# AUTOMATED INDOOR HYDROPONIC SYSTEM USING RASPBERRY PI

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**THESIS**

**Department of Computer Engineering**
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## APPROVAL SHEET

Undergraduate thesis titled **Automated Hydroponic System Using Raspberry Pi** prepared and submitted by John Ferry U. Alvarez, Sunshine Loise G. Avila, Danielle Jasmine F. Batucal, Alexandra Casil, Joenel B. de los Santos, Stephen E. Domingo Jr., Brian Victor L. Galiza and Nelmark John A. Padunan in partial fulfillment of the requirements for the degree of Bachelor of Science in Computer Engineering, is hereby endorsed.

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## BIOGRAPHICAL SKETCH

John Ferry U. Alvarez was born on January 19, 1999 in Magsingal, Ilocos Sur as the eldest of Ferdinand Alvarez and Marilyn Alvarez.

He took his primary education at Barbarit Elementary School. He is a consistent honor student and graduated as the salutatorian in 2011 in the said school. He continued his secondary school at Magsingal National High School. He is a hardworking student, and with that effort, he received a few excellence awards. In his four years in High School, he also participated in different activities and contest within the school and outside the school. Also participated in local and regional boy scout camping.

In 2015, he was admitted at Mariano Marcos State University under the Bachelor of Science in Mechanical Engineering. With this challenged in life he got failed that course and got shifted to Bachelor of Science in Computer Engineering. At that moment he realized that he must to take another mile with his efforts and sacrifices. During his college days, he encountered a lot of difficulties and struggles. He experienced failing a few exams and got late to passed different requirements in different subjects. What made him to fight is that he has perseverance. He kept pushing himself even in hard times and he got a very supportive family and friends who is always giving him hope and love. He knew that he had to work hard because he is the eldest son. He needs to do his best to fulfill the needs of his family and he want to payback their sacrifices and to give them a good quality life.

He is guided by the principles and believes in the saying "*As we express our gratitude, we must never forget that the highest appreciation is not to utter words, but to live by them*." - John F. Kennedy.

**JOHN FERRY U. ALVAREZ**

## BIOGRAPHICAL SKETCH

The author, Sunshine Loise G. Avila, is in her fifth year of study at Mariano Marcos State University, where she is pursuing Bachelor of Science in Computer Engineering. She was born in Batac City, Ilocos Norte, on October 6, 1997, and now resides in Brgy. #7 Caunayan, Batac City, Ilocos Norte. She is the eldest of Mr. Nasser Che B. Avila and Benilyn G. Avila.

Mariano Marcos Memorial Elementary School (MMMES) was there she received her primary education. She was SPG officer from 3rd to 6th grad during her primary schooling. She was well-known for her talents, which included dancing, singing, and acting. She completed her secondary education at Batac National High School (Poblacion Campus). Her favorite quote is "Try and try until you succeed," since she feels that if you stop trying after you fail, you will never be able to fulfill your hopes and goals in life**.**

**SUNSHINE LOISE G. AVILA**

## BIOGRAPHICAL SKETCH

The author was born on November 22, 1998 in Mariano Marcos Memorial Hospital & Medical Center, Batac Ilocos Norte. She is the first child of Mr. Raymel S. Batucal and Mrs. Lorelyee F. Batucal.

She graduated from the Hilario Valdez Memorial Elementary School in the year 2011. She finished her secondary education at Immaculate Conception Academy, City of Batac in the year 2015. She continues her tertiary level at Mariano Marcos State University with the degree of Bachelor of Science in Computer Engineering program the same year.

Her goals in life and her family were her greatest motivation to pursue her studies. Coupled with hard work and perseverance, she followed her dream to become an Engineer. She was also a volleyball varsity player at Mariano Marcos State University.

She always believe that no obstacles could hinder her to achieve her dreams and aspirations in life and she always try her best to reach those dreams with the constant guidance of her family, friends, and most especially, the guidance of the Lord Almighty.

**DANIELLE JASMINE F. BATUCAL**

## BIOGRAPHICAL SKETCH

The author, Alexandra Casil is born on March 20, The author, Alexandra Casil is born on March 20, 1998 in Laoag City, Ilocos Norte. She is the daughter of Jesusa Casil and Renato Fontejon and is currently residing in Brgy #22 Nagbacalan Paoay Ilocos Norte.

She took her primary and secondary education at Immaculate Conception Academy (ICA). She was an officer since First year up to Fourth year in high school. She is in her fifth year of study at Mariano Marcos State University where she is pursuing Bachelor of Science in Computer Engineering.

She is well-known for being an entrepreneur at a young age, hardworking and a friend to all. She lives by the saying “The future belongs to those who believe in the beauty of their dreams.”

**ALEXANDRA CASIL**

## BIOGRAPHICAL SKETCH

Joenel B. de los Santos is a simple, humble and a kind person. Joenel de los Santos was born at Banna, Ilocos Norte on August 08, 1998. He is the youngest among the five children of Mr. Reynaldo de los Santos and Mrs. Manita de los Santos residing at Brgy. #4 Marcos, BAnna, Ilocos Norte. When he was a kid, he loves to go outside with his neighbors playing a traditional game such as patintero, luksong kabayo, and etc. which are not likely played nowadaysdue to technology. He took his primary education at Banna Central Elementary Schoolbeing an honor pupil and known as a tennis player. Years after, he finished his secondary education at Banna National High School.

In 2015, he was admitted to Mariano Marcos State University, College of Engineering, pursuing Bachelor of Science in Mechanical Engineering. But due to struggles he had encountered in his college life, he was unable to finish that course and shifted to another department which is in Computer Engineering Department. And now, SY 2021, in God's grace he is now a graduating student.

Whatever happens, always trust God. Even when things seems to be unclear, put your sight to the Lord and he will show you the path.

**JOENEL B. DE LOS SANTOS**

## BIOGRAPHICAL SKETCH

Stephen E Domingo Jr, was born on November 6, 1996 in Sta. Rosa Laguna as the second son of Mr. and Mrs. Stephen E. Domingo Sr.

He took his primary education at Lubnac Elementary School of Vintar, also take his secondary education at Saint Nicholas Academy of Vintar, graduated having a medal of Music Award. He also participate in many activities during his high school days, he is also a hard working student and a talented student. After he graduated in 2013, he go work to help his parent and decided to save money for his college.

In 2016, he was admitted at Mariano Marcos State University and take Bachelor of Science in Computer Engineering, during his college life he experience lots of failures but he did not give up to those struggles and continued pursuing his study. In life we will experience lots of failures but still don’t give up to your dreams, be strong and always trust God plans for you.

**STEPHEN E. DOMINGO JR.**

## BIOGRAPHICAL SKETCH

Brian Victor L. Galiza was born on January 19, 1999 in Banna, Ilocos Norte as the eldest of Roldan Galiza and Celeste Galiza

He grew in a simple family and have 3 brothers and 1 sister. He took his primary education at Banna Central Elementary School and he is very playful but he is diligent and smart because he knew his family's hardships. He continued his secondary school at Banna National High school. in high school he was involved in many troubles, organizations, and he was one of the guidance list but he changed for the family and became his motivation he is hardworking student and with that effort, he was a deserving student and also participated in different activities and he was the one of the chosen student for a competition for computer website for their TLE.

He was admitted into Mariano Marcos State University's Bachelor of Science in Mechanical Engineering program in 2015. With this life struggle, he failed the course and was shifted to Bachelor of Science in Computer Engineering program. He realized he wanted to go beyond and beyond in terms of his efforts and sacrifices at that time. He failed several exams and was late in meeting various requirements in various subjects. His perseverance drove him to fight. He never gave up, even in the face of overwhelming odds, and he has a loving and compassionate family and friends. Since he was the oldest kid, he realized he had to work hard. He must do his utmost to accommodate the expectations of his family, and he desires to repay their contributions by providing them with a decent standard of living.

He is guided by the principles and believes in the saying "*Believe in yourself and all that you are. Know that there is something inside you that is greater than any obstacle*." – Christian D. Larson

**BRIAN VICTOR L. GALIZA**

## BIOGRAPHICAL SKETCH

Nelmark John A. Padunan was born on September 4, 1997, in Brgy. 1 Ricarte, Batac City, Ilocos Norte. As the eldest child of Noel Padunan and Melanie Padunan.

Nelmark grew in a simple family and have a three sister and at a young age, he's father thought him first how to read and how to write. He took he's primary education when he was 6 years old at Mariano Marcos Elementary School. He was a consistent baseball player and graduated as an artist of the year in 2010 in the said school. As he goes to next level, he is diffident a little bit afraid. He continued he's secondary education at Batac National High School. As a student he joined various activities like arts and sports all four years in high school he engaged he's self in the said activities then he graduated at the said school.

In 2014, he was admitted at Mariano Marcos State University at Batac City under the Bachelor of Science in Ceramic Engineering. With this great challenge in life he focus on his study and didn't get any extra-curricular-activities. During he's first year in school it was all good for him but then when he was second year he encountered a lot of difficulties and struggles. He experienced failing a few of he's exam and wasn't able to pass on time of he's requirements. So he failed to become a ceramic engineering then he chose to shift course in Computer Engineering. He's family supported him in he's choice because they know that he can do it one last time for he's dream. And what he wanted was to give back the sacrifices given to him by he's parents.

We don't know what lies ahead of us, but one thing is for sure, we shouldn't stop learning because life never stop teaching. And Kerry Washington said, *"Your life* *is your story and the adventure ahead of you is the journey to fulfill your own purpose and potential".*

**NELMARK JOHN A. PADUNAN**

## ACKNOWLEDGEMENT

It was a laborious process to turn a dream become a reality. It had its ups and downs, and though success was not always assured, we learned from our mistakes. But without the people who believed in us and supported us throughout the study, we would not have made it through and succeeded in the end.

First and foremost, we’d like to express our gratitude to our thesis adviser, **Engr. Lovina Siechrist T. Agbayani**, who believed in us and pushed us to keep going regardless of the deadline, as well as for the guidance and insight she provided during the course of our research. We thank her for always encouraging us to do our best and for his unwavering support and dedication in counseling us from the beginning to the finish of our studies. We admire her since he never failed to provide a helpful hand when we needed it most, assisting us with our thesis during difficult moments. Without her unwavering commitment, devotion, care, and unconditional love, we don’t know what we’d do.

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Third, we'd want to express our gratitude to our **CPE Faculties** for providing their inventive ideas, which helps us in improving our potential and skills in our field of study. We thank them from the bottom of our hearts.

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To everybody whom we missed to mention, we want to extend our gratitude to each and every one of you for your love and support.

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**J. Alvarez**
**S. Avila**
**D. Batucal**
**A. Casil**
**J. de los Santos**
**S. Domingo**
**B. Galiza**
**N. Padunan**

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# ABSTRACT

**ALVAREZ, JOHN FERRY U.; AVILA, SUNSHINE LOISE G.; BATUCAL, DANIELLE JASMINE F.; CASIL, ALEXANDRA; DE LOS SANTOS, JOENEL B.; DOMINGO JR, STEPHEN E.; GALIZA, BRIAN VICTOR L.; PADUNAN, NELMARK JOHN A.** 2021. **Automated Indoor Hydroponic System Using Raspberry Pi.** Undergraduate Thesis. College of Engineering, Mariano Marcos State University, City of Batac 2906 Ilocos Norte.

Adviser: ENGR. LOVINA SIECHRIST T. AGBAYANI

This thesis entitled **Automated Indoor Hydroponics System Using Raspberry Pi,** aims to design a system to expand and improve the utilization of hydroponics as well as to create an environmentally system for indoor plant growth and most importantly, its automated and to keep human intervention at a minimum. This project accomplishes automation by utilizing various technologies, Esp32, Raspberry Pi, Sonoff, sensors such as DHT22, PH, EC and water temperature. The user is only required to plant a seedling and set initial parameters. Once done, the system is able to maintain the parameters for the healthy plant growth.

This study will help farmers to minimize human interaction with the plant and most especially it will help them to increase their production of crops. It is proven that the system has been accurate, in scheduling all the devices and providing all the necessary parameters needed for the plant to able to grow faster.

# AUTOMATED INDOOR HYDROPONIC SYSTEM USING RASPBERRY PI

Undergraduate thesis submitted in partial fulfillment of the requirements for the degree of Bachelor in Science in Computer Engineering from the Mariano Marcos State University, City of Batac, Ilocos Norte. Prepared under the guidance of Engr. Lovina Siechrist T. Agbayani.


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## INTRODUCTION

### Background of the Study

Farming is the process of land planting or stock raising. Farmers face problems affecting agriculture, including new threats and opportunities every day, from feeding a growing global population to generating more food on fewer acres while minimizing their environmental footprint, while meeting stringent new pollution standards. The population is growing, it is assumed to be about 9.7 billion by 2050, and we need to increase agricultural production to those billion people (Dikitanan et al., 2017). Indoor farming is a technique of growing plants or crops, typically on a wide scale, fully indoors. This farming method also uses growing techniques such as hydroponics and uses artificial lights to provide plants with the nutrients and light levels necessary for growth. Hydroponics is the practice of growing plants using only water, nutrients, and a growing medium.

Automated Hydroponic System is primarily growing plants without the use of soil. Hydroponics provide a range of benefits over the traditional methods of growing crops. It will help to produce greater harvest of fruits and vegetables of better quality, and a consistent year-round yield that cannot be achieve by using soil or growing outdoors. Farmers in Ilocos Norte produced food in terms of traditional method of farming. However, with the current state of the environment, the shifting of weather patterns or climate change highly threatened the condition of plants, the income of the farmers and had also threatened food production.

In the conventional method of farming, farmers require good soil quality with natural soil and strengths in minerals. It also needs running costs for weed plowing and removal, and also needs a vast volume of water and space. In the case of seasonal plants, the yield does not fulfill the needs of consumers and the productivity needs of farmers (Bakhtar et al., 2018). With these circumstances, this is where Hydroponics come to action. Hydroponics comes from the Greek word “hydro” means water and “ponos” means labor is a developing plant method that does not use soil, but uses nutrient-based water to conserve planting space and does not contaminate the soil with chemicals (Kularbphettong et al., 2019). To combat the chemical side effects that result in toxicity and other adverse effects, hydroponics is a viable alternative to soil sterilization. The finest feature is that nutrients can be better managed and monitored than in soil-grown crops (Tembe et al., 2018).Traditional farming, requires numerous amount of resources such as fertilizers, pesticides, plenty of water and a soil that contains right amount of minerals in order to produce good and upright yield and at the same time, to assure food security. However, even with these resources, there are many farmers who cannot produce good quality of harvest due to the unexpected calamities caused by the climate change.

The traditional farming system is incapable of meeting present and future food demands. As a result, there is a pressing need to create a new agricultural technique that encourages plants to develop more quickly. This system should be able to meet the rapidly increasing demand at a low cost and with minimal natural resource consumption. As the world's population grows, so does the demand for food production. Meanwhile, traditional soil-based farming will be insufficient to meet the world's expanding food need. As a result, new agricultural and planting system approaches must be developed in order to avert future food crises (Gashgari et al., 2018).

In the province, existing hydroponics are monitored manually. Also hydroponics automation using sensors are not yet adopted and implemented. Thus, the maintenance of parameters essential to the plant is difficult to monitor and analyze. Therefore, in this study, the researchers strives to find a solution by using the effectivity of the Automated Hydroponic System using Rpi by growing a lettuce plant. According to (Changmai et al., 2018), the farmer does not have to prepare the soil, and watering and fertilizing are usually built into the hydroponics farm, one of the advantages of hydroponics farming is lower labor costs. Because most hydroponics farms are only partially automated, integrating the Internet of Things to obtain better and more accurate data and fully automate the farm is much easier. The growth and mortality rate will be taken accounted as it is to be compared with the rates from traditional farming. With the increasing population all throughout the world comes a greater demand of food and resources. Traditional farming alone cannot meet the worldwide need of food that is why adapting a new system that could be used for a more convenient and faster production is really necessary. A system that is able to cover the fast-growing demand with less cost and minimum consumption of natural resources. Whereas an Automated Hydroponic System using Raspberry Pi saves water, it requires careful calibration and monitoring of its water quality parameters in order to increase its efficient productivity rate. It provides a profitable and sustainable hydroponic system that contributes significantly to the province's food insecurity by automating the process.

## Statement of the Problem

The study seeks to evaluate the effectiveness of using the Automated Hydroponics System using Raspberry Pi to the growing condition of the lettuce plant in terms of traditional farming by comparing the growth rate and mortality of the plants. The general problem was specify below:

1. There are little space for farmers to grow plants and because of soil infertility that implies a lack of qualities that allow it to provide nutrient elements and compounds in sufficient quantities and in proper balance for the growth of specific plants and the weather condition as it changes by time.
2. Farmers always manually monitoring to check the situation of their plants.
3. A changing climate is leading to more occurrences of extreme events such as droughts (moisture deficits) and floods (moisture surpluses), which have a negative impact on crop growth and yields.

## Objectives of the Study

The study aims to develop an Automated Hydroponics System Using Raspberry Pi to address the problem to reduce the cost of resources of the farmers, lessen the manual use of water consumption and to avoid food waste and low yield due to climate change.

Specifically, this study aims to:

1. Develop an Automated Indoor Hydroponic System for the growing lettuce plants;
2. Design and develop a web-based application that can automatically monitor and control the environmental and water parameters; And
3. Evaluate the efficiency of the system by comparing the traditional farming to the automated indoor hydroponic system in terms of:

A. Growth rate
    i. Height
    ii. No. of Leaves
    iii. Weight
B. Mortality Rate

## Significance of the Study

This study is giving an opportunity to anyone who's willing to adapt a new system of farming. Specifically, it is beneficial to the following:

**Farmers**. Plants will not be affected by weather changes. Therefore, farmers can grow vegetables all year round and increase their yield. Also, it lowers the pesticide usage.

**People residing in urban areas.** They can create self-sustaining nutrient-rich food even without using soil.

**People without enough space for raising plants.**

## Scope and Limitation of the Study

The study was conducted at Barangay Rayuray, Batac City Ilocos Norte. The study focused on NFT technique which test the lettuce plants ability to produce yield. It mainly focused on the growth and mortality of plants and also the efficiency of the system.

Furthermore, the study also controlled and monitored the environmental and water quality parameters such as pH (Power of Hydrogen), EC (electrical conductivity), Temperature and humidity. The pH is an important indicator of water quality since it determines how acidic or alkaline the water is. Also with EC, it determined on how the water can carry the total amounts of current. The temperature and humidity was observed to maintain the appropriate temperature inside the room needed for the lettuce plants. . Lastly, a Sonoff was used to control the Actuators such as pump, aerator, fan, and grow lights.

To automate the process, an ESP32 was used as microcontroller, and Raspberry Pi were used as a local mqtt broker and a remote broker for the remote monitoring section of the system.

## Definition of Terms

In this section of the research are the terms that were used by the researchers throughout the study.

**Arduino IDE** The Arduino Software (IDE) includes a text editor for writing code, a message area, a text terminal, a toolbar with buttons for basic operations, and a series of menus. It communicates with the Arduino and Genuino

| | |
|---|---|
| | devices by connecting to them and uploading code. |
| **EC (Electrical Conductivity)** | This refers to a material's ability to bear a current of the amount of electrical current it can carry. |
| **Dissolved Oxygen** | Air pump will be used as the oxygen source of the system. The air pump will be submerged into the water so that the dissolved oxygen needed will be maintained. |
| **Growing Medium** | A growing medium is intended to aerate and encourage the plant's root system, as well as water and nutrient. |
| **Hydroponics** | Using water to grow plants without soil, referred to as soilless culture. |
| **Message Queuing Telemetry Transport (MQTT)** | Is a lightweight publish-subscribe network protocol for sending and receiving messages. |
| **NFT** | Growing system that constantly recirculates a stream of nutrient rich water through food grade PVC for growing leaf crops such as lettuces and smaller herbs. |
| **Nutrient Solution** | A nutrient solution for hydroponic systems is an aqueous solution containing mainly inorganics |

| | |
|---|---|
| | ions from soluble salts of essential elements for higher plants. |
| **pH** | Measurement on how acidic or basic (alkaline) a solution is. A pH less than 7 is acidic. A pH more than 7 is neutral. |
| **Raspberry Pi (Rpi)** | Its serves as local MQTT broker |
| **Reservoir** | Serves as the storage space for fluids for the hydroponics. |
| **Sensors** | Instruments that measure environmental and water parameters such as (EC, PH, DHT22) |
| **Microsoft (SQL)** | It is use to retrieve data, edit table contents, or work on the database or tables' configuration using MSSQL, which would provide a user interface to apply database operations. |
| **ESP32** | Serves as microcontroller attached in the sensors. |
| **SONOFF** | Its function is to control the actuators and subscribe to the topics set by the user. |

# REVIEW OF RELATED LITERATURE

## Hydroponics System

Hydroponics is a branch of hydroculture. It is the method of soilless cultivation of plants. The plants obtain nourishment instead of soil by mineral nutrients dissolved in water. "Hydro" meaning water and "Ponics" meaning labor, derive from the word hydroponics. For thousands of years, the concept of soilless gardening or hy12droponics has been around. Babylon's Hanging Gardens and China's Floating Gardens are two of the earliest examples of hydroponics (Gardens & Benefits, 2016).

Hydroponics is a method of growing plants that takes use of this fact by supplying all of the nutrients in their inorganic form in a liquid solution, either with or without solid substrate. Compared to soil-based systems, hydroponics has various advantages. When root tissue is removed from the soil, it is frequently mechanically sheared, resulting in tissue loss or injury. This is especially true for lateral roots and root hairs, which are fine root structures. Hydroponic systems without an inert particle media allow for a less intrusive separation of root and shoot tissue while maintaining a constant supply of oxygen. The nutrient solution in hydroponics can be saturated with air before to use and replaced frequently, or air can be constantly provided in the solution during the plant's life cycle (Nguyen et al., 2016)

The nutrients used in hydroponic systems can come from an array of different sources, including (but not limited to) fish excrement, duck manure, or purchased chemical fertilizers. Only the roots of terrestrial plants are exposed to the nutritious liquid, or the roots are physically supported by an inert media such as perlite or gravel (Ekoungoulou et al., 2020).

Hydroponic systems, according to farmers, allow them to increase their potential for continuous development in a short growing time, need less space and can produce plants anywhere, i.e. in small spaces with a regulated atmosphere for growth. Growers also respond that hydroponics often makes it possible for them to have higher productivity and yields without any climate and weather constraints. Furthermore, farmers have also argued that hydroponic production efficiency is superior because it uses a highly regulated ecosystem and it makes for more homogeneous development without any lack of nutrients and water. In addition, hydroponics are not dependent on seasonality, and their productivity is thus higher and more homogeneous during the year. Growers often claim that hydroponic development is faster, and since cultural practices such as plowing, weeding, soil fertilization and crop rotation do not need them, they are light and clean. Multiple experiments have shown that hydroponic vegetables have stronger characteristics than natural soil-based vegetables [32, 33]. (Aires, 2018)

## Types of Hydroponics

There are five main types of hydroponics system. The wick system, deep water culture, ebb and flow system, drip system and the nutrient film technique (NFT).

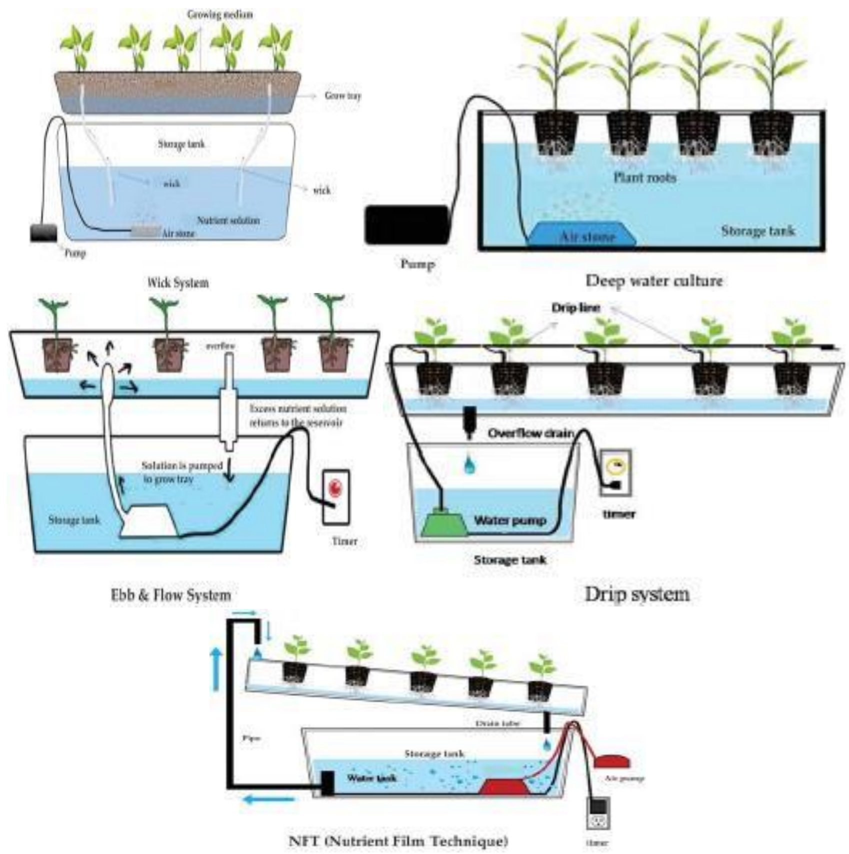



Figure 1. Diagram of various structures of hydroponic system

1. **Wick System.** Plants are mounted in an absorbent medium such as coco coir, vermiculite, or perlite, with a nylon wick running from the roots to a nutrient solution reservoir. Capillary action delivers water or nutrient solution to plants. This system is ideal for small plants, herbs, and spices, but it is ineffective for plants that need a lot of water.

2. **Nutrient Film Technique (NFT)**. Water or nutrient solution circulates in the system and reaches the growth tray through a water pump that does not have a timer (Domingues et al., 2012). The system is slanted slightly to allow nutrient solution to flow through the roots and back into the reservoir.

Plants with roots hanging in a hydroponic solution are put in a channel or tube.

3. **Drip system**. Drip hydroponics is a common method used by both home and commercial growers. With the aid of a pump, water or nutrient solution from the reservoir is delivered to individual plant roots in an adequate proportion (Rouphael and Colla, 2005). Plants are generally grown in a medium that is fairly absorbent so that the nutrient solution drips slowly. Various crops can be cultivated in a systematic manner while conserving water.

4. **Deep water culture**. Plant roots are suspended in nutrient-rich water in deep water culture, and air is delivered directly to the roots through an air stone. A classic example of this device is the hydroponics buckets system. Plants are put in net pots with their roots suspended in nutrient solution, where they rapidly grow in a large mass.

5. **Ebb and flow system**. This is the first commercial hydroponic device that operates on the flood and drain principle. Nutrient solution and water from the reservoir are pumped into the grow bed through a water pump until it reaches a certain level and stays there for a certain period of time, providing nutrients and moisture to the plants (Sharma et al., 2018).

## Hydroponic vs. Traditional Method

In the conventional method of farming, farmers require good soil quality with natural soil, strengths in minerals. It also needs running costs for weed plowing and removal and also needs a vast volume of water and space. In the case of seasonal plants, the yield does not fulfill the needs of consumers and the productivity needs of farmers. For these purposes, an agricultural method needs lower cost requirements. The important factors such as light, water temperature and humidity can be managed and regulated easily throughout the year. Hydroponic farming is described in this proposed work; the growing method of plants without any use of soil & sunlight. The plants are grown in this system with their roots exposed to a mixture of minerals with water rather than underground soil. Inside the device, the temperature and humidity are continuously controlled using sensors. Using magnetic float switches, the liquid level is tracked within the pipes and regulated using solenoid valves. Watering and humidity control is achieved with the aid of a microcontroller kit connected to the internet's wireless sensor network that detects humidity, temperature, and water level. This technique is a form of weather- independent style of indoor agriculture that also avoids the cost of plowing and labor work. With the use of this IoT technology, from a remote location, the authorized person may monitor the real- time status of the growth of the plant (Bakhtar et al., 2018). Nutrient intake during crop growth determines crop success. Excessive use of chemical products in agriculture is a source of concern because of the multiple issues it produces, including increased nitrate concentrations in the fruit, decreased soil fertility, soil and groundwater contamination due to excessive use of N fertilizers (e.g. urea), and animal waste (e.g. untreated cattle manure) producing a rise in nitrate concentrations (N-NO3) (Akinnuoye-Adelabu et al., 2019).

In the hydroponics system, the roots of plants are suspended in nutrient-rich water so that they can grow without any chemicals being needed. Both home gardeners and commercial vegetables are provided to grow food in areas where it is not practical or cost-effective in the conventional soil scheme. Plants can produce 20-25 percent higher yields in the hydroponic system than a soil-based system with 2-5 times greater productivity. There has been a great deal of questioning as to whether hydroponic plants are necessarily better than soil-grown plants. An experimental study conducted by Maeva Makendi revealed a competitive analysis between hydroponic and soil system growth of the plant. “If the hydroponic plants and plants grown in soil are given the same germinating and growing conditions, the hydroponic plants would do the same, if not better, than the plants grown in soil," the hypothesis said. The experiment was carried out for one month on various types of plants. Hydroponic plants have germinated and have evolved more rapidly than soil plants. A research conducted by Samangooei and others compared two of the key methods of food production, soil-less and soil-based systems, and the productivity outcome was similar to the Makendi study. According to Sardare, soil-less crops are healthier and consistently more reliable than soil-grown crops. (Gashgari et al., 2018)

According to (Magni, 2016), Indigenous or traditional knowledge refers to the collection of knowledge that involves local people's cultural customs, practices , values and methods in various fields that give them a unique identity.

## Botany of Lettuce

Lettuce (*Lactuca sativa)* originated in Europe and Southwest Asia. It belongs to the Asteraceae family, which contains between 23,000 and 30,000 species, and is considered to be the largest family of plants. Nowadays, owing to its high nutritional value and medicinal importance, the consumption of lettuce has spread tremendously throughout the world. A high genetic diversity arising from its polyphyletic origin and a complex phase of domestication characterizes L. sativa. A source of quasi-total vitamins, lettuce contains many minerals, including calcium, phosphorus, iodine, iron, copper, and arsenic. (https://www.sciencedirect.com/topics/biochemistry-genetics-and-molecular-biology/lettuce, 2020).

Hydroponic crops are among the most common. The lettuce (Lactuca sativa L.) is the leading producer, owing to its pioneering status as a hydroponic crop in the country, as well as the fact that it is the easiest to manage and has the shortest cycle (45 to 60 days), ensuring a faster return on investment (Soares et al., 2020). For growth and development, this vegetable need a lot of nitrogen. Plant spacing is an important requirement for achieving optimum vegetative growth and an important feature of crop production for optimum output in lettuce growing. Plant spacing that is optimal allows efficient use of natural resources and facilitates intercultural activities. It aids in the growth of more leaves, branches, and healthy foliage (Hasan et al., 2017).

Figure 2. Lettuce (*Lactuca sativa)*

This figure shows a variety of lettuce which is Batavia.

**Raspberry Pi**

The Raspberry Pi is a low-cost micro Linux computer the size of a credit card. The Raspberry Pi project's mission was to build a low-cost computer that would help students develop their programming skills and hardware understanding. The new Raspberry Pi model has 1 GB of RAM, a quad-core ARM Cortex-A53 processor running at 1200 MHz, and basic functionality that allows hobbyists, tech enthusiasts, and students to use it for DIY projects. The Raspberry Pi is open hardware except for its main processor, the Broadcom SoC, which controls the board's main components such as the CPU, graphics, memory, and USB controller. (Developed & Kaur, 2017)

Figure 3. Raspberry Pi.

The figure shows the Raspberry Pi which serves as the local MQTT broker

## Growing Medium

A growing medium is intended to aerate and encourage the plant's root system, as well as water and nutrients (Gardens & Benefits, 2016).

In addition to (Bhattacharya, 2017), an inert medium which does not provide the plant with any nutrients is the growing medium for hydroponic gardening. It just provides the base for the development of the roots. The different types of growth media available for hydroponically growing plants are Coco coir fibre Rockwool, Perlite, Vermiculite, LECA, Expanded clay, Natural or Synthetic Sponge, Crushed granite, Sand, Scoria, Gravel. In a hydroponic environment, a rising medium helps one to apply the right amount of nutrients and also track the pH. In addition, there are many benefits of using a rising medium other than soil, which include:

1. Prevention of infestations of roots,
2. Retention of sufficient water and oxygen and

3. Increased draining aeration.

Figure 4. Growing Medium.

The figure shows the growing medium which is coco peat.

## Automated Hydroponic System

Plants cultivated hydroponically develop quicker and healthier than plants grown in soil because they don't have to contend with soil borne infections, and all of the food and water they require is delivered directly to their roots 24 hours a day, seven days a week. Hydroponics was once thought to be a system in which no growing media was needed at all, such as the nutrient film technique in vegetables. However, it is now widely understood that a soilless growth media is frequently employed to physically support the plant root system and provide a suitable solution buffer surrounding the root system. Hydroponics is a basic process that is similar to growing plants in soil in many aspects. Plants require food, water, and oxygen to survive. It's easy to feed plants only what they require when you cut it down to those three items. The science of growing plants without soil is known as hydroponics. The plants may survive solely on the nutrient solution; the medium serves just to sustain the plants and their root systems (Rapate et al., 2019). In the current analysis, the automatic hydroponic system is regulated and supervised by numerous electronic sensors, such as indicator of water volume, humidity sensor, temperature sensor etc. Mechanical and electronics are protected by present work information for use in agriculture. Both the factors, such as it is possible to monitor and manage temperature, humidity and water flow. (Jagtap et al., 2018).

Hydroponics is a method of growing a plant in water combined with a mineral fertilizer solution in soil with less culture with a continuous supply of oxygen with indirect light at room temperature. In contrast to the soil environment, the system consumes less water and fertilizer. The field processes of the open field method are not part of the human work of plowing, hoeing and weeding hydroponics. As roots receive nutrients and oxygen directly from the water medium through the diffusion process, the growth rate and efficiency of the plant are increased. The parameters calculated and tracked are pH, humidity, water electrical conductivity and water nutrient concentration, which are useful for the design and production of hydroponic controllers and regulated automation systems in order to sustain optimum plant growth. (Wagh Vijendra Pokharkar Assistant Professor & Bastade Priyanka Surwase, 2016).

## ESP32 Wifi Module

The ESP32 is a single 2.4 GHz WI-Fi and Bluetooth combo chip made in TSMC's ultra-low-power 40 nm process. It's designed to provide the best power and RF output in a wide range of applications and power scenarios, demonstrating robustness, flexibility, and durability. ESP32 is a microcontroller that can be used in smartphone, portable electronics, and Internet-of-Things (IoT) devices. It has many of the cutting-edge low-power chip features, such as fine-grained clock gating, various power modes, and dynamic power scaling. In a low-power IoT sensor hub program, for example, ESP32 is woken up on a regular basis and only when a specific condition is observed. The chip's energy consumption is reduced by using a low-duty cycle. The power amplifier's performance can also be adjusted, allowing for the best possible trade- off between contact range, data rate, and power usage. (Espressif Systems, 2019).

Figure 5. ESP32 WiFi Module

This figure shows the Esp32 that serves as the microcontroller.

## Nutrient Solution

For hydroponic crops, nutrient solution is a significant and necessary source of nutrients. The nutrient solution's formulation, EC and pH, concentration, and solution temperature are the primary parameters that influence the nutrient solution's quality. Carbon, hydrogen, oxygen, nitrogen, phosphorus, potassium, calcium, magnesium, sulphur, iron, copper, zinc, manganese, molybdenum, boron, chlorine, and nickel are normally regarded essential for most plants. Carbon, hydrogen, and oxygen are obtained immediately from the atmosphere, whereas the remaining elements must be obtained from the nutritional solution (Patil et al., 2020)

The pH and EC of the nutrient solution are critical for optimal plant growth and should be handled properly. For most crops, the ideal EC range for hydroponics is 1.5 to 2.5 dS m-1. Due to osmotic pressure, higher EC prevents nutrient absorption, whereas lower EC has a negative impact on plant health and yield. As a result, proper EC management in hydroponics will provide an important method for increasing vegetable yield and quality (Gruda, 2009). For eg, tomato yield increased as the EC of the nutrient solution increased from 0 to 3 dSm-1, but decreased as the EC increased from 3 to 5 dSm-1 due to increased water stress (Zhang et al., 2016). At the vegetative, middle vegetative, and generative phases, EC levels of 1.5, 2 and 3 dS m-1 increased crop height, fruit number, and pepper fresh weight, respectively. Once the plant matures, it can modify the nutrient solution's structure by depleting specific nutrients more quickly than others, withdrawing water from the solution, and changing the pH by excreting acidity or alkalinity. Wang et al. (2017) discovered that a combination of three acids ($HNO_3$, $H_3PO_4$, and $H_2SO_4$) was much more efficient than a single acid in retaining an optimum pH of 5.5 to 6.5 in a solution. A change in pH can induce nutritional imbalance, causing the plant to display signs of deficiency or toxicity. As a result, it's important to keep an eye on the pH, EC, and nutrient levels in a hydroponic solution. (Sharma et al., 2018).


Figure 6. Nutrient Solution.

This figure shows the nutrient solution used in hydroponic system which is Nutri Hydro.

## Sonoff

These devices create a connection to the user and give them the ability to track and manage their surroundings. They will be tracked and controlled regionally or centrally via a HEMaaS network using a Sonoff wireless switch (The Sonoff is a system that will be connected to the power lines and will be able to remotely turn on and off any device. It has a voltage range of 90–250 V and can handle a maximum current of

10 A). The majority of traditional household appliances are compatible with the Sonoff (modern, voltage) variety currently on the market. A Main Command and Control Unit (MCCU), a Sonoff wireless switch, a Smart meter, a Gateway router, and a Community Cloud Management panel make up the system (CCM). The MCCU is the network's primary intuition, responsible for activating grid alarms based on the results of the gadget learning algorithms. It also has an input port that acts as a video display device for user input signals, providing consumer data to the device. Off with his son The MCCU sends a signal to the switches enter port, which causes the appliance to turn off or on. The power station receives data on energy demand from the smart meter in order to maintain regular network intensity control. The smart meter and CCM are located outside of the gateway router and are separated by a secure firewall.

The town's electricity substation keeps track of CCM. According to its age and distribution, the substation has a set amount of available electricity for the city to use. CCM receives feedback from the substation and sends commands to each domestic's MCCU, which changes the energy conservation plan as a result. (Shirsat et al., 2020)


Figure 7. SONOFF.

This figure shows the sonoff which receives the users command

## pH Sensor

The analog pH meter V2 is programmed to determine the pH of a solution and reflect its acidity or alkalinity. It's widely used in aquaponics, aquaculture, and ambient water research, among other things. The onboard voltage regulator chip can handle a large voltage range of 3.3 to 5.5V, making it compliant with all 5V and 3.3V main control boards. The hardware-filtered output signal has a low jitter. The software library uses a two-point calibration system, which allows it to automatically distinguish two standard buffer solutions (4.0 and 7.0), making it extremely easy and convenient. The pH of a solution is a measurement of its acidity or alkalinity. The hydrogen ion concentration index is another name for it. The pH scale measures the activity of hydrogen ions in a solution. The pH scale is used in a variety of applications in medicine, chemistry, and agriculture. The pH is usually a number between 0 and 14. (Cytron Technologies Sdn. Bhd., 2019)

Calibration liquids must be used to calibrate the pH probe [8]. We can modify the pH of the water before introducing the young plant into the system by measuring the pH. After adding nutrients, the pH was corrected to be between 5.6 and 6 after using distilled water with a base pH near to 7. Because pH is temperature dependent, measuring the pH of the water at constant temperatures is critical [9]. The pH of the water was changed using acidic and basic solutions after it was heated to 25°C (Palande et al., 2018).

The pH of the solution determines the mobility of the nutrients. When micronutrients become more mobile, they are rapidly taken by plants in excess of what the plant requires. As a result, the plant becomes toxic. When micronutrients are less mobile, the plant has difficulty absorbing nutrients, resulting in shortages. As a result, controlling the pH in a hydroponics system is critical to the crop's health and vitality. Essential nutrients and micronutrients will not be available for plant uptake if the pH is not in the proper range. This can result in vitamin deficits and, in the worst-case scenario, death (Kulkarni, 2017).

Figure 8. pH Sensor.

This figure shows the pH sensor which is used to read the acidity and alkalinity of the water.

### Electrical Conductivity

The analog electrical conductivity sensor/meter (K=10) is designed to test liquids with a high electrical conductivity, such as seawater, condensed brine, and other high electrical conductivity liquids. The measuring frequency is up to 100 milliseconds per centimeter. It accepts a large voltage input of 35 volts and is compliant with both 5 and 3.3 volt key control boards; The probe's excitation source is an AC signal, which essentially decreases polarization, increases accuracy, and extends the probe's life; the software library employs a single-point calibration system that can automatically classify regular buffer solution, making it easy and handy.

The reciprocal of an object's resistivity, which is analogous to the material's ability to bear current, is conductivity. The conductivity of a liquid solution is an indicator of its ability to conduct electricity. The conductivity of water is a significant indicator of its consistency. It may indicate the amount of electrolytes in the water. (https://wiki.dfrobot.com/GravityAnalog_Electrical_Conductivity_SensorMeter_V2K%3D1SKU_DFR0300).

Nutrients are applied in the form of salts, which break down into ions when they dissolve in water. Because of their positive and negative ions, these ions conduct electricity. As a result, as more ions are added to the solution, the conductivity of the solution increases. As a result, EC is a reliable indicator of the amount of salts in a solution. A greater EC indicates a larger concentration of salt, whereas a lower EC indicates a lower concentration of salt. Excessively high nutrient levels cause osmotic stress, ion toxicity, and nutrient imbalance, whereas excessively low values cause nutrient deficiencies and reduced plant growth. The total salt concentration of a nutrient solution is the most significant property in soilless cultivation (Dunn & Singh, 2016).

Figure 9. Electrical Conductivity Sensor.

This figure shows the electrical conductivity that can measure the potential for the material to conduct electricity.

## Conceptual Framework

The figure below shows the concept of the study which composed of three phases. In this study, the researchers proposed an Automated Indoor Hydroponic System using Rpi to evaluate the lettuce plant over Traditional Farming in terms of growth, mortality and efficiency of the plant.

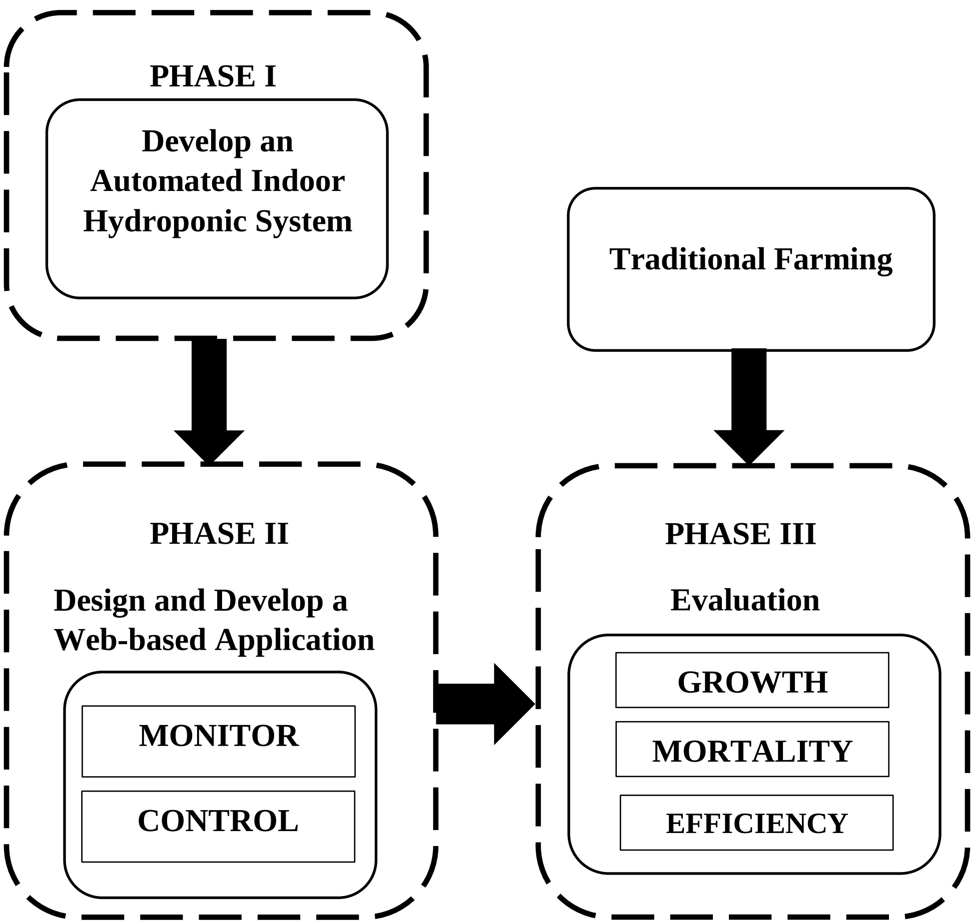



**Figure 10. Concept of the study**

# METHODOLOGY

## Locale of the study

The researchers of this study will develop an Automated Hydroponic System and the chosen test site for the project is at Barangay Rayuray, Batac City Ilocos Norte. This place for the execution of the project was chosen primarily to benefit farmers living within the community since the presence of the irrigation facilities as well as monitoring and maintenance is transparent. This system is developed with primary objective to increase the levels of productivity among farmers, improve their quality of life and advocate a more sustainable living not just for the farmers but for the welfare of the entire community as well. The medium to be tested is the planting of lettuces by researchers as it is an important factor determining the success of the implementation for the system. It also provides a long-term solution as it does not only cater the needs of lettuce on a micro perspective level but on a wider scope, eventually beneficial to the entire locality.

## Research Design

In the concept of the analysis and assessment of the method, this section of the study presented and analyzed the procedures of the various phases.

**Phase 1: Development of the System**

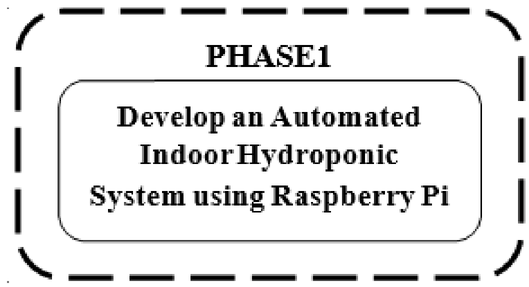



**Figure 11. Development of the Automated Hydroponic System**

In the first phase, the researchers developed an Automated Indoor Hydroponic System using Raspberry Pi. At the core of this automated hydroponic system is the Raspberry Pi single board computer. A Raspberry Pi that serves as a MQTT Local Broker that is connected to ESP32. The local Broker will send data to the remote broker having a service app that listens to the mqtt topics and save it to database. To reduce the farmer's cost of resources, to lessen water consumption manually, to avoid low yield and food waste due to climate change.

The researchers will automate a water pump and aerator that will automatically ON every 30 minutes from 6:00 am to 6:30pm to maintain the moist of the growing medium in order to grow the lettuce well. Water pump regulate nutrients in the water. Only immerse the pump in the water and connect the outlet to an appropriate pipe or hose. To infuse the water with oxygen for the plant to absorb through its roots, an air pump is used. The grow lights are set to a 17 hours ON cycle to simulate daytime. LED lights have smaller heat signature, so it can be placed 6-12 inches over plants, respectively. The best arrangement is to hang or place lights over the plant beds, since it mimics natural sunlight from above and exposes all the sides and leaves of a plant to artificial light. Lettuce requires a long duration nor an intense amount of exposure to light in order to grow.

Sensor automation can take measurements at a predefined interval, but then ensure that the readings are processed from such sensors so that they can be used for evaluation.

Table 1. List of sensors that will utilize in the system.

| Sensor Type | Sensor Name | Description |
|---|---|---|
| **Water Quality Sensors** | Ph sensor | Measures the water's acidity or alkalinity level |
| | EC sensor | Measures the electrical conductivity in a solution. |
| | Water temperature sensor | Measures the temperature of the water. |
| **Environmental Sensors** | Temperature sensor | Measures the temperature of its environment. |
| | Humidity Sensor | Measures and monitors the amount of water present in the surrounding air. |

The table below shows the sensors we used that utilized in the system. We used water quality sensors to easily monitor the Electrical Conductivity, pH level and the water temperature. The researchers also used environmental sensors such that the temperature and the humidity sensors.

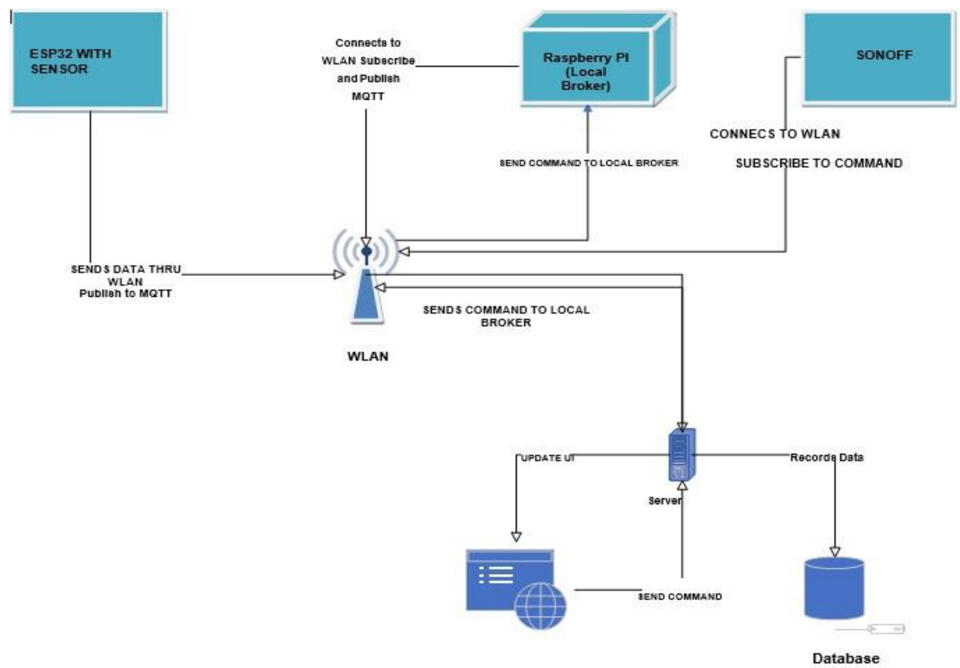



Figure 12. System Architecture

Figure 12 shows how sensor reading from esp32 with (DHT,EC,PH) was fetched and stored in the database, through MQTT and PUBSUBCLIENT, esp32 then connects to Local MQTT Broker which is the Raspberry Pi, Raspberry Pi then connects to Remote MQTT Server, In the server, there is a service that reads MQTT Queries/Payloads. The Payloads will be parsed through this service using MQTTNET, a .Net framework package that subscribes and publishes to MQTT Server. The parsed payload will be then saved to the database using entity framework (LINQ). A separate app (API) using .net core 3.3 will then be used as an interface for the web client to fetch/get data. Any actions by the web client is coursed-through the API. The user will send a command thru MQTT, commands channel then the SONOFF's will subscribe to commands channel and wait for commands set by the user.

**Phase 2: Design and develop a Web-Based Application**

The figure below was the presentation of the automated part of the system. Manipulated programs were used in the monitoring and controlling of the system. Moreover, the flowchart of the automated system will be drawn below.

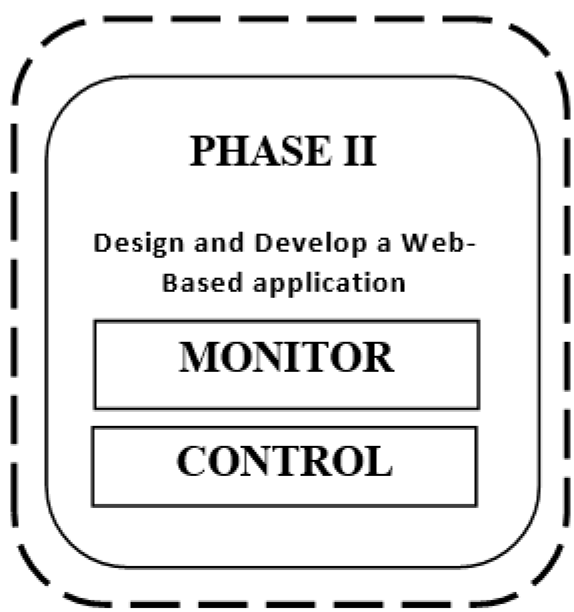



Figure 13. Automation through manipulated programs.

In the second phase, a block called Web based app referred to the software, programs, and applications needed in the automation area. Phase II consists of monitoring and controlling of the system. The monitoring of the water quality parameters such as the pH level, ec level, humidity and water temperature through the use of analog/digital sensors. The data monitored will be gathered by those sensors goes through the esp32, Raspberry Pi (serves as MQTT Broker) and Remote MQTT to store data readings in a database. The actuators that we will be controlling will be controlled using Sonoff also goes through the Raspberry Pi (serves as MQTT Broker) and Remote MQTT to store set commands in the database. Phase II shows the general representation of software and hardware implementation in the system.

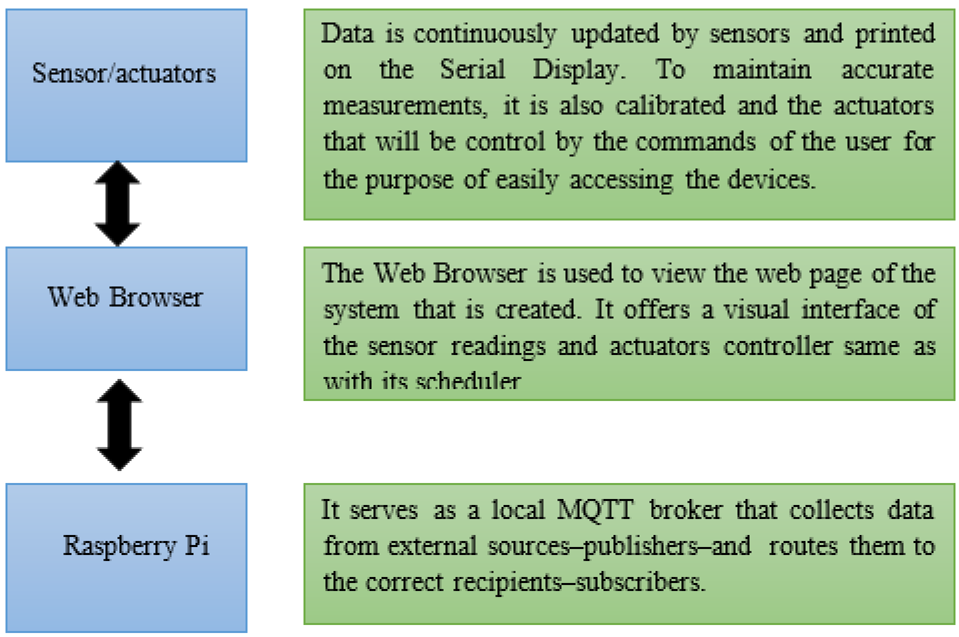



Figure 14. Overview of the System

The figure below shows how the hardware and the software interacted with each other in retrieving the data read by the sensors.

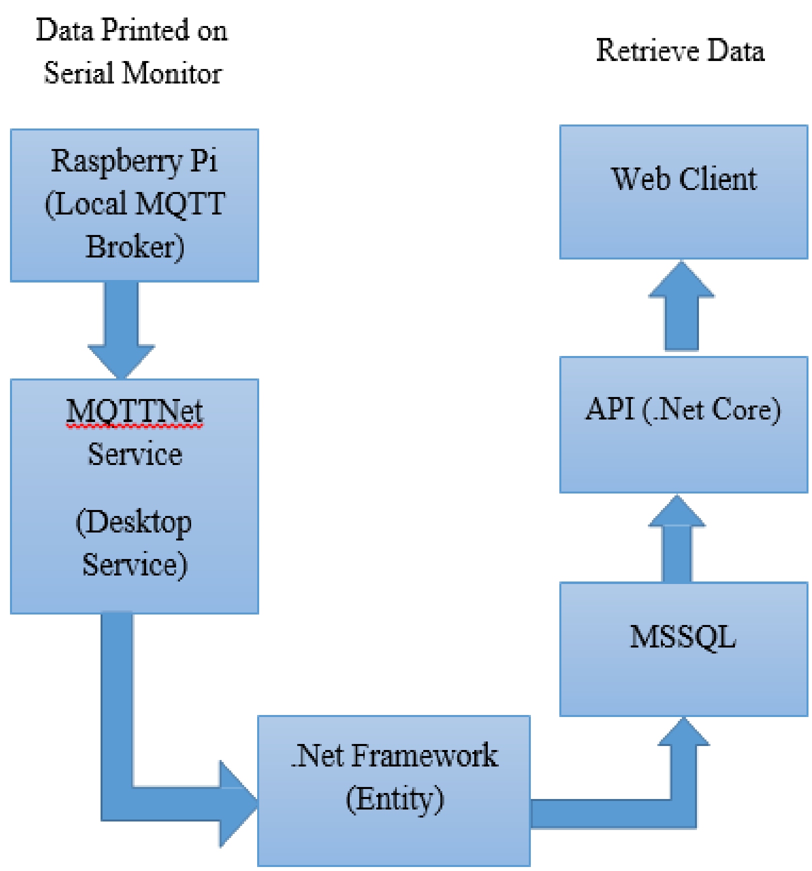



Figure 15. Stored Data and Retrieved Data of the Sensors.

Figure 14 shows how the sensor readings from the esp32 with (dht,EC,PH) is fetched and stored in the database using MQTT and PUBSUBCLIENT. The esp32 then connects to the local MQTT Broker, which is the Raspberry Pi, and the Raspberry Pi then connects to the Remote MQTT Server. MQTTNET, a.Net application kit that subscribes and publishes to MQTT Server, can be used to parse the payloads via this service. Using object framework, the parsed payload will be saved to the archive (LINQ). The web client would then use a different app (API) written in.net core 3.3 as an interface to fetch/get data. All web client activities are routed via the API.

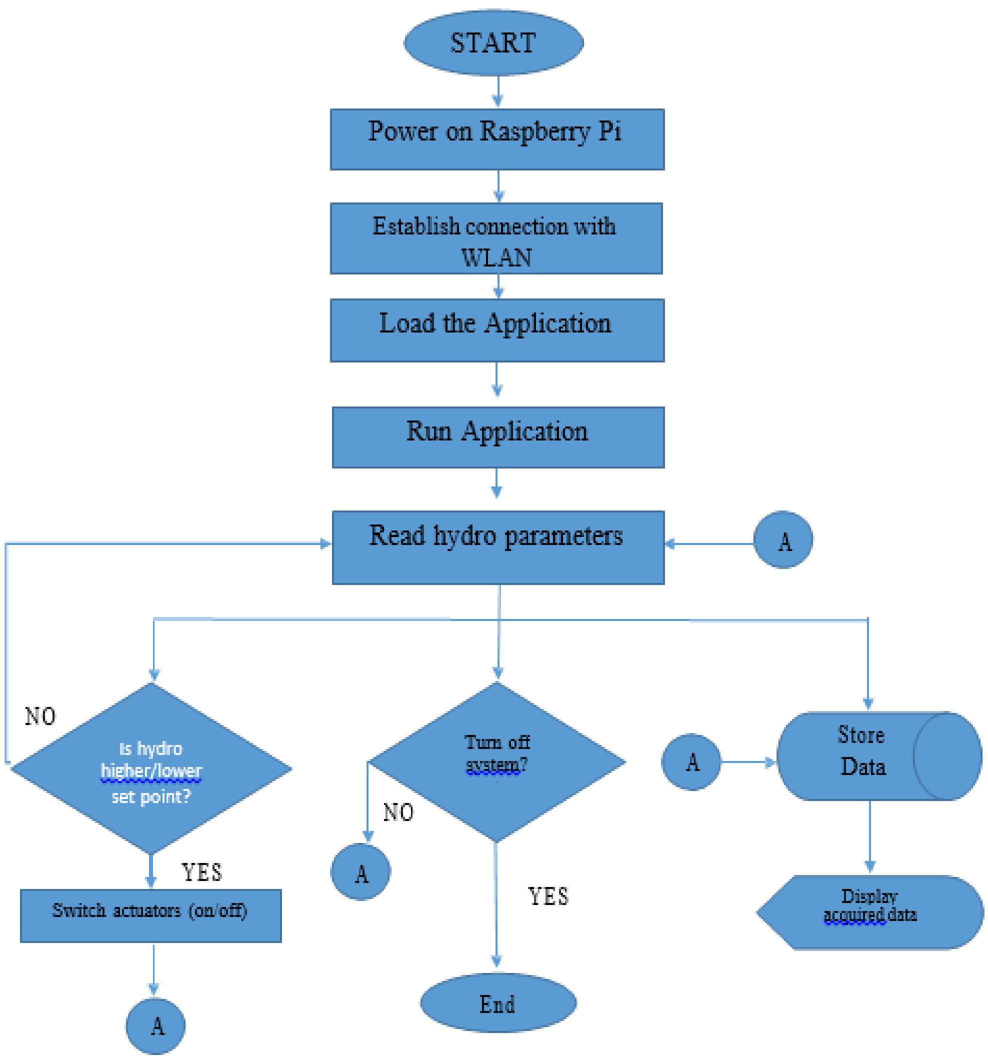



Figure 16. Overall process of monitoring and controlling the indoor vertical farming System

The figure above, shows the process of controlling and monitoring the Automated Indoor Hydroponic System. Upon starting the system, the Raspberry Pi must turn on then it will establish the WLAN connection. When connected, it will load and run the web application and read the hydro parameters. The actuators will automatically switch either on or off when they reach their corresponding time and schedule set by the user. Then the data read by the system will store in the database and those data will display to the web application.

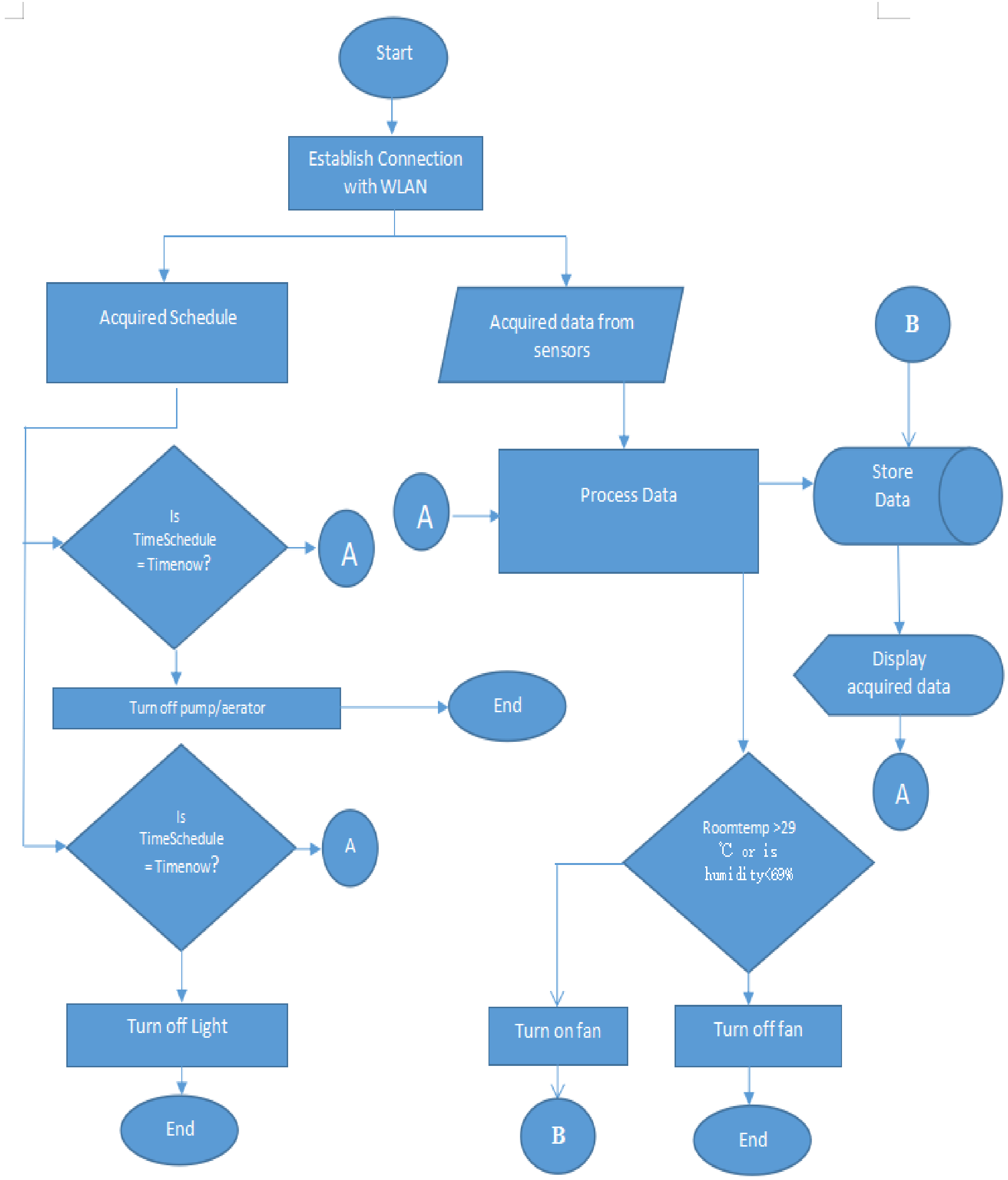



Figure 17. Sensor and Actuators.

This figure 17, shows on how the sensors and actuators run and operate with their designated schedule and time. When the actuators (pump, aerator, grow light) connected to WLAN, they will respond to their given acquired schedule and when they reach the given schedule, they will automatically switch on/off. Also with the sensors (pH, EC, Dht22) will process the data. The pH sensor will read whether the solution is alkaline or acidic and the EC sensor will measure the electrical conductivity in a solution. The DHT22 and fan is connected. When the room temperature is greater than 29 degrees Celsius, the fan will automatically turn on. And those data gathered will be processed and it will store in the database and will display to the web application.

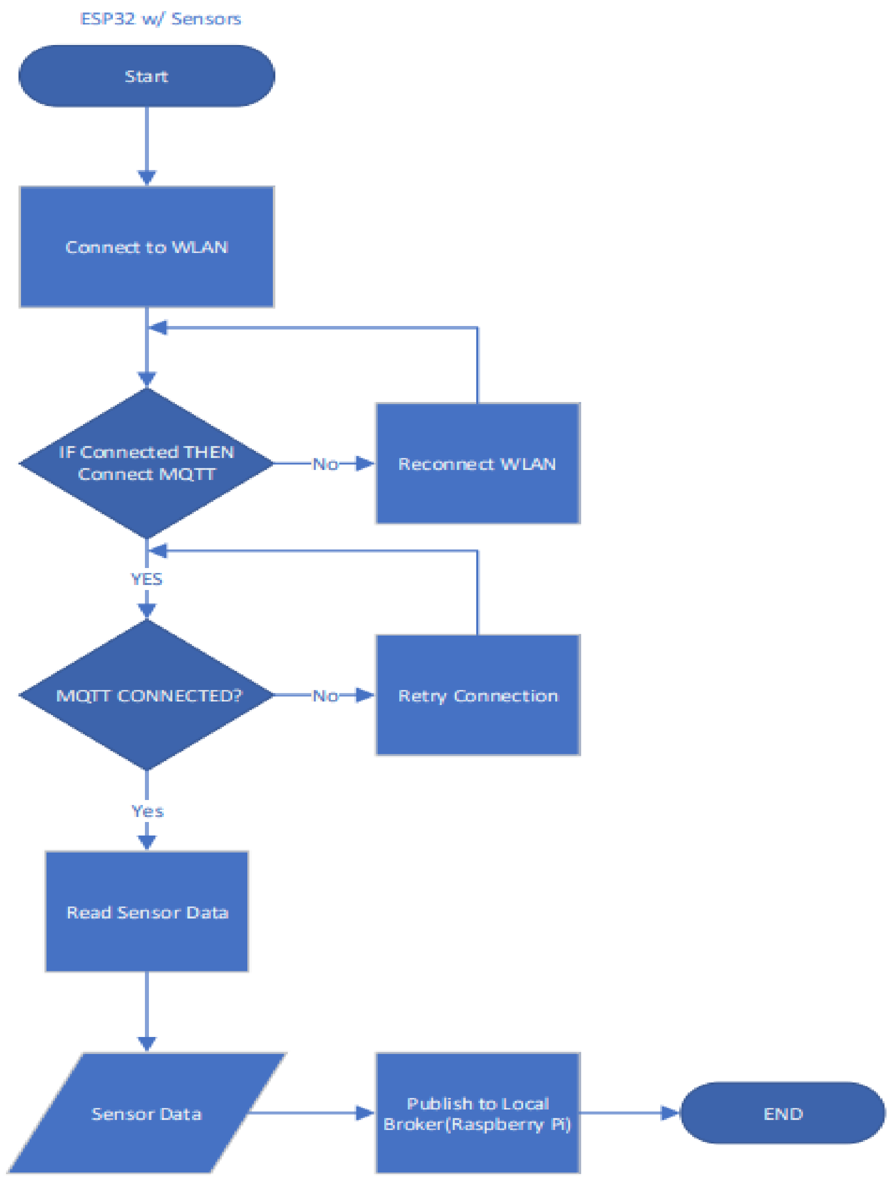



Figure 18. ESP32 with sensors.

The figure above, represent on how the ESP32 with sensors published data to the local broker. Upon starting, ESP32 with sensors should be connected to the WLAN. If connected, then MQTT also connects to the WLAN. If successfully connected, it will read data from the sensors and those data will publish to the local broker which is the Raspberry Pi.

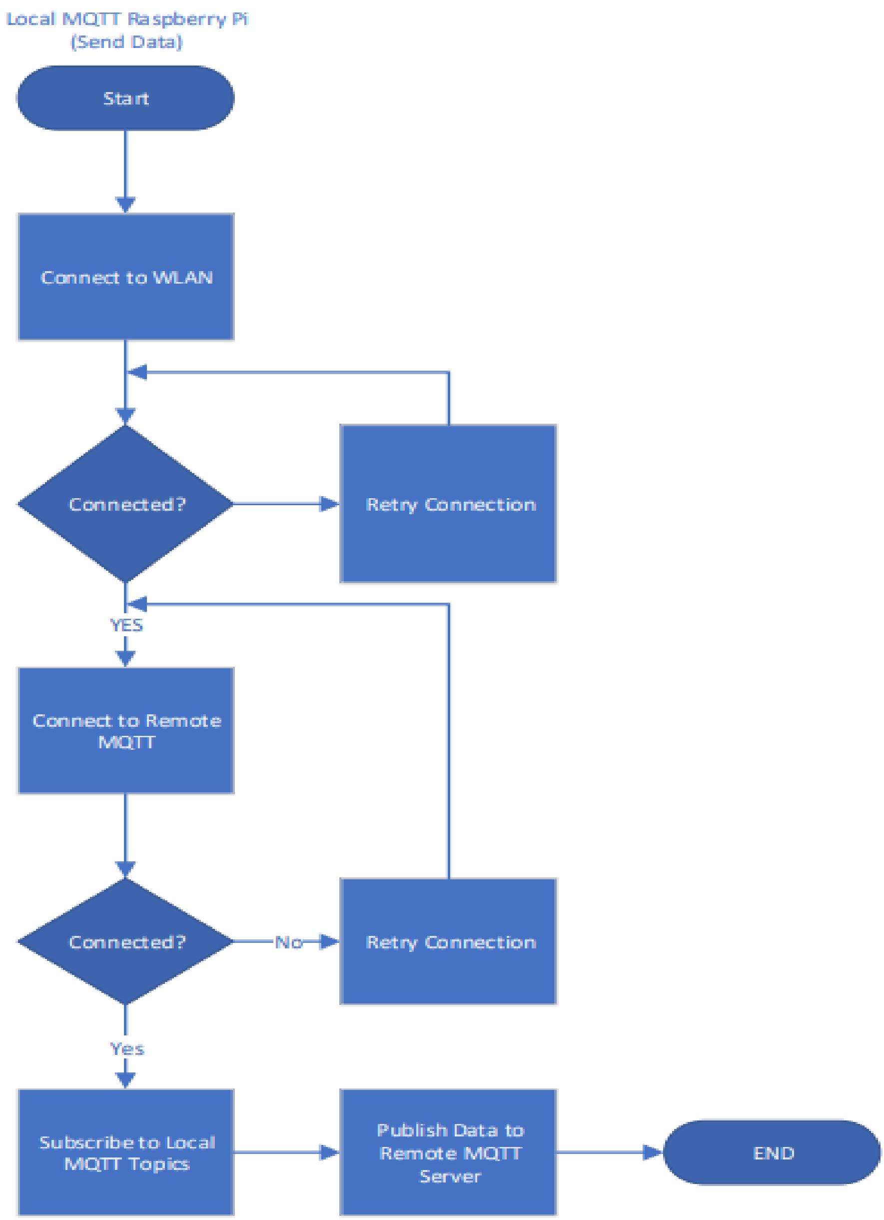



Figure 19. Local MQTT Raspberry Pi (Send Data)

The figure 19, shows on how the local mqtt raspberry pi sends data to the remote MQTT server. The local MQTT broker should be connected to the WLAN. If connected, then remote MQTT also connects. If connected, it will subscribe to local mqtt to publish data into remote MQTT server.

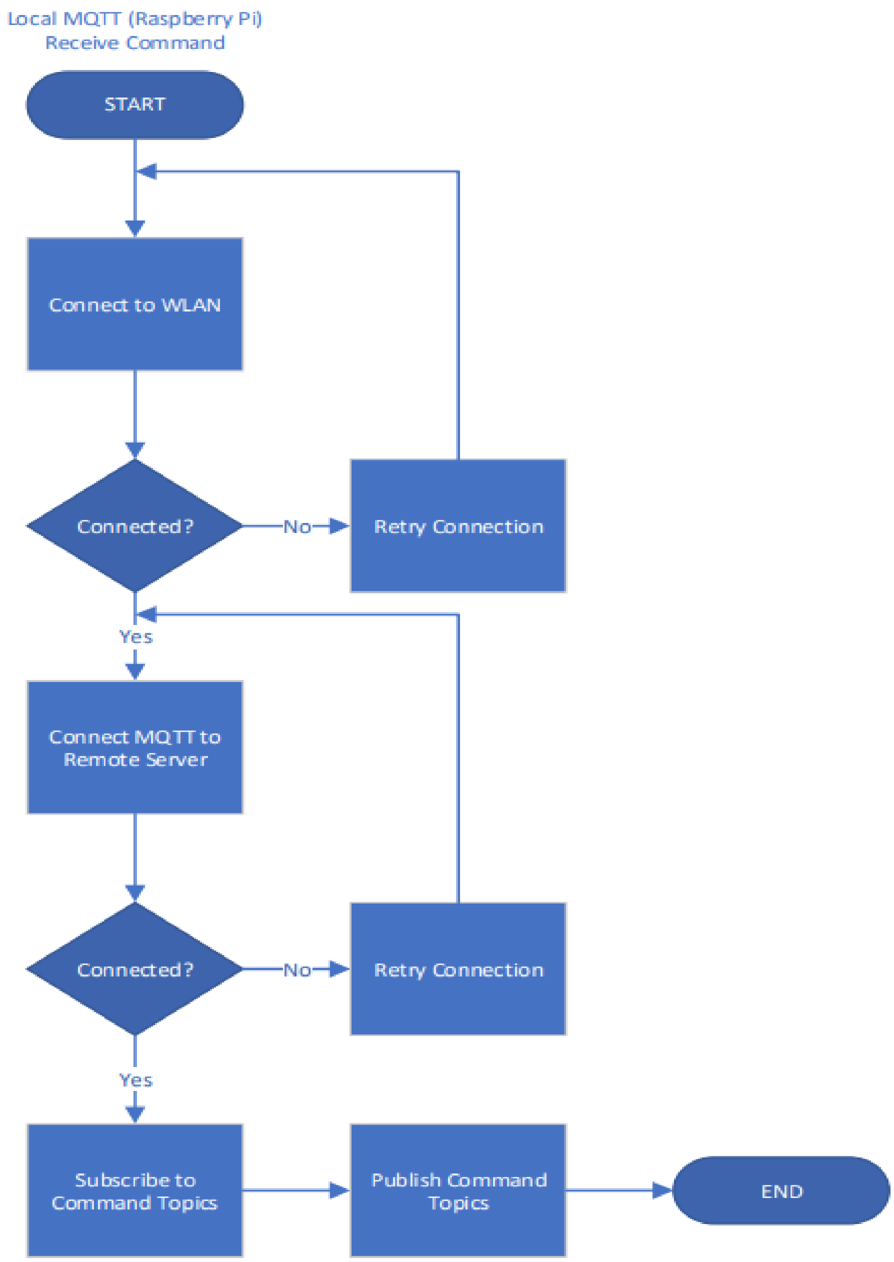



Figure 20. Local MQTT Raspberry Pi (Receives command)

The figure above, shows on how local mqtt raspberry pi receives the command. Upon starting, it should be connected to the WLAN. If local mqtt connects to remote server, it will subscribe to command topics, then it will publish command topics.

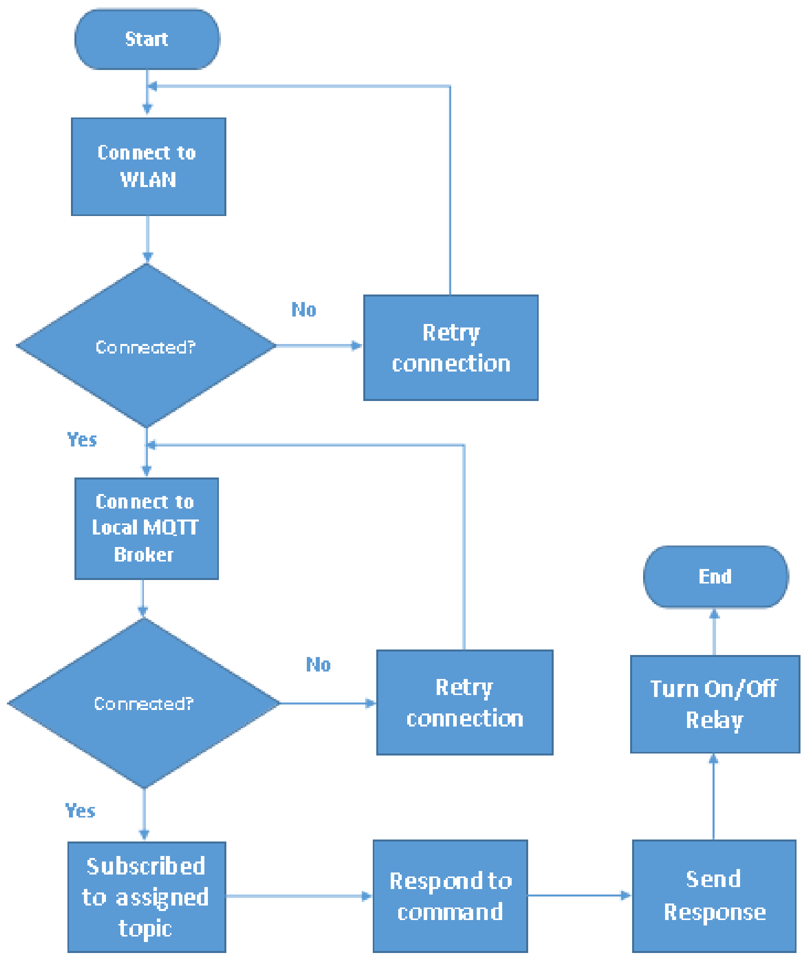



Figure 21. Sonoff Command

The figure above, represents sonoff command. The sonoff should be connected to the WLAN and connects to local mqtt broker then subscribe to assigned topics such as pump, aerator, fan and lights and they will respond to the command either on or off.

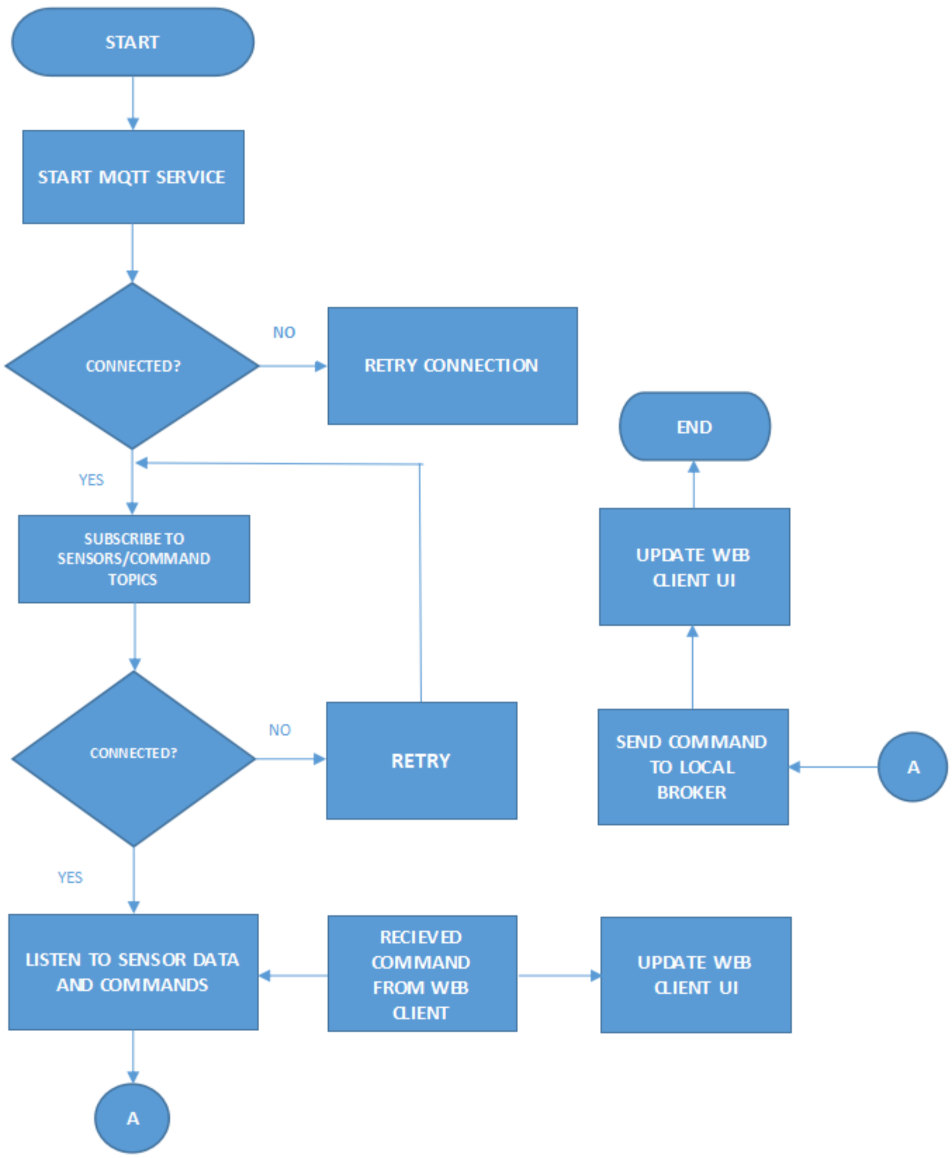



Figure 22. Remote MQTT Server

The figure above, shows the remote mqtt server. Upon starting the mqtt service, it should be connected to the WLAN. Then it will subscribes to sensor/command topics. If it is successfully subscribed, the service will listen to the sensor data and commands and Send this command to Local broker and it will display to the web client UI.

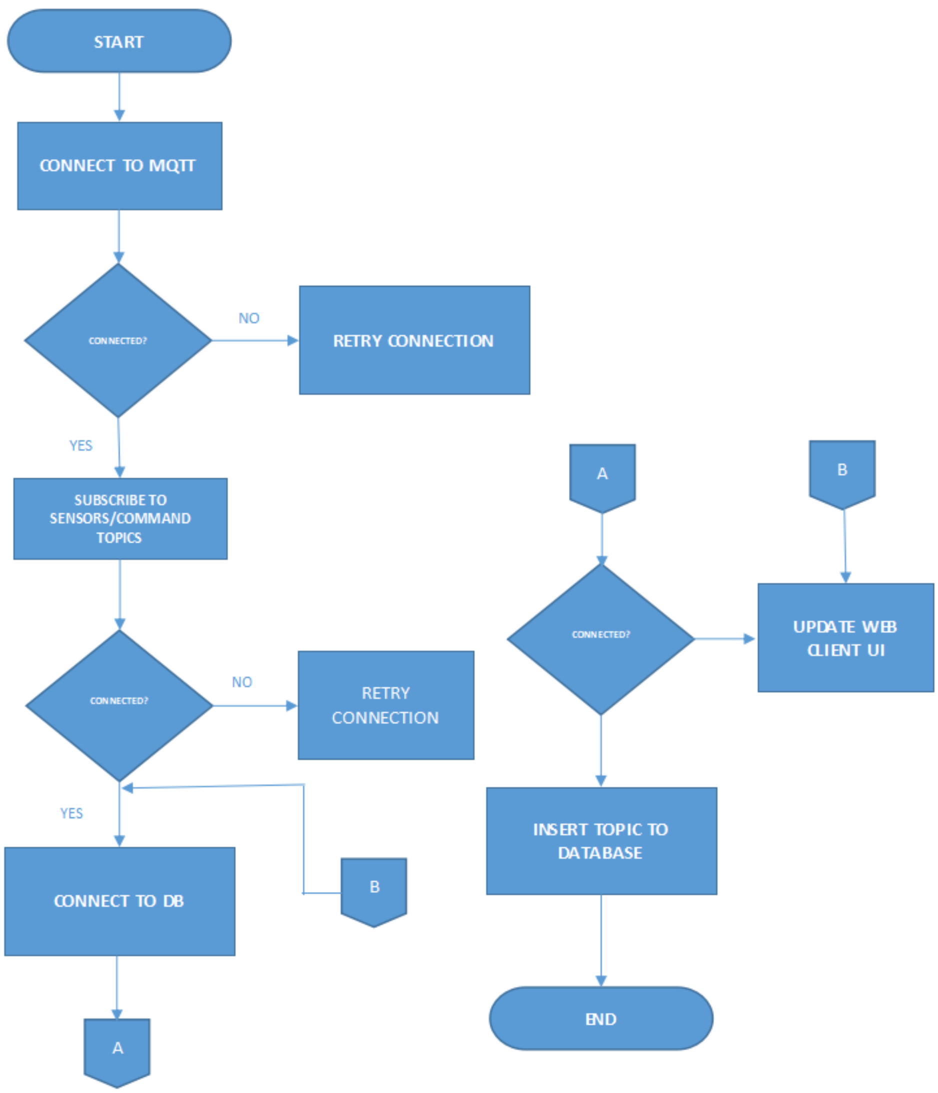



Figure 23. MQTT Service (Data Recording)

The figure 23, represents the mqtt service on how it will record data. The service will connect to MQTT and subscribe to sensor and commands topics. If successfully subscribed, it will connect to the database. If connected, topic will inserted to the database.

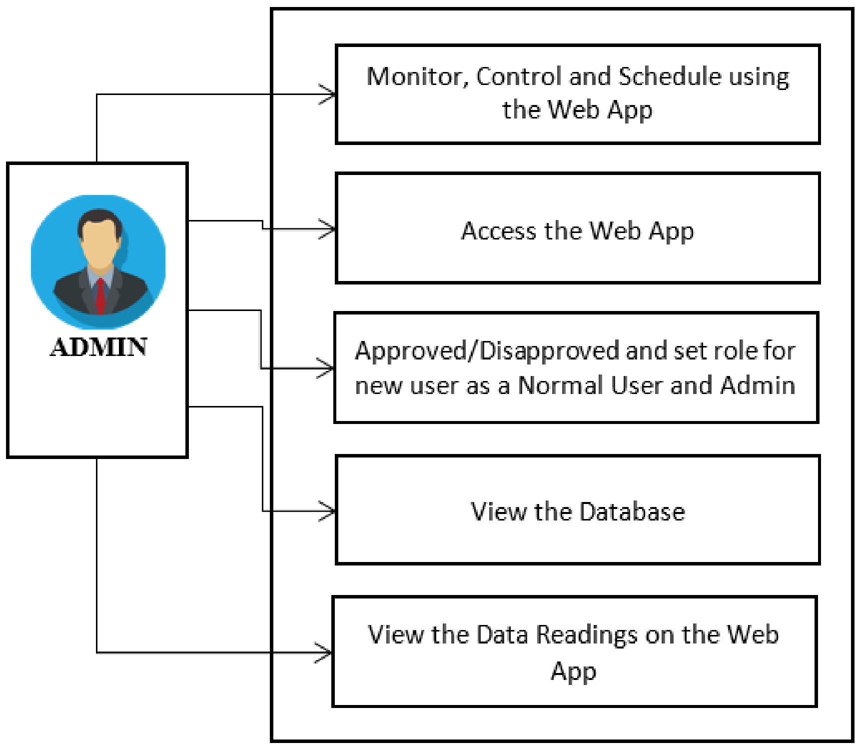



Figure 24. Used Case (Admin)

The figure 24 shows the admin capabilities such as, first, the admin can monitor, control and schedule using the Web app. Second, the admin can access the web app. Third, the admin can approved/disapproved and set a role for new users as a normal users. Fourth, the admin can view the data reading in the web app. And lastly, the admin view the database of our system.

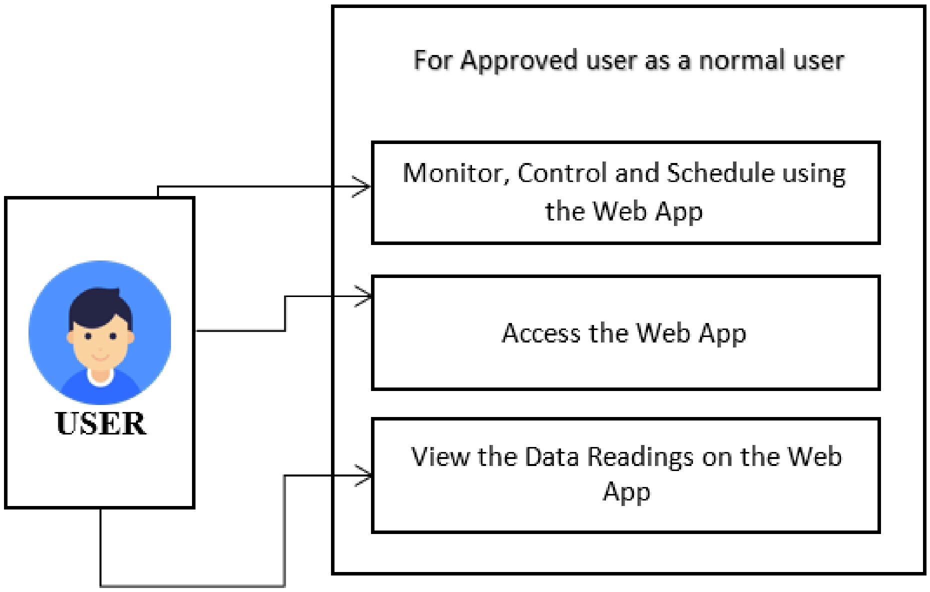



Figure 25. Used Case (User)

The figure 25 shows the user capabilities such as, first, the user can monitor, control and schedule using the Web app. Second, the user can access the web app. And lastly, the admin can view the data reading in the web app.

**Phase 3: Evaluation of lettuce plant according to growth, mortality and its efficiency through Automated Hydroponic System using Raspberry Pi over Traditional farming.**

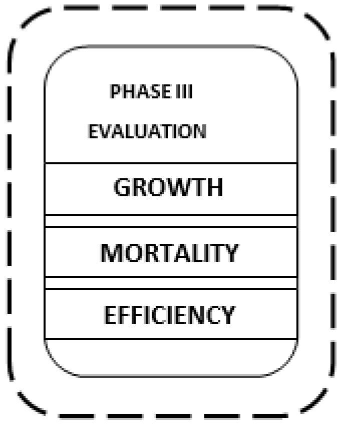



Figure 26. Evaluation of lettuce plant according to growth, mortality and its efficiency through Automated Hydroponic System using Raspberry Pi over Traditional Farming.

In the third phase, it displays a block containing the system's assessment parameters that determine whether or not the hydroponics system is capable of solving the problem. The evaluation assessed the system's growth, mortality and the plants efficiency compared to traditional agriculture. The findings of the review have determined if the method implemented is beneficial and helpful in solving the food security dilemma.

**Statistical Tool**

Table 2. Test scenarios for the functionality test of the web application.

| Items | Device | Test Step | Expected Result | Status |
|---|---|---|---|---|
| 1 | All Sensors | CONNECT | All devices have link | OK |
| 2 | pH Level Reading | GET -data | Display pH level reading | |
| 3 | Water Temperature Reading | GET -data | Display water temperature reading | |
| 4 | EC Reading | GET -data | Display EC reading | Failed |
| 5 | Humidity Reading | GET -data | Display Humidity | |
| 6 | Room Temperature | GET -data | Display Temperature | OK |
| 7 | Light Switch | ON | 1.Turn on the light switch | Triggered |
| | | OFF | 2.Turn off the light switch | |
| 8 | Water/Air Pump | ON | 1.Turn on the water pump | Triggered |
| | | OFF | 2. Turn off the water pump | |

The table shows that all devices e.g sensors and actuators will be connected to test the functionality of the web application. The web application will display the readings/data of the pH sensor, water temperature sensor, EC sensor, room temperature and Humidity sensor coming from the MQTT remote broker. It also displays the scheduled command of the actuators e.g light switch, water pump, and air pump whether on or off set by the user.

## Functionality Test

| ITEM | ACTUATOR | SCENARIO | EXPECTED RESULT | TEST | | | | | | | | | | TOTAL |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | |
| 1 | GROW LIGHTS | The user will test the grow lights 10x | The grow lights will on/off 10x through the web app | | | | | | | | | | | |
| | | The user will schedule a certain time in the web app where the grow lights will automatically on/off. | The grow lights will automatically on/off. | | | | | | | | | | | |
| 2 | PUMP AND AERATOR | The user will test the pump and aerator 10x | The pump and aerator will on/off 10x through the web app | | | | | | | | | | | |
| | | The user will schedule a certain time in the web app where the pump and aerator will automatically on/off. | The pump and aerator will automatically on/off. | | | | | | | | | | | |

| | | | |
|---|---|---|---|
| 3 | FAN | The user will test the fan10x | The grow fan will on/off 10x through the web app |
| | | The user will schedule a certain time in the web app where the fan will automatically on/off. | The fan will automatically on/off. |

The efficiency of the system proposed would be assessed using the success rate. The success rate is determined by calculating the number of successful attempts on the program by the total number of experiments, compounded by 100 percent as seen below:

$$Success\ Rate = \frac{Number\ of\ successful\ attemps}{Total\ number\ of\ trials\ from\ the\ sample}\ x\ 100$$

Table 3**.** Comparison of the height of lettuce in centimeter between automated hydroponic system and traditional farming.

| | Height of lettuce using traditional farming, cm | Height of lettuce using Automated Hydroponics System, cm |
|---|---|---|
| Plot 1 | Cm | Cm |
| Plot 2 | | |
| Plot 3 | | |
| Plot 4 | | |

The researchers evaluated the following statistics using a t-test. Below is the formula used in calculating the test statistic t:

**Test statistic:** $(\bar{x}_1 - \bar{x}_2) \ / \ s_p(\sqrt{1/n_1 + 1/n_2})$

Where $\bar{x}_1$ and $\bar{x}_2$ are the sample means, $n_1$ and $n_2$ are the sample sizes, and $s_p$ is calculated as $s_p = \sqrt{(n_1-1)s_1^2 + (n_2-1)s_2^2 \ / \ (n_1+n_2-2)}$ and $s_1^2$ and $s_2^2$ are the sample variances.

**Null Hypothesis, $H_o$:** There is no significant difference in the mean height of lettuce using the traditional farming.

**Alternative Hypothesis, Ha:** There is a significant difference in the mean height of lettuce using the traditional farming.

Table 4. Comparison of the Number of leaves of the lettuce between automated hydroponic system and traditional farming.

| | Number of leaves of the Lettuce using Traditional Farming | Number of leaves of the Lettuce using Automated Indoor Hydroponic System |
|---|---|---|
| Plot 1 | pieces | Pieces |
| Plot 2 | | |
| Plot 3 | | |
| Plot 4 | | |

In table 4, it is the comparison of the number of leaves of the lettuce between the traditional farming and the Automated Indoor Hydroponic System. The researchers used the formula of the mean in computing the data. The formula in getting the mean is the Sum of all Data divided by the Total number of plot.

Table 5. First plot Overall data of the Automated Hydroponic System and Traditional Farming

| | | Plant Height | | No. of Leaves | | Mortality | |
|---|---|---|---|---|---|---|---|
| | **PLOT 1** | **Traditional** | **Automated** | **Traditional** | **Automated** | **Traditional** | **Automated** |
| | 1 | | | | | | |
| | 2 | | | | | | |
| | 3 | | | | | | |
| | 4 | | | | | | |
| | 5 | | | | | | |
| | 6 | | | | | | |
| | 7 | | | | | | |
| | 8 | | | | | | |
| | 9 | | | | | | |
| | 10 | | | | | | |
| | 11 | | | | | | |
| | 12 | | | | | | |
| MEAN | | | | | | | |

The table above shows the first plot overall data of the Automated Hydroponic System and the Traditional farming. The researchers used the formula of the mean in computing the data. The formula of the mean is the Sum of all data divided by the Total Number of plot.

Table 6. Second plot Overall data of the Automated Hydroponic System and Traditional Farming

| | | Plant Height | | No. of Leaves | | Mortality | |
|---|---|---|---|---|---|---|---|
| | **PLOT 2** | **Traditional** | **Automated** | **Traditional** | **Automated** | **Traditional** | **Automated** |
| | 1 | | | | | | |
| | 2 | | | | | | |
| | 3 | | | | | | |
| | 4 | | | | | | |
| | 5 | | | | | | |
| | 6 | | | | | | |
| | 7 | | | | | | |
| | 8 | | | | | | |
| | 9 | | | | | | |
| | 10 | | | | | | |
| | 11 | | | | | | |
| | 12 | | | | | | |
| MEAN | | | | | | | |

The table 6, shows the second plot overall data of the Automated Hydroponic System and the Traditional farming. The researchers used the formula of the mean in computing the data. The formula of the mean is the Sum of all data divided by the Total Number of plot.

Table 7. Third plot Overall data of the Automated Hydroponic System and Traditional Farming.

| | | Plant Height | | No. of Leaves | | Mortality | |
|---|---|---|---|---|---|---|---|
| | **PLOT 3** | **Traditional** | **Automated** | **Traditional** | **Automated** | **Traditional** | **Automated** |
| | 1 | | | | | | |
| | 2 | | | | | | |
| | 3 | | | | | | |
| | 4 | | | | | | |
| | 5 | | | | | | |
| | 6 | | | | | | |
| | 7 | | | | | | |
| | 8 | | | | | | |

| | | | | | | |
|---|---|---|---|---|---|---|
| 9 | | | | | | |
| 10 | | | | | | |
| 11 | | | | | | |
| 12 | | | | | | |
| MEAN | | | | | | |

The table 7, shows the second plot overall data of the Automated Hydroponic System and the Traditional farming. The researchers used the formula of the mean in computing the data. The formula of the mean is the Sum of all data divided by the Total Number of plot.

Table 8. Fourth plot Overall data of the Automated Hydroponic System and Traditional Farming.

| | Plant Height | | No. of Leaves | | Mortality | |
|---|---|---|---|---|---|---|
| **PLOT 4** | **Traditional** | **Automated** | **Traditional** | **Automated** | **Traditional** | **Automated** |
| 1 | | | | | | |
| 2 | | | | | | |
| 3 | | | | | | |
| 4 | | | | | | |
| 5 | | | | | | |
| 6 | | | | | | |
| 7 | | | | | | |
| 8 | | | | | | |
| 9 | | | | | | |
| 10 | | | | | | |
| 11 | | | | | | |
| 12 | | | | | | |
| MEAN | | | | | | |

The table above shows the fourth plot overall data of the Automated Hydroponic System and the Traditional farming. The researchers used the formula of the mean in computing the data. The formula of the mean is the Sum of all data divided by the Total Number of plot

Table 9. The Mortality Rate Percentage of the lettuce between Traditional farming and Automated Indoor Hydroponic System

| | Traditional Farming | Automated Indoor Hydroponic System |
|---|---|---|
| Mortality Rate (%) | | |

In table 9, the researchers solved the percentage of the Mortality Rate. The formula used is No. of Dead Lettuce divided by Total number of planted Lettuce multiply by 100%.

## Research Instruments

### MATERIALS

**Web Client:**

**Flutter with Dart.** Flutter is an open-source UI software kit created by google. It is used to develop applications for Android, iOS, Linux, Mac, Windows, Google Fuchsia, and the web from a single codebase.

**VS CODE**. Visual Studio Code is a freeware source-code editor made by Microsoft for Windows, Linux and macOS. Features include support for debugging, syntax highlighting, intelligent code completion, snippets, code refactoring, and embedded Git. Users can change the theme, keyboard shortcuts, preferences, and install extensions that add additional functionality.

**MQTT Client/Library**. The MQTT client is a piece of software that publishes and subscribes to topics. The MQTT library is a client library that enables mbed devices to use the mqtt protocol.

.**net core 3.0**. Windows desktop applications, specifically Windows Forms, Windows Presentation Framework (WPF), and UWP XAML, are supported by .NET Core3. You'll be able to run new and current Windows desktop applications on .NET Core and take advantage of all of its features.

**Desktop Service (saving to DB)**

**Winforms .net(c#)**. Windows Forms is a UI framework for building Windows desktop apps. It provides one of the most productive ways to create desktop apps based on the visual designer provided in Visual Studio. Functionality such as drag-and-drop placement of visual controls makes it easy to build desktop apps.

**MQTTNet Library**. MQTTnet is a high performance. NET library for MQTT based communication. It provides a MQTT client and a MQTT server (broker).

**Entity Framework**. The Entity Framework uses information in the model and mapping files to translate object queries against entity types represented in the conceptual model into data source-specific queries. Query results are materialized into objects that the Entity Framework manages.

**SQL Server**. SQL Server follows a table structure based on rows, allowing connection of data and functions while maintaining the data's security and consistency.

Checks in the relational model of the server work to ensure that database transactions are processed consistently.

### MQTT Service

**MQTT (Mosquitto) Broker**. The job of an MQTT broker is to filter messages based on topic, and then distribute them to subscribers. There is no direct connection between a publisher and subscriber. All clients can publish (broadcast) and subscribe (receive). MQTT brokers do not normally store messages.

### Hardware

**Water pipe**. The water pipe is a channel where the water can flow to give the lettuce nutrient with nutrient solution. This is a polyvinyl chloride (PVC) pipe.

**Plastic cups**. To give the roots access to the hydroponic nutrient solution, plastic net pots are just pots with holes in them.

**Drip hose**. This is used to irrigate the lettuce plants and it is made of level hose.

**Aerator**. Aerators are various mechanical instruments, such as dirt or water, used for aeration or replacing air with another material. To bring oxygen to the water, these instruments are used.

**Water pump**. This pump is used to recirculate the water with nutrient element needed for the lettuce plants.

**Water tank**. It is used provide storage of water for hydroponic system.

**Nutrient solution (Nutri Hydro)**. It is carefully proportioned liquid fertilizer use in hydroponic gardening.

**Growing medium (Cocopeat)**. Provides air circulation to the roots of lettuce plants.

**Led Grow Light**. Used as a single source of light. LEDs help plants expand at a lower rate, using full-spectrum lighting.

**Water Temperature Sensor (DS18B20)**. The 1-Wire DS18B20 is a digital temperature sensor. Celsius degrees of 9 to 12-bit accuracy are recorded, from -55 to 125 (+/-0.5). Each sensor has a special 64-bit serial number engraved into it which makes it possible to use a large number of sensors on one data bus.

**Temperature and humidity Sensor (DHT22)**. Use to measure temperature and humidity inside the room.

**pH sensor (SEN0161-V2)**. Use to calculate the water's acidity or alkalinity level.

**Ec Sensor**. The electrical conductivity of a solution is measured using an electrical conductivity meter (EC meter). It is commonly used in hydroponics, aquaculture, aquaponics, and freshwater systems to track the amount of nutrients, salts, and impurities in the water.

**ESP32**. Via the DTM beacon mechanism, ESP32 stays linked with the router. ESP32 disables the WiFi module in two DTIM Beacon cycles to conserve power and wak es up immediately prior to the next arrival of the Beacon. The DTIM Beacon interval time of the router, which is normally 100 ms to 1000 ms, specifies the sleep time.

**Ph Down**. The word pH Down applies to consumer goods or popular household items that are added to a hydroponic nutrient solution to lower the pH levels and make the solution become more acidic.

**Seed Trays**. Plant germination trays, also known as seed trays, are a convenient way to start growing your own crops from seed. Sowing the seeds in trays makes it easier to fit them into propagators or put them on sunny windowsills, where they'll have a better chance of germinating.

**Experimental Set-Up**

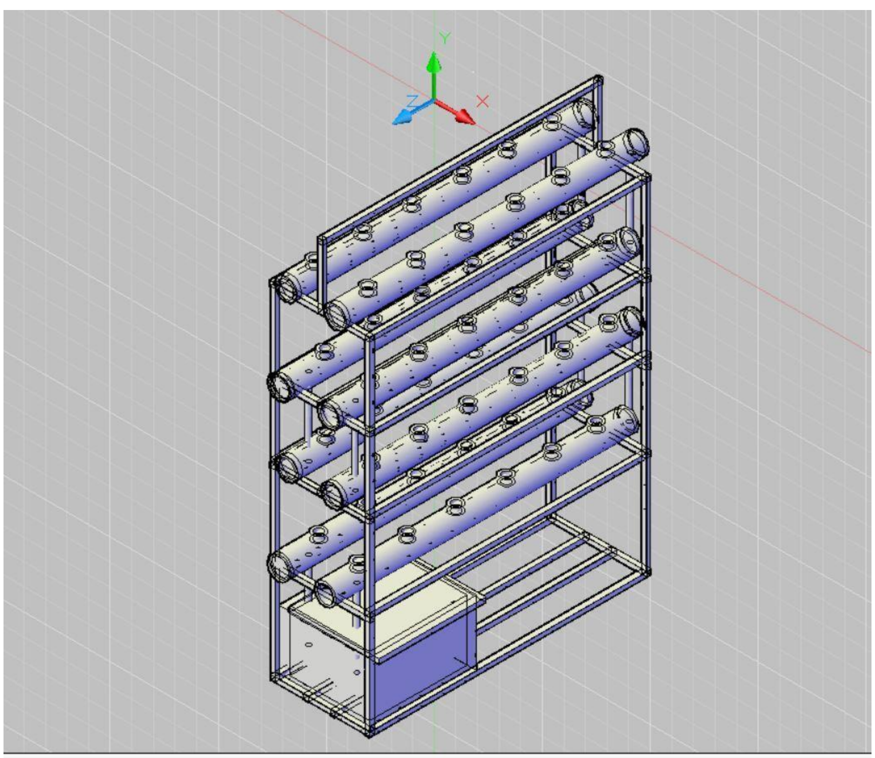



Figure 27. Overall view of the NFT System

The figure above shows the overall view of the system. The Raspberry Pi was placed inside the room below the exhaust fan near the door. It serves as the mqtt broker. The pH sensor was submerged in the reservoir. It was used to calculate the water's acidity or alkalinity level. The EC sensor was submerged in the reservoir. It is used to measure the electrical conductivity of a solution using an electrical conductivity meter. Temperature and humidity sensor (DHT22) was placed in the middle of the room. Used to measure temperature and humidity inside the room. ESP32 was attached to the pH, Ec and DHT22 sensors. It served as the microcontroller of the system. The grow lights were attached on the stand at the top of every pipe. Used as a single source of light. The water pump was attached at the top cover of the reservoir. It was used to recirculate the water with nutrient element needed for the lettuce plants. The aerator was submerged in the reservoir. It was used to bring oxygen to the water. Sonoff was attached at the left and right part of the stand and the other is attached near the exhaust fan. It was used to create a connection to the user to be able to remotely turn on and off any device. Water temperature sensor (DS18B20) was submerged in the reservoir. It was used to measure the temperature of the water. The exhaust fan was placed on the wall near the door. Used to circulate the air inside the room. The water tank was placed at the lower part of the stand. It was used provide storage of water for hydroponic system. The water pipe was placed on the stand layer by layer. A channel where the water can flow to give the lettuce nutrient with nutrient solution. Drip hose was placed at the end of every pipe. Used to irrigate the lettuce plants and it is made of level hose. Styro cup was placed in the pipe hole. Used to give the roots access to the hydroponic nutrient solution. The extension cord was attached at the right and left part of the stand. Used to provide power to the system.

## RESULTS AND DISCUSSION

### The Developed Automated Indoor Hydroponic System using Raspberry Pi

The Figure 28 below show the assembled Automated Indoor Hydroponic System with the lettuce plant.

Figure 28. Actual photo of the system

The Figure shows the assembled Automated Indoor Hydroponic System. The researchers created an Automated Hydroponics System Using Raspberry Pi to address the problem to reduce the cost of resources of the farmers, lessen the manual use of water consumption and to avoid food waste and low yield due to climate change. The figure shows the complete and actual setup of the study.

The researchers, in conducting their study made use of 8 pieces of PVC. Each of the PVC provides room for 6 slots which can be used to plant the lettuce which yielded 48 slots. The capacity of the container is 48 liters. As shown on the figure above it was designed at the bottom part of the system.

The system was programmed to water the plant from 6 am to 6 pm in 30 minutes duration. In the entire duration of the study, lights are turned on from 6 am to 10 pm.

**Water Parameters Sensors**

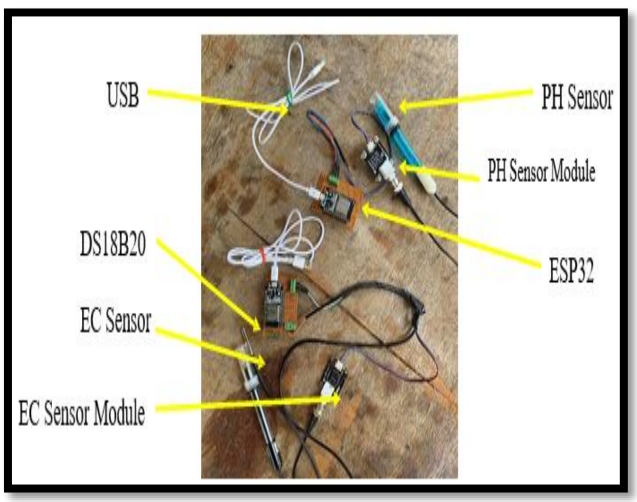



Figure 29. Water Parameters Sensors

The figure shows the different sensors used in the study to monitor the water quality parameters. The Ph sensor, Ec sensor and Water temperature (DS18B20). The sensors were controlled by the ESP32 and the RPi for storing the data readings in the database.

## Actuators


Figure 30. Actuators

The figure below shows the different actuators used in the study to control the system. The Water Pump, Aerator and the Exhaust Fan. The actuators were controlled by the SONOFF.

## Sowing of the Lettuce Plant

Figure 31. First day of sowing

This figure shows the sowing part of the seedlings, the researchers planted 56 seedlings for the traditional and 56 seedlings for the hydroponic.

Figure 32. Third Day of Sowing

The figure shows that the seeds has germinated. Was quite exciting to see something sprout from the soil and coco peat.

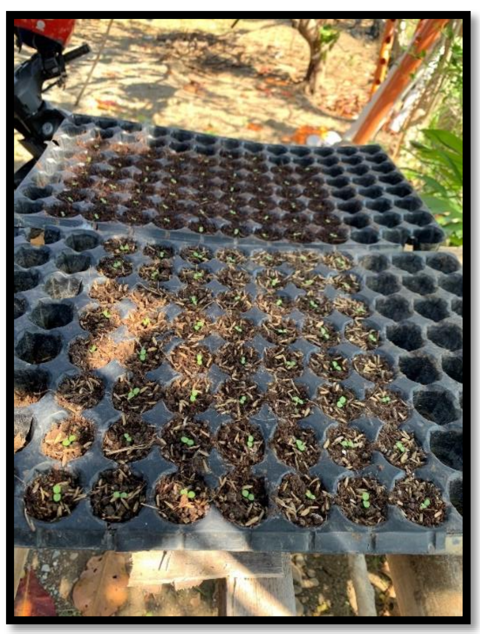


Figure 33. Fifth Day of Sowing

The figure shows that the plant is growing quickly. It has healthy looking green leaves.

Figure 34. Seventh Day of Sowing

The figure shows that the plant has grown quite a bit over the last 2 days and sprouted few more leaves. It looks healthy and strong.

Figure 35. Fourteenth Day of Sowing

The figure shows that the seedlings are now at the majestic height, there are leaves poking out everywhere. It is perfectly green, strong and healthy. The seedlings are ready to be transplanted.

## Transplant

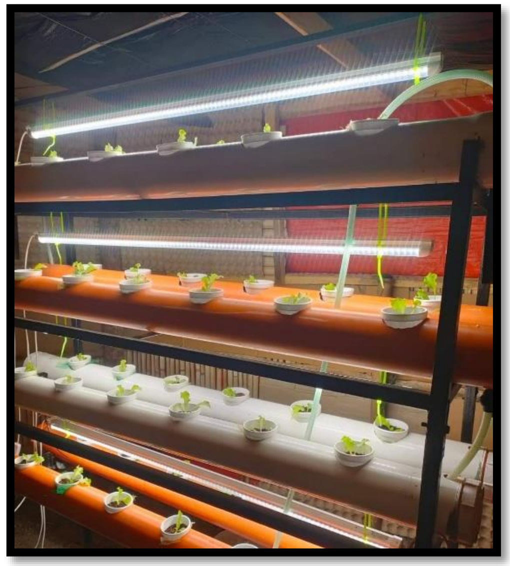


Figure 36. Fifteenth Day and the Day for transplant in Hydroponics System

The figure above shows the transplanted lettuce. The researchers transplanted 48 seedlings in the hydro.

Figure 37. Fifteenth Day and the Day for transplant in Traditional Farming

The figure above shows the transplanted lettuce. The researchers transplanted 48 seedlings in the traditional farming.

## Harvest

Figure 38. Day 43 Harvesting of lettuce in Hydroponics

The figure shows that the lettuce is ready to be harvested in Hydroponic Farming. The researchers harvested in the 43rd day of the lettuce. Basing from the total harvested lettuce (in grams) it is evident that using the Automated Indoor Hydroponic System gives more produce than the Traditional Farming. The harvested lettuce in Hydroponic system is heavier than the Traditional Farming. There are no deaths in Indoor Hydroponic System.

Figure 39. Day 57 Harvesting of lettuce in Traditional Farming

The figure shows that the lettuce is ready to be harvested in Traditional Farming. The researchers harvested in the 57th day of the lettuce. The weigh in Traditional Farming is lighter compared to Indoor Hydroponic Farming. Traditional Farming is more prone to deaths due to weather condition which causes less harvest.

### The Developed Web-based Application

This part of the study discussed the Web Interface of the system. This section contains the system's log in section, dashboard as well as controllers, data, and system monitoring.

## Log In Section

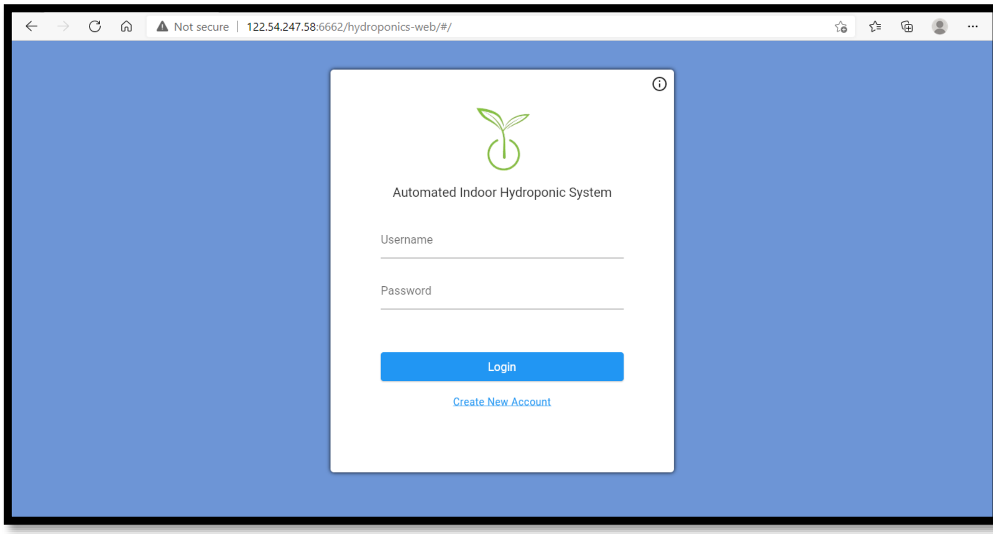



Figure 40. Login Form of the System

The figure shows the Automated Hydroponic System Login page. Through entering their username and password on the login tab, a user can obtain access to the Automated Hydroponic System web page.

The user must have an account in the login portion of the web page in order to access the system's main page, you must be approved first by the admin for the security of the web page.

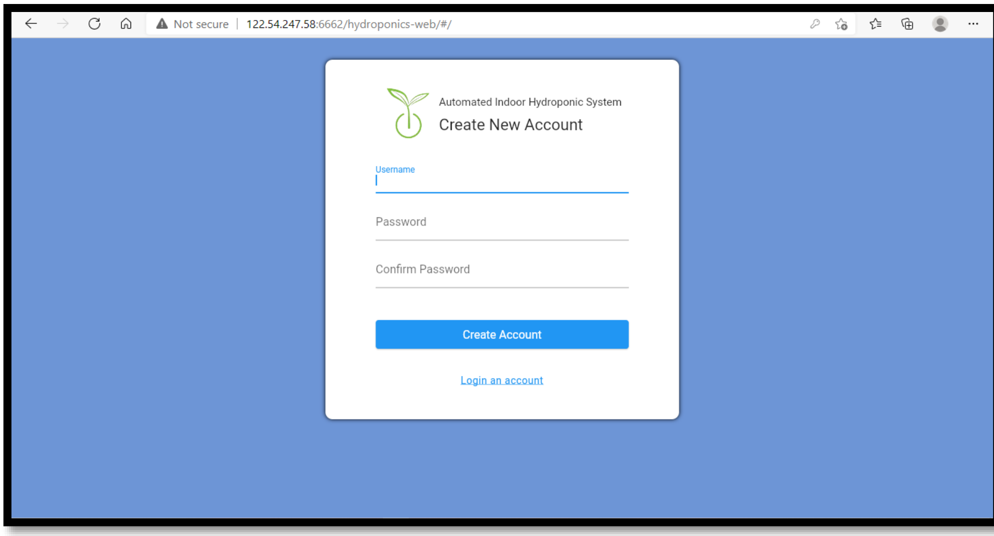



Figure 41. Create New Account Form of the System

In the Create new account form of the system, the user should register first an account to login and to access the Automated Hydroponic System web page. You must be approved first in order to access the web page. After the approval you can now accessed the web page. After logging in, you will be redirected to the Automated Hydroponic System dashboard.

**Web Page Dashboard Section**

The Data page is the main part of the Automated Hydroponic System. The figure below shows the data page of the Web System. This composed all the data from the sensors in real time, which monitored the water and environmental parameters such as temperature, humidity, pH level and EC level. As well as to control and schedule the actuators such as grow lights, fan, pump and aerator.


Figure 42. Web Page Dashboard of the System

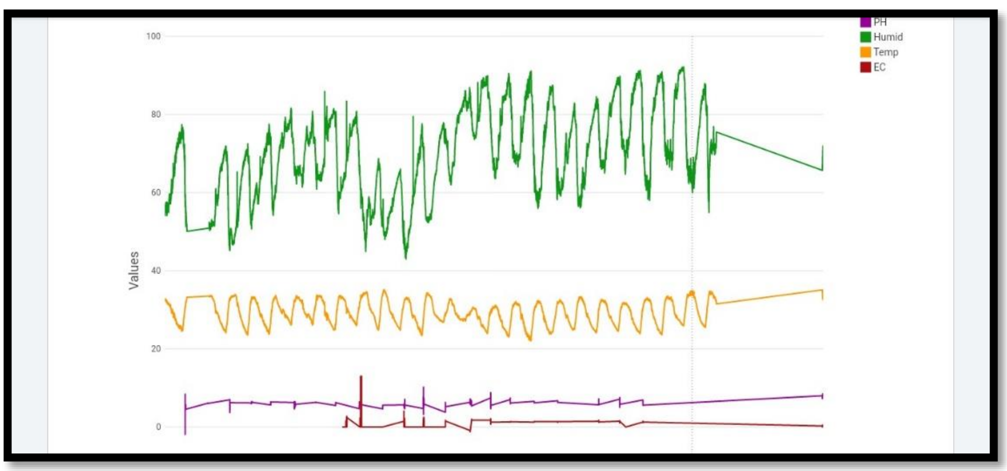



Figure 43. Data Section in the Web

The Data Section displayed the data reading and information from the sensor into a line graph. In the first table of the data, the line graph represents the humidity reading of the sensor. And the second table is the line graph of the temperature reading of the sensor. The third table is the line graph of the pH level reading of the sensor. Lastly is the line graph of the EC level reading of the sensor. The sensor will collect the data every minute. On April 8, the researchers gathered the first data. The ph and ec data ended five days before the harvest while the temperature and humidity data ended on May 5.

## The Web Page Scheduler Section

On this section, the user or admin can schedule a certain time to automatically run the actuators of the system. The researchers scheduled the pump and aerator from 6 am to 6 pm with the time interval of 30 minutes. Also, the grow lights was scheduled from 6 am to 10 pm. The fan cannot be scheduled because it will automatically on/off due to its condition (30 degrees Celsius above, ON. 29 degrees Celsius below, OFF).

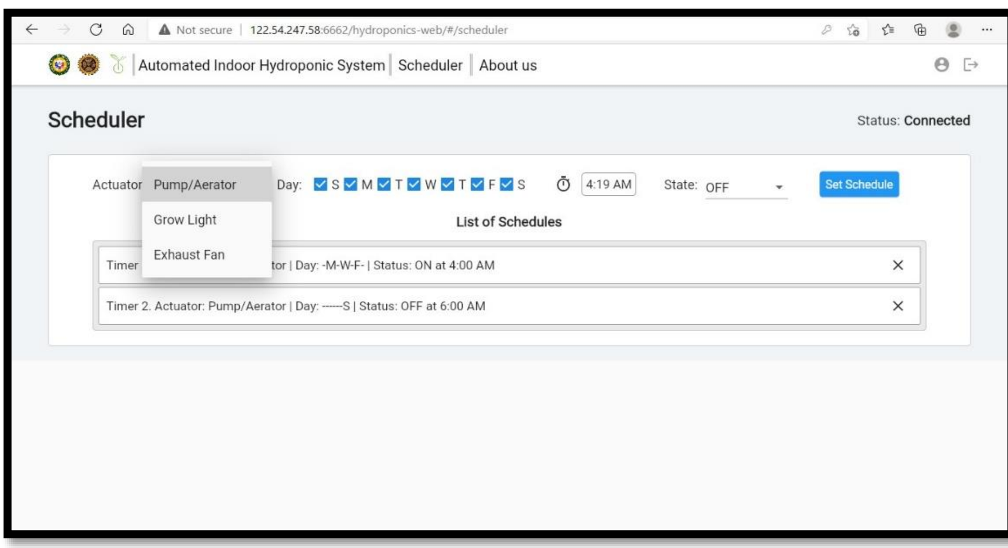



Figure 44. Web Page Scheduler of the System

**Evaluation of the Automated Indoor Hydroponic System and Traditional Farming**

Table 10. Functionality Test for the time-based via web app Result

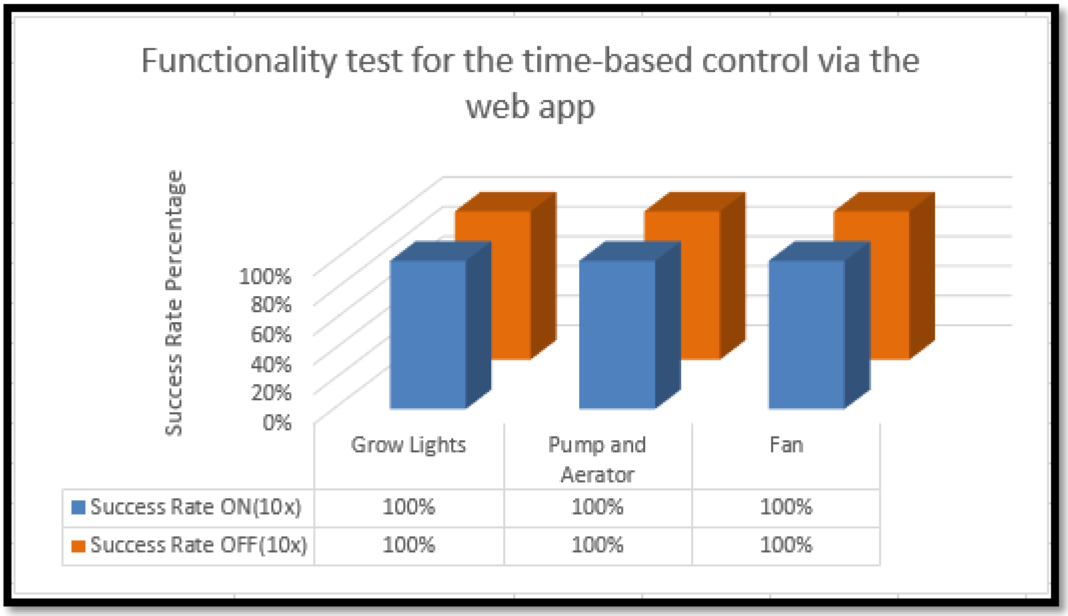
| Device | Action | Expected Result | Actual Result | | | | | | | | | | Success Rate |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | |
| Grow lights | ON | 1. Turn on grow lights | / | / | / | / | / | / | / | / | / | / | 100% |
| | OFF | 2. Turn off grow lights | / | / | / | / | / | / | / | / | / | / | 100% |
| Pump and aerator | ON | 1. Turn on Pump and aerator | / | / | / | / | / | / | / | / | / | / | 100% |
| | OFF | 2. Turn off Pump and aerator | / | / | / | / | / | / | / | / | / | / | 100% |
| Fan | ON | 3. Turn on Fan | / | / | / | / | / | / | / | / | / | / | 100% |
| | OFF | 4. Turn off Fan | / | / | / | / | / | / | / | / | / | / | 100% |

The table above shows the overall result of the systems' functionality by testing it 10 times on/off in terms of accessing it in time-based via the web application. The expected result have been fully satisfied showing its success rate 100 percent working. This prove that all the devices that have been test is functioning well to its specific actions.

Table 11. Functionality Test for the manual control via web application

| Device | Action | Expected Result | Actual Result 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | Success Rate |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Grow lights | ON | 1. Turn on grow lights | / | / | / | / | / | / | / | / | / | / | 100% |
| | OFF | 2. Turn off grow lights | / | / | / | / | / | / | / | / | / | / | 100% |
| Pump and aerator | ON | 1. Turn on Pump and aerator | / | / | / | / | / | / | / | / | / | / | 100% |
| | OFF | 2. Turn off Pump and aerator | / | / | / | / | / | / | / | / | / | / | 100% |
| Fan | ON | 1. Turn on Fan | / | / | / | / | / | / | / | / | / | / | 100% |
| | OFF | 2. Turn off Fan | / | / | / | / | / | / | / | / | / | / | 100% |

The table above shows the overall result of the systems' functionality by testing it 10 times on/off in terms of manually controlling it via the web application. The expected result have been fully satisfied showing its success rate 100 percent working. This prove that all the devices that have been test is functioning well to its specific actions.




| | Grow Lights | Pump and Aerator | Fan |
|---|---|---|---|
| Success Rate ON(10x) | 100% | 100% | 100% |
| Success Rate OFF(10x) | 100% | 100% | 100% |

Figure 45. Functionality Success Rate for the time-based control via the web application

This figure 45, shows on how the actuators respond upon automatically turning them on/off to see the success rate of its actuators.

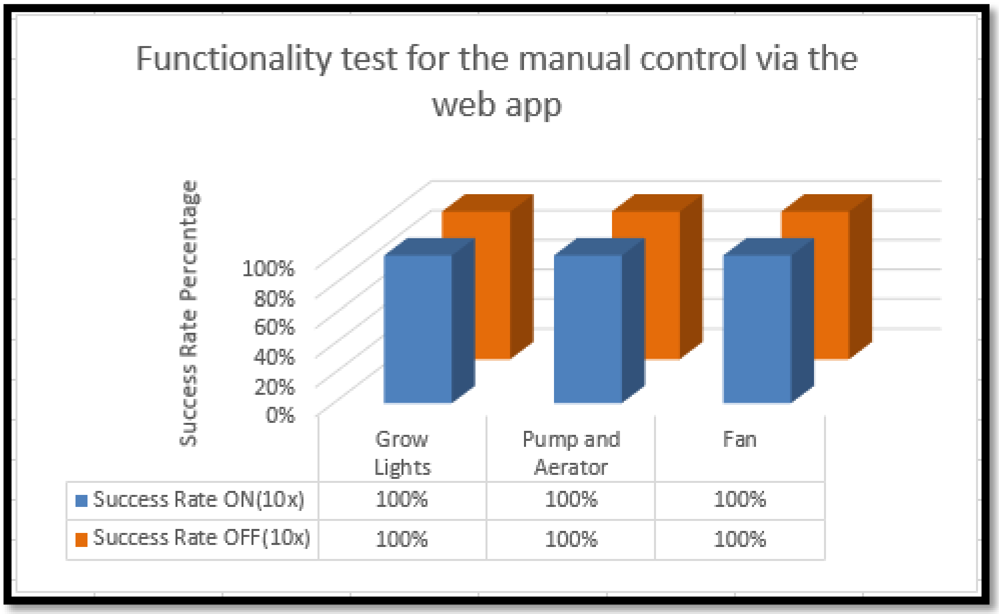



Figure 46. Functionality Test Success Rate for the Manual Control via the Web application

The figure 46, shows on how the actuators respond upon manually turning them on/off to see the success rate of its actuators.

## Data Comparison

Table 12. Plot 1 difference of Traditional Farming and Automated Indoor Hydroponic System through Plant Height, Number of Leaves and Mortality of the plant.

| | Plant Height | | No. of Leaves | | Mortality | |
|---|---|---|---|---|---|---|
| **PLOT 1** | **Traditional** | **Automated** | **Traditional** | **Automated** | **Traditional** | **Automated** |
| 1 | 0 | 27.1 | 0 | 10 | DEAD | - |
| 2 | 12 | 26.3 | 8 | 10 | - | - |
| 3 | 14.5 | 30 | 8 | 13 | - | - |
| 4 | 14.9 | 28 | 9 | 16 | - | - |
| 5 | 18 | 25 | 10 | 16 | - | - |
| 6 | 14 | 25 | 9 | 11 | - | - |

| | | | | | | |
|---|---|---|---|---|---|---|
| | 7 | 13.6 | 22.4 | 8 | 10 | - | - |
| | 8 | 19 | 21.3 | 13 | 9 | - | - |
| | 9 | 15.5 | 23.4 | 13 | 13 | - | - |
| | 10 | 0 | 25 | 0 | 12 | DEAD | |
| | 11 | 19.6 | 26.3 | 15 | 13 | - | - |
| | 12 | 7 | 25.2 | 7 | 12 | - | - |
| MEAN | | 12.3 | 25.4 | 8.3 | 12.1 | | |

The table 12 shows the Plant height in cm, the number of leaves and the mortality of the plant. Overall, the table shows that in traditional mode there were 2 mortality or deaths and automated modes of planting, there is no mortality or death among all 24 plants. In plant height, the computed mean in Automated Indoor Hydroponic System, 25.4 is greater than traditional farming, 12.3. However, in the number of leaves of Automated Indoor Hydroponic System has a greater number of leaves compared to traditional farming.

Table 13. Plot 2 difference of Traditional Farming and Automated Indoor Hydroponic System through Plant Height, No. Of Leaves and Mortality of the plant.

| | | Plant Height | | No. of Leaves | | Mortality | |
|---|---|---|---|---|---|---|---|
| | **PLOT 2** | **Traditional** | **Automated** | **Traditional** | **Automated** | **Traditional** | **Automated** |
| | 1 | 7.7 | 28.1 | 6 | 10 | - | - |
| | 2 | 17.5 | 27.2 | 13 | 10 | - | - |
| | 3 | 20.2 | 30.4 | 12 | 12 | - | - |
| | 4 | 17.8 | 29.9 | 8 | 16 | - | - |
| | 5 | 21.5 | 26.2 | 12 | 16 | - | - |
| | 6 | 23 | 26.2 | 14 | 12 | - | - |
| | 7 | 20 | 23.4 | 10 | 12 | - | - |
| | 8 | 24.1 | 22.3 | 17 | 10 | - | - |
| | 9 | 24 | 24.5 | 15 | 13 | - | - |
| | 10 | 24.5 | 27.1 | 15 | 12 | - | - |
| | 11 | 23.6 | 27.2 | 14 | 13 | - | - |
| | 12 | 23.2 | 26.2 | 14 | 13 | - | - |
| MEAN | | 20.6 | 26.6 | 12.5 | 12.4 | | |

The table 13 shows the second plot overall data of Automated Indoor Hydroponic System and Traditional Farming through plant height (cm), No. of leaves and the mortality of the lettuce. In plant height, the computed mean in Automated Indoor Hydroponic System, 26.6 is greater than traditional farming, 20.6. However, in the number of leaves of Automated Indoor Hydroponic System and traditional farming were almost the same which has a .1 difference. It shows in the table above that in the second plot there were no lettuce died.

Table 14. Plot 3 difference of Traditional Farming and Automated Indoor Hydroponic System through Plant Height, No. Of Leaves and Mortality of the plant.

| | | Plant Height | | No. of Leaves | | Mortality | |
|---|---|---|---|---|---|---|---|
| | **PLOT 3** | **Traditional** | **Automated** | **Traditional** | **Automated** | **Traditional** | **Automated** |
| | 1 | 9.5 | 27.5 | 13 | 10 | - | - |
| | 2 | 9.7 | 26.4 | 5 | 9 | - | - |
| | 3 | 10 | 29.2 | 7 | 10 | - | - |
| | 4 | 11.8 | 28.9 | 10 | 14 | - | - |
| | 5 | 10.7 | 25.9 | 7 | 15 | - | - |
| | 6 | 17.5 | 25.7 | 10 | 11 | - | - |
| | 7 | 18.7 | 23.1 | 14 | 10 | - | - |
| | 8 | 20.5 | 21.2 | 17 | 9 | - | - |
| | 9 | 21 | 23.9 | 15 | 10 | - | - |
| | 10 | 21.6 | 26.7 | 13 | 11 | - | - |
| | 11 | 21.8 | 26.1 | 17 | 11 | - | - |
| | 12 | 23 | 26.1 | 18 | 11 | - | - |
| MEAN | | 16.3 | 25.9 | 12.2 | 10.9 | | |

The table illustrates the Plant height in cm, the number of leaves and the mortality of the plant. Overall, the table shows that in both traditional and automated modes of planting, there is no mortality or death among all 24 plants. In plant height, the computed mean in Automated Indoor Hydroponic System, 25.9 is greater than traditional farming, 16.3. However, in the number of leaves of Automated Indoor Hydroponic System and traditional farming were almost the same.

Table 15. Plot 4 difference of Traditional Farming and Automated Indoor Hydroponic System through Plant Height, No. Of Leaves and Mortality of the plant.

| | | Plant Height | | No. of Leaves | | Mortality | |
|---|---|---|---|---|---|---|---|
| | **PLOT 4** | **Traditional** | **Automated** | **Traditional** | **Automated** | **Traditional** | **Automated** |
| | 1 | 13 | 26.1 | 9 | 9 | - | - |
| | 2 | 10.8 | 24.3 | 7 | 10 | - | - |
| | 3 | 10.4 | 29.6 | 8 | 11 | - | - |
| | 4 | 15 | 27.3 | 8 | 14 | - | - |
| | 5 | 15.2 | 23.8 | 7 | 13 | - | - |
| | 6 | 16.4 | 23.8 | 9 | 10 | - | - |
| | 7 | 18 | 21.3 | 10 | 10 | - | - |
| | 8 | 19.3 | 20.1 | 12 | 9 | - | - |
| | 9 | 21.3 | 21.9 | 15 | 11 | - | - |
| | 10 | 17 | 23.6 | 13 | 11 | | |
| | 11 | 0 | 25.9 | 0 | 12 | DEAD | - |
| | 12 | 22.4 | 24.8 | 21 | 10 | - | - |
| MEAN | | 14.9 | 24.4 | 9.9 | 10.8 | | |

The table illustrates the Plant height in cm, the number of leaves and the mortality of the plant. Overall, the table shows that in traditional method there is 1 mortality or death and automated modes of planting, there is no mortality or death among all 24 plants. In plant height, the computed mean in Automated Indoor Hydroponic System, 24.4 is much greater than traditional farming, 14.9. However, in the number of leaves of Automated Indoor Hydroponic System and traditional farming were almost the same.

**T-Test (Height)**

Table 16. Comparison of Plant height of Automated Indoor Hydroponic System and Traditional Faming using T-Test.

| | Traditional Farming | Automated Hydroponics System |
|---|---|---|
| plot 1 | 12.3 cm | 25.4 cm |
| plot 2 | 20.6 cm | 26.6 cm |
| plot 3 | 16.3 cm | 25.9 cm |
| plot 4 | 14.9 cm | 24.4 cm |

| | *Height of lettuce using traditional farming, cm* | *Height of lettuce using Automated Hydroponics System, cm* |
|---|---|---|
| Mean | 16.025 | 25.575 |
| Variance | 12.04916667 | 0.855833333 |
| Observations | 4 | 4 |
| Pooled Variance | 6.4525 | |
| Hypothesized Mean Difference | 0 | |
| Df | 6 | |
| t Stat | -5.316849446 | |
| P(T<=t) one-tail | 0.000900294 | |
| t Critical one-tail | 1.943180281 | |
| P(T<=t) two-tail | 0.001800588 | |
| t Critical two-tail | 2.446911851 | |

The table shows above is the difference of data of the height of Automated Hydroponic and Traditional Farming. If you looked into the table, the lettuce in Hydroponic farming is taller than Traditional Farming. The computed mean of height of the lettuce in Automated Indoor Hydroponic System is 25.575 cm and 16.025 cm in the traditional faming, which indicates that the height of lettuce in Automated Indoor Hydroponic System is greater than the height of lettuce in Traditional Farming.

**T-Test (Number of Leaves)**

Table 17. Comparison of Number of leaves of Automated Indoor Hydroponic System and Traditional Faming using T-Test.

| | Traditional Farming | Automated Hydroponics System |
|---|---|---|
| plot 1 | 8.3 | 12.1 |
| plot 2 | 12.5 | 12.4 |
| plot 3 | 12.2 | 10.9 |
| plot 4 | 9.9 | 10.8 |

| | *No. of leaves of the lettuce Using Traditional Farming* | *No. of leaves of the lettuce Using Automated Hydroponic System* |
|---|---|---|
| Mean | 10.725 | 11.55 |
| Variance | 3.9625 | 0.67 |
| Observations | 4 | 4 |
| Pooled Variance | 2.31625 | |
| Hypothesized Mean Difference | 0 | |
| Df | 6 | |
| t Stat | -0.766613089 | |
| P(T<=t) one-tail | 0.236193261 | |
| t Critical one-tail | 1.943180281 | |
| P(T<=t) two-tail | 0.472386523 | |
| t Critical two-tail | 2.446911851 | |

The data above shows the result of the data of the number of leaves of lettuce in Automated Hydroponic System and Traditional Farming. It shows that the number of leaves in every plot were almost the same. The computed mean of leaves of the lettuce in Automated Indoor Hydroponic System is 11.55 and 10.725 in the traditional faming, which indicates that the number of leaves in Automated Indoor Hydroponic System is greater than the number of leaves in Traditional Farming.

## Mortality Rate

Table 18. The percentage of the mortality rate in traditional farming and automated indoor hydroponic system.

| | Traditional Farming | Automated Hydroponics System |
|---|---|---|
| Mortality Rate % | 6.25% | 0% |

The data presented above shows the mortality rate of traditional farming which is 6.25% compared to 0% for automated hydroponics from this study which implies that than traditional farming.

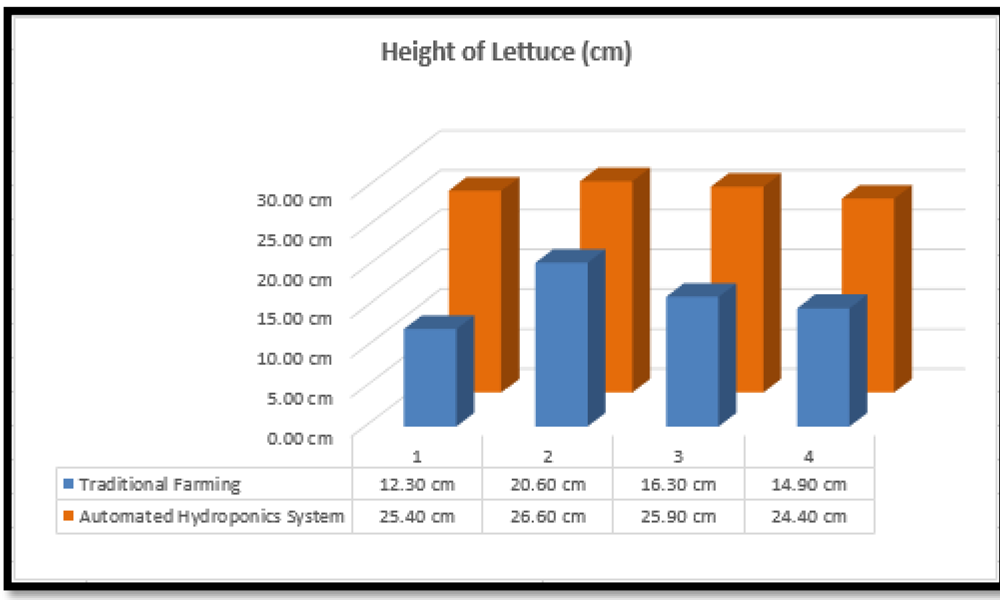
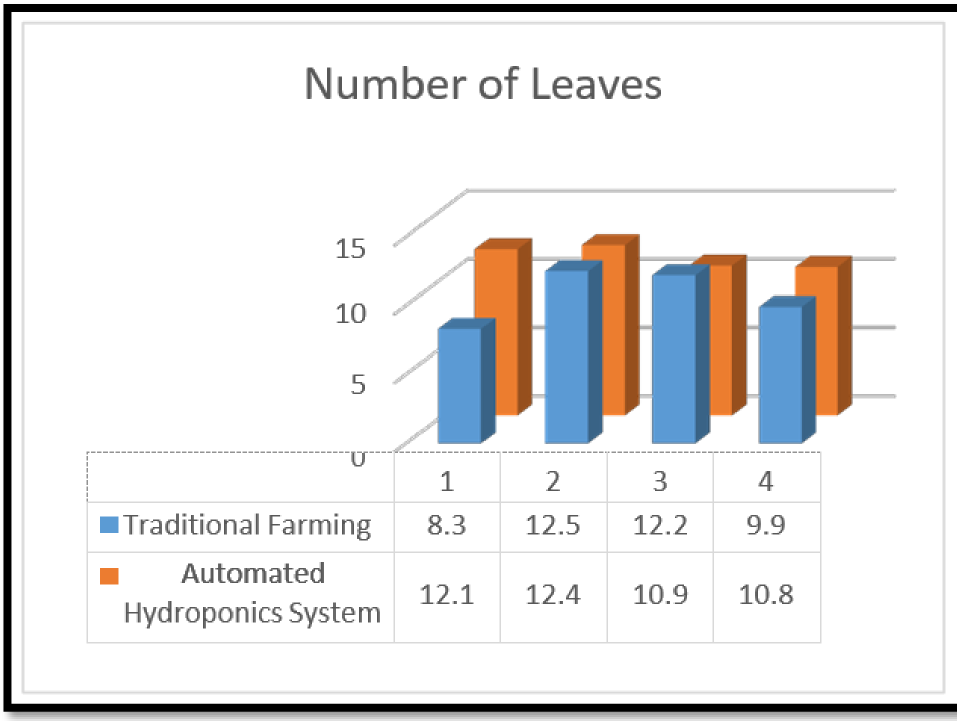



Figure 47. Data tally of the Height of Lettuce

The figure 47 shows the difference in height of every plot in Automated Hydroponic System and Traditional Farming. It shows that the height of the lettuces in all the plots in automated hydroponic system is greater than the traditional farming.




| | 1 | 2 | 3 | 4 |
|---|---|---|---|---|
| Traditional Farming | 8.3 | 12.5 | 12.2 | 9.9 |
| Automated Hydroponics System | 12.1 | 12.4 | 10.9 | 10.8 |

Figure 48. Data tally of the Number of leaves of Lettuce

This figure shows the number of leaves on every plot in Automated Hydroponic System and Traditional Farming. It shows that the total number of leaves in every plot in traditional farming and automated hydroponic system were almost the same.

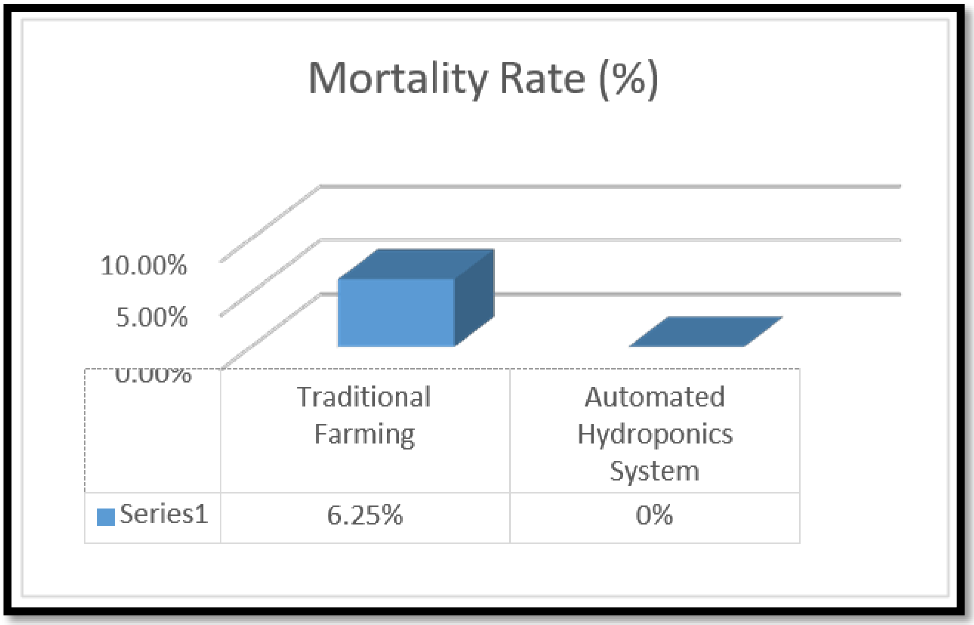



Figure 49. The total percentage of the Mortality Rate of the Lettuce

The table illustrates the mortality of the plant in traditional farming and Automated Indoor Hydroponic Farming. In Hydroponic farming, there is no mortality of death among plants while in traditional farming there were 6.25 percent death of plants.

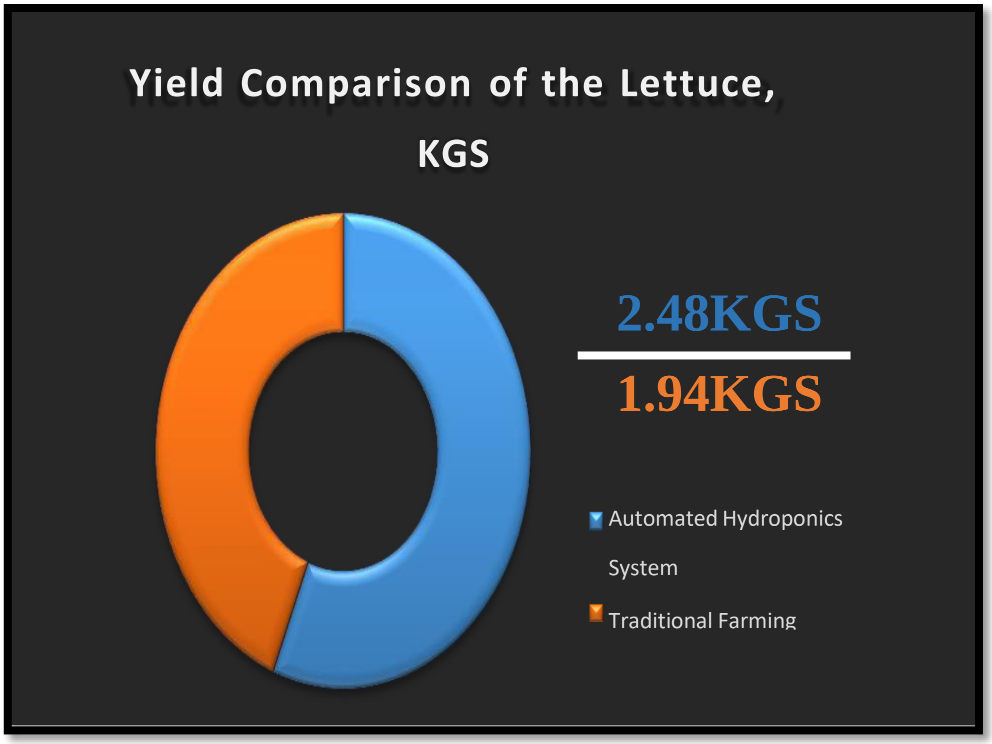



Figure 50. Yield Comparison of the Lettuce, KGS

The figure presented in figure 50 show the total harvested lettuce (in kilograms). It is evident that using the Automated Indoor Hydroponic System gives more produce than the Traditional Farming.

# SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

## Summary of Findings

The development of the system was based on the design of the project. The goal of the study is to reduce the farmer's effort, their cost of resources and lessen the manual use of water where automated hydroponic is the way to settle that. The system aimed to monitor and control the actuators (aerator, water pump, grow lights, and exhaust fan) by using sensors, and is programmed to automatically on/off. The assembly of the Automated Indoor Hydroponics System Using Raspberry Pi was done at Brgy. Rayuray, Batac City, Ilocos Norte.

Raspberry Pi, ESP32, Sonoff, and Sensors (Ph sensor, Ec sensor, DHT22 sensors, and DS18B20 sensors) were the main components of the system. Raspberry Pi serves as the local mqtt broker, ESP32 was the microcontroller of the system, Sonoff used to receive the commands to automatically on/off the actuators, Ph sensor for the calculation of the water's acidity or alkalinity level, Ec sensor for measuring the electrical conductivity of a solution using an electrical conductivity meter, DHT22 (temperature & humidity) sensor used to measure temperature and humidity inside the room, and DS18B20 (water level) sensor for measuring the temperature of the water. The coding and wiring were based on the libraries available on the internet.

The operation of the actuators of the system were programmed to be automated depends on the scheduled time given by the user. During the research, Water Pump & Aerator starts to automatically on/off for every 30 mins from 6am-6pm daily, Grow

Lights will automatically on at 6am and off at 10pm daily, and the exhaust fan will automatically on when the temperature & humidity in the room reaches 29 and up in degrees celsius and will turn off when it's lower than 29 degrees.

Different mediums and programming languages were contributed to the success of the study. For the web client: Flutter with Dart, VS CODE, MQTT Client/Library, .net core 3.0. For desktop service (saving to DB), Winforms .net(c#), MQTTNet Library, Entity Framework, SQL Server. Simple material costing was used to determine the cost of the system.

The whole system costed **₱33,708.00** which is shown on Appendix F, the bill of materials.

## Conclusions

The researcher aimed to create a fully automated hydroponic system that was low cost and fairly easy for the average user to operate. Through the usage of a Raspberry Pi, open source software, and a few sensors this goal was accomplished. The automated hydroponic system maintained the parameters needed for the test plant to thrive and was able to incorporate an IoT network for remote monitoring and control.

A few advantages of the Automated hydroponic system is that there is complete control over the aspects that allow a plant to grow, it can be customized to fit the need of a variety of plants, and it does not rely on the outs ide atmosphere or environment to succeed.

When compared to traditional farming hydroponic system proved its importance through its complete automation aspect as well as its ability. Due to the use of constant feeding of nutrients and water, the hydroponic plants have grown much taller and produce more leaves quicker than the plants growing in normal soil. The experiment conducted with this project also concluded that the use of hydroponic system would result in larger and faster result.

Thus the functionality of the entire system and our desired objectives has been satisfied, and therefore we conclude that using the Automated Indoor Hydroponic System is more efficient than traditional farming.

## Recommendations

The researchers of this study highly recommend the following for future improvements and developments for a further research study. This includes the following:

1. It is also possible to make the device solar-powered.
2. Use other kinds of variety of plants experimentally.
3. Notify the user whenever the readings of sensor through GSM module or email.
4. Use two grow lights per layer to avoid bolting of the lettuces.
5. Use some growing medium when sowing in traditional farming and hydroponic farming
6. Make an automation that can detect when it is needed to add a nutrient solution or refill the water.

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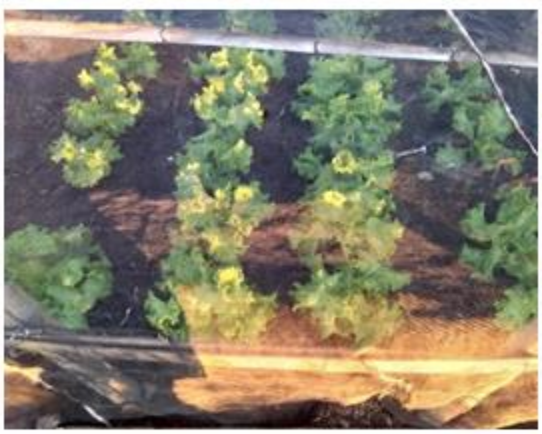
# APPENDICES

## Appendix A. Preparation in assembling the NFT system

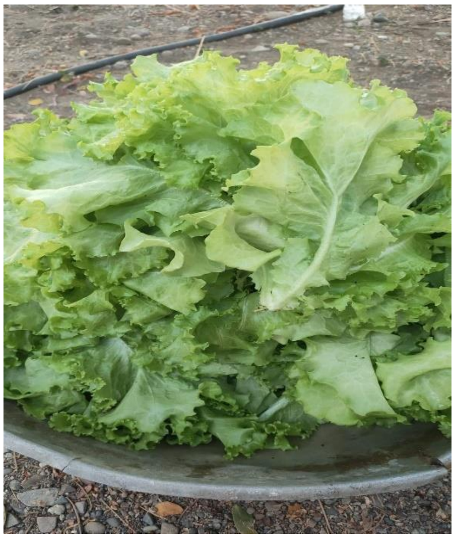
## Appendix B. Preparation for the Traditional farming


**Appendix C. The researchers Automated Indoor Hydroponic System**

**Appendix D. The researchers' lettuce plants in traditional farming**



**Appendix E. The harvested lettuce plants in Automated Hydroponic System and Traditional Farming**



**Appendix F. Functionality Test Results**

FUNCTIONALITY TEST CASES (FARMER)

| ITEM | ACTUATOR | SCENARIO | EXPECTED RESULT | TEST 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | TOTAL |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | GROW LIGHTS | The user will test the grow lights 10x | The grow lights will on/off 10x through the web app | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | 100% |

| | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | The user will schedule a certain time in the web app where the grow lights will automatically on/off. | The grow lights will automatically on/off. | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | 100% |
| 2 | PUMP AND AERATOR | The user will test the pump and aerator 10x | The pump and aerator will on/off 10x through the web app | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | 100% |
| | | The user will schedule a certain time in the web app where the pump and aerator will automatically on/off. | The pump and aerator will automatically on/off. | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | 100% |
| 3 | FAN | The user will test the fan10x | The grow fan will on/off 10x through the web app | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | 100% |

| | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | The user will schedule a certain time in the web app where the fan will automatically on/off. | The fan will automatically on/off. | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | 100% |

FUNCTIONALITY TEST CASES (FARMER)

| ITEM | ACTUATOR | SCENARIO | EXPECTED RESULT | TEST | | | | | | | | | | TOTAL |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | |
| 1 | GROW LIGHTS | The user will test the grow lights 10x | The grow lights will on/off 10x through the web app | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | 100% |
| | | The user will schedule a certain time in the web app where the grow lights will automatically on/off. | The grow lights will automatically on/off. | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | 100% |
| 2 | PUMP AND AERATOR | The user will test the pump and aerator 10x | The pump and aerator will on/off 10x through the web app | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | 100% |

| | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | The user will schedule a certain time in the web app where the pump and aerator will automatically on/off. | The pump and aerator will automatically on/off. | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | 100% |
| 3 | FAN | The user will test the fan10x | The grow fan will on/off 10x through the web app | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | 100% |
| | | The user will schedule a certain time in the web app where the fan will automatically on/off. | The fan will automatically on/off. | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | 100% |

FUNCTIONALITY TEST CASES (FARMER)

| ITEM | ACTUATOR | SCENARIO | EXPECTED RESULT | TEST | | | | | | | | | | TOTAL |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | |
| 1 | GROW LIGHTS | The user will test the grow lights 10x | The grow lights will on/off 10x through the web app | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | 100% |

| | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | The user will schedule a certain time in the web app where the grow lights will automatically on/off. | The grow lights will automatically on/off. | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | 100% |
| 2 | PUMP AND AERATOR | The user will test the pump and aerator 10x | The pump and aerator will on/off 10x through the web app | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | 100% |
| | | The user will schedule a certain time in the web app where the pump and aerator will automatically on/off. | The pump and aerator will automatically on/off. | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | 100% |
| 3 | FAN | The user will test the fan10x | The grow fan will on/off 10x through the web app | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | 100% |

| | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | The user will schedule a certain time in the web app where the fan will automatically on/off. | The fan will automatically on/off. | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | 100% |

FUNCTIONALITY TEST CASES (FARMER)

| ITEM | ACTUATOR | SCENARIO | EXPECTED RESULT | TEST | | | | | | | | | | TOTAL |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | |
| 1 | GROW LIGHTS | The user will test the grow lights 10x | The grow lights will on/off 10x through the web app | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | 100% |
| | | The user will schedule a certain time in the web app where the grow lights will automatically on/off. | The grow lights will automatically on/off. | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | 100% |

| | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2 | PUMP AND AERATOR | The user will test the pump and aerator 10x | The pump and aerator will on/off 10x through the web app | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | 100% |
| | | The user will schedule a certain time in the web app where the pump and aerator will automatically on/off. | The pump and aerator will automatically on/off. | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | 100% |
| 3 | FAN | The user will test the fan10x | The grow fan will on/off 10x through the web app | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | 100% |
| | | The user will schedule a certain time in the web app where the fan will automatically on/off. | The fan will automatically on/off. | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | 100% |

FUNCTIONALITY TEST CASES (FARMER)

| ITEM | ACTUATOR | SCENARIO | EXPECTED RESULT | TEST | | | | | | | | | | TOTAL |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | |

| | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | GROW LIGHTS | The user will test the grow lights 10x | The grow lights will on/off 10x through the web app | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | 100% |
| | | The user will schedule a certain time in the web app where the grow lights will automatically on/off. | The grow lights will automatically on/off. | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | 100% |
| 2 | PUMP AND AERATOR | The user will test the pump and aerator 10x | The pump and aerator will on/off 10x through the web app | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | 100% |
| | | The user will schedule a certain time in the web app where the pump and aerator will automatically on/off. | The pump and aerator will automatically on/off. | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | 100% |
| 3 | FAN | The user will test the fan10x | The grow fan will on/off 10x through the web app | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | 100% |

| | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | The user will schedule a certain time in the web app where the fan will automatically on/off. | The fan will automatically on/off. | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | 100% |

FUNCTIONALITY TEST CASES (FARMER)

| ITEM | ACTUATOR | SCENARIO | EXPECTED RESULT | TEST | | | | | | | | | | TOTAL |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | |
| 1 | GROW LIGHTS | The user will test the grow lights 10x | The grow lights will on/off 10x through the web app | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | 100% |
| | | The user will schedule a certain time in the web app where the grow lights will automatically on/off. | The grow lights will automatically on/off. | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | 100% |

| | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2 | PUMP AND AERATOR | The user will test the pump and aerator 10x | The pump and aerator will on/off 10x through the web app | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | 100% |
| | | The user will schedule a certain time in the web app where the pump and aerator will automatically on/off. | The pump and aerator will automatically on/off. | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | 100% |
| 3 | FAN | The user will test the fan10x | The grow fan will on/off 10x through the web app | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | 100% |
| | | The user will schedule a certain time in the web app where the fan will automatically on/off. | The fan will automatically on/off. | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | 100% |

FUNCTIONALITY TEST CASES (FARMER)

| ITEM | ACTUATOR | SCENARIO | EXPECTED RESULT | TEST | | | | | | | | | | TOTAL |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | |

| | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | GROW LIGHTS | The user will test the grow lights 10x | The grow lights will on/off 10x through the web app | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | 100% |
| | | The user will schedule a certain time in the web app where the grow lights will automatically on/off. | The grow lights will automatically on/off. | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | 100% |
| 2 | PUMP AND AERATOR | The user will test the pump and aerator 10x | The pump and aerator will on/off 10x through the web app | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | 100% |
| | | The user will schedule a certain time in the web app where the pump and aerator will automatically on/off. | The pump and aerator will automatically on/off. | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | 100% |
| 3 | FAN | The user will test the fan10x | The grow fan will on/off 10x through the web app | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | 100% |

| | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | The user will schedule a certain time in the web app where the fan will automatically on/off. | The fan will automatically on/off. | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | 100% |

FUNCTIONALITY TEST CASES (STUDENT)

| ITEM | ACTUATOR | SCENARIO | EXPECTED RESULT | TEST | | | | | | | | | | TOTAL |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | |
| 1 | GROW LIGHTS | The user will test the grow lights 10x | The grow lights will on/off 10x through the web app | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | 100% |
| | | The user will schedule a certain time in the web app where the grow lights will automatically on/off. | The grow lights will automatically on/off. | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | 100% |

| | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2 | PUMP AND AERATOR | The user will test the pump and aerator 10x | The pump and aerator will on/off 10x through the web app | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | 100% |
| | | The user will schedule a certain time in the web app where the pump and aerator will automatically on/off. | The pump and aerator will automatically on/off. | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | 100% |
| 3 | FAN | The user will test the fan10x | The grow fan will on/off 10x through the web app | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | 100% |
| | | The user will schedule a certain time in the web app where the fan will automatically on/off. | The fan will automatically on/off. | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | 100% |

FUNCTIONALITY TEST CASES (STUDENT)

| ITEM | ACTUATOR | SCENARIO | EXPECTED RESULT | TEST | | | | | | | | | | TOTAL |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | |

| | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | GROW LIGHTS | The user will test the grow lights 10x | The grow lights will on/off 10x through the web app | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | 100% |
| | | The user will schedule a certain time in the web app where the grow lights will automatically on/off. | The grow lights will automatically on/off. | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | 100% |
| 2 | PUMP AND AERATOR | The user will test the pump and aerator 10x | The pump and aerator will on/off 10x through the web app | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | 100% |
| | | The user will schedule a certain time in the web app where the pump and aerator will automatically on/off. | The pump and aerator will automatically on/off. | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | 100% |
| 3 | FAN | The user will test the fan10x | The grow fan will on/off 10x through the web app | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | 100% |

| | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | The user will schedule a certain time in the web app where the fan will automatically on/off. | The fan will automatically on/off. | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | 100% |

FUNCTIONALITY TEST CASES (INSTRUCTOR)

| ITEM | ACTUATOR | SCENARIO | EXPECTED RESULT | TEST | | | | | | | | | | TOTAL |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | |
| 1 | GROW LIGHTS | The user will test the grow lights 10x | The grow lights will on/off 10x through the web app | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | 100% |
| | | The user will schedule a certain time in the web app where the grow lights will automatically on/off. | The grow lights will automatically on/off. | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | 100% |

| | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2 | PUMP AND AERATOR | The user will test the pump and aerator 10x | The pump and aerator will on/off 10x through the web app | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | 100% |
| | | The user will schedule a certain time in the web app where the pump and aerator will automatically on/off. | The pump and aerator will automatically on/off. | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | 100% |
| 3 | FAN | The user will test the fan10x | The grow fan will on/off 10x through the web app | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | 100% |
| | | The user will schedule a certain time in the web app where the fan will automatically on/off. | The fan will automatically on/off. | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | 100% |

## Appendix G. Bill of Materials

| Components | Amount (Php) |
|---|---|
| Raspberry Pi | 4,000.00 |
| ESP32 (3 pieces) | 867.00 |
| SONOFF(4 pieces) | 1,176.00 |
| EC Sensor | 5,170.00 |
| pH Sensor | 2,499.00 |
| DHT22 Sensor | 269.00 |
| Exhaust Fan | 1,030.00 |
| Water Pump | 1,130.00 |
| Aerator | 930.00 |
| Grow Lights (4 pieces) | 3,656.00 |
| PVC Pipe (4 pieces) and PVC Clean Cut(8 pieces) | 2,680.00 |
| Storage box | 550.00 |
| Angle Bar (4 pieces) | 2,000.00 |
| Hose | 90.00 |
| Cocopeat(25 kg) | 625.00 |

| | |
|---|---|
| Nutrient Solution – NutriHydro (1 set, 1 litter) | 588.00 |
| NutriHydro pH Down Adjuster (500 ML) | 288.00 |
| Others (Electric Bill, Drinking Water, Electric Wires, etc) | 6,160.00 |
| **TOTAL** | **33,708.00** |