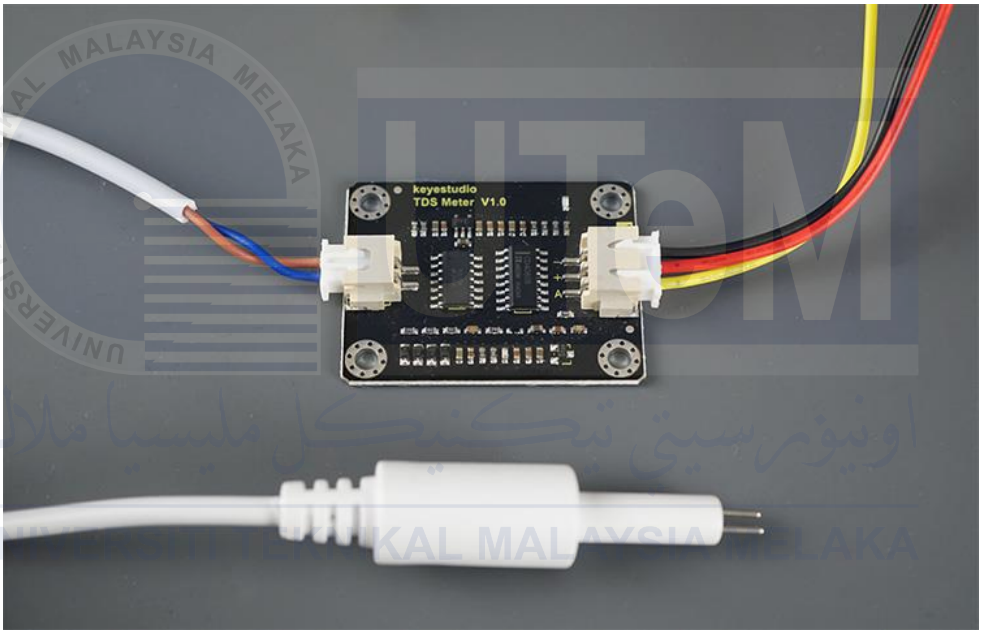


Figure 11 TDS Sensor (Santos & Santos, 2022)

Table 5 Specification of TDS Sensor

| No | Specification | TDS Sensor |
|---|---|---|
| 1 | Input Voltage | 3.3 ~ 5.5V |
| 2 | Output Voltage | 0 ~ 2.3V |
| 3 | TDS Measurement Range | 0 ~ 1000ppm |
| 4 | TDS Measurement Accuracy | ± 10% F.S. (25 ℃) |
| 5 | Working Current | 3 ~ 6mA |

### 3.2.2.3 Peristaltic pump

A peristaltic pump moves fluids through a flexible tube by rhythmically compressing and releasing it, ensuring sterile and controlled flow. Commonly used in medical, laboratory, and industrial applications, it keeps fluids from contacting moving parts.

Figure 12 Peristaltic Pump (MAKERS Electronics, We Make the Future, 2024)



Table 6 Specification of the Peristaltic Pump

| No | Specification | Peristaltic Pump |
|---|---|---|
| 1 | Input Voltage | 12V |
| 2 | Flow Rate | 37 ml/min |
| 3 | Operating Current | 0.25A |
| 4 | Outside diameter of water outlet | 5 mm |
| 5 | Inside diameter of water outlet | 3 mm |

## 3.3 Second milestone

After the installation of sensors and actuators on the system has been completed. Then the process of programming the system will be done, this is done to activate the sensor to get data readings. In this study, the programming language will be used such as c++, online simulation cannot be done because there is no desired sensor in the simulation apps such as no TDS sensor in most Ciruito.io simulation apps. The analysis consists of monitoring growth and health of the cultivation and adjusting the system accordingly in order to achieve optimal results.

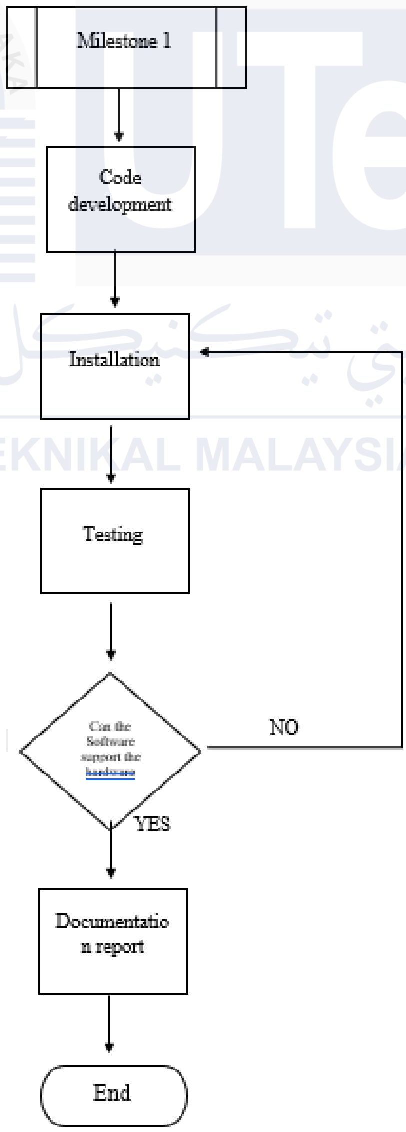


Figure 13 The flowchart of milestone 2

### 3.3.2 Software

Below is a list of the software that will be utilize for this project. The selection of this programming language and software is intended to guarantee the project's success and usability.

#### 3.3.2.1 Arduino IDE (Integrated Development Environment)


Figure 14 Arduino IDE



a software application used for programming and uploading code to Arduino microcontroller boards. It provides a user-friendly interface that allows users to write code in a language derived from C/C++ and includes various tools to help with code development and debugging.

### 3.3.3 Block Diagram

The block schematic illustrates the nutrient dosing system built around the ESP32 microcontroller, wherein a TDS sensor measures Total Dissolved Solids in solution and sends those readings to the ESP32, which is used to digitally process the data for providing an actuation signal to pump nutrients A and B. Therefore, the unit will be supplied with a voltage value from 2.2 to 3.6V to keep most components within specifications. The ESP32 module enables wireless communication, via Wi-Fi, with the Blynk application. It therefore allows for real-time monitoring and control of the system remotely. With such a setup, automated efficient nutrient management of the solution is guaranteed.



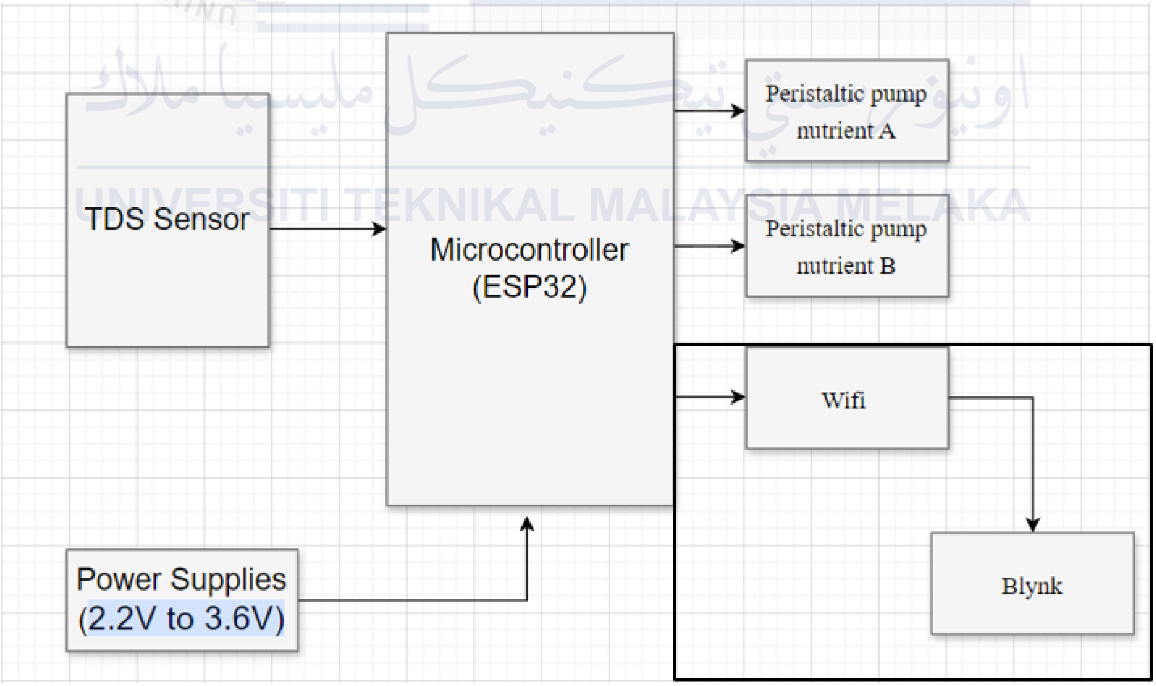


Figure 15 The block diagram of the system

The TDS sensor of this system measures the nutrient concentration within the tank. Based on readings, it would then trigger a peristaltic pump, which will dispense the amount of fertilizer in dosages based on the plant's age. When the needed quantity of nutrient is reached, it automatically stops.

Mixing different nutrient solution combinations using various ratios of Fertilizer A and Fertilizer B to try to test and get the best nutrient combination for appropriate plant growth. Plants will be measured in their growth after a fixed period of time. The measurements done in the process will be passed to a smartphone for further monitoring and analysis through an ESP32 microprocessor.

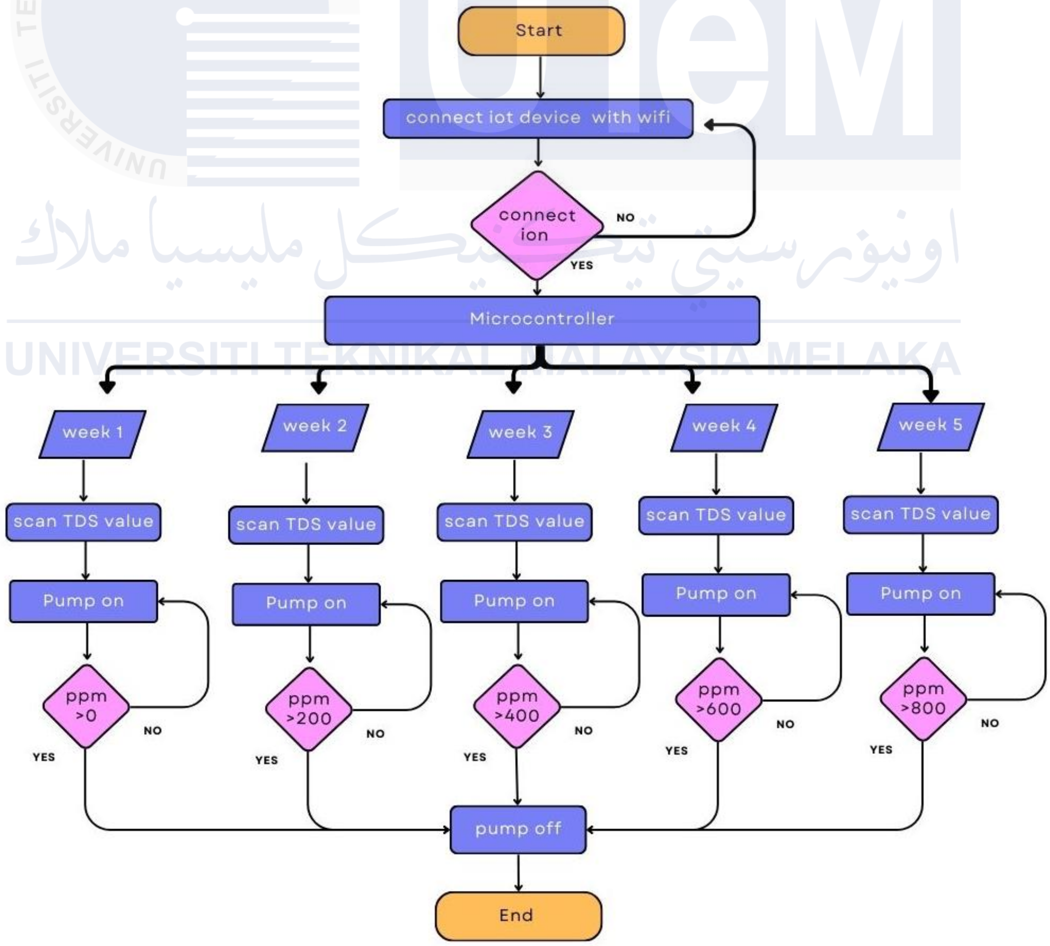


Figure 16 flowchart of the Operational Process of an Automatic Dosing System

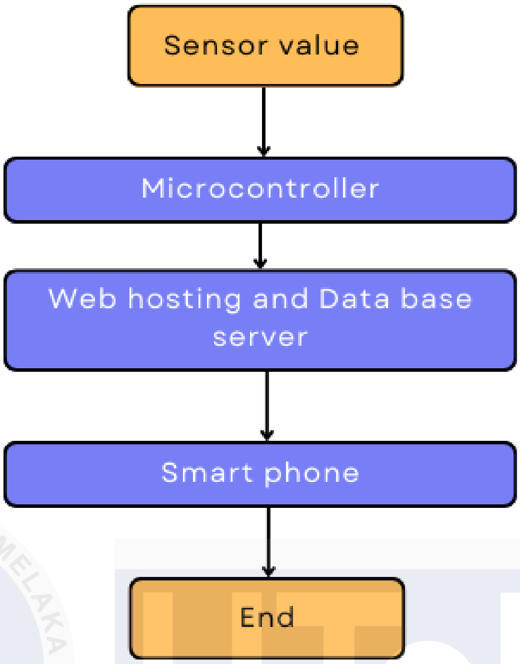


Figure 17 The flowchart of monitoring system

After the sensor reads the total dissolved solids (TDS) value, the data is transferred to a database server via the microcontroller. The server stores the information. The user can access the data online



## 3.4 Summary

In this section the research focuses on creating a system that automatically doses nutrients for a system. The goal is to deliver nutrients efficiently without intervention. The process involves setting up the hardware and handling data in a manner. The setup includes sensors, actuators and microcontrollers such, as ESP32, TDS sensor and peristaltic pump. The system measures the levels activates the pump as needed. Sends information to a smartphone through a cloud server. It then outlines the components, with their specifications before moving on to programming using C++ and Arduino IDE to promote plant growth

# CHAPTER 4

# RESULT & DISCUSSION

## 4.0 Introduction

This chapter presents the results and analysis of the development of an automatic dosing system. The experiment was conducted in a real environment using a 5-liter tank to simulate actual operating conditions. Nutrient concentrations of 200 ppm, 400 ppm, 600 ppm, and 800 ppm were used as reference points based on the requirements for plant growth. A TDS (Total Dissolved Solids) meter was used to measure the nutrient concentration, serving as a benchmark for calibration.



## 4.1 Result

Table 7 presents the simulation results of the automatic nutrient dosing system. The experiments were conducted using different TDS setpoints over multiple weeks. For each setpoint, the TDS values measured by the sensor were compared with those recorded by a standard TDS meter. Three readings were taken for each test, and the average TDS values for both the meter and the sensor were calculated. The percentage error was also determined to evaluate the precision of the system. The detailed results are summarized in Table 7

Table 7 Result of Automatic Nutrient Dosing System

| week | TDS setpoint (ppm) | TDS meter (ppm) | | | avg | TDS sensor (ppm) | | | avg | Error% |
|---|---|---|---|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | | 1 | 2 | 3 | | |
| 2 | 200 | 155 | 156 | 163 | 158.0 | 217 | 222 | 221 | 220.0 | -39.2 |
| 3 | 400 | 363 | 371 | 365 | 366.3 | 499 | 495 | 535 | 509.7 | -39.1 |
| 4 | 600 | 558 | 559 | 562 | 559.7 | 684 | 684 | 687 | 685.0 | -22.4 |
| 5 | 800 | 916 | 936 | 915 | 922.3 | 863 | 862 | 862 | 862.3 | 6.5 |

The TDS sensor showed significant errors at lower setpoints, such as -39.24% at 200 ppm and -39.13% at 400 ppm. However, its accuracy improved at higher setpoints, with a minimum error of 6.51% at 800 ppm. This suggests the sensor is more reliable for higher nutrient concentrations, but further calibration is needed, particularly for lower concentrations. One factor contributing to this issue is the delayed reading caused by the distance between the TDS sensor and the peristaltic pump. This delay affects the system's ability to stop the pump at the correct nutrient levels. Improving accuracy can be achieved by positioning the sensor closer to the pump, enabling faster and more precise readings.

### 4.1.1 Prototype

The sample machine is made up of an ESP32, TDS sensor, two peristaltic pump, and Tank pump. The system was powered by one 12V , 3V Direct Current adapters plug and 12v alternating Current adapters plug. The machine case was designed to conceal the wires of all the components. The size of the sample machine is 152 x 195 x 80 mm. Figure 18 shows the prototype of Automatic Waste Sorting Machine.

Figure 18 Project Prototype

### 4.1.2 Web/Mobile User Interface

The Web/Mobile User Interface of this automatic hydroponic dosing system allows for efficiency and ease of control over the system. Its design is focused on simplicity, making it user-friendly while allowing users to manage the nutrient dosing process by means of their mobile device or web browser from a remote location. In hydroponics, the interface is necessary to optimize the environment for plant growth. It helps for monitoring the main parameters and automating dosing tasks, making the system more reliable and easier to use.

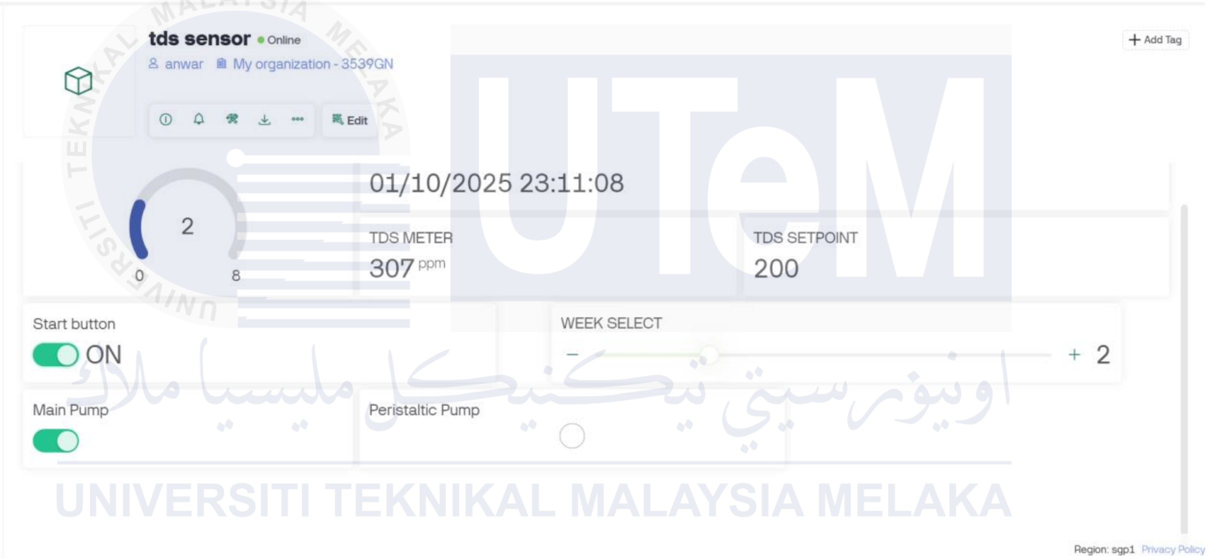


Figure 19 Web user Interface

In Figure 19 has a real-time data, such as TDS, is given on the interface about the concentration of nutrients in the water. One can select the target TDS value desired, choose the week of the plant's growth cycle using the week selector slider so that the system delivers the right amount at the right time. Key controls include a start button to turn the system on/off, an indicator for the main pump, and one for the peristaltic dosing pump to enable showing whether or not either of these components is operating. This interface, with clear layout and not complicated controls, provides for ease of operation such that even completely inexperienced people can manage a hydroponic system quite easily.

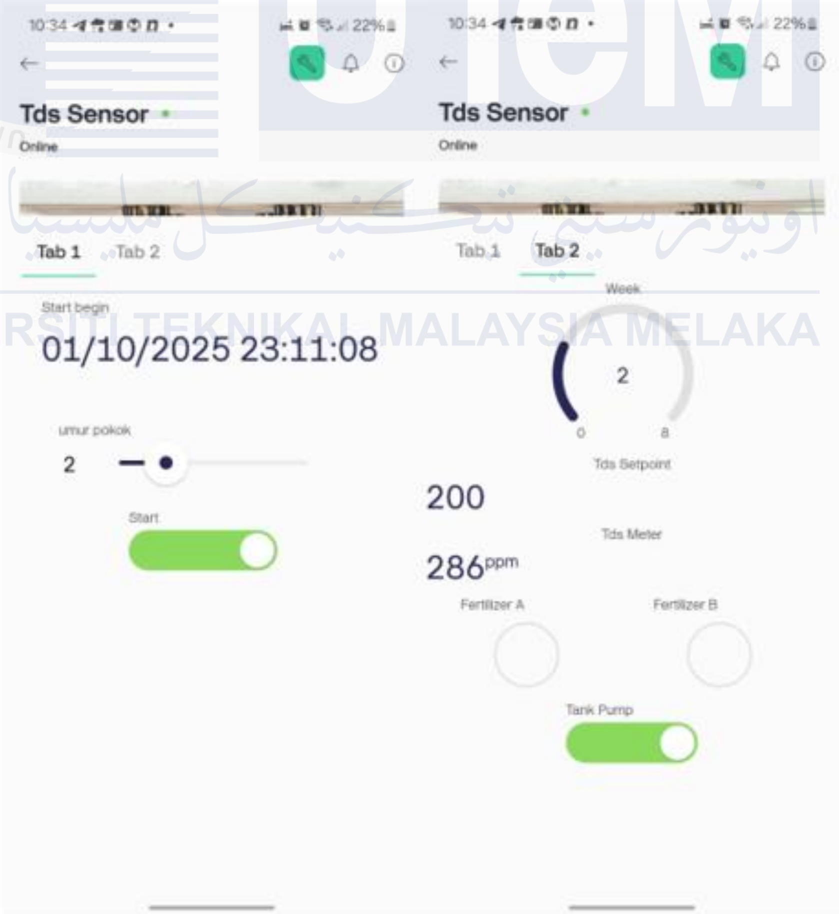


Figure 20 Smartphone Interface

### 4.1.3 Plant Growth

At early age of the growth of plant the critical need of the plant is water, to make sure it can grow easily and hydrated, the age of the plant is currently between 1 and 6 days.

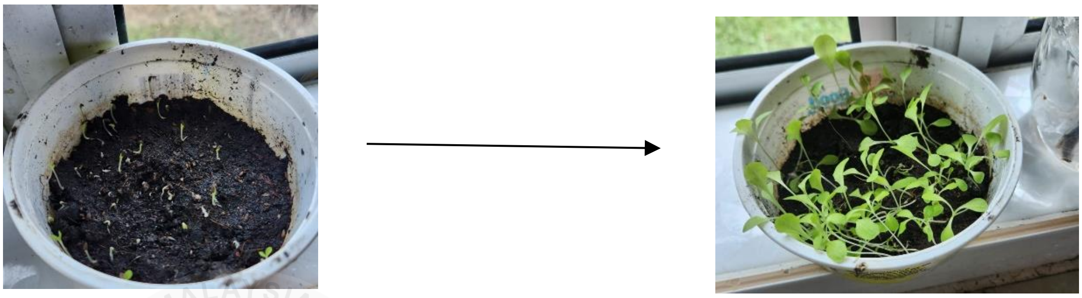

Figure 21 Day 1 to 6 of growth plant

During the transition from week 1 to week 2, the plant will undergo a process in which it is placed in water, allowing the roots to develop and grow, ensuring the plant establishes a stronger foundation for further growth.

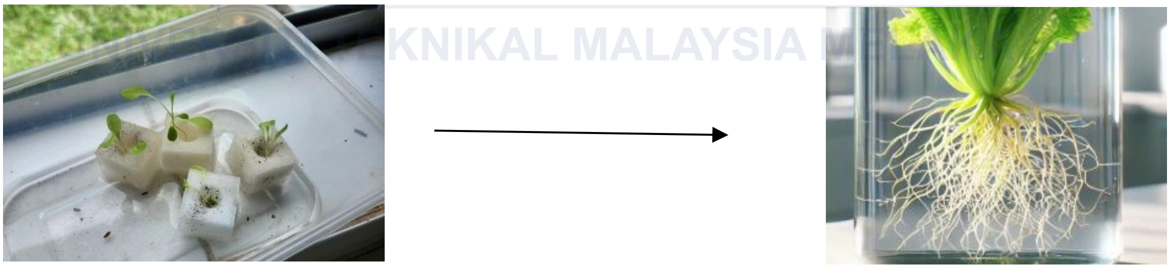

Figure 22 Week 1 To week 2 of growth plant

Starting in week 2, we ensure that the root system of the plant is well-developed and suitable for hydroponic growth. We carefully transfer the plant into a specialized pot designed for hydroponic systems, making sure that the roots are properly positioned to optimize nutrient absorption, after which we integrate the pot into the hydroponic system and install an automatic dosing system to continuously monitor and deliver precise amounts of nutrients.

Figure 23 Transfer the plant at hydroponic system

## 4.2 Analysis and Disscusion of Sensors

Figure 24 Illustration about the amount of nutrient solution

From the figure 24 show that from 5-liter tank is reduce to 1-liter tank to make the test. In this test, as much as 5ml of fertilizer a and fertilizer b are put into 1 liter of water, then the reading is recorded to be compared with the current reading and the actual reading. This reading is taken 3 times to get an accurate reading, and this process is repeated with 10ml and 15ml of nutrient solution

Table 8 he data of amount of nutrient solution using TDS sensor

| Nutrient solution A&B (ml) | TDS Sensor (ppm) | | | Avg | Volume (L) | Error % |
|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | | | |
| 5 | 500 | 495 | 494 | 496.3 | 1 | -0.73333 |
| 10 | 550 | 560 | 561 | 557.0 | 1 | -25.7333 |
| 15 | 559 | 557 | 560 | 558.7 | 1 | -51.4203 |

the data in the table above is a reading of the value of TDS sensor and TDS meter, the TDS sensor can be calibrating by comparing between TDS meter and Sensor and get the percentage of error. The formula of Error has shown below:

Equation 1 Formula of Error %

$$\% \, Error = \frac{|Measure - Real|}{Real} \times 100 = \%$$

The calculation of error is required because the error data obtained can help to make a calibration for the TDS sensor by resetting the TDS sensor reading by adding percentage error to reduce the reading of error

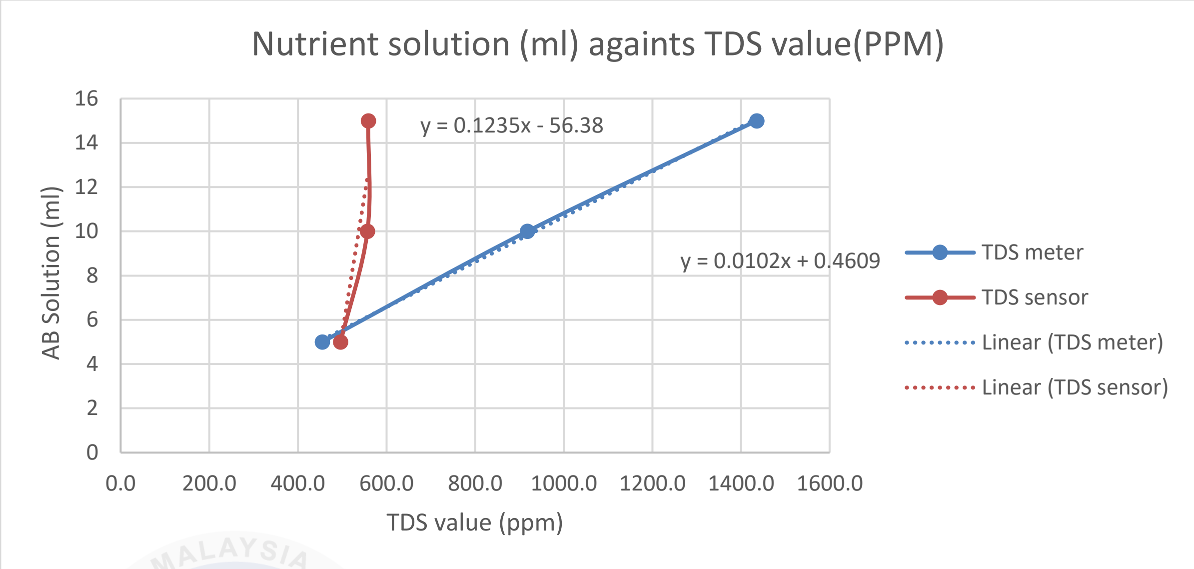


Figure 25 The graph of Ab solution against TDS value

From the graph, the TDS meter has more accurate data compared to the TDS sensor. The TDS meter shows a gradient of 0.0102, almost the same as the gradient reading for real data 0.0151. The TDS sensor reading has a significant difference with a 0.1235 gradient. This is because the TDS sensor has not been calibrated and have a maximum reading of around 560 ppm. From this graph, by using y = 0.0102x + 0.4609 equation, tell that 200 ppm of nutrient solution need 2.5 ml volume for 1-liter tank of nutrient solution, this means for a tank containing 5 liters of water, 12.5ml is needed

### 4.2.1 Improving the accuracy and stability of sensor

After Accuracy and stability are important features in any system because these will guarantee the reliability of the data. This section tries to solve problems occurring with the TDS sensor: in particular, inaccuracy and instability problems caused by fluctuation in power. In this regard, possible solutions for better performance were explored by means of calibration, different power, and additional capacitors.

#### 4.2.1.1 Accuracy of the TDS Sensor

After identifying issues with the TDS sensor's ppm readings, it was determined that the primary cause of the inaccuracies was the lack of calibration. Below is the data obtained after calibrating the TDS sensor:

Table 9 Value of TDS sensor after calibration

| water solution (ppm) | reading | | | avg | error % |
|---|---|---|---|---|---|
| | 1 | 2 | 3 | | |
| 200 | 217 | 230 | 256 | 234.3 | 17.2 |
| 400 | 466 | 471 | 465 | 467.3 | 16.8 |
| 600 | 655 | 682 | 669 | 668.7 | 11.4 |
| 800 | 873 | 853 | 786 | 784.7 | -1.9 |

This calibration significantly improved the accuracy of the sensor's readings, making it more reliable for use in the system. The error of the percentage was drop from 51% to 17% The calibration was specifically adjusted to align with the nutrient requirements of Lactuca sativa, which necessitates accurate readings at 200 ppm, 400 ppm, 600 ppm, and 800 ppm for optimal growth.

#### 4.2.1.2 Stability of the Sensor

Everything was integrated into the system, including the two relays and two 12V motors, but a number of issues arose. First of all, it was realized that the power was not enough; hence, the reading from the TDS sensor was not stable.

This problem became more evident whenever the relays were turned on to supply the fertilizer pump because it reduced the amount of power available for the TDS sensor; this made the reading unstable and broke the connection between the ESP32 microcontroller and the internet. The table below summarizes the unstable data during the active and inactive states of the relay:

Table 10 Unstable Data Readings

| Reading Attempt | Water Solution (ppm) | TDS Reading (ppm) with Relay ON | ESP32 Wi-Fi Status |
|---|---|---|---|
| 1 | 800 | 764 | on |
| 2 | 800 | 0 | off |
| 3 | 800 | 654 | on |
| 4 | 800 | 0 | off |
| 5 | 800 | 672 | on |
| 6 | 800 | 0 | off |
| 7 | 800 | 0 | 0ff |
| 8 | 800 | 590 | on |
| 9 | 800 | 0 | off |
| 10 | 800 | 0 | off |

From the data TDS Sensor from the table, it is evident that the ESP32 microcontroller faces issues related to the electrical aspects of the system when the relay remains active ("Relay ON"). The primary problem arises from power instability, which significantly impacts both the TDS sensor readings and the ESP32's Wi-Fi connectivity.

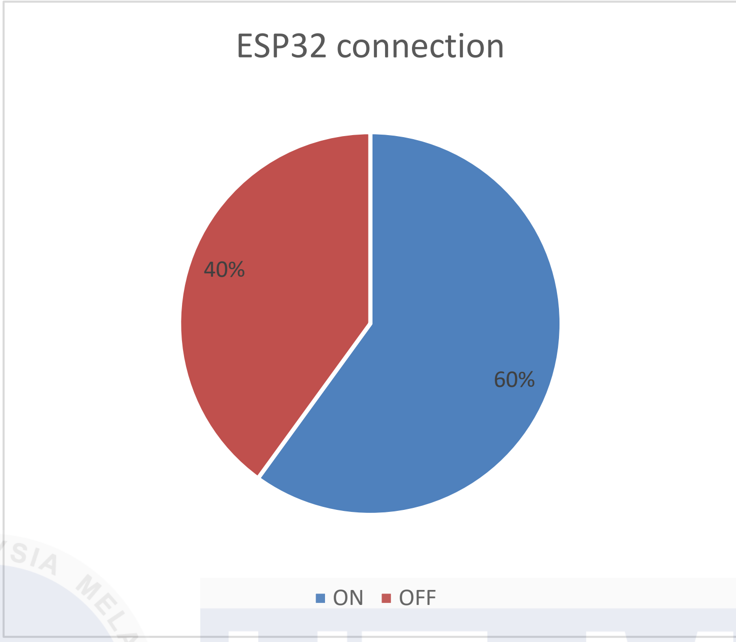


Figure 26 Pie chart of wifi connection of esp32

This pie chart describes the connectivity status of the ESP32 module during operation; it was ON for 60% and OFF for 40% of the time. An uptime of 60% implies that the ESP32 stays connected through Wi-Fi for most of its operation time in the system, whereby any form of monitoring or control in the hydroponic setup becomes very efficient. However, the 40% downtime underlines significant intermittent issues in connectivity where remote monitoring and control are disrupted.

This may be because of reasons such as electrical interference due to the relay, which can draw too much current and create instability; poor power supply stabilization concerning the ESP32 microcontroller; or it can be some hardware or environmental problem. Thus, the data underlines the need for system improvements, like power supply isolation, addition of capacitors for stabilization, or optimization of relay usage, which will minimize Wi-Fi downtime and increase the overall system reliability and performance.

#### 4.2.1.2.1 Solution for Stabilization of Sensor

To address the system's instability two key solutions were implemented, Firstly, isolating the power supply for the TDS sensor and the ESP32 microcontroller to minimize interference from relays and motors. Second is by installing additional capacitors to provide supplementary power during operation, ensuring stable voltage levels for the sensor and other critical components. These measures significantly improved the system's stability as demonstrated by the results shown in the table below.

Table 11 Stabilized Data Readings

| Reading Attempt | Water solution | TDS Reading (ppm) with Relay ON | ESP32 Wi-Fi Status |
|---|---|---|---|
| 1 | 800 | 783 | on |
| 2 | 800 | 785 | on |
| 3 | 800 | 786 | on |
| 4 | 800 | 783 | on |
| 5 | 800 | 783 | on |
| 6 | 800 | 786 | on |
| 7 | 800 | 785 | on |
| 8 | 800 | 786 | on |
| 9 | 800 | 786 | on |
| 10 | 800 | 785 | on |

The data is evident that the calibration process markedly improved the accuracy of the TDS sensor that reducing errors. Furthermore, the implementation of a separate power supply and capacitors accurately stabilized the sensors readings even during relay activation. These Improvements ensure reliable sensor performance and uninterrupted system operation. These improvements assure the continuous improvement of a highly reliable sensor operation.

### 4.3 Analysis and Disscusion of pump performance

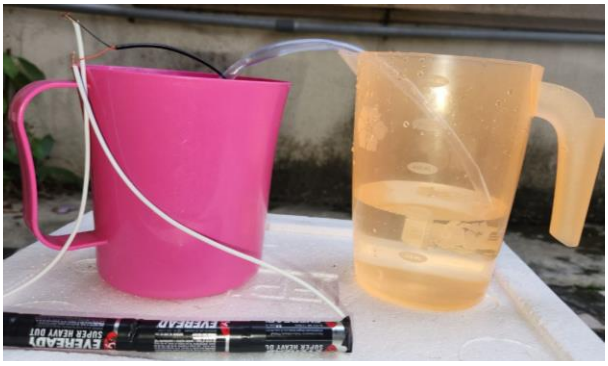

Figure 27 The experiment of submersible pump characteristic

From the figure 27 Shows how to get a flowrate reading by taking a time reading for water to be transferred from a cup to a jug with a volume of 400ml. This experiment was done by changing the battery voltage reading starting from 3v, 4.5v and 6v. The data reading results are shown in the table below

Table 12 The Data of submersible pump

| Voltage (V) | Time Taken (s) | | | Average (s) | Fluid volume (ml) | Flowrate, Q (ml/s) | Flowrate (l/min) |
|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | | | | |
| 3 | 18.42 | 18.31 | 19.50 | 18.74 | 400 | 21.34 | 1.281 |
| 4.5 | 12.10 | 12.08 | 11.90 | 12.03 | 400 | 33.25 | 1.995 |
| 6 | 10.97 | 10.59 | 9.99 | 10.52 | 400 | 38.02 | 2.28 |

the data in the table above is a reading of the time taken to fill 400ml of water into the jug from the value of the flowrate value in l/m can be found by using this equation:

Equation 2 Formula of Flowrate

$$Q = \frac{Volume, V}{Time, t} = \frac{ml}{s}$$

For example:

$$\frac{400\ ml}{18.74\ s} = 21.35\frac{ml}{s}$$

- Convert milliliters to liters: 1mL = 0.001L
- Convert seconds to minutes: 1 minute = 60 seconds.

$$Q = 21.35\frac{ml}{s} \times 0.001\frac{L}{ml} = 0.02135\frac{L}{s}$$

$$Q = 0.02135\frac{L}{s} \times 60\frac{s}{min} = 1.281\frac{L}{min}$$

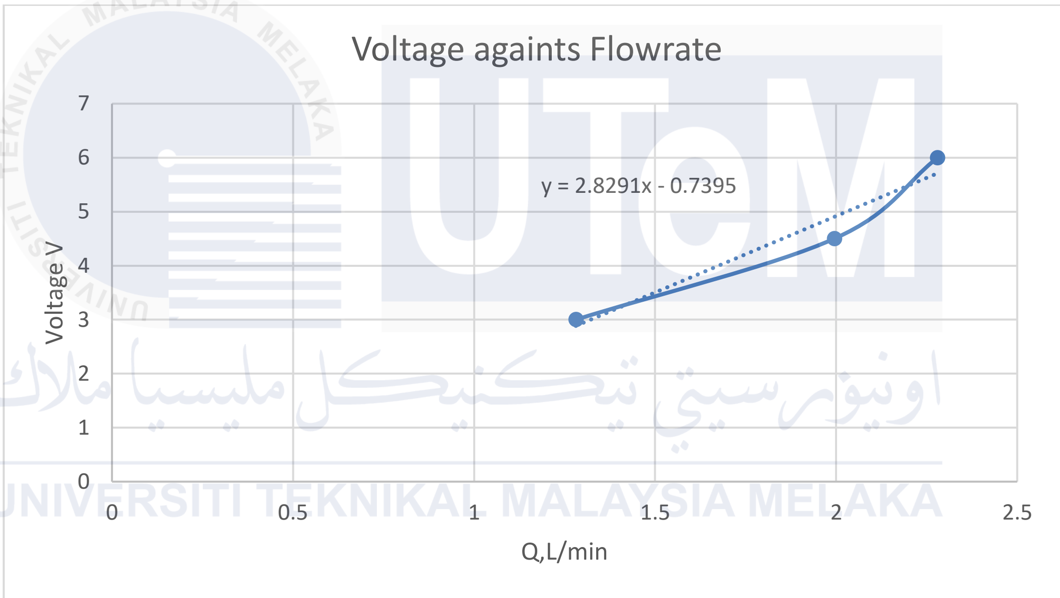


Figure 28 Graph of voltage against the flowrate

From the result, the submersible pump flowrate is 33.25 ml/s not suitable to be a fertilizer pump. This is because the flowrate of this pump is >12.5ml volume of solution in 5-liter tank. This pump can make waste of nutrient solution.

On the other hand, the submersible pump can be a tank pump to supply water for the hydroponic system, this is due to the high flowrate this pump can supply. From the equation the pump with flowrate 1.5 l/min can get by using 3.5-volt current

### 4.3.1 Issues with Pump Performance and Durability

The problems with the pump started to appear when it was tested under real conditions and it had to transfer the water to a height of 0.75 meters. It could not raise the water at that height; instead, it just burnt out, as seen in the Figure 29 below.

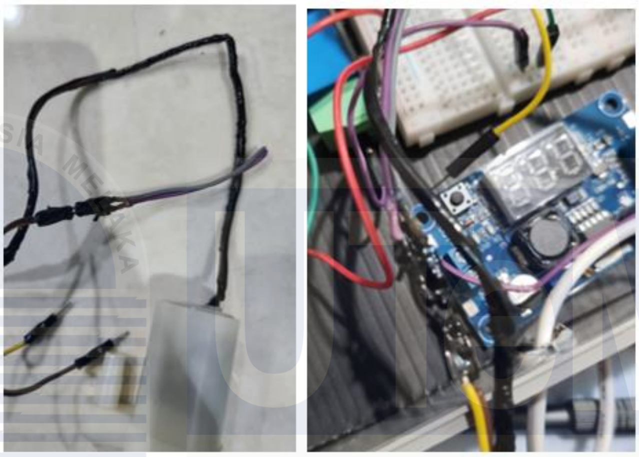

Figure 29 Burnt pump due to inability to lift water



The new AC pump was introduced as a proactive solution to address the issue of overloading in pumps, which has been a common challenge in many operational systems. Overloading can lead to significant problems such as reduced efficiency, increased wear and tear, and ultimately, pump failure. By using the 12V pump, that can transfer 1.5l/min the aim is to optimize performance while maintaining reliability and longevity.

## 4.4 Summary

This present work deals with the elaboration-development and performance evaluation of some components of the hydroponic system, such as pumps, nutrient solution, and sensor calibration. Investigations on submersible and peristaltic pumps are done by placing much emphasis on cost reduction and efficiency in performance. The flow rate and energy consumption of the submerged pump were performed. From there, it is unfit for nutrient dosing since its flow rate was on the higher scale, but could possibly work as a water supply pump for the hydroponic setup.

Nutrient solution tests had been done with a TDS meter and sensor to check the concentration of solution A and solution B. Large discrepancies were detected in the sensor readings and subsequently corrected by calibration, reducing these errors and discrepancies. In this chapter, the importance of sensor calibration to get the right nutrient dosing was discussed in order to have better plant growth.

The power stability problems of the TDS sensor were resolved by separating power supplies and adding capacitors to improve system reliability. Real-time monitoring and control were possible through the addition of a Web/Mobile User Interface, further simplifying nutrient dosing for the user. The chapter thus provides insight into attempts to make the system more efficient, accurate, and user-friendly.

# CHAPTER 5

# CONCLUSION AND RECOMMENDATIONS

## 5.0 Conclusion

The scope and potential for automated hydroponic nutrient dosing using IoT technology in plant cultivation is very good. The proposed system integrates sensors, microcontrollers, and user interfaces to make the management of nutrients much easier. The calibration of the TDS sensor gave better accuracy, reduced error margins, and ensured proper nutrient delivery to the plants for better growth. The submersible pump was unsuitable for nutrient dosing due to its high flow rate but showed promise as a reliable water supply pump. Stability and accuracy issues were mitigated through enhanced power management and sensor calibration. The user-friendly Web/Mobile interface further simplifies monitoring and control, making the system accessible even to beginners. Overall, the project successfully addresses key challenges in automated hydroponics, setting the foundation for further advancements.

## 5.1 Recommendation

Improvements have been identified that aim at making the system reach its fullest potential in effective and reliable performance. These recommendations would meet not only the present limitations but also ensure the system is optimized for wider applications. The enhancements should focus on improving the usability, functionality, and adaptability of the system to reach more users, be able to meet changing needs, and remain reliable in the long term. Some of the enhancements include the following:

a) User-Friendly Design: Refining the interface to provide more intuitive controls and detailed guidance will make the system more accessible to users with varying levels of technical expertise.

b) Ease of Installation: Standardizing the system's components and creating a modular design can simplify installation and setup processes, encouraging adoption.

c) Improved Performance: Optimizing sensor calibration and pump selection to better match nutrient dosing requirements will enhance efficiency and accuracy in nutrient delivery.

d) Water Level Sensor Integration: Including water level sensors can prevent operational disruptions by detecting low water levels in the tank and triggering timely refills.

e) Standalone Electrical System: Incorporating solar panels can make the system energy-independent, reducing reliance on external power sources and promoting sustainability.

f) Customizable nutrient and weekly set points will enable the cultivation of various vegetable types in the hydroponic setup..

## 5.2 Challenging

Despite its success, the project encountered several challenges that highlight areas for improvement:

a) Cost Considerations: High costs for IoT components and specialized sensors remain a barrier to broader implementation. Exploring cost-effective alternatives could improve accessibility.

b) Weather Variability: Maintaining optimal plant growth in fluctuating environmental conditions remains a challenge. Developing adaptive algorithms to adjust system operations in response to weather changes can address this issue.

c) Technical Stability: Ensuring uninterrupted power supply and stable connectivity is essential for seamless operation. Addressing these through robust design and backup solutions is critical.

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