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SMAQ: Smart Aquaponics System Using IoT Technology

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ABSTRACT

The study was conducted in Payatas Controlled Disposal Facility, which was closed permanently in 2017 due to environmental and human health concerns. The area is proposed to undergo redevelopment to promote eco-tourism through ecological park constructions and climate-friendly livelihood projects. Aquaponics is one of the projects that is eco-sustainable of growing fish and plants. In aid for better food quality, this study focused on the development of the technology-based aquaponic system equipped with multiple sensors, actuators, and Arduino. The essential parameters in fish and plant's growth are monitored such as the pH level, dissolved oxygen and temperature of the water, light intensity, and air temperature. Moreover, the system utilized PID algorithm in maintaining the level of the water flowing to the plants to avoid water overflow. Nile tilapia and romaine lettuce are the types of fish and plants cultured in the system. The performance of the developed aquaponics attained a conclusion that there is an upside effect to the tilapias and lettuce in terms of their size and weight, compared to what the traditional aquaponic system produces. The use of technology in the aquaponic system made it more efficient and sustainable, reducing the need for manual monitoring and control. The system's automated sensors and actuators enabled control of the environmental factors affecting the growth of the fish and plants, providing a promising solution to the challenges faced in sustainable agriculture, particularly in urban areas.

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THE PROBLEM AND ITS SETTING

1.1 Introduction

Payatas is a barangay in Quezon City mainly known for its dumpsite. With years of continuous waste disposal, where every day 500 trucks dump 1200 tons of garbage from the city, the Payatas dumpsite developed this massive mountain of waste that would constantly set on fire causing it to produce plumes of smoke; hence people dubbed it the 'Second Smokey Mountain' [1]. Throughout the years, it was closed and reopened multiple times; one was because of the tragedy in July 2000, and the other was its harmful effects on human health and the environment [2]. Aside from the diseases that the dumpsite can cause, it also releases leachates that enter drainage channels and creeks, contaminating water resources such as rivers and dams near it. It also creates landfill gas (LFG) that is potentially explosive and harmful [3]. It was permanently closed off in 2017 plans for its plans for rehabilitation have long been under discussion [4].

One of the Department of Science and Technology (DOST) rehabilitation projects for Payatas is building an aquaponics system. The use of this type of food production system has been progressively increasing especially in urban areas because it occupies less space than traditional farming, is sustainable, and is environmentally friendly [5]. Numerous research on aquaponics has already implemented automatic monitoring and maintaining of parameters. Usually, the differences between research studies are the sensor or actuators used to monitor or maintain parameters and their focusing variable. The research conducted by Santos e al. is the automatic monitoring and controlling of the water quality parameters of aquaponics. It uses LCD to display the water quality parameters, and for the results, it focuses on the accuracy of the sensors, when testing the needed parameters [6]. In the study conducted by Tolentino et al., the researchers developed an android application that lets the user monitor and control the aquaponics setup remotely. The devices used in this setup are the glass electrode, pH, temperature, and moisture sensor, where results are constantly updated real-time and can be accessed using the Aquadroid app. The drivers installed in the system, which are the 12V DC Feeder, Peristaltic Buffer Device, and Aerator, perform correction on the system based on the resulting parameters gathered from the sensors [7]. In another research by Galido et al., the researchers developed a solar-powered smart aquaponics that has system monitoring and automatic correction. Three setups were created: the Ion-Sensitive Field Effect Transistor pH monitored setup, glass electrode pH monitored design, and uncontrolled setup to show the IFET-based pH sensor's superiority over the two. The water monitoring is displayed in the Aquadroid android application, while the abnormality detection and correction of the system were sent using email [8].

While various research studies have explored automatic monitoring and control of aquaponics systems, differences exist in the sensors and actuators used and the specific variables focused on.

This study addresses the gap by deploying a fully automated smart aquaponics system that prioritizes water and plant monitoring to optimize plant and fish growth. The objective was to create a self-sustainable system capable of producing high-quality food while conserving water, energy, and nutrients. The study involved designing and constructing a fully automated aquaponics setup, configuring sensors and control devices, and utilizing an Arduino Mega microcontroller to manage the required parameters.

By developing this innovative aquaponics system, the study aimed to contribute to the rehabilitation of Payatas in collaboration with the DOST and TUP-Manila. The self-sustainable nature of the system, coupled with automatic monitoring and maintenance of crucial parameters, can potentially save valuable resources like water and energy. The outcomes of this study offer Payatas-based farmers a more efficient and sustainable approach to fish and vegetable cultivation, promoting the overall revitalization of the community.

1.2 Background of the Study

Aquaponics, a combination of hydroponics and aquaculture, has emerged as an innovative approach to sustainable food production. By creating a symbiotic connection between plants and aquatic life, this system offers the potential to address the increasing demand for food in urban areas. However, aquaponics presents unique challenges due to its fish and plant life integration. To overcome these challenges and maximize the benefits of aquaponics, the application of technology for monitoring and controlling purposes has gained significant attention.

In the study conducted by Dutta et al., an IoT-based aquaponics monitoring system was developed. Sensors were utilized to acquire essential parameters such as water pH level, temperature, and air humidity, with the data transmitted to a Liquid Crystal Display (LCD). The system employed the Wi-Fi capabilities of a Raspberry Pi to connect to a web server and store the acquired parameters. Any deviations from the optimal range triggered warnings on the LCD and the server, ensuring timely corrective measures. The results indicated that this study offered a viable alternative to traditional aquaponics and hydroponics methods. [9]

Similarly, Hardyanto et al. implemented a smart aquaponics system using IoT technology. Sensors for water density, light intensity, and humidity, along with an actuator pumping motor, were employed. Monitoring and control were facilitated through smartphones, with wireless communication established using a Microcontroller Atmega 328r and ESP8266 module. The collected parameter data were displayed on smartphone applications, while solar panels served as the power source for the system. The study concluded that smart aquaponics using IoT technology could be implemented in small-scale trials. [10]

In another research by Tolentino et al., a smart aquaponics system was deployed in a greenhouse with controlled temperature. Real-time parameters such as water temperature, pH level, light intensity, air temperature, and humidity were monitored using sensors. Corrective devices were employed, including grow lights, exhaust and inlet fans, an evaporative cooler, an aerator, and a peristaltic buffer. The system's monitoring and control were facilitated by an Android device connected through IoT. Additionally, the research delved into the application of image processing to compare the growth of plants in conventional soil-based farming and the smart aquaponics system. The researchers suggested further exploration of fish growth monitoring through image processing, optimizing light intensity to enhance plant growth, and utilizing image processing for disease detection. [11]

Furthermore, Galido et al. [8] developed a solar-powered smart aquaponics system employing IoT. Three setup systems were built: the ISFET-monitored setup, the glass-electrode-sensor-monitored setup, and the uncontrolled setup (typical aquaponics setup). The controlled setups included automated feeders and could be accessed through IoT technology. Water parameters such as pH level and temperature were detected, and corrective actions were implemented using actuators. The study found that the ISFET pH sensor provided more accurate readings than the glass-electrode sensor. Furthermore, the plants and fish reared in the ISFET-monitored setup demonstrated accelerated growth compared to the other setups.

In the study conducted by Khaoula et al., the focus was on monitoring water quality and environmental parameters in aquaponics systems using IoT. The system utilized a NodeMCU, solar panel, and rechargeable battery for control. Nine sensors were deployed, including pH, sunlight, water level, water temperature, EC, soil moisture, total dissolved solids (TDS), temperature and humidity, and ion sensors for ammonia, nitrate, and nitrite. The acquired data were transmitted to the cloud and accessible through an end-device application. The study recommended further work on enhancing system security and scalability and monitoring system health. [12]

1.3 Research Gap

Traditionally, aquaponics systems have relied on manual maintenance to ensure the ideal growth of both plants and fish. However, this study has successfully addressed the need for automation in aquaponics by implementing a fully automated system. While previous studies have focused on automating water and environmental parameter detection, this research specifically focused on automating the water pump, which plays a crucial role in regulating plant water flow.

Using a PID algorithm program, the water flow rate within the aquaponics system was precisely controlled. The implementation of PID algorithms in various control applications has been well-established, and the findings from hydroponics technology research have indicated that controlled water flow rates significantly influence plant growth and productivity. This study has achieved several notable outcomes with the deployment of a fully automated aquaponics system.

Firstly, automation has created an optimal environment for plants and fish, increasing production rates and improving overall system efficiency. The automation process eliminated manual intervention, providing convenience and reducing labor requirements. Furthermore, by precisely controlling the water flow, the study has enhanced the quality of the produced crops, ensuring consistent and desirable characteristics.

The successful implementation of a fully automated aquaponics system offers significant benefits to farmers and stakeholders. It streamlines the production process, reduces labor costs, and increases overall productivity. The findings of this study provide valuable insights into the automation of aquaponics systems and serve as a foundation for further advancements in the field.

1.4 Research Objectives

1.4.1 General Objectives

The general objective of this study is to develop a fully automated aquaponics system for Romaine Lettuce and Nile Tilapia, utilizing Arduino Mega.

1.4.2 Specific Objectives

The specific objectives of this study were as follows:

1. To build an aquaponics system consisting of a fish tank, sump tank, brush filter, biofilter, and PVC pipes for the hydroponic unit.
2. To fully automate the aquaponics system by utilizing an automatic feeder, synthesizing sensors, correcting devices, and Arduino Mega for monitoring and regulation of fish tank water quality and environment parameters affecting the growth of Nile Tilapia and Romaine Lettuce in the system.
3. To implement a PID algorithm for precise control of the water pump to optimize plant growth.
4. To compare the effectiveness of the developed system to the results

of the uncontrolled aquaponics system in terms of the weight and size of tilapia and the size of the canopy area of romaine lettuce using T-Test.

1.5 Significance of the Study

The efficient management of environmental factors such as light, water levels, temperature, conductivity, dissolved oxygen, and oxidation-reduction potential has been crucial in achieving higher fish and vegetable production yields for Payatas farmers. The implementation of a fully automated aquaponics system in Payatas, Quezon City, as part of the collaborative project between the Department of Science and Technology (DOST) and TUP-Manila, has facilitated the adoption of an efficient approach to cultivating fish and vegetables in the area.

This research has contributed to the modernization and rehabilitation of Payatas by integrating various technologies for system monitoring and management, offering potential farmers in the area a more efficient method of food production. Aquaponics, included in the Department of Science and Technology's Harmonized National Research and Development Agenda (HNRDA), has aligned with the country's efforts to promote sustainable agriculture and aquatic resources.

Adopting aquaponics addresses several Sustainable Development Goals (SDGs), including ending hunger, ensuring food security, promoting sustainable agriculture, building resilient infrastructure, fostering innovation, and ensuring sustainable consumption and production patterns. Aquaponics offers a viable solution to food security and sustainable development by efficiently producing food and creating livelihood opportunities.

Furthermore, this study has demonstrated the benefits of a smart aquaponics system, providing valuable insights for future modifications and improvements in the field. It has also benefited various stakeholders, including the environment through reduced use of polluting chemicals, the community by promoting sustainable food production, the local government unit (LGU) in advocating advanced tools for farmers, and the farmers by enabling food production and habitat restoration. Additionally, future researchers can use this study as a solid foundation and high-quality reference for further innovations and advancements in aquaponics.

1.6 Scope and Limitations

This study focused on designing, developing, and evaluating a fully automated aquaponics system using Arduino Mega as the controlling device. The research was conducted within the context of Payatas, a specific community in collaboration with the Department of Science and Technology (DOST) and the Technological University of the Philippines (TUP-Manila).

The aquaponics system consisted of a fish tank, sump tank, brush filter, and Atlanta downspout for the hydroponic unit. An Arduino Mega microcontroller was utilized in conjunction with sensors and correction devices to automate the system. When parameters deviated from the ideal conditions for cultivating tilapia and lettuce, the correction devices were employed. Water parameter detection involved synthesizing sensors for measuring pH level, water temperature, and dissolved oxygen. In the case of acidic water pH, a bilge pump automatically released the reserved water from the sump tank to maintain a neutral pH. An aerator was used as a correction device if the dissolved oxygen level dropped below the desired threshold—environmental parameter detection involved sensors for air temperature, humidity, and light (LDR). The radiator fans would activate automatically as the air temperature increased to the desired set temperature. To ensure sufficient light for lettuce growth, grow lights were employed as an alternative light source during periods of insufficient sunlight.

Furthermore, this study implemented a PID control algorithm to regulate the water flow through the Atlanta downspout, which was used for cultivating lettuce. This was achieved by controlling the pressure released by the bilge pump. In conjunction with ultrasonic sensors, the Arduino Nano microcontroller was utilized to monitor the water level and trigger the necessary adjustments to the bilge pump's pressure. The heuristic tuning method was implemented and tested to identify the optimal PID algorithm.

It is important to mention that this study was conducted collaboratively by two teams and focused solely on hardware. The development of a web application for remote monitoring and control of the aquaponics setup via the Internet was outside the scope of this research.

1.7 Definition of Terms

Aquaponics - a system that combines hydroponics (the practice of growing plants in water) with aquaculture (the practice of producing aquatic animals) in a mutually beneficial setting. In this system, fish waste serves as plant food and plants work to keep fish water clean.

Aeration - is the act of introducing air into a liquid or substance, promoting its mixing or dissolution. This process involves bringing water and air close to eliminate dissolved gases and facilitate the oxidation of substances like iron, hydrogen sulfide, and volatile organic chemicals (VOCs).

Bilge Pump - is used to maintain a neutral pH level in the water by releasing reserved water from the sump tank when acidity levels are detected. It also regulates water flow through the Atlanta downspout for lettuce cultivation. Controlled by the Arduino Nano microcontroller, the pump adjusts water pressure and flow rate to ensure optimal pH levels and water circulation in the aquaponics system.

Brush Filter - is commonly used in aquaculture facilities. It is also widely used in aquaponics systems to assist in the removal of fine particles produced by fish waste.

Black Box - In this project, the term "Black Box" refers to an enclosed chassis that houses the Arduino and other wiring components. It provides protection, organization, and ensures the proper functioning of the internal electronic hardware.

Controlling devices - refer to the equipment or mechanisms used to regulate and manipulate various aspects of a system or process. These devices are designed to monitor and adjust specific parameters to maintain desired conditions or achieve specific outcomes. In the context of aquaponics systems, controlling devices are used to manage factors such as water flow, temperature, pH level, dissolved oxygen, and lighting. They can include pumps, valves, sensors, actuators, relays, timers, and other components that enable automated control and regulation of the system. The proper selection and implementation of controlling devices are crucial for maintaining optimal conditions and ensuring the well-being and productivity of both plants and fish in the aquaponics system.

Dissolved oxygen - is the measurement of oxygen gas that is present in water. It has a crucial role in ensuring the survival and well-being of aquatic organisms, including fish and plants. The concentration of dissolved oxygen in water is influenced by factors such as temperature, water flow, and the presence of photosynthetic organisms.

Heuristic Tuning - involved iteratively adjusting the parameters of the PID control algorithm for water flow in the aquaponics system. The goal was to identify the most effective configuration by observing the system's response and making informed adjustments based on practical insights and heuristics, rather than relying solely on mathematical models or rigorous optimization techniques.

Nitrification - is a biological process in which nitrogen compounds, particularly ammonia, are transformed by microorganisms into nitrite and nitrate.

pH level - is an indicator of the acidity or alkalinity of a solution, representing the concentration of hydrogen ions (H+). In aquaponics systems, maintaining the appropriate pH level is vital for the overall health and well-being of the fish and plants.

PID Controller - is a device used in industrial settings to regulate process variables like pressure, flow, temperature, and speed. This controller incorporates a control loop feedback mechanism to manage and stabilize these variables effectively.

Chapter 2

REVIEW OF RELATED LITERATURE AND STUDIES

This chapter provides an overview of the related literature as well as studies that are directlyrelated to the topic.

2.1 Smart Aquaponics

In research conducted by Haryanto et al., smart aquaponics was explored as a bio-integrated farming system combined with IoT-based electronic technology. This innovative approach utilizes aquaculture ponds or water containers with excess feed nutrients as a source of nutrition or hydroponic growing medium. The study findings indicate that the sensors employed, particularly ultrasonic, pH, and temperature sensors, demonstrated a high level of accuracy. The transmission and reception of sensor data to an IoT-based server operated smoothly via a WiFi connection. Notably, the plant and fish growth in the smart aquaponics system thrived within the 25 to 30 degrees Celsius temperature range, with the pond water maintaining a pH level between 7 and 7.5. Additionally, the fish were fed three times daily [10].

2.1.1 Aquaponics

Aquaponics is a sustainable farming method that integrates aquaculture and hydroponics, allowing fish and plants to be grown together in a closed-loop system. The continuous increase in ammonia in land-based aquaculture and the need for excessive fertilizer and water replacement in hydroponics can be effectively addressed by utilizing a recirculating aquaponics system. In this system, the fish provide nutrients to the plants, while the plants naturally filter and purify the water, creating a mutually beneficial relationship [13].

2.1.2 Important Biological Components of Aquaponics

Aquaponics is a closed system that combines hydroponics, soilless farming, and aquaculture. Aquaponics comprises three biological components: fish, plants, and bacteria. vegetables: is a farming technique that combines recirculating aquaculture with hydroponic vegetables; the fish water is used as fertilizer for the plants, and the plants clean the water for the fish. As a result, value-added, local production of both fish and vegetables is possible using the same water [13].

2.1.2.1 Fish

The presence of fish plays a vital role in the functioning of an aquaponics system. Fish and their feed waste serve as a valuable source of plant nutrients, contributing to the system's recirculation process. According to a study by H. Yildiz et al., the health of the fish is a crucial factor in ensuring the sustainability of aquaponics. Therefore, the factors that promote the well-being of the fish are equally significant for the overall success of the system [14].

2.1.2.2 Plants

According to A. Shu, the primary goal of the aquaponics system is to cultivate plants in an eco-friendly manner to ensure food security. The plants in this system not only benefit from it, but they also have a crucial role in the overall cycle. Acting as natural filters, they actively collect nitrates from the water, purifying it and enabling its recirculation back to the fish. As they absorb nutrients, particularly nitrates, which can harm the fish, the plants eliminate the need to remove waste from the fish tank manually [15].

2.1.2.3 Bacteria

Aquaponics goes beyond the cultivation of fish and plants; it also encompasses the growth of bacteria, which acts as a crucial intermediary between the two. These bacterial colonies, known as biofilters, are indispensable for the survival of both plants and fish within the system [13].

In the research conducted by Lennard, it is emphasized that the current understanding in aquaponic research and industry suggests that refraining from aquatic sterilization or disinfection allows the system water to develop a diverse and intricate aquatic ecology teeming with various microbiological life forms. This fosters an ecosystem reminiscent of a natural environment, where a wide array of microbiological organisms interact with one another and other organisms present in the system, such as fish and plants [16].

2.1.3 Maintaining a Healthy Bacterial Colony

Bacteria are an essential part of aquaponics; they are involved in different processes, like nitrification, denitrification, and organic matter decomposition. Maintaining a healthy bacterial colony can also create a healthy environment for the plants and fish in the system [17].

2.1.3.1 – 2 Water Temperature and pH

In a study, Galido et al. [8] investigated two monitored subsystems, namely ISFET and glass-electrode pH sensors, primarily focused on measuring two critical water parameters: pH level and temperature. These parameters were carefully monitored, and the acquired results were compared to standard values suitable for the aquaponics system. If a parameter deviated from the standard measurement range, the system had an automated correction mechanism to address the issue.

2.1.3.3 Dissolved Oxygen

Dissolved oxygen is an essential part of the nitrification process of bacteria [18]. A study by Wongkiew [19] shows that the denitrification process occurs mainly when the dissolved oxygen is low and in order to reduce the denitrification in the biofilter, the amount of dissolved oxygen should be increased. The book by Somerville et al. [20] stated that the optimum level of dissolved oxygen is at 4-8 mg/liters.

2.1.4 Aquaponics System Balancing

To ensure efficient nutrient removal, aquaponics systems need to be adequately sized to maintain a balance between nutrient production from fish culture and nutrient uptake by plants [21].

2.1.4.1 Nitrate Balance

According to a study by R. Montanhini and A. Ostrensky, maintaining nutrient balance is another crucial aspect of aquaponics. The primary source of nutrients in the system is fish feed, which undergoes the nitrification process. The feed can be categorized into digested, uneaten, and soluble fish excretes [21].

2.1.5 Internet of Things (IoT)

In a study by N.C. Azemi et al. an IoT-based control and monitoring system for aquaponics were proposed. The system allows for monitoring water, temperature, and pH levels, which can be accessed through smartphones and browsers. Additionally, it enables the control of lights and water pumps via the Internet. The system incorporates a Raspberry Pi device as the gateway for sensor readings, an Arduino Uno for monitoring, and an Arduino Nano for control [22].

A separate study by A. Shaout and S. G. Scott [23] suggested using IoT fuzzy logic in operating and monitoring an aquaponic ecosystem. The system monitors water temperature, pH, air temperature, and brightness while controlling a light, heater, and alarm. The system's input/output hardware interface is the Arduino Uno R3 board.

2.2 Water Quality in Aquaponics

The water within an aquaponic system serves as the vital medium through which plants and fish obtain essential nutrients and oxygen. Effectively managing an aquaponic system requires careful maintenance of its key parameters to meet the needs of all organisms involved. Water quality is a critical factor influencing the well-being of the fish, plants, and bacteria within the system [24].

2.2.1 Most Important Water Quality Parameters

Water quality has different important factors or parameters according to Tolentino et al. [25]. If the water quality declines the health and growth of the fishes and crops will be affected. This study was set to develop an IoT-based intensive Aquaculture monitoring system that soon concluded that aquaculture environment can be optimized for fish by constructing a monitoring and correction system.

2.2.1.1 pH

In a comprehensive review article by Mishra et al., water quality management in aquaculture practices, specifically focusing on pH levels, is highlighted as a crucial aspect. Maintaining appropriate pH levels is vital to prevent detrimental impacts on fish, crops, and beneficial microbes within the system. The article presents gathered data and reviews past studies, concluding that innovative and sustainable aquaculture techniques are essential. The exploration of advanced technology and integrated systems is necessary to ensure a continuous food supply and enhance the potential for fresh food production [26].

2.2.1.2 Factors That Affect the pH

According to Atlas Scientific Environment Robotics, since there is no physical-chemical relationship between pH and dissolved oxygen, it has no effect on dissolved oxygen. However, temperature, carbon dioxide, carbonate/bicarbonate ions, and the breakdown of organic material have the biggest impact on changing the pH in water. DO can also have an indirect impact on pH occasionally [42].

2.2.1.2.1 Temperature

The solubility of CO2 reduces with rising surface temperatures; as a result, the pH of the water increases, making it more alkaline. The pH of the water naturally decreases as the temperature drops, making the water more acidic [42].

2.2.1.2.2 Carbon Dioxide (CO_2)

Hydrogen ions (H+) are significant in this context as an increase in H+ ions leads to a decrease in water pH. This acidification effect occurs as carbon dioxide (CO2) levels rise. Consequently, CO2 has various impacts on pH. When plants engage in photosynthesis within the water, the pH tends to increase due to the removal of carbon dioxide by the plants [42].

2.2.1.2.3 Ions (Carbonate and Bicarbonate)

The pH level of water can be affected by the presence of carbonate and bicarbonate ions. Sufficient amounts of these ions can cause water with a neutral pH to become alkaline. Conversely, if the water is acidic, the carbonate and bicarbonate ions can help bring the pH back to a neutral level [42].

2.2.1.2.4 Decomposition of Organic Material

Since organic matter and living things contain carbon, when they disintegrate, they release that carbon into the water. When organic chemicals are liberated, CO2 enters the water because they are often unstable and rapidly oxidized. Therefore, as was already explained above, the same action occurs when carbon dioxide is produced; a rise in H+ lowers pH and vice versa [42].

2.2.1.3 Relationship Between Dissolved Oxygen and Water Temperature

According to the Water Science School, the concentration of dissolved oxygen in surface water is influenced by the seasonal and daily temperature cycle. In contrast to warm water, cold water can retain dissolved oxygen more. This results in the highest dissolved oxygen concentration in winter and early spring, when the water temperature is low. Conversely, the dissolved oxygen concentration tends to be lower during the summer and fall when the water temperature is high. Therefore, there is an inverse relationship between dissolved oxygen concentration and water temperature [43].

2.2.2 Source of Aquaponic Water

The water quality of your aquaponics system will be significantly influenced by the source of water you use. Before using water in your system, it is best practice to test it for chemicals and contaminants. After the system is up and running, minimal water additions are necessary to account for losses due to evaporation and transpiration. The following are among the frequently used water sources in aquaponics systems [27].

2.2.2.1 Rainwater

Utilizing rainwater as a water source in aquaponics systems offers several advantages. Rainwater is naturally neutral in pH and contains minimal levels of carbonate hardness (KH), general hardness (GH), and low salinity. Collecting rainwater is also an effective method for reducing operational expenses associated with the system [20].

2.2.2.2 Tap or Municipal Water

Municipal water sources are commonly treated with various chemicals to ensure their safety for human consumption. However, some chemicals, such as chlorine and chloramines, can harm fish and other organisms in an aquaponics system. To mitigate this issue, it is recommended to let the water sit in a container for up to 48 hours, allowing the chlorine to dissipate into the atmosphere before refilling the aquaponics unit. Additionally, the quality of the water can also be influenced by the composition of the bedrock from which the water is initially extracted [20].

2.2.2.3 Filtered Water

Filtered water, depending on the filtration method employed, such as reverse osmosis or carbon filtering, effectively eliminates a significant portion of metals and ions, resulting in a high level of safety for users. Furthermore, filtered water is readily modifiable by adding acid if needed, providing flexibility in adjusting its properties. [20].

2.2.3 Manipulation of pH

A book by King and Southern [13] stated that the three main components of aquaponics, the fish, plants and bacteria have different needs regarding their pH level. Balancing the pH level is a vital thing so all three can work together.

2.2.4 Water Testing

Water testing is a valuable tool for assessing the system's equilibrium. Elevated or diminished nitrate levels may indicate an imbalance, such as an overabundance of plants or insufficient fish. Growing nitrate levels are favorable, indicating adequate nutrients for the plants. However, if nitrate surpasses 150 mg/liter, water exchange becomes necessary to maintain optimal conditions.

Regular water testing is crucial for maintaining optimal water quality in aquaponics systems. Conducting weekly water tests to ensure that all parameters are within the desired range is recommended. However, testing frequency can be reduced as aquaponic units mature and stabilize. Periodic testing is still necessary, particularly when an issue is suspected.

Daily monitoring of the health and well-being of the fish and plants in the system can provide valuable insights. However, it should not replace water testing as a comprehensive quality assessment. [27].

2.3 Design of Aquaponic Units

The commercialized aquaponics system must have its essential components for it to operate properly [13]. These essential components will be the fish tank, the mechanical and biological filtration, the plant growing units (media beds, NFT pipes or DWC canals), and the water/air pumps.

2.3.1 Essential Components of an Aquaponic unit

Different components must be considered to build a commercialized aquaponic system based on your desired output [13]. Such as the fish tank and aerator as it is stated to be very essential as it is necessary for the fish culture [28]. Here also comes the other essential components such as filtrations, sump tank, plumbing materials, water testing kits and the NFTs.

2.3.1.1 Fish Tank

Lance Beecher et al, state that the fish tank is necessary for fish culture and should be large enough for the fish to flourish and grow. Fish in the tank must be comfortable and stress-free for the system to function properly. Criteria for fish tanks may include whether the container is new or used, the manufacturing material, and the tank's size and shape. Using a recycled tank in an aquaponics system is frequently cost-effective; however, knowing the history of the tank container is crucial. Liquid totes, for example, are accessible from liquid freight transporters; nevertheless, if that tote originally contained dangerous chemicals or other items that may be harmful to fish, it should be discarded or reused [28].

2.3.1.2 Filtration – Mechanical and Biological

D. Allen Pattillo's study states that the biological filter in an aquaponic system harnesses the activity of beneficial bacteria to convert harmful byproducts of fish digestion into non-toxic compounds that plants can utilize. The biofilter comprises a substrate that creates an optimal environment for the growth and thriving of bacteria exposed to water and air. The bacteria play a crucial role in converting toxic ammonia and nitrite into nitrate. However, factors such as surface area for bacterial growth, temperature, dissolved oxygen levels, alkalinity, pH, and availability of ammonia and nitrite can influence the efficiency of the biological breakdown process [29].

2.3.1.3 Aeration

Aeration is essential in aquaponics systems for delivering enough dissolved oxygen for fish survival, helpful bacteria in the filter unit, and enough amounts for plant development. The aeration system consists of an air pump that creates compressed air, tubing that transports the compressed air to the tank's bottom, and air stones that bubble air into the system. Similar to water flow, it is critical to precisely size the aeration system to deliver an adequate level of dissolved oxygen throughout the aquaponic system. Aeration also moves water in the unit, which aids in the delivery of suspended materials to the filtering system [28].

2.3.1.4 Sump Tank

The sump tank is the aquaponic system's central collection point for water, as it operates on gravity. Positioned at the system's lowest point, the sump tank also functions as a reservoir, typically devoid of any plants or fish. It proves to be an ideal location for blending chemical and nutritional additives that need to dissolve before entering the system. Additionally, it is recommended to introduce different biofilter substrates or cleaner species, such as mosquito fish, redear sunfish, or juvenile tilapia, into the sump tank while ensuring they are kept away from the pump intake. In the

Iowa State system, the sump tank houses the pump, serving as the initial point from where water is transported to other system components [29].

2.3.1.5 Plumbing Materials

Water movement within the system components is facilitated through plumbing, which can vary in size and material depending on its intended purpose. PVC (polyvinyl chloride) is a popular choice due to its durability, lightweight nature, affordability, ease of handling, and widespread availability, making it highly prevalent in recirculating aquaculture systems. For low-pressure and small-scale applications, vinyl tubing can be suitable. Steel pipes offer exceptional strength and may be preferred for specific purposes; however, they are susceptible to rust and corrosion when exposed to seawater. Copper is commonly used in household applications due to its natural antimicrobial properties and ability to withstand high water temperatures. Although copper has its benefits, it is more expensive, requires skill for proper connections, and can be detrimental to crustaceans such as crayfish, shrimp, and prawns [29].

2.3.1.6 Water Testing Kits

Water quality - the health of the water – is measured using this method. Water test kits employ chemicals added to a water sample to determine the levels of essential parameters. Examples of this parameters are dissolved oxygen, nitrite, nitrate, alkalinity, temperature, ammonia, pH [30]

2.3.1.7 Nutrient Film Technique

The aquaponics-adapted Nutrient Film Technology (NFT) technology provides versatility for plants with short and extended growth cycles. The actual NFT technology is widely used and very productive in the hydroponics business. The traditional NFT technology is modified to work in an aquaponics unit. Because of severe bacterial growth obstructing the lower diameter tubing, these changes involve replacing it with larger diameter pipe material. Furthermore, large-diameter PVC pipe (4- and 6-inch) could be used as channels for plant cultivation instead of pricey commercially available channel material [31].

2.4 Plants in Aquaponics

Aquaponics is a great food production system if the fish and plants are given proper care. [16] The water that flows in plants' aquaponics must have the right parameters to have a better growth also considering the temperature, light intensity and the humidity.

2.4.1 Water Quality for Plants

In their writings, W. Lennard and S. Goddek [16] emphasize the fundamental role of water in aquaponics, as it serves as the primary medium that connects the system's two main components. Water acts as the conduit for nutrient resources, facilitating their transport and distribution throughout the system. Furthermore, water is crucial in establishing the chemical environment in which plants are cultivated.

2.4.1.1 Temperature with Correlation on Season

According to the article written by M. Dyer, high temperatures have a variety of plant growth. The effects of heat on photosynthesis, in which plants utilize carbon dioxide to make oxygen, and respiration, in which plants use oxygen to produce carbon dioxide, are the most visible. According to the Colorado State University Extension experts, these processes accelerate as temperature rise. When temperatures reach unacceptably high levels (which vary depending on the plant), the two processes become imbalanced. Temperature has a wide range of effects on plants and is controlled by elements such as exposure to sunlight, moisture drainage, elevation, temperature differential between day and night, and proximity to surrounding rock structure (thermal heat mass) [32].

2.4.1.2 Light Intensity

According to H.A. Ahmed et al.'s article on the growth of leafy vegetables in a controlled environment with artificial lighting, standard ambient daylight falls within the range of 10,000 to 25,000 lux. The study explores the effects of light, air velocity, temperature, and CO_2 concentration on plant growth in a controlled environment. It reveals optimal plant growth and light use efficiency with a light intensity of 200-250 μmol m^(-2) s^(-1) and a photoperiod of 16-18 hours using red and blue LEDs. The recommended ratio of blue light is between 5% and 20%. Light intensity plays a significant role in plant productivity and light use efficiency, defined as the ratio of the chemical energy of the accumulated dry weight of the plant shoot to the accumulated light energy received by the plant canopy [33].

2.4.1.3 Air and Humidity

Ahmed et al.'s study investigate how light, air velocity, relative humidity, and carbon dioxide concentration affect the growth and development of lettuce. The findings emphasize that maintaining an air temperature range of 22–25 °C during light periods enhances carbon dioxide availability, improving lettuce growth. A humidity level within the 70-80% range also promotes vegetative growth [33].

2.5 Fish in Aquaponics

Proper care of fish is essential for ensuring an efficient food production system in aquaponics, similar to the care required for plants. Fish, a diverse group of aquatic vertebrates with gills, rely on their gills to extract oxygen from the water and eliminate carbon dioxide and metabolic waste. Being ectothermic or cold-blooded, the body temperature of a fish fluctuates according to the water temperature [16].

2.5.1 Water Quality for the Fish

Maintaining the appropriate water parameters is crucial for the entire aquaponics system as it serves as a shared medium for the two major components: the fish and the plants [16]. Water quality includes all physical, chemical, and biological variables influencing water's useful use. A water quality variable is any property of water that influences the survival, reproduction, growth, production, or management of fish in any way. There are obviously many water quality variables in pond fish culture. Fortunately, only a handful of these are generally significant. These are the variables that fish farmers should focus on and try to control to some extent through management strategies.

2.5.1.1 pH

According to a book by Somerville et al., fish can tolerate a broad pH range but exhibit optimal performance within the pH range of 6.5-8.5. Rapid and substantial fluctuations in pH, particularly changes of 0.3 within 12-24 hours, can be detrimental and potentially fatal to fish. Therefore, it is crucial to maintain a stable pH level. Carbonate buffering is highly recommended to prevent significant pH swings as much as possible [20].

2.5.1.2 Dissolved oxygen

In a study conducted by H. Yavuzcan Yildiz, it is highlighted that the primary water quality factor to consider in aquaponic systems, similar to conventional aquaculture setups, is dissolved oxygen (DO). Fish rely on passive diffusion through their gills to extract oxygen from the water. To facilitate this process, an appropriate concentration of DO in the water is crucial, as it allows for efficient energy transfer and supports optimal fish growth, feed efficiency, and swimming capacity. When DO concentrations drop below the fish's requirements, they increase the opercular breathing rate and gasping [14].

In another book by Somerville et al., it is mentioned that most fish typically require a minimum of 4-5 mg/liter of DO in practical terms. Following these guidelines ensures adequate DO levels. It is essential to avoid overstocking the fish and to limit the fish load to at most 20 kg per 1000 liters of total water volume. Implementing dynamic water flows incorporating cascading water returning to the system aids in aeration and DO addition. Whenever possible, the use of air pumps is recommended. The suggested rate is 5-8 liters of air per minute per cubic meter of water, distributed through at least two air stones placed throughout the fish tank. Having backup aeration systems is essential to an aquaponic system, providing contingency measures during power outages or equipment failures. Simple battery backups for air pumps have proven invaluable in safeguarding fish health in the industry [20].

2.5.1.3 Temperature

A study published by Claggett K et al. [34] focuses on creating a functional self- sustaining aquaponics by maintaining a temperature with specified operational parameters generally ranging from 70F +/- 7.5F based on Bluegill Fish. The requirement factor also includes keeping the dissolved oxygen maintained and the proper water level aquatic tier.

The temperature system is established to achieve favorable outcomes by utilizing three temperature sensors, a fan, and a water tank heater distributed throughout the tank. The air sensor is the third sensor, while the two water sensors are calibrated to provide an average water temperature reading. The sensor on the breadboard measures the temperature of the air.

According to Somerville et al., farmers must research the optimal temperature range for each fish species. Tropical fish generally thrive within a temperature range of 22-32 °C, whereas cold-water fish prefer temperatures ranging from 10 to 18 degrees Celsius. Some temperate water fish, such as common carp and largemouth bass, can tolerate temperatures ranging from 5 to 30 degrees Celsius. Maintaining a constant temperature within the suitable range for the fish species ensures their well-being, facilitates rapid growth, and improves feed conversion efficiency (FCR). Moreover, maintaining optimal temperatures reduces the risk of diseases. Water heaters, coolers, and thermal insulation are helpful tools for maintaining a consistent temperature level. However, these measures may not be as effective in regions with high energy costs. It is often preferable to cultivate fish species that are naturally adapted to the local environmental conditions [20].

2.5.1.4 Nitrogen

According to Somerville et al., ammonia and nitrite pose significant toxicity risks to fish and are often called "invisible assassins." Even at concentrations above 1 mg/liter, both compounds are considered harmful, contributing to fish stress and adverse health effects. In a well-established aquaponic system, the presence of ammonia and nitrite should be virtually undetectable. Converting these toxic chemicals into less harmful forms lies solely with the biofilter. Detectable ammonia and nitrite levels indicate an imbalance in the system, possibly due to an undersized or malfunctioning biofilter.

Ammonia toxicity is more pronounced in warm environments, mainly with high pH. Therefore, even small amounts of detectable ammonia can be hazardous. Water tests for total ammonia nitrogen (TAN) are conducted to detect ionized and unionized ammonia forms. Symptoms of ammonia and nitrite poisoning in fish include red streaks on the body, gills, and eyes, scraping against the tank walls, gasping for air at the water's surface, lethargy, and potential mortality. On the other hand, nitrate is considerably less toxic to most fish, and they can generally tolerate levels exceeding 400 mg/liter [20].

2.6 Implementing PID Controller in Arduino Board

Arduino-based PID controller can be used to regulate temperature, flow, pressure, speed and other processes by implementing the Proportional, Integral, and Derivative (PID) controller.

2.6.1 PID Controller

Thermostat is a device that regulates temperature commonly in enclosed areas. It is typically found in refrigerators, ovens and water heaters. But using this device costs great consumption of energy. Thus, Erham et al. [35] designed a PID controller based on an Arduino Uno R3 with application to a household refrigerator. The concept of PID controller is to improve the on- off controller. The design of their system consists of two parts. The hardware unit and program unit. Hardware consists of a controller, sensors and actuators. The controller system is made up of where Arduino uno with PID control algorithm uploaded. For measuring compartment temperature, sensor DS18B20 was used. Meanwhile, actuator was Variable Speed Drive (VSD) also called Inverter which can vary both its voltage output and frequency and sent to a compressor motor. The algorithm of the program includes calculating error between input set temperature (Ts) and the temperature that the sensor reads (Tc). If the error is less than 20 degrees Celsius set temperature, then calculation of output controller occurs. If output > 255 is true, then output = 255 and If output < 0 is true, then output = 0. The mentioned conditions of output limit a VSD

(Inverter) maximum input of 10 and 0, respectively and cooling process can keep a setpoint value. By setting those new criteria, they were able to maintain desired temperature with steady-state error of about 0.044°C. The procured steady state error was able to save 30% energy.

A study by A. F. Subahi et al. [36] used Proportional-Integral-Derive (PID) controller for temperature control inside a greenhouse and compared it to a traditional temperature control system. The result of this study shows that there is a decrease in energy used when the On/Off control was applied after applying PID controller compared to traditional system.

In research by R. Laksmana et al., a PID controller was employed to monitor and regulate the pH level in their Hydroponics system. The Ziegler-Nichols (Z-N) method was utilized to determine the PID coefficients, including the proportional gain (Kp), integral time (Ti), and derivative time (Td). The PID controller is defined by equation (1), where the error (e) is calculated as the difference between the set point (SP), specified by the desired pH value, and the process variable (PV) obtained from the pH sensor in the functioning PID control system, as shown in equation (2) [37].

(1) $$u(t) = K\left[e(t) + \frac{1}{T_i}\right]\int_0^t e(t)dt + T_d \frac{d}{dy}e(t)$$

(2) $$e = SP - PV$$

2.6.2 PID Tuning

In a study by F. Joseph et al., it state the importance of controller tuning in feedback controllers it also lists the different classifications of PID tuning which are the Classical techniques and Computational or Optimizations techniques [38].

2.7 Factors to Consider for Harvesting

According to the study of Roberto Flores [39], where it just simply evaluates aquaponic foods productions, there is always a factor to consider for harvesting. For fish, it is the weight in grams. And as for the lettuces, it is also the weight and whether or not the plant is salable; it was based on the classification according to the size and color of each unit.

2.7.1 Lettuce

A study from S. Birrel et al. [40], stated that the lettuces must have a stem of 1-2mm protruding to go under the correct length. The harvested produce should exhibit cleanliness with minimal browning and should not have any damage to the outer leaves. If any outer leaves remain after harvesting, they should be removed. The table below is some parameters being watched to know if the lettuces are good to harvest. This study was made having the objective to provide a developing robotic system for harvesting such as lettuces, and lately achieved by the researchers.

Parameters	Specification
Height of lettuce plant	30 cm
Diameter of lettuce	20 cm
Diameter of lettuce stem	Approximately 30 cm

2.7.2 Tilapia

According to the study of C. Ragasa [41], where the objective is to accelerate the pond aquaculture development beyond COVID, The Tilapia is sold in various sizes depending on the timing. It can be categorized into sizes 1-4, size4 means more than 800g, size3 means 600-800grams, size2 ranges 450- 600g, and size1 ranges from 300-450g. But the regular size just ranges from 200-300g, which means if those weights are achieved, it is ready for harvest.

2.8 Online Interview with an Aquaponics Farmer Through Zoom Meeting

The interview was done for the researchers to understand better how to run aquaponics, including the vital parameters that will affect the growth of Nile Tilapia and Romain Lettuce, as well as any problems that may arise while running the system. It was conducted on July 1, 2021.

2.8.1 Data Collection Summary

Ferdinand Peran has been an Aquaponics Farmer since 2017 and is the owner of Aquaponics Quezon City, which can be found at 36 Saint Joseph Street, Dona Juana Subd., Bgy. Holy Spirit, QC, Quezon City, Philippines. He not only builds systems or sells parts but also teaches how to build systems and consults on aquaponics systems and production problems.

And while meeting him on the Zoom platform, the data below was gathered.

Table 2.1 Gathered Data from the Zoom Meeting

Elements	Information Gathered
Leafy Greens	• growing time: 30 days • Optimal growth pH level: 6
Nile Tilapia (fingerlings)	• Growing time: 3 – 4 months • Optimal growth pH level: 7 • Regular size for harvest: 1 kilo = 3 tilapia
Placing of Tilapia in the system	• 1 week after water circulation or also known as recycling to form good bacteria (even a small of amount of ammonia) • Best practice: putting 2pcs of shrimp head in the system
Placing of Lettuce in the system	• 1 week after putting the tilapia in, waste from the fish after feeding them contributes to the bacteria in

	the system andserves as a nutrient source for the lettuce
Freshwater water test kit (usedfor monitoring)	• Water pH, ammonia content, pH level of water, nitrite, andnitrates • pH: 6.5 – 7.5 • Ammonia: 0.25
Fish Feeding	• Early in the morning, around 7 a.m., and early in theafternoon • If the fish finish the food you gave them in 30 seconds, the food is insufficient, and you should add another cup untilyou know how much food they need.
Stocking density of fish	• 5 liters = 1 fish • The maximum number of fish in a 10,000 liters tank is 200.It is normal for 30 percent of the fish to die.
Decreasing the pH level	• Phosphoric acid
Increasing the pH level	• Calcium Carbonate • Natural way: oyster shall in a net to be out on sump tank

Chapter 3

RESEARCH METHODOLOGY

3.1 Research Design

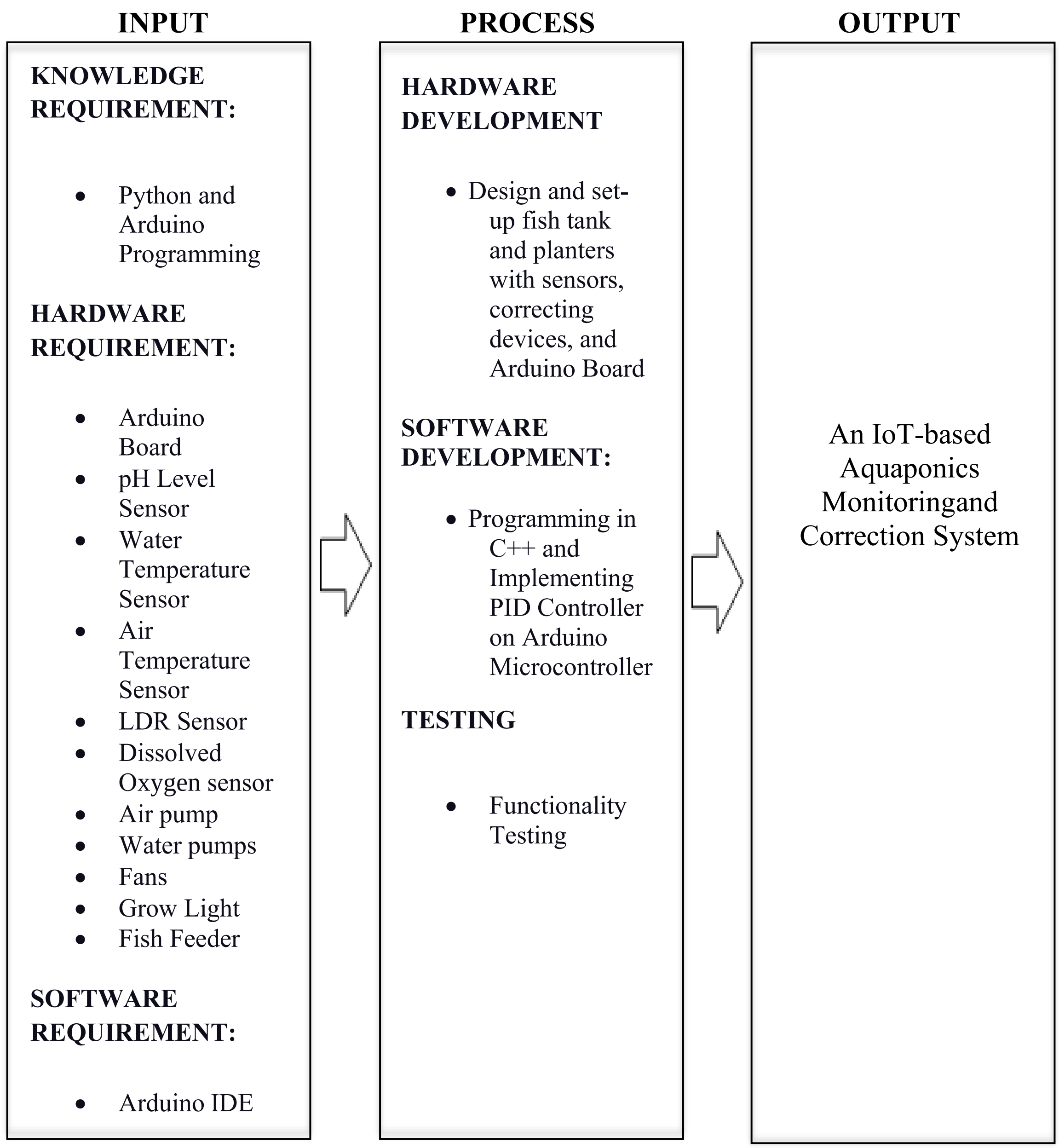

Figure 3.1 Conceptual Framework

The study employed a Developmental Research design, encompassing a systematic approach to designing and developing products to achieve specific goals. Its primary objective was introducing innovative advancements in deploying smart aquaponics systems within Brgy. Payatas, Quezon City.

3.1.1 Block Diagram

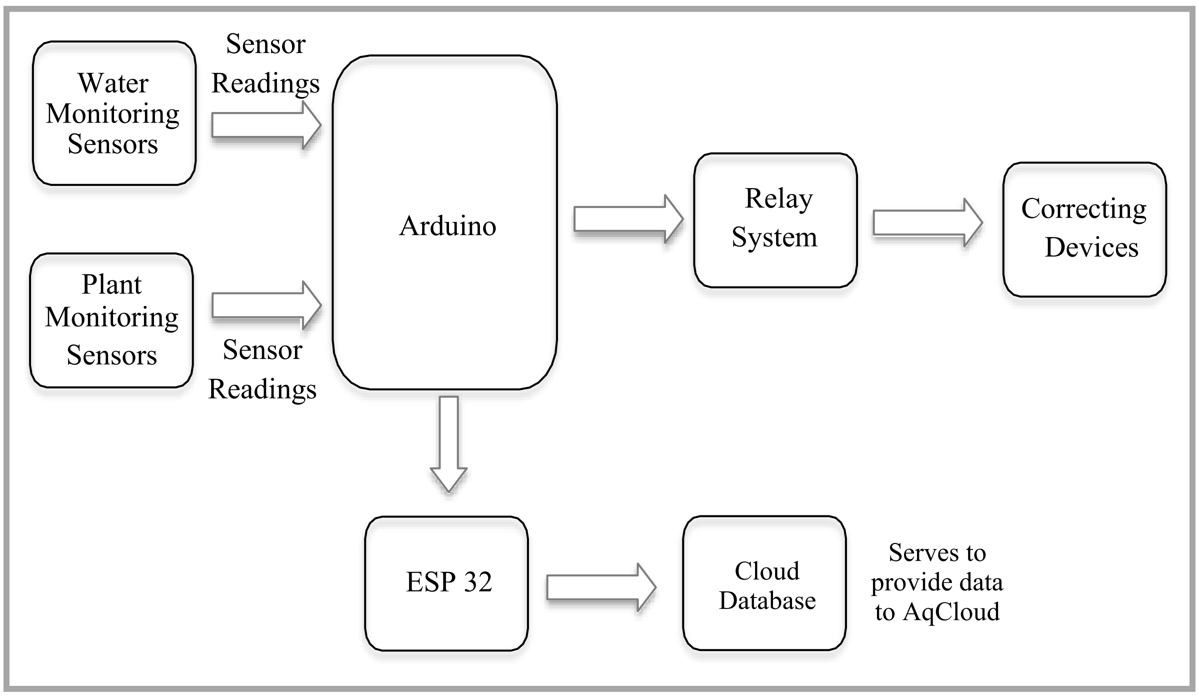

Figure 3.2 Simplified System's Block Diagram

Figure 3.2 shows the simplified block diagram of the system. The water and plant monitoring sensors measure the system's Water Temperature, pH level, Dissolved Oxygen (DO) level, Air Temperature, and Light Intensity. The sensor readings are then transmitted to the Arduino board, which triggers specific actuators to maintain the key indicators within their desired range. The output data are also sent to Firebase (Cloud

Database) for IoT access.

3.2 Research Process Flow

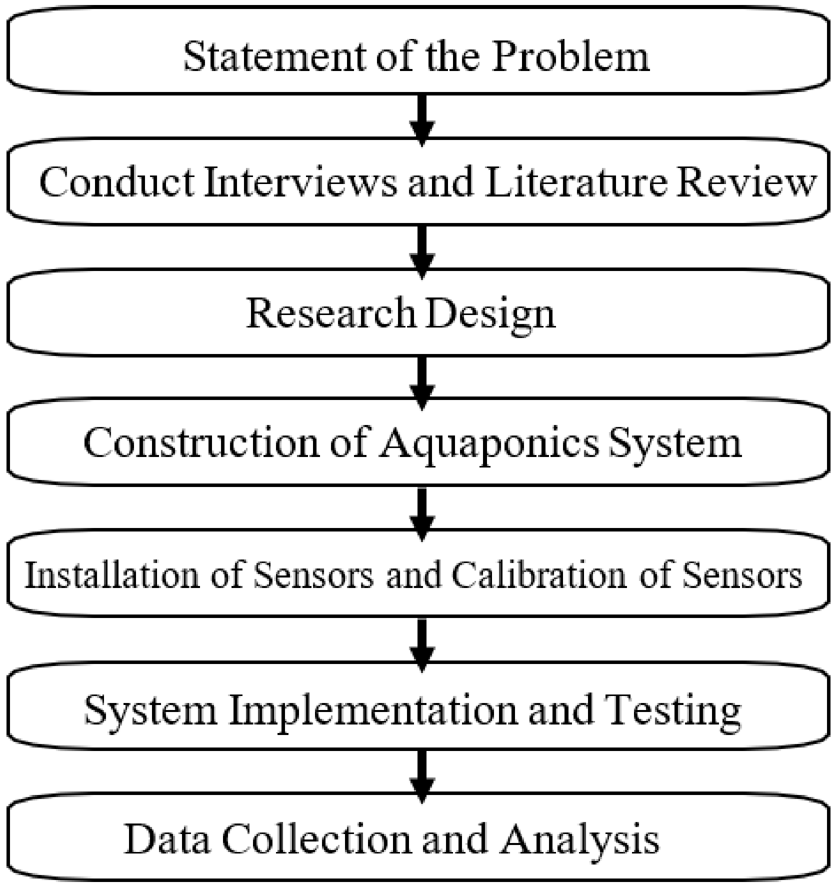

Figure 3.3 Research Process Flow

The research process begins with problem identification and conducting interviews to gather insights and literature reviews to understand the existing knowledge in the field. Based on this, a research design is formulated. Initially, the aquaponics system was constructed, and by then, the sensors to monitor the fish and plant parameters were installed. Moreover, the sensors were calibrated to ensure accurate measurements. The testing of the developed system was conducted to evaluate the performance, so the height of lettuce leaves and length of tilapia were measured. The parameters offer valuable insights into the plants' and fish' growth and progress in the aquaponics system. The data collected were analyzed to derive meaningful insights. Findings and conclusions were drawn from the analysis, providing valuable information on the system's performance and effectiveness.

3.3 Project Development

3.3.1 Hardware Development

The system's design comprises tanks (for aquaculture), grow pipes (for hydroponics) and greenhouse. These three components are necessary for providing a nice and healthy environment for both plants and fish to thrive.

3.3.1.1 Aquaculture Section

The system's fish tank was made of fiberglass and has a dimension of two meters in width, one meter in length, and 0.5 meters in height.

Inside the fish tank, there was an acrylic casing where the water pumps were installed. Additionally, brush filters were incorporated to aid in preserving water clarity, ensuring the survival and development of the fish. These filters guard against potential pump clogging caused by sediment accumulation in the system. The brush's size was 60 cm or 24 inches.

A sump tank was positioned below the fish tank, which serves as a water reservoir. It was designed to be utilized in adjusting the pH level of the tank using a water pump and provides the advantage of supplying water to the tank and enhancing stability, reducing fluctuations in pH and salinity.

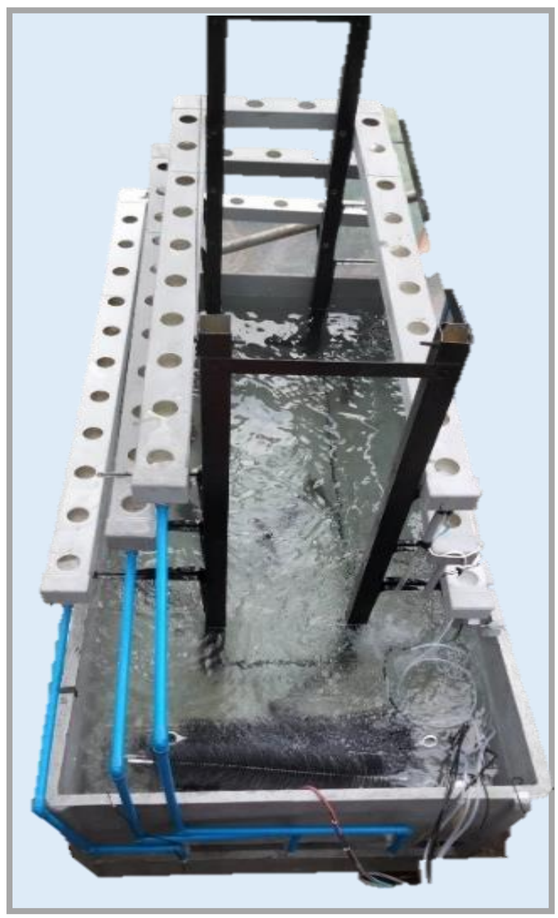

Figure 3.4 Aquaculture and Hydroponics

3.3.2 Plant Cultivation Section

3.3.2.1 Design of grow pipes

Fifteen pieces of tubular downspout PVC pipes were used and placed horizontally with holes that hold the net pots of the plants. The water flowed back to the tank at the end of the

Figure 3.5 Grow pipes with installed grow lights

3.3.2.2 PVC pipe from fish tank to grow pipes

Blue PVC pipes were installed and connected to the pumps inside the fish tank. It serves as a way for the water from the tank to travel to the three levels of downspout.

Figure 3.6 Piping System from the fish tank to the grow pipes

3.3.3 Full Automation of the Aquaponic System

The process was divided into two main components: the connection of sensors, correcting devices, the integration of an IoT (Internet of Things) system using Arduino Board, and the implementation of a PID (Proportional-Integral-Derivative) control algorithm. These components work together to automate and optimize various aspects of the system, including data collection, monitoring, and control, ultimately ensuring the efficient operation of the aquaponics system.

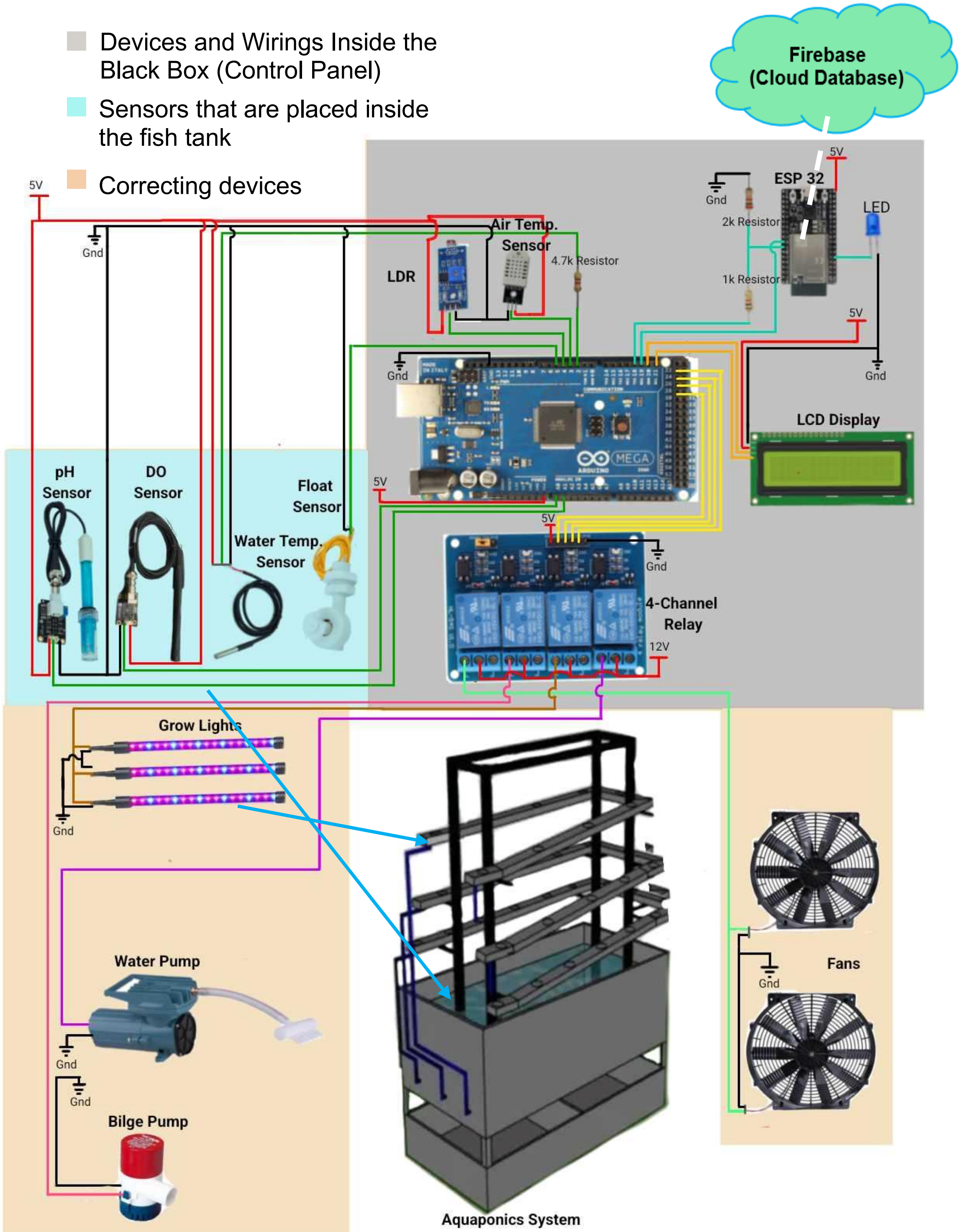

Figure 3.7 Setup of Sensors, Correcting Devices and IoT Connection

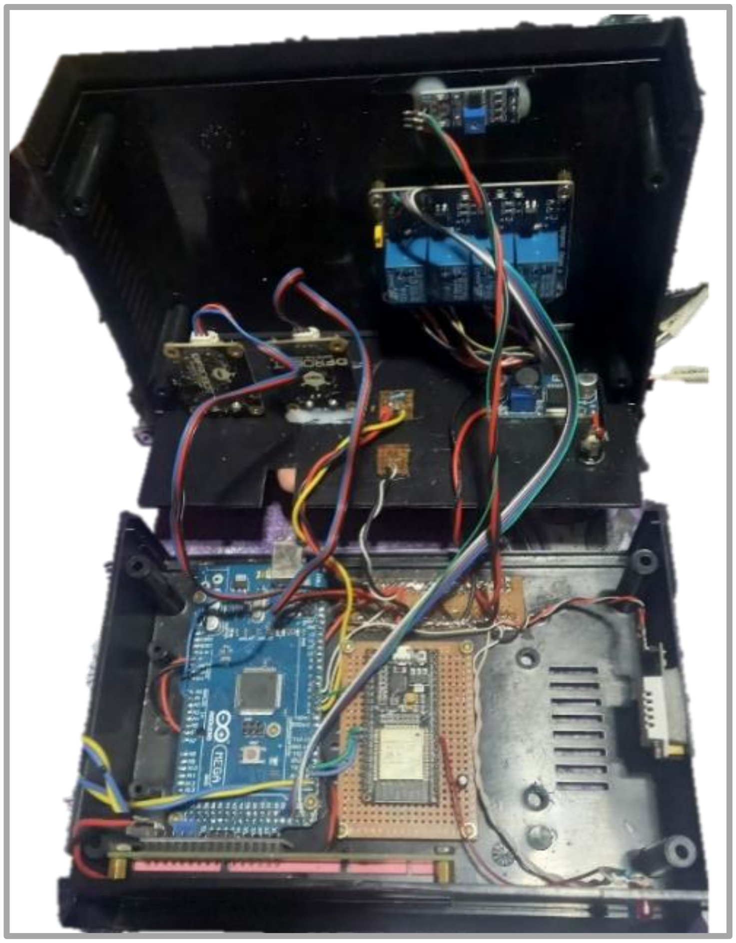

Figure 3.8 Actual Setup inside the Black Box

In Figures 3.7 and 3.8, the system setup illustrates the key components and connections involved. The Arduino Board serves as the central control unit, managing various aspects of the system. The sensors measuring DO level, pH level, water temperature, air temperature, light intensity, and float sensors were connected to the Arduino Board.

A 4-Channel relay was also connected to the Arduino Board, acting as a switch to control the power supply to the correcting devices. The relay facilitates the activation or deactivation of these devices based on the data received from the sensors. Furthermore, an LCD screen was connected to the Arduino Board, providing real-time visualization for the on-site observers of the collected data for easy monitoring.

To transmit the gathered data to the AqCloud Team's Cloud Database (Firebase), ESP32 was also connected to the Arduino Board. It allows for seamless data transfer from the sensors to the cloud, enabling real-time data access and displays on their website. Overall, the setup depicted in Figure 3.4 highlights the components and connections necessary for the full automation of the aquaponics system.

Table 3.1 Sensors and Correcting Devices

Sensor	Correcting Device
• pH Senor - placed in the water inside the fish tank.	• Water Pump - it is placed inside the acrylic casing installed inside the fish tank. It gets it water from the sump tank.
• Dissolved Oxygen (DO) sensor - placed in the water inside the fish tank	• Air Pump - It is placed in the table beside the fish tank. It is connected to a hose that delivers oxygen from the device to the water in the fish tank.
• Water Temperature Sensor - placed in the water inside the fish tank	• Fans - Inlet and Exhaust fans are placed in the walls of the greenhouse.
• LDR sensor - placed inside the black box but its light sensor is outside.	• Grow Lights - It is placed above the plants.

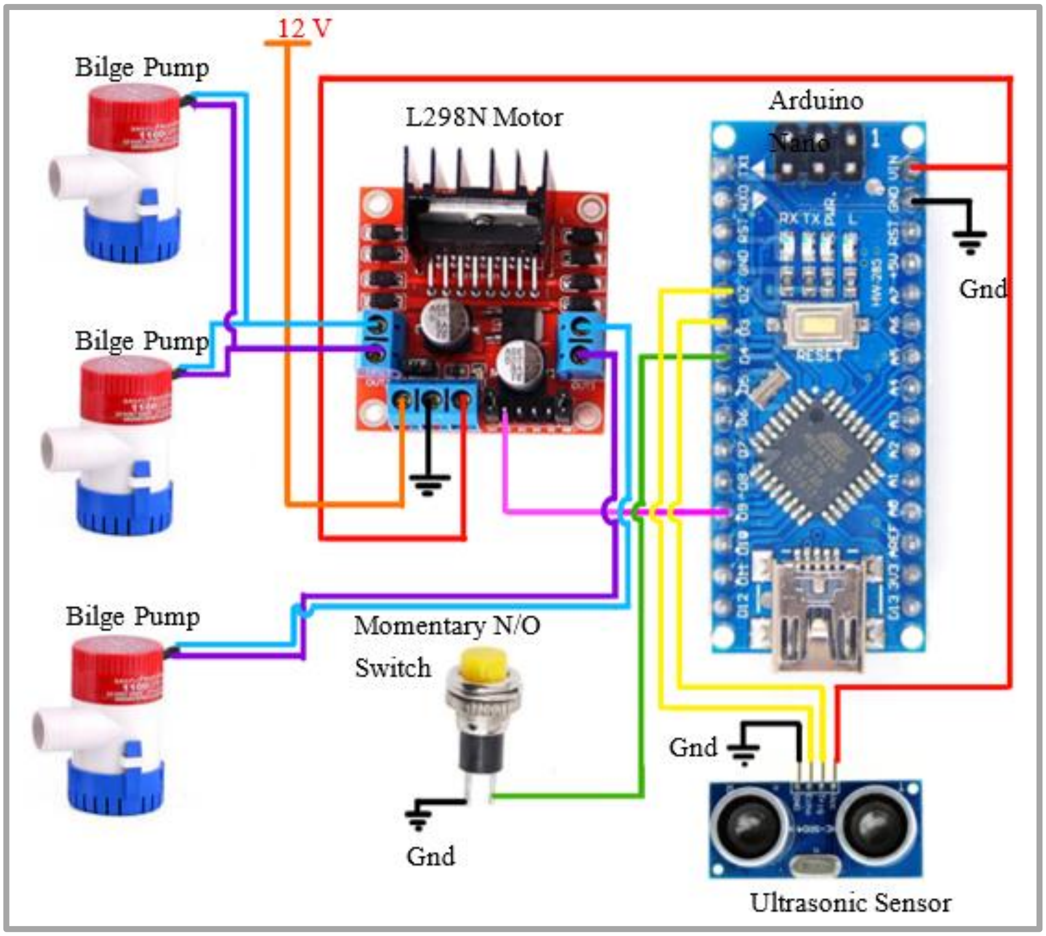

Figure 3.9 Setup for Water Level Correction of Downspout with the implementation of PID Algorithm

Figure 3.9 shows the setup for water level correction in the downspout. The PID algorithm was implemented to automatically activate the pumps when the water level is too low, and it turns off the pumps once the desired water level is reached. An ultrasonic sensor was utilized to measure the water level, while three bilge pumps were employed to control the water within the three-layered downspout.

3.3.4 Power Management

Figure 3.10 Power Management

Figure 3.10 illustrates the power management system of the aquaponics setup. It consists of three power supplies: two switch-mode power supplies that convert 220V AC to 12V DC, which provide power to the 12V correction devices, including the Air Pump, water pump, and fans. The third power supply converts 220V AC to 5V DC, which powers the grow lights and the system's black box. Inside the black box was the Arduino board, which controls the sensors. Furthermore, an automatic feeder is powered by two AAA batteries.

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3.3.5 Program for gathering data

3.3.5.1 Water and environment parameters

The optimal environment to nurture Nile tilapia and Romaine lettuce was the primary basis of the program created for automation. The table below summarizes the water and plant environment's optimal range in growing fish and plants.

Table 3.2 Optimal Parameters to grow Nile Tilapia

Water Parameters	Optimal Range
pH Level	7 – 8
Water Temperature	22 – 32 °C
Dissolved Oxygen	4 – 8 mg/L

Table 3.3 Optimal parameters to grow Romaine Lettuce

Plant Environment Parameters	Optimal Range
Air Temperature	22 – 25 °C / 70 – 80 %
Light Intensity	Moderate amount of light during daytime

3.3.5.2 Program Flowchart

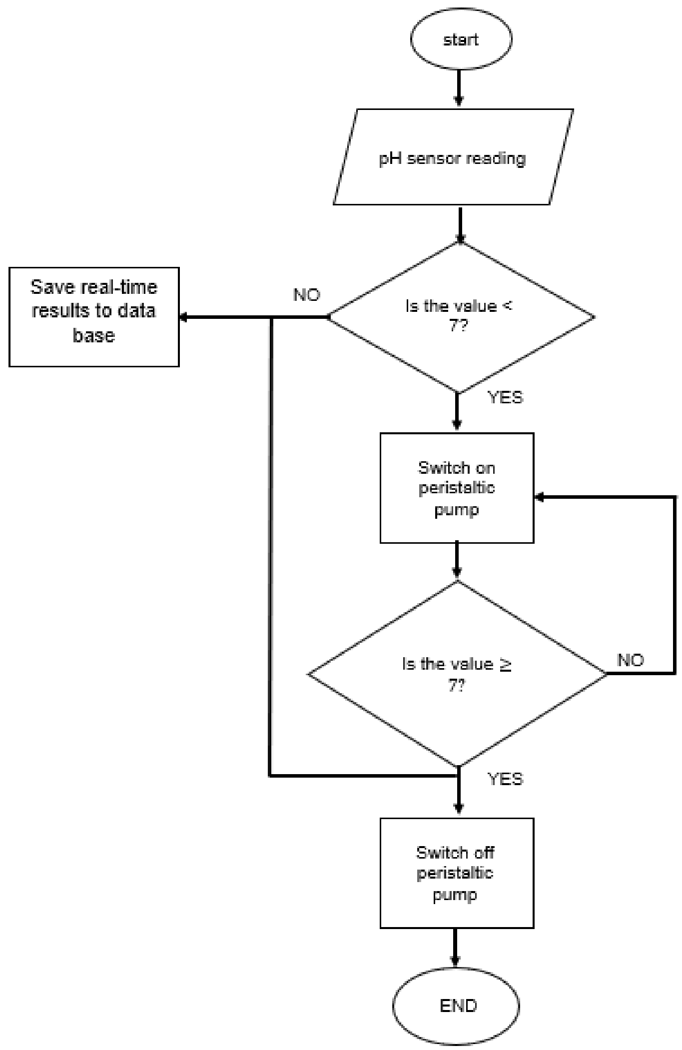

Figure 3.11 pH Flow Chart

The fish tank's ideal pH range is 7 to 8. Thus, as shown in Figure 3.11, if the pH gets lower than 7, the water pump automatically releases water from the sump tank to the fish tank until the pH level returns to the ideal level.

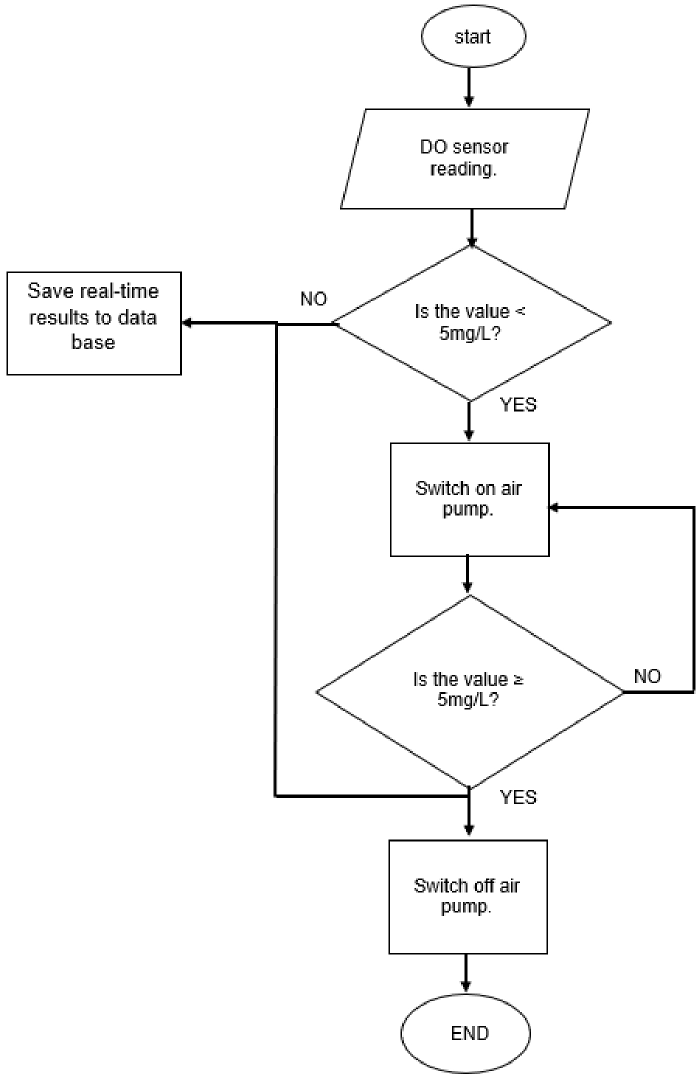

Figure 3.12 DO Flow Chart

Dissolved oxygen between the optimal range is 5mg/L. Thus, the program in Figure 3.12 shows that the air pump automatically turns on if the reading DO is less than five mg/L.

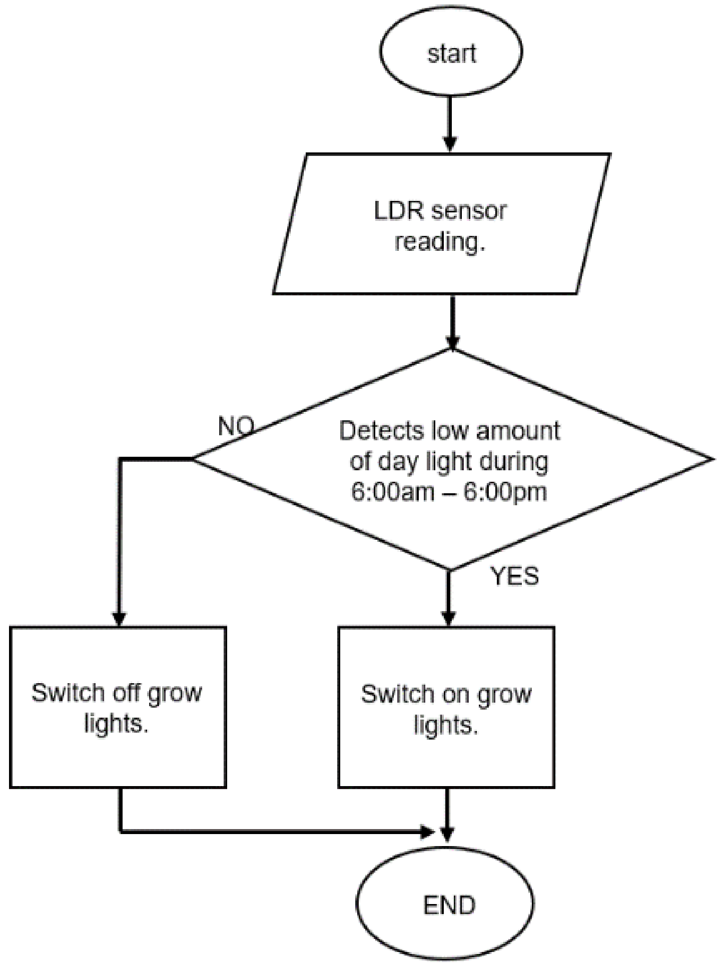

Figure 3.13 Light Control Flow Chart

Figure 3.13 shows the program created for automated grow lights. The LDR detects if there is sunlight present, and if it doesn't detect any sunlight during the day, the grow lights automatically turn on.

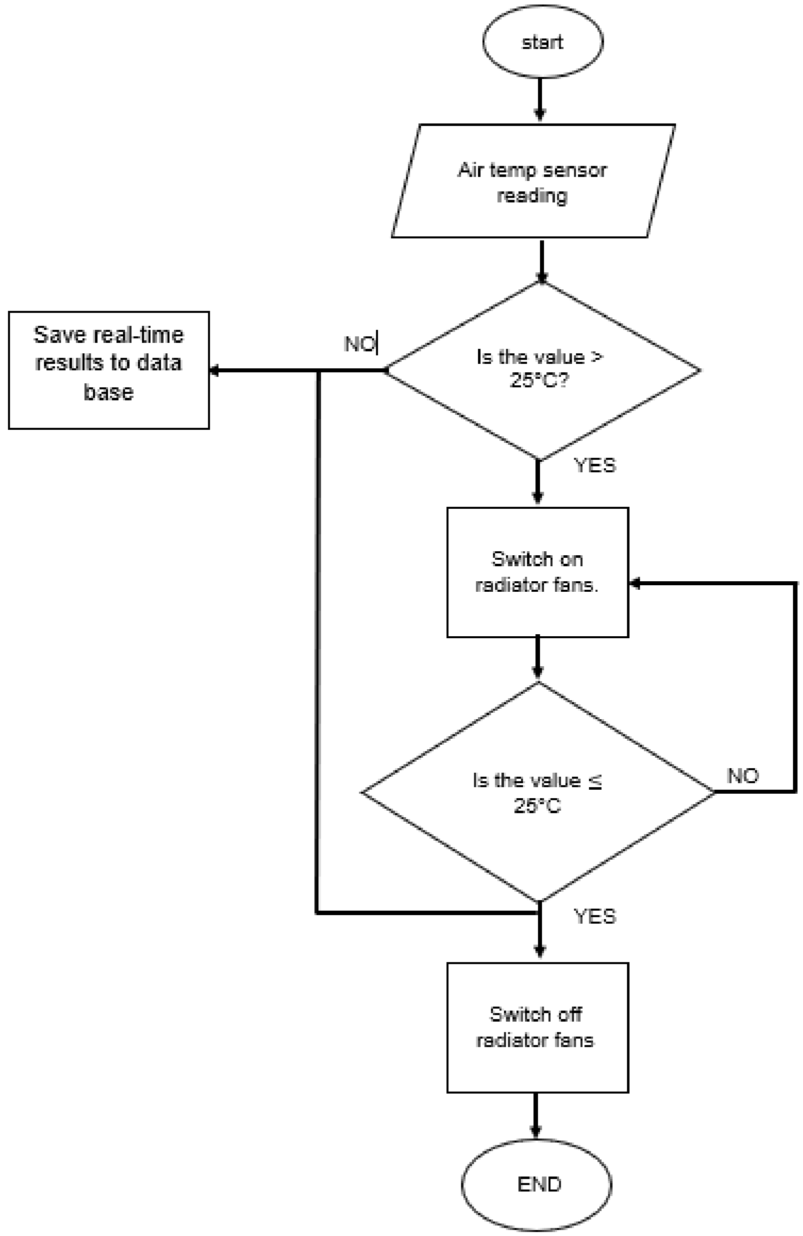

Figure 3.14 Air Temp. Flow Chart

In Figure 3.14, if the value is greater than 25 degrees Celsius, the fans automatically turn on until the value changes into the acceptable temperature range.

3.4 Comparing effectiveness of the developed system to the results of the uncontrolled aquaponics system

Comparing effectiveness was crucial to monitor how things are being done in the automated system compared to the uncontrolled one.

3.4.1 Data Collection

The developed system's effectiveness was evaluated by comparing it to the traditional aquaponic setup. The developed system was equipped with various sensors, correcting devices, and an Arduino Board. The water and environmental parameters that influenced the growth of Nile Tilapia and Romaine Lettuce were being monitored. In contrast, the traditional Aquaponics was an uncontrolled system where the researchers manually took care of the Nile Tilapia and Romaine Lettuce without any automated monitoring or regulation.

The researchers gathered and observed the outcomes of both systems for a whole month. Specifically, they measured Nile Tilapia and the leaves of Romaine Lettuce using a ruler to get the length of the fish and height and length of the lettuce. This comparison allowed them to monitor and assess the differences in production between the two processes, considering factors such as convenience and efficiency. To observe the significant changes of production, the measurement was conducted every day – one fish and lettuce per day.

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Figure 3.17 Fish from SMART Aquaponics

Figure 3.18 Fish from Traditional Aquaponics

Figure 3.19 Measuring lettuce Figure

Figure 3.20 Lettuce from the 2-aquaponics set-up

3.4.2 Statistical Test

This study utilized two aquaponics setups: a developed system and an uncontrolled one. The efficiency of the developed smart aquaponics system was evaluated with the help of statistical analysis using the independent samples t-test. The independent samples t-test compared the means of two independent samples, explicitly comparing the tilapias and lettuce from the smart aquaponics system to the samples obtained from the uncontrolled system aquaponics. This analysis aims to determine if there was a statistically significant difference in the means of these variables between the two systems.

The T-test formula is as follows:

$$t = (\bar{x}_1 - \bar{x}_2) / \sqrt{((s_1^2/n_1) + (s_2^2/n_2))}$$

Where:

$\bar{x}_1$ and $\bar{x}_2$ are the means of the two samples

s_1^2 and s_2^2 are the variances of the two samples

n_1 and n_2 are the sample sizes of the two samples

3.5 Project Work Plan

		%	Present	Sep-22	Oct-22						Nov-22					Dec-22				Jan-23				Feb-22				Mar-22					Apr-22				May-22				Jun-22			
				26-29	30-7	30-6	7-13	14-20	21-27	28-3	4-10	11-17	18-24	25-1	2-8	9-15	16-22	23-29	30-5	6-12	13-19	20-26	27-2	3-9	10-16	17-23	24-2	3-9	10-16	17-23	24-30	31-6	7-13	14-20	21-27	28-4	5-11	12-18	19-25	26-1	2-8	9-15	16-22	23-29
Building Aquaponics System	Canvassing and Procurement of Ma	5%	5%																																									
	Finalizing design layout of an aquap	3%	3%																																									
	Construction of Greenhouse	8%	8%																																									
	Arrangement of tanks: Fish tanks, su	5%	5%																																									
	Placing the water pumps and siphoi	6%	6%																																									
	Contruction of the Atlanta downspo	5%	5%																																									
	Putting germinated lettuce in net po	3%	3%																																									
Automating Aquaponics System	Procurement and canvassing of mat	4%	4%																																									
	Callibration of sensors	6%	6%																																									
	Establishing connections - Programi	12%	12%																																									
	Setting up the sensors and actuator	5%	5%																																									
Implementing PID Control Algorithm	Procurement and canvassing of mat	3%	3%																																									
	Implement Trial and Error Tuning M	5%	5%																																									
Comparing the effectiveness of the developed system to the uncontrolled aquaponics system	Growing of Tilapia and Lettuce	10%	10%																																									
	Data collection of weight and length	7%	7%																																									
	Conducting T-test	5%	5%																																									
	Giving/sending data to the software	8%	8%																																									
	Comparing the effectiveness of the	100%	100%	6%	2%	4%	1%	1%	5%	5%	3%	0%	3%	1%	0%	3%	2%	2%	5%	6%	3%	2%	3%	5%	0%	1%	3%	0%	1%	0%	0%	0%	1%	2%	0%	1%	6%	5%	3%	3%	5%	8%	0%	0%

Chapter 4

RESULTS AND DISCUSSION

This chapter presents a comprehensive analysis and discussion of the findings, offering valuable insights into the effects of the system on plant and fish growth, resource utilization efficiency, and overall system functionality. The results obtained from the study provide a deeper understanding of the system's performance and its potential implications for sustainable aquaponics practices. By examining key factors such as plant and fish growth rates, resource consumption, and system functionality, we gain valuable knowledge that can contribute to the advancement and optimization of aquaponics systems.

4.1 Project Technical Description

The Smart Aquaponics system represents an advanced approach to cultivating Nile Tilapia and Romaine Lettuces, leveraging IoT (Internet of Things) technology. This innovative system incorporates sensors to monitor important variables and employs correcting devices to maintain ideal conditions for growth. The gathered data from these sensors is transmitted to Firebase, a cloud-based platform, enabling real-time monitoring and control through a user-friendly web application. Through the integration of IoT technology, the aquaponics system achieves efficient and automated management, creating an optimal environment for the growth of fish and plants.

4.2 Project Limitations and Capabilities

The Smart Aquaponics system housed 150 Nile Tilapia and 30 Romaine Lettuces. It employed various sensors to monitor crucial parameters such as pH, dissolved oxygen, water and air temperature, light exposure, and water level. Real-time adjustments of the water pumps were achieved through three Arduino nano devices programmed with the PID algorithm.

The fish tank has a capacity of 1000 liters, although only 800 liters were currently used to provide sufficient space for the fish, excluding the sump tank. The sump tank played a vital role in maintaining stable pH levels by storing additional water to address any detected pH instability. Collected sensor data was seamlessly transmitted to Firebase for secure storage and analysis.

The system featured a three-layered downspout connected to the tank using blue PVC pipes, along with integrated brush filters to remove sludge and prevent pipe blockages.

Considering scalability and potential for larger-scale production, it's important to note the system's limitations and capabilities. Further development and optimization may be needed to enhance capacity and efficiency.

4.3 Results/Findings and Analysis

4.3.1 Romaine Lettuce

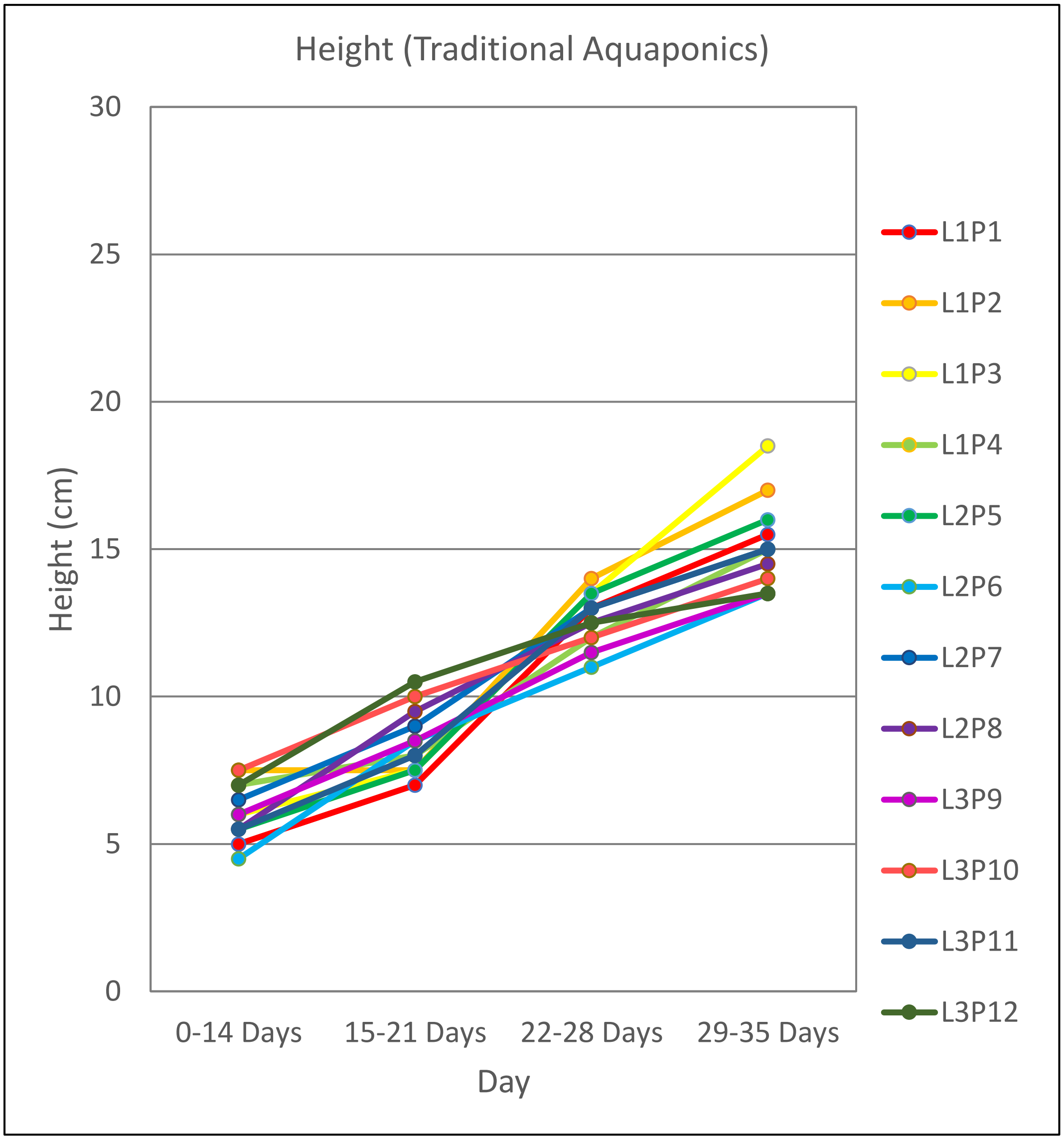

Figure 4.1 Graph for the Height (cm) of the Lettuce in Traditional Aquaponics

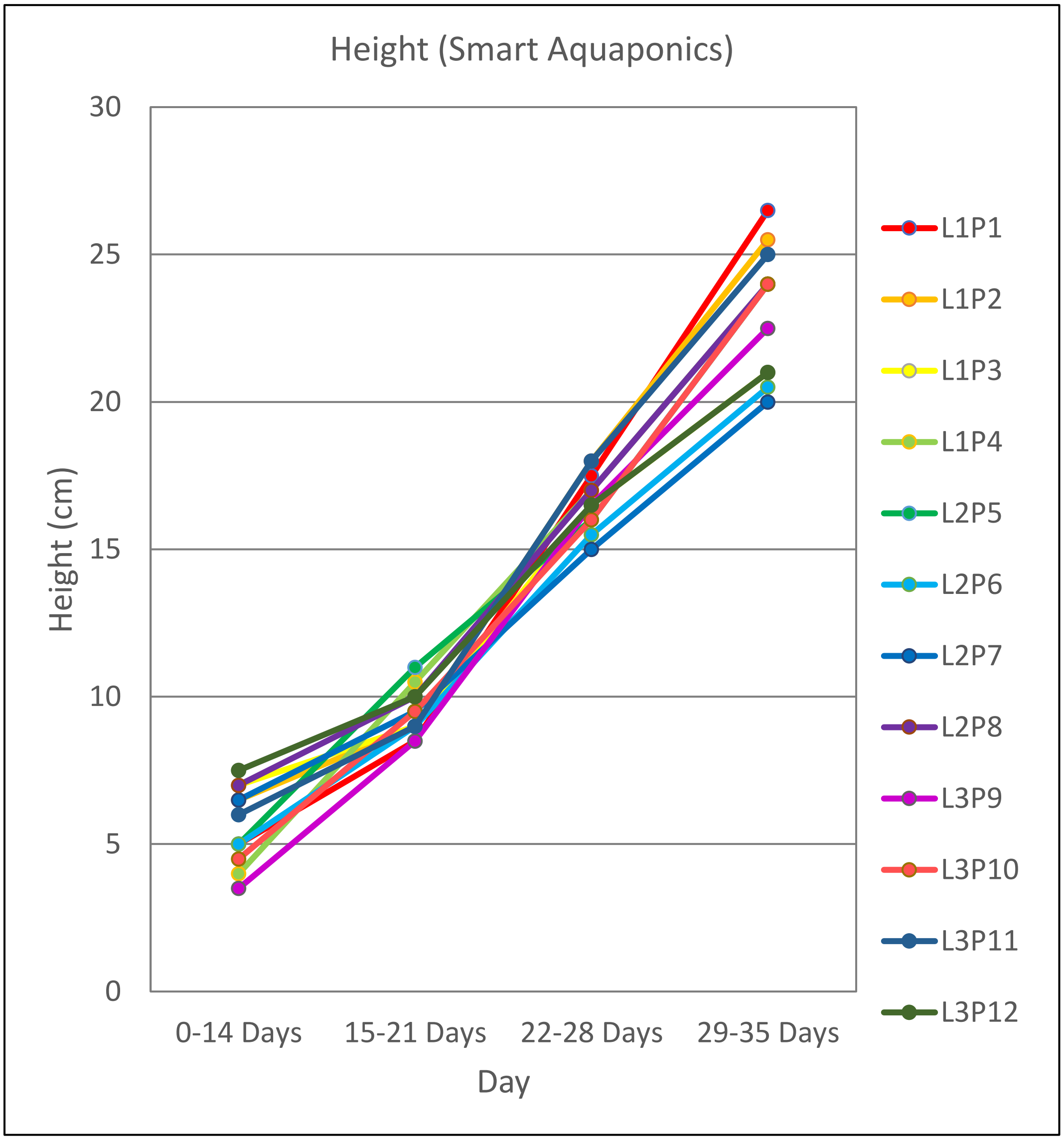

Figure 4.2 Graph for the Height (cm) of the Lettuce in Smart Aquaponics

Figures 4.1 and 4.2 display the measured height in centimeters of twelve lettuce samples (four lettuce in each layer) for both the Smart Aquaponics and Traditional methods (See Table A.1 and A.2, respectively, in Appendix A). Comparison of the results reveals that the lettuce in the Smart Aquaponics system demonstrates notably greater height measurements compared to those obtained in the Traditional method.

Table 4.1 Lettuce Height Growth Percentage

Plant	Smart Aquaponics Height Growth (%)	Traditional Aquaponics Height Growth (%)
Plant 1 (Layer 1)	57.87	36.75
Plant 2 (Layer 1)	47.12	28.43
Plant 3 (Layer 1)	35.53	36.37
Plant 4 (Layer 1)	68.42	23.44
Plant 5 (Layer 2)	56.64	36.22
Plant 6 (Layer 2)	50.19	37.043
Plant 7 (Layer 2)	35.56	26.66
Plant 8 (Layer 2)	39.24	31.52
Plant 9 (Layer 3)	69.07	24.90
Plant 10 (Layer 3)	60.51	18.54
Plant 11 (Layer 3)	49.01	31.30
Plant 12 (Layer 3)	33.98	20.38

Table 4.1 displays the average height growth percentage of 12 lettuce samples cultivated in both the Traditional Aquaponics and Smart Aquaponics. Upon analyzing the data, it becomes evident that the Smart Aquaponics system exhibits higher growth percentages compared to the Traditional system. This implies that the lettuce grown in the Smart Aquaponics system experiences greater height growth rates.

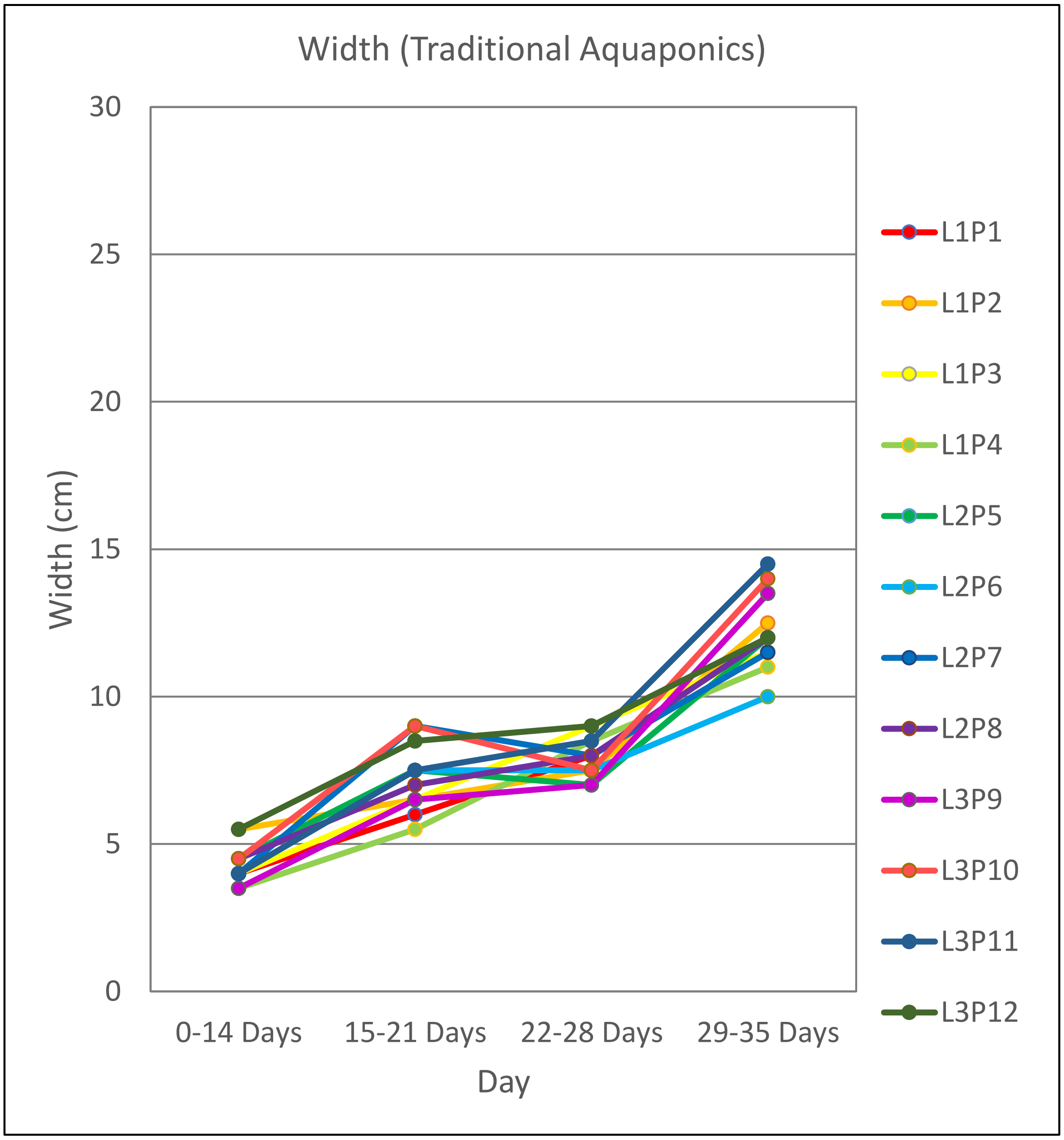

Figure 4.3 Graph for the Width (cm) of the Lettuce in Traditional Aquaponics

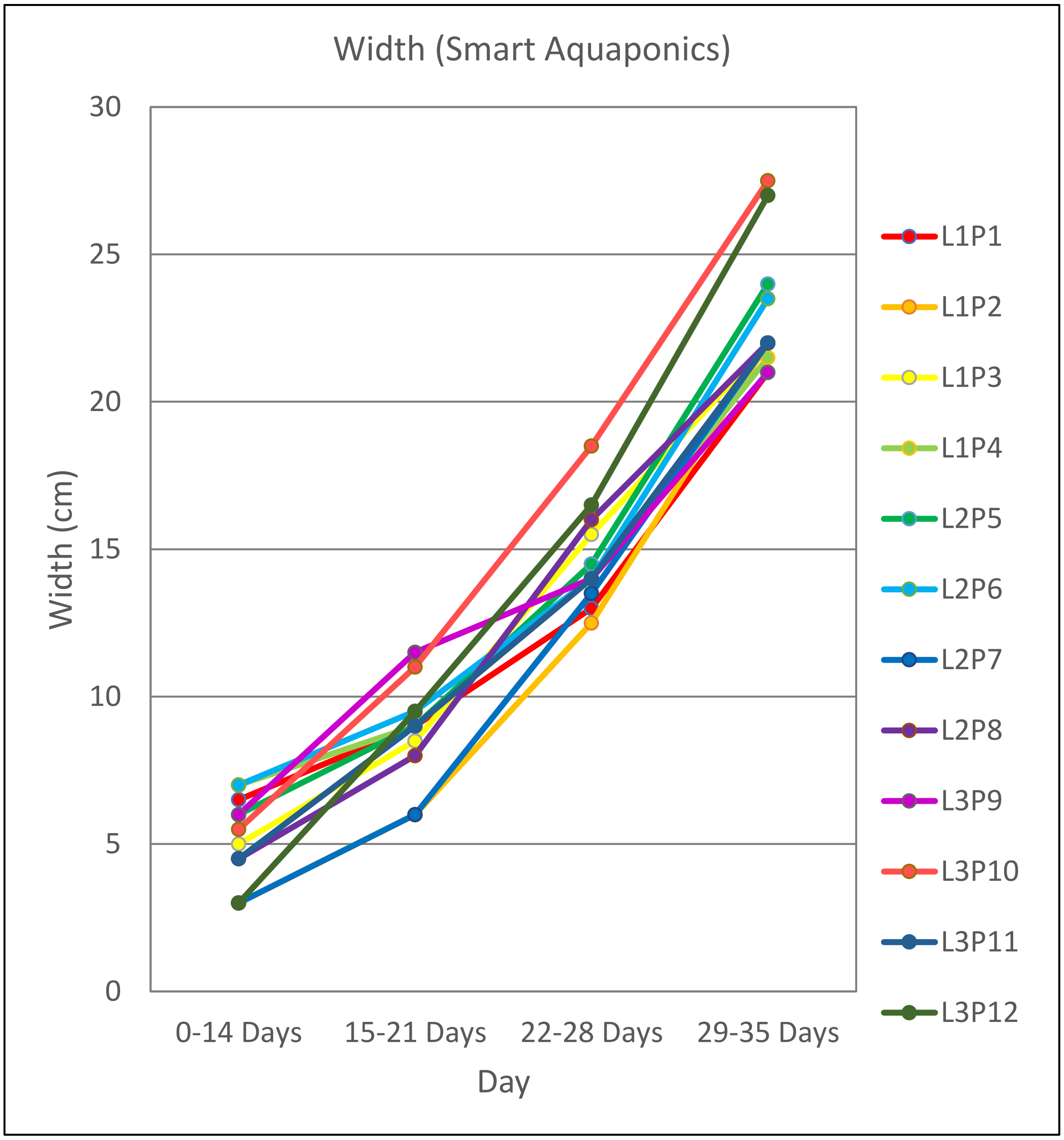

Figure 4.4 Graph for the Width (cm) of the Lettuce in Smart Aquaponics

Figures 4.3 and 4.4 display the measured width in centimeters of twelve lettuce samples (four lettuce in each layer) for both the Smart Aquaponics and Traditional methods systems (See Table A.3 and A.4, respectively, in Appendix A). A comparison of the results reveals that the lettuce in the Smart Aquaponics system demonstrates notably greater width measurements compared to those obtained in the Traditional method.

Table 4.2 Lettuce Width Growth Percentage

Plant	Smart Aquaponics Width Growth (%)	Traditional Aquaponics Width Growth (%)
Plant 1 (Layer 1)	36.11	32.41
Plant 2 (Layer 1)	76.08	25.52
Plant 3 (Layer 1)	48.57	34.21
Plant 4 (Layer 1)	36.35	36.01
Plant 5 (Layer 2)	46.43	34.02
Plant 6 (Layer 2)	38.47	31.52
Plant 7 (Layer 2)	74.78	41.44
Plant 8 (Layer 2)	54.98	43.07
Plant 9 (Layer 3)	41.71	48.91
Plant 10 (Layer 3)	56.17	43.07
Plant 11 (Layer 3)	53.74	44.17
Plant 12 (Layer 3)	89.36	23.90

Table 4.2 displays the average width growth percentage of 12 lettuce samples cultivated in both the Traditional Aquaponics and Smart Aquaponics systems. Upon analyzing the data, it becomes evident that the Smart Aquaponics system exhibits higher growth percentages compared to the Traditional system. This implies that the lettuce grown in the Smart Aquaponics system experiences greater width growth rates.

Table 4.3 t-Test for the Height Growth Rate of Lettuce

	Smart Aquaponic Setup	**Traditional Aquaponics Setup**
Mean	50.26	29.30
Variance	142.21	38.91
Sample Size	12	12
Degrees of Freedom	22	
Pooled Variance	90.56	
Hypothesized Mean Difference	0	
t-value	5.396228	
P(T<=t) one-tail	0.000019	
P(T<=t) two-tail	0.000038	

Table 4.12 presents the t-Test results conducted to compare the height growth of lettuce in the Smart Aquaponics and Traditional Aquaponics setups. The average height growth rate of lettuce in the Smart Aquaponics system is 50.26%, which is 71.53% higher than the height growth rate of 29.3% observed in the Traditional Aquaponics system. The null hypothesis (H_0) assumes no significant difference between the height growth rates of the two setups, while the alternative hypothesis (H_1) suggests a significant difference, with the Smart Aquaponics system exhibiting a higher growth rate. With a predetermined statistical significance level of 0.05, the null hypothesis is rejected due to a p-value below 0.05, providing evidence of a significant difference in the height

growth rates between the two systems.

Table 4.4 t-Test for the Width Growth Rate of Lettuce

	Smart Aquaponic Setup	**Traditional Aquaponics Setup**
Mean	54.40	36.52
Variance	272.64	53.65
Sample Size	12	12
Degrees of Freedom	22	
Pooled Variance	163.14	
Hypothesized Mean Difference	0	
t-value	3.427847	
P(T<=t) one-tail	0.001743	
P(T<=t) two-tail	0.003487	

Table 4.4 presents the t-Test results conducted to compare the width growth of lettuce in the Smart Aquaponics and Traditional Aquaponics setups. The average width growth rate of lettuce in the Smart Aquaponics system is 54.40%, which is 48.94% higher than the width growth rate of 36.52% observed in the Traditional Aquaponics system. The null hypothesis (H_0) assumes no significant difference between the width growth rates of the two setups, while the alternative hypothesis (H_1) suggests a significant difference, with the Smart Aquaponics system exhibiting a higher growth rate. With a predetermined statistical significance level of

0.05, the null hypothesis is rejected due to a p-value below 0.05, providing evidence of a significant difference in the width growth rates between the two systems.

4.3.2 Nile Tilapia

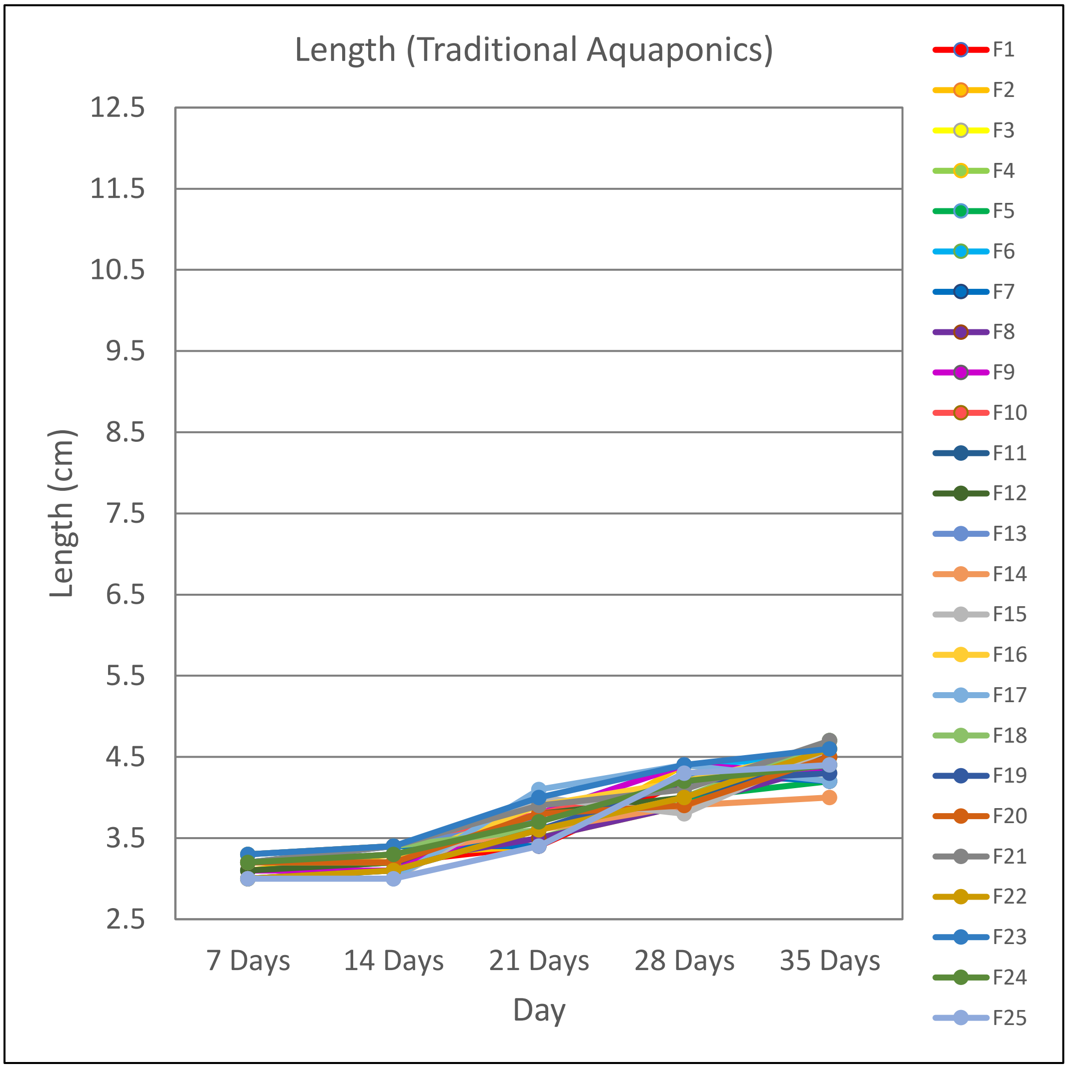

Figure 4.5 Graph for the Length (cm) of the Tilapia in Traditional Aquaponics

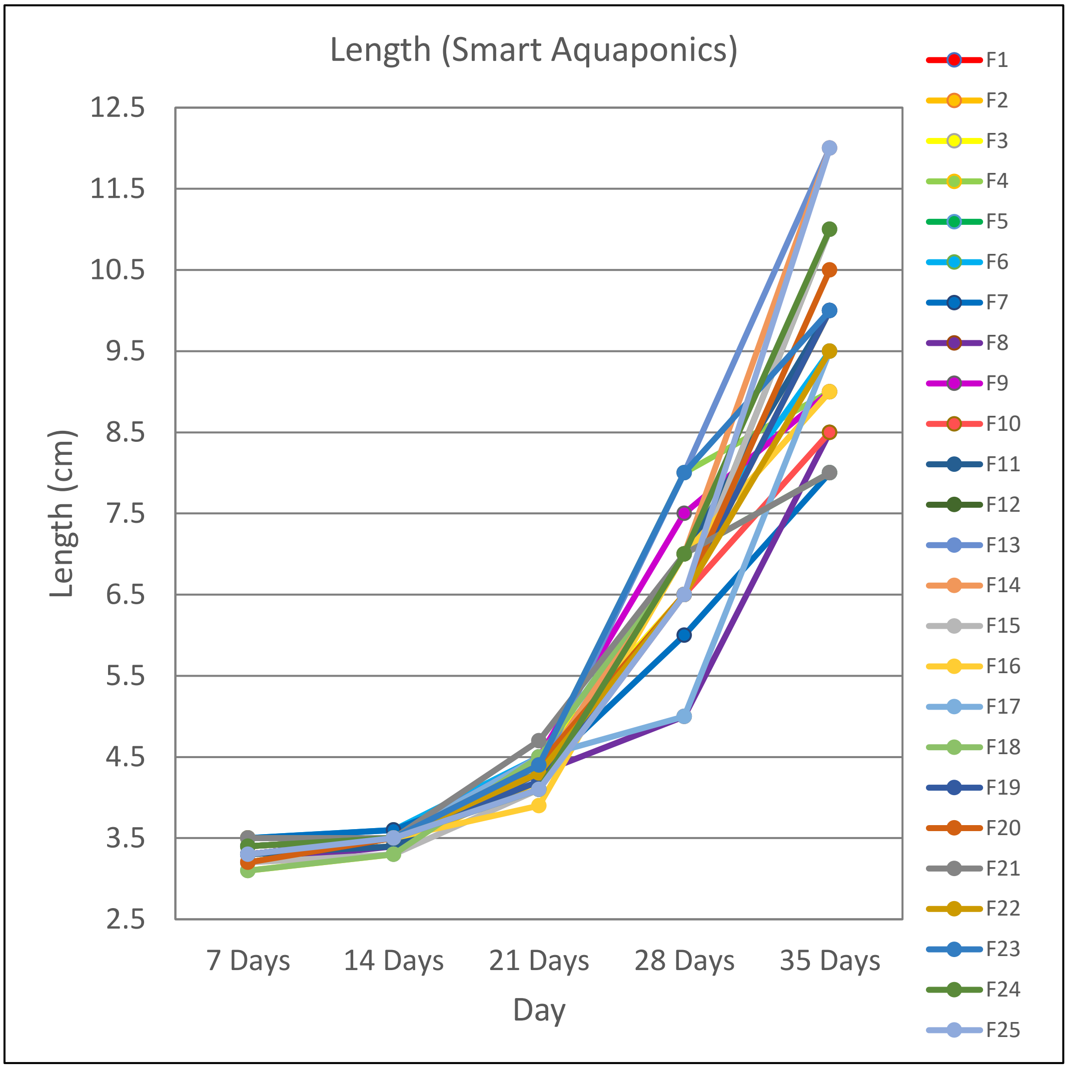

Figure 4.6 Graph for the Length (cm) of the Tilapia in Smart Aquaponics

Figures 4.5 and 4.6 display the measured length in centimeters of twenty-five tilapia samples for both the Smart Aquaponics and Traditional methods (See Table A.5 and A.6, respectively, in Appendix A). A comparison of the results reveals that the tilapia in the Smart Aquaponics system demonstrates notably greater length measurements compared to those obtained in the Traditional method.

Table 4.5 Tilapia Length Growth Percentage

Fish	Smart Aquaponics Length Growth (%)	Traditional Aquaponics Length Growth (%)
Fish 1	33.23	9.23
Fish 2	30.45	8.59
Fish 3	35.28	9.05
Fish 4	30.75	9.67
Fish 5	27.06	7.96
Fish 6	29.79	10.99
Fish 7	23.79	7.60
Fish 8	29.75	8.41
Fish 9	30.32	9.02
Fish 10	27.35	8.12
Fish 11	33.79	8.96
Fish 12	38.01	11.18
Fish 13	39.73	7.53
Fish 14	40.00	5.78
Fish 15	38.78	12.35
Fish 16	29.87	9.77
Fish 17	33.16	9.86
Fish 18	28.17	9.38
Fish 19	33.67	9.63
Fish 20	36.09	9.19
Fish 21	24.38	10.18
Fish 22	30.78	11.39
Fish 23	33.87	8.81
Fish 24	36.99	8.38
Fish 25	41.59	10.53

Table 4.5 displays the average length growth percentage of 25 tilapia samples cultivated in both the Traditional Aquaponics and Smart Aquaponics systems. Upon analyzing the data, it becomes evident that the Smart Aquaponics system exhibits higher growth percentages compared to the Traditional system. This implies that the tilapia grown in the Smart Aquaponics system experiences greater length growth rates.

Table 4.6 t-Test for the Length Growth Rate of Tilapia

	Smart Aquaponic Setup	**Traditional Aquaponics Setup**
Mean	32.66459228	9.262027116
Variance	21.42281119	0.896711774
Sample Size	25	25
Degrees of Freedom	48	
Pooled Variance	11.15976148	
Hypothesized Mean Difference	0	
t-value	24.76800424	
P(T<=t) one-tail	0.00001	
P(T<=t) two-tail	0.00001	

Table 4.5 presents the t-Test results conducted to compare the length growth of tilapia in the Smart Aquaponics and Traditional Aquaponics setups. The average length growth rate of tilapia in the Smart Aquaponics system is 32.66%, which is 248.38% higher than the width growth rate of 9.26% observed in the Traditional Aquaponics system. The null hypothesis (H_0) assumes no significant difference between the length growth rates of the two setups, while the alternative hypothesis (H_1) suggests a significant difference, with the Smart Aquaponics system exhibiting a higher growth rate. With a predetermined statistical significance level of 0.05, the null hypothesis is rejected due to a p-value below 0.05, providing evidence of a significant difference in the length growth rates between the two systems.

4.3.3 Smart Aquaponics Evaluation Results

SD – Strongly Disagree, D – Disagree, N – Neutral, A – Agree, **5A** – Strongly Agree.					
Survey Statement	**Expert / Owner**				
	1	**2**	**3**	**4**	**5**
Overall Satisfaction					
1. The Smart Aquaponics System meets my expectations and requirements.	**SA**	**SA**	**A**	**SA**	**SA**
Usability					
2. The interface and controls of the system were intuitive and easy to use.	**A**	**SA**	**A**	**SA**	**SA**
Performance					
3. The system effectively monitored and controlled water quality, temperature, pH, and nutrient levels.	**SA**	**SA**	**SA**	**SA**	**SA**
Design and efficiency					
4. The system design optimally utilizes available space to maximize efficiency.	**A**	**SA**	**SA**	**SA**	**SA**
5. The system design optimize water recirculation and filtration processes.	**SA**	**SA**	**SA**	**SA**	**SA**
6. The system demonstrated resource efficiency regarding water consumption and nutrient utilization.	**SA**	**SA**	**A**	**A**	**SA**
7. The system significantly reduced resource usage compared to traditional farming methods.	**SA**	**SA**	**SA**	**SA**	**SA**
8. The Smart Aquaponics system excels in terms of efficiency, surpassing the performance of the traditional approach.	**SA**	**SA**	**SA**	**SA**	**SA**
Reliability					
9. The system operated reliably without major technical issues or malfunctions.	**SA**	**SA**	**SA**	**SA**	**SA**
10. The system consistently performed as expected and met the set requirements.	**SA**	**SA**	**SA**	**SA**	**SA**
Productivity and Yield					
11. The quality of products (plants and fish) generated by the system was satisfactory.	**A**	**SA**	**A**	**SA**	**SA**
12. The quantity of products met expectations and was sufficient.	**A**	**SA**	**A**	**SA**	**SA**

Figure 4.7 Tabulated Smart Aquaponics Evaluation Results

The survey was conducted among five experts and owners of smart aquaponics systems to assess their satisfaction and perception of various aspects of the system. Overall, the participants expressed high satisfaction with the Smart Aquaponics System. Regarding overall satisfaction, 60% of the participants agreed that the system met their expectations and requirements. This indicates a positive reception of the system and suggests that it effectively fulfilled the users' needs.

Regarding usability, 80% of the participants agreed that the interface and controls of the system were intuitive and easy to use. This highlights the user-friendly nature of the system, making it accessible and convenient for operators. All participants (100%) strongly agreed that the system effectively monitored and controlled water quality, temperature, pH, and nutrient levels. This demonstrates the system's strong performance in maintaining optimal plant and fish growth conditions, ensuring a productive and healthy aquaponics environment.

Regarding design and efficiency, 80% of the participants strongly agreed that the system optimally utilized available space to maximize efficiency. They also recognized the system's resource efficiency, particularly regarding water consumption and nutrient utilization. This indicates that the system's design was well-received for its ability to maximize output while minimizing resource usage. Regarding reliability, all participants (100%) strongly agreed that the system operated reliably without major technical issues or malfunctions. This underscores the system's dependability, instilling confidence in its consistent performance and functionality.

Regarding productivity and yield, 80% of the participants agreed that the quality of products, including plants and fish, generated by the system was satisfactory. Additionally, they expressed general agreement regarding the number of products, indicating that the system met their expectations in terms of output. Overall, the survey results demonstrate a positive reception of the Smart Aquaponics System among experts and owners. The system received high performance, reliability, usability, design, efficiency, and productivity ratings. These findings validate the system's potential to enhance aquaponics farming practices and improve yields and sustainability in food production.

Chapter 5

CONCLUSION AND RECOMMENDATIONS

5.1 Summary of Findings

The Smart Aquaponics system, powered by Arduino Mega, presents a promising and viable solution for achieving sustainable food production by integrating aquaculture and hydroponics in an automated setup. This study aimed to develop and evaluate the performance of the Smart Aquaponics system, specifically focusing on Romaine Lettuce and Nile Tilapia. The research objectives included building a fully automated aquaponics system utilizing Arduino Mega for monitoring and regulation, implementing a PID algorithm for precise control, and comparing the system's effectiveness against traditional aquaponics setups. Additionally, user satisfaction was assessed through a survey.

1. Growth Rates: The statistical analysis of growth rates revealed significant differences between the Smart and Traditional Aquaponics systems. Lettuce's average height growth rate in the Smart Aquaponics system was 50.26%, 71.53% higher than the height growth rate of 29.3% observed in the Traditional Aquaponics system (p-value < 0.05). Similarly, the average width growth rate of lettuce in the Smart Aquaponics system was 54.40%, showing a 48.94% increase compared to the width growth rate of 36.52% in the Traditional Aquaponics system (p-value < 0.05). Furthermore, tilapia's average length growth rate in the Smart Aquaponics system was 32.66%, significantly higher

(248.38%) than the width growth rate of 9.26% in the Traditional Aquaponics system (p-value < 0.05). These findings indicate that the Smart Aquaponics system positively influenced the growth and development of lettuce and tilapia.

2. User Satisfaction: The survey conducted among experts and owners of smart aquaponics systems provided valuable insights into user satisfaction. The results indicated high satisfaction levels across various aspects of the Smart Aquaponics system. Expressly, 60% of the participants agreed that the system met their expectations and requirements. Furthermore, 80% agreed that the interface and controls were intuitive and easy to use. All participants (100%) strongly agreed that the system effectively monitored and controlled water quality, temperature, pH, and nutrient levels. Additionally, 80% of the participants agreed that the system optimally utilized available space to maximize efficiency. Overall, the survey results highlight the positive user experience and confidence in the functionality of the Smart Aquaponics system.

5.2 Conclusion

Based on the findings of this study, we conclude the following:

1. The Smart Aquaponics system outperforms traditional aquaponics setups regarding growth rates for both lettuce and tilapia. The system's automated features, precise control through the PID algorithm, and

monitoring capabilities contribute to superior plant and fish development.

2. User satisfaction with the Smart Aquaponics system is high, indicating that the system effectively meets users' requirements. The intuitive controls, reliable operation, and efficient space utilization enhance the user experience.
3. The results highlight the potential of the Smart Aquaponics system to revolutionize urban agriculture, promote sustainable practices, and address the increasing demand for locally grown produce.

5.3 Recommendations

Based on the findings and conclusions of this study, the following recommendations are proposed:

1. Further development and optimization: Continuously invest in research and development to improve the Smart Aquaponics system. This includes refining the system's capacity, enhancing sensor capabilities for more comprehensive monitoring, and exploring advanced water management techniques. It is recommended to consistently implement updates and upgrades to stay aligned with the latest technological advancements and best practices.
2. Establish educational initiatives and training programs to promote the adoption and proper operation of the Smart Aquaponics system. These programs should target individuals interested in aquaponics, including

farmers, students, and entrepreneurs. Users can maximize the system's benefits and ensure its effective and efficient operation by providing knowledge and skills.

3. Foster collaboration among stakeholders, including researchers, industry experts, and aquaponics system owners. Encourage sharing experiences, insights, and best practices to facilitate continuous improvement and innovation within the aquaponics community. Collaboration can help address challenges, exchange ideas, and collectively work towards achieving sustainable food production goals.
4. Encourage further research into alternative system designs, different fish species, and plant varieties suitable for aquaponics. By doing so, farmers will have an expanded array of choices, allowing them to diversify their production methods and increase their agricultural options. Exploring different combinations of fish and plants can lead to optimized symbiotic relationships and higher overall system performance.
5. Consideration of advanced sensors: Investigate the use of advanced sensors, such as the DYP-A02YY Waterproof Ultrasonic Ranging Sensor, to enhance the performance and efficiency of the Smart Aquaponics system. These sensors can provide more accurate and real-time data on water quality parameters, enabling better control and optimization of the system.
6. Market development and consumer awareness: Promote the benefits of

locally grown produce from the Smart Aquaponics system to consumers. Highlight the system's ability to produce fresh, nutritious, sustainable food with minimal environmental impact. This can be achieved through marketing campaigns, community engagement, and collaborations with local food organizations.

By implementing these recommendations, the Smart Aquaponics system can be further improved, scaled up for large-scale production, and contribute significantly to sustainable food production. To fully unlock the potential of aquaponics and meet the increasing demand for nutritious and eco-friendly food, it is essential to prioritize ongoing research, foster collaboration among stakeholders, and prioritize education and knowledge-sharing.

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APPENDIX A

TABLES

Table A.1 Lettuce Height in Traditional Aquaponics

Lettuce Height (cm)					
Plant	**7 Days**	**14 Days**	**21 Days**	**28 Days**	**35 Days**
Plant 1 (Layer 1)	3.1	5	7	13	15.5
Plant 2 (Layer 1)	3	7.5	7.5	14	17
Plant 3 (Layer 1)	3.1	6	7.5	13.5	18.5
Plant 4 (Layer 1)	3.1	7	8	12	15
Plant 5 (Layer 2)	2.9	5.5	7.5	13.5	16
Plant 6 (Layer 2)	3.1	4.5	8.5	11	13.5
Plant 7 (Layer 2)	3.2	6.5	9	13	15
Plant 8 (Layer 2)	3.1	5.5	9.5	12.5	14.5
Plant 9 (Layer 3)	2.8	6	8.5	11.5	13.5
Plant 10 (Layer 3)	3.3	7.5	10	12	14
Plant 11 (Layer 3)	2.8	5.5	8	13	15
Plant 12 (Layer 3)	3.1	7	10.5	12.5	13.5
Average	**3.05**	**6.13**	**8.46**	**12.63**	**15.08**

Table A.2 of Lettuce Height in Smart Aquaponics

Lettuce Height (cm)					
Plant	**7 Days**	**14 Days**	**21 Days**	**28 Days**	**35 Days**
Plant 1 (Layer 1)	3	5	8.5	17.5	29
Plant 2 (Layer 1)	3.1	6.5	9	18	30.5
Plant 3 (Layer 1)	3.1	7	9	16.5	28.5
Plant 4 (Layer 1)	2.9	4	10.5	17	26.5
Plant 5 (Layer 2)	2.8	5	11	16	28
Plant 6 (Layer 2)	3.3	5	9	15.5	27
Plant 7 (Layer 2)	3.2	6.5	9.5	15	24.5
Plant 8 (Layer 2)	3.1	7	10	17	25
Plant 9 (Layer 3)	2.8	3.5	8.5	16.5	26.5
Plant 10 (Layer 3)	3	4.5	9.5	16	24.5
Plant 11 (Layer 3)	3.1	6	9	18	25
Plant 12 (Layer 3)	2.9	7.5	10	16.5	24.5
Average	**11.37**	**5.63**	**9.46**	**16.63**	**26.63**

Table A.3 Lettuce Width in **Traditional Aquaponics**

Lettuce Width (cm)					
Plant	**7 Days**	**14 Days**	**21 Days**	**28 Days**	**35 Days**
Plant 1 (Layer 1)	3.9	4	6	8	11.5
Plant 2 (Layer 1)	5.4	5.5	6.5	7.5	12.5
Plant 3 (Layer 1)	3.7	4	6.5	9	11.5
Plant 4 (Layer 1)	3.4	3.5	5.5	8.5	11
Plant 5 (Layer 2)	4.3	4.5	7.5	7	12
Plant 6 (Layer 2)	3.8	4	7.5	7.5	10
Plant 7 (Layer 2)	3.7	4	9	8	11.5
Plant 8 (Layer 2)	4.4	4.5	7	8	12
Plant 9 (Layer 3)	3.2	3.5	6.5	7	13.5
Plant 10 (Layer 3)	4.4	4.5	9	7.5	14
Plant 11 (Layer 3)	3.8	4	7.5	8.5	14.5
Plant 12 (Layer 3)	5.4	5.5	8.5	9	12
Average	**49.4**	**51.5**	**87**	**95.5**	**146**

Table A.4 Lettuce Width in **Smart Aquaponics**

Lettuce Width (cm)					
Plant	**7 Days**	**14 Days**	**21 Days**	**28 Days**	**35 Days**
Plant 1 (Layer 1)	6.5	6.5	9	13	21
Plant 2 (Layer 1)	2.5	3	6	12.5	22
Plant 3 (Layer 1)	5	5	8.5	15.5	22
Plant 4 (Layer 1)	6.5	7	9	14	21.5
Plant 5 (Layer 2)	5.5	6	9	14.5	24
Plant 6 (Layer 2)	6.8	7	9.5	14	23.5
Plant 7 (Layer 2)	2.7	3	6	13.5	22
Plant 8 (Layer 2)	4.3	4.5	8	16	22
Plant 9 (Layer 3)	5.8	6	11.5	14	21
Plant 10 (Layer 3)	5.1	5.5	11	18.5	27.5
Plant 11 (Layer 3)	4.4	4.5	9	14	22
Plant 12 (Layer 3)	2.9	3	9.5	16.5	27
Average	**58**	**61**	**106**	**176**	**275.5**

Table A.5 of Tilapia Length in **Traditional Aquaponics**

Tilapia Length (cm)					
Fish	**7 Days**	**14 Days**	**21 Days**	**28 Days**	**35 Days**
Fish 1	3.2	3.2	3.4	4.2	4.5
Fish 2	3.1	3.3	3.4	4.4	4.2
Fish 3	3.2	3.2	3.5	3.9	4.5
Fish 4	3.2	3.2	3.5	4	4.6
Fish 5	3.1	3.2	3.6	4	4.2
Fish 6	3	3.1	3.8	4.4	4.5
Fish 7	3.2	3.4	3.4	4.3	4.2
Fish 8	3.2	3.2	3.5	3.9	4.4
Fish 9	3.1	3.1	3.8	4.4	4.3
Fish 10	3.3	3.4	3.8	4.2	4.5
Fish 11	3.2	3.3	3.6	4	4.5
Fish 12	3.1	3.2	3.8	4	4.7
Fish 13	3.3	3.4	3.7	4.2	4.4
Fish 14	3.2	3.3	3.6	3.9	4
Fish 15	3	3	4	3.8	4.6
Fish 16	3.2	3.2	3.9	4.2	4.6
Fish 17	3	3	4.1	4.4	4.2
Fish 18	3.3	3.4	3.6	4	4.7
Fish 19	3	3.1	3.6	4.2	4.3
Fish 20	3.2	3.2	3.8	3.9	4.5
Fish 21	3.2	3.4	3.9	4.1	4.7
Fish 22	3	3.1	3.6	4	4.6
Fish 23	3.3	3.4	4	4.4	4.6
Fish 24	3.2	3.3	3.7	4.2	4.4
Fish 25	3	3	3.4	4.3	4.4
Average	**3.152**	**3.224**	**3.68**	**4.132**	**4.444**

Table A.6 of Tilapia Length in **Smart Aquaponics**

Tilapia Length (cm)					
Fish	**7 Days**	**14 Days**	**21 Days**	**28 Days**	**35 Days**
Fish 1	3.3	3.5	4.5	6.5	10
Fish 2	3.3	3.4	4.2	7	9
Fish 3	3.1	3.3	4.5	6.5	10
Fish 4	3.4	3.5	4.4	8	9
Fish 5	3.3	3.5	4.1	7	8
Fish 6	3.5	3.6	4.5	7	9.5
Fish 7	3.5	3.6	4.3	6	8
Fish 8	3.2	3.4	4.3	5	8.5
Fish 9	3.3	3.5	4.5	7.5	9
Fish 10	3.4	3.5	4.1	6.5	8.5
Fish 11	3.3	3.4	4.3	7	10.0
Fish 12	3.2	3.5	4.4	6.5	11
Fish 13	3.5	3.5	4.3	8	12
Fish 14	3.4	3.5	4.3	7	12
Fish 15	3.2	3.3	4.1	6.5	11
Fish 16	3.5	3.5	3.9	7	9
Fish 17	3.4	3.5	4.5	5	9.5
Fish 18	3.1	3.3	4.5	7	8
Fish 19	3.3	3.5	4.2	6.5	10
Fish 20	3.2	3.5	4.4	6.5	10.5
Fish 21	3.5	3.5	4.7	7	8.0
Fish 22	3.4	3.5	4.3	6.5	9.5
Fish 23	3.4	3.5	4.4	8	10
Fish 24	3.4	3.5	4.1	7	11
Fish 25	3.3	3.5	4.1	6.5	12
Average	**3.336**	**3.472**	**4.316**	**6.76**	**9.72**

APPENDIX B

BILL OF MATERIALS

AUTOMATION			
ITEM	QTY.	UNIT PRICE	AMOUNT
Arduino Mega R3 w/ cable	1	850	850
DF Robot Gravity: Analog PH Sensor/Meter Kit v2	1	2500	2500
Waterproof Temperature Sensor DS181320	1	200	200
AM2320 Digital Temperature & Humidity	1	300	300
DF Robot Gravity: Analog DO Sensor Meter kit for	1	12000	12000
MOD-LM393	1	50	50
ESP32 38pins	1	350	350
4 channel relay module	1	159	159
DS3231 RTC module	1	125	125
Hi Link 12V 220 VAC - 12 VDC	1	180	180
LM25965	1	45	45
2 Channel relay 5V	1	79	79
Power Supply 5A/12V	1	500	500
Power Supply 29A/12V	1	2750	2750
Power Supply	1	2900	2900
Arduino Nano unsoldered w/out cable	2	290	580
Nano unsoldered w/o cable	1	350	350
MPQ 904	1	2800	2800
Raspberry Pi 4B (4 GB)	1	8200	8200
Raspberry Pi Peripherals	1	1472	1472
Motor Driver 43A BTS7960	4	305	1220
ODSCN Webcam	1	549	549
Rapoo Camera 1	1	1199	1199
Rapoo Camera 1	1	1199	1199
Monitor	1	2000	2000
Ultrasonic Sensors	10	49	490
ESP32 38 pins	1	350	350
Grow lights (12m)	1	956	956
Float switch	4	150	600
TOTAL			**44953**

HARDWARE			
ITEM	QTY.	UNIT PRICE	AMOUNT
Duracon with holes	12	250	3000
Duracon Endcap	6	100	600
PVC pipes 1/2	3	70	210
PVC elbow 1/2	11	13	143
PVC clamp	3	4	12
Solvent	2	100	200
Hose 1/2	1	15	15
Vulcaseal	2	220	440
M.D. Bit 5/16	1	180	180
Flat Bar 3/16 x 1 1/2	4	370	1480
Tubular 2x2	1	570	570
5/16 x 3 1/2 w/ washer	9	10	90
5/16 x 3 w/ washer	26	18	468
Auto wire #18	1	385	385
Flat Cord #14	5	65	325
Coupling 1/2	3	15	45
R. Plug	1	35	35
hinges 1x2	3	9	27
paint brush #1	1	30	30
red oxide (n)	1	140	140
mighty bond	2	45	90
sealant clear	4	160	640
bisagra	3	120	360
Paint	1	150	150
paint brush	2	18	36
Automotive wires (120m)	1	384.5	384.5
TOTAL			**10055.5**

OTHERS			
ITEM	QTY.	UNIT PRICE	AMOUNT
Fish tank	1	40120	40120
1L Sodium Hydroxide Solution	1	900	900
Aux Fan 10 PVC 12V	4	680	2720
Bilge Pump	1	1488.3	1488.3
Net Cups (150 pcs)	1	405	405
Automatic Fish Feeder	1	723	723
Acrylic Case (Camera)	1	1300	1300
Acrylic Board	1	1800	1800
Hose for aerator	24	10	240
Acrylic Case (Filter)	1	800	800
Brush Filter	12	54	648
Waterproof Anti fog Film	1	221	221
Chassis	1	3750	3750
TOTAL			**55115.3**
GROSS AMOUNT			110123.8

APPENDIX C

SURVEY FORM

TECHNOLOGICAL UNIVERSITYOF THE PHILIPPINES
Ayala Boulevard, Ermita, Manila
COLLEGE OF ENGINEERING
Electronics Engineering Department

Introduction: The researchers involved in this study are required to administer a questionnaire to evaluate diverse factors and parameters, entitle *"Smart Aquaponics System Using IoT Technology"*.

Instructions: Please rate each criterion and choose one answer if your assessment meets this rating. Select one best answer from the following options. **1** – Strongly Disagree, **2** – Disagree, **3** – Neutral, **4** – Agree, **5** – Strongly Agree**.**

Survey Statement	**Rating**				
	1	**2**	**3**	**4**	**5**
Overall Satisfaction					
1. The Smart Aquaponics System meets my expectations and requirements.					
Usability					
2. The interface and controls of the system were intuitive and easy to use.					
Performance					
3. The system effectively monitored and controlled water quality, temperature, pH, and nutrient levels.					
Design and efficiency					
4. The system design optimally utilizes available space to maximize efficiency.					
5. The system design optimize water recirculation and filtration processes.					
6. The system demonstrated resource efficiency regarding water consumption and nutrient utilization.					
7. The system significantly reduced resource usage compared to traditional farming methods.					
8. The Smart Aquaponics system excels in terms of efficiency, surpassing the performance of the traditional approach.					
Reliability					
9. The system operated reliably without major technical issues or malfunctions.					
10. The system consistently performed as expected and met the set requirements.					
Productivity and Yield					
11. The quality of products (plants and fish) generated by the system was satisfactory.					
12. The quantity of products met expectations and was sufficient.					

APPENDIX D

CODE FOR SENSORS AND PID ALGORITHM

aquaponicsIOT-PID_waterPump

```
/*
 * Program ID: aquaponicsIOT-PID_waterPump.ino
 * Program by:
 *
 * Date Start:
 *   Date End:
 *
 *    Version: 1.00
 *    Modules:
 *
 *
 *
 *
 *
 *      About: Aquaponics IOT with PID controlled water flow for
plant..
 *
 *
 *
 *
 */


//=================================================================
//
// Load libraries.
//
//=================================================================
//
#include <EEPROM.h>


//=================================================================
//
// Pin definitions.
//
//=================================================================
//
const int trigPin = 2;
const int echoPin = 3;
const int setPin = 4;
const int pumpPin = 9;


//=================================================================
//
// Global variables and constants.
//
//=================================================================
```

```
//

// Define the PID constants
double kp = 20.0;
double ki = 0.0;
double kd = 0.0;

// Define the setpoint and other PID variables
double setpoint = 5.0; // in cm
double input = 0.0;
double output = 0.0;
double error = 0.0;
double lastError = 0.0;
double integral = 0.0;
double derivative = 0.0;

// Define the sample time and the PID limits
unsigned long lastTime = 0;
unsigned long sampleTime = 1000;
double minOutput = 0.0;
double maxOutput = 255.0;


void setup(){
  char marker;

  Serial.begin(115200);

  EEPROM.begin();

  // Set the pin modes
  pinMode(trigPin, OUTPUT);
  pinMode(echoPin, INPUT);
  pinMode(pumpPin, OUTPUT);
  pinMode(setPin, INPUT_PULLUP);
  pinMode(13, OUTPUT);

  digitalWrite(13, LOW);

  marker = EEPROM.read(250); // read a byte from EEPROM at
address 0
  if (marker == 'x' || marker == 120){ // check if the byte
contains the character 'x'
    EEPROM.get(0, setpoint); // read the value from the first
address of the EEPROM
  }
  else{
    setpoint = 10;
    EEPROM.write(250, 'x');
    EEPROM.put(0, setpoint); // save the value to the first
address of the EEPROM
    delay(100);
```

```
    Serial.println("Initial set point saved.");
  }
}


void loop(){
  double doublePWM = 0.0;

  // Calculate the time since the last sample
  unsigned long now = millis();
  unsigned long timeChange = now - lastTime;

  // Check if it is time to update the PID output
  // if (timeChange >= sampleTime){
    // Read the input from the ultrasonic sensor

    digitalWrite(trigPin, LOW);
    delayMicroseconds(2);
    digitalWrite(trigPin, HIGH);
    delayMicroseconds(10);
    digitalWrite(trigPin, LOW);
    long duration = pulseIn(echoPin, HIGH);
    input = duration * 0.034 / 2.0; // in cm

    // Set button pressed, not the set point and save to memory.
    if (digitalRead(setPin) == LOW){
      delay(500);
      setpoint = input;
      EEPROM.write(250, 'x');
      EEPROM.put(0, setpoint); // save the value to the first
address of the EEPROM
      for (int i = 0; i < 4; i++ ){
        digitalWrite(13, HIGH);
        delay(100);
        digitalWrite(13, LOW);
        delay(100);
      }
      digitalWrite(13, LOW);
    }

    // Serial.print("input:");
    // Serial.println(input);

    // Calculate the error
    // error = input - setpoint;

    // Calculate the integral and derivative terms
    // integral += error * timeChange;
    // derivative = (error - lastError) / timeChange;

    // Calculate the PID output
    // output = kp * error + ki * integral + kd * derivative;
```

```
    if (input < setpoint) input = setpoint;

    // Limit the output to the specified range
    doublePWM = mapDouble(input, setpoint, setpoint + /* pipe
depth in cm*/ 5, 60, 255);

    Serial.println(doublePWM);

    // Set the output to the pump
    analogWrite(pumpPin, doublePWM);

    // Update the last error and time
    // lastError = error;
    // lastTime = now;
  // }
}


double mapDouble(double x, double in_min, double in_max, double
out_min, double out_max) {
  // Handle the special case when the input value is outside the
input range
  if (x <= in_min) {
    return out_min;
  }
  if (x > in_max) {
    return out_max;
  }

  // Perform the linear mapping
  double mappedValue = (x - in_min) * (out_max - out_min) /
(in_max - in_min) + out_min;
  return mappedValue;
}
```

aquaponicsIOT-PID

```
/*
 * Program ID: aquaponicsIOT-PID.ino
 * Program by:
 *
 * Date Start:
 *   Date End:
 *
 *    Version: 1.00
 *    Modules:
 *
 *
```

```
 *
 *
 *
 *      About: Aquaponics IOT with PID controlled water flow for
plant..
 *
 *
 *
 *
 */

//=================================================================
//
// Load libraries.
//
//=================================================================
//
#include <Arduino.h>
#include "DFRobot_PH.h"
#include <EEPROM.h>
#include <OneWire.h>
#include <DallasTemperature.h>
#include <dht.h>
#include <LiquidCrystal_I2C.h>
#include <LibPrintf.h>


//=================================================================
//
// Pin definitions.
//
//=================================================================
//
#define DO_PIN        A0
#define PH_PIN        A1
#define ONE_WIRE_BUS  2


//=================================================================
//
// Macros definitions.
//
//=================================================================
//
#define CAL1_V (1976) // mv  DO Calibration factor.
#define CAL1_T (25)   // â„ƒ


//=================================================================
//
// Object creation.
```

```
//
//=================================================================
//
OneWire oneWire(ONE_WIRE_BUS);
DallasTemperature waterTemp(&oneWire);    // Temperature probe in
water.
DFRobot_PH ph;                            // pH Sensor.
LiquidCrystal_I2C lcd(0x27,20,4);         // LCD instance.
dht DHT;                                  // Temperature and
humidity sesor.


//=================================================================
//
// Global variables and constants.
//
//=================================================================
//
byte Celcius[8] = {0x18,0x18,0x06,0x09,0x08,0x09,0x06,0x00};

// Dissolved oxygen constants.
const uint16_t DO_Table[41] = {
    14460, 14220, 13820, 13440, 13090, 12740, 12420, 12110,
11810, 11530,
    11260, 11010, 10770, 10530, 10300, 10080, 9860, 9660, 9460,
9270,
    9080, 8900, 8730, 8570, 8410, 8250, 8110, 7960, 7820, 7690,
    7560, 7430, 7300, 7180, 7070, 6950, 6840, 6730, 6630, 6530,
6410};

// ADC constants.
const int Vref = 5000;        // Voltage reference in millivolt.
const int ADC_Res = 1024;     // Analog to digital conversion
resolution.

// Sensors treshold.
const float DOTreshold = 4.5;
const float airTemperatureTreshold = 25;
const int pHTreshold = 7;

// pin assignment.

const int dhtPin = 3;         // Pin where the Temperature and
Humidity sensor is connected.
const int lightSensPin = 4;   // Pin where the light sensor is
connected.
const int bubblePin = 22;     // Pin where the relay for the
Aerator is connected.
const int growLightPin = 24;  // Pin where the relay for the
growligh is connected.
const int pHPumpPin = 26;     // Pin where the relay for the
water pump for pH correction is connected.
```

```
const int fanPin = 28;        // Pin where the relay for the
intake/exhaust fans are connected.


void setup(){
  Serial.begin(115200);
  Serial1.begin(9600);

  ph.begin();
  waterTemp.begin();

  pinMode(lightSensPin, INPUT);
  pinMode(bubblePin, OUTPUT);
  pinMode(growLightPin, OUTPUT);
  pinMode(pHPumpPin, OUTPUT);
  pinMode(fanPin, OUTPUT);

  digitalWrite(bubblePin, HIGH);
  digitalWrite(growLightPin, HIGH);
  digitalWrite(pHPumpPin, HIGH);
  digitalWrite(fanPin, HIGH);

  lcd.init();
  lcd.createChar(1, Celcius);
  lcd.backlight();
  lcd.clear();
                                 //          1
                                 //01234567890123456789
  lcd.setCursor(0,0); lcd.print(F(" AQUAPONIC MONITOR  "));
  lcd.setCursor(0,1); lcd.print(F("===================="));
  lcd.setCursor(0,2); lcd.print(F("Warming up. Please  "));
  lcd.setCursor(0,3); lcd.print(F("wait...             "));

  delay(5000);
  Serial.println("Sensor readout.");
}


void loop(){

  float doADC_Raw = 0;
  float doADC_Voltage = 0;
  float phADC_Raw = 0;
  float phADC_Voltage = 0;
  float airTemperature = 0.00;

  float waterTemperature = 0.00;
  float dissolvedOxygen = 0.00;
  int phValue = 0;

  // Read sensors.
  waterTemp.requestTemperatures();
```

```
  waterTemperature = waterTemp.getTempCByIndex(0);
  doADC_Raw = analogRead(DO_PIN);
  phADC_Raw = analogRead(PH_PIN);
  DHT.read22(dhtPin);
  airTemperature = DHT.temperature; // Gets the values of the
temperature

  // Process sensor raw redings.
  doADC_Voltage = Vref * doADC_Raw / ADC_Res;
  phADC_Voltage = Vref * phADC_Raw / ADC_Res;

  dissolvedOxygen = readDO(doADC_Voltage,
(uint8_t)waterTemperature);  // convert voltage to DO with
temperature compensation
  phValue = ph.readPH(phADC_Voltage, waterTemperature);       //
convert voltage to pH with temperature compensation

  printf("H2O Temp %.2f, DO %.2f, pH %i, Air Temp %.2f\n",
waterTemperature, dissolvedOxygen, phValue, airTemperature);

                                //          1
                                //01234567890123456789
  lcd.setCursor(0,0); lcd.print(F(" AQUAPONIC MONITOR  "));
  lcd.setCursor(0,1); lcd.print(F("                    "));
  lcd.setCursor(0,2); lcd.print(F("                    "));
  lcd.setCursor(0,3); lcd.print(F("                    "));

  lcd.setCursor(0,1); lcd.print(dissolvedOxygen);
  lcd.setCursor(0,2); lcd.print(phValue);
  lcd.setCursor(0,3); lcd.print(waterTemperature); lcd.print("
"); lcd.write(1);

  lcd.setCursor(10,1); lcd.print(airTemperature); lcd.print(" ");
lcd.write(1);


//=================================================================
//
  // Update firebase throug ESP32.
//

//=================================================================
//
  if (Serial1.available() > 0){   // Check for ESP32's request.
    while (Serial1.available()) Serial1.read();

    Serial1.print(waterTemperature);
    Serial1.print(',');
    Serial1.print(dissolvedOxygen);
    Serial1.print(',');
    Serial1.print(phValue);
    Serial1.print(',');
```

```
    Serial1.print(airTemperature);
    Serial1.print(',');
    Serial1.println(0);
  }



//================================================================
//
  // Actuators control.
//

//================================================================
//

  // Growlight
  if (digitalRead(lightSensPin) == 1){
    digitalWrite(growLightPin, LOW);
  }
  else{
    digitalWrite(growLightPin, HIGH);
  }

  // Bubble  for dissolved oxygen.
  if (dissolvedOxygen < DOTreshold){
    digitalWrite(bubblePin, LOW);
  }
  else{
    digitalWrite(bubblePin, HIGH);
  }

  // Water pump for pH Correction.
  if (phValue < pHTreshold){
    digitalWrite(pHPumpPin, LOW);
  }
  else{
    digitalWrite(pHPumpPin, HIGH);
  }

  // Air temparature
  if (airTemperature > airTemperatureTreshold){
    digitalWrite(fanPin, LOW);
  }
  else{
    digitalWrite(fanPin, HIGH);
  }

  delay(2000);
}


// Read DO sensor function.
```

```
int16_t readDO(uint32_t voltage_mv, uint8_t temperature_c){
  uint16_t V_saturation = (uint32_t)CAL1_V + (uint32_t)35 *
temperature_c - (uint32_t)CAL1_T * 35;
  return (voltage_mv * DO_Table[temperature_c] / V_saturation) /
1000;
}
```

aquaponicsIOT-PIDESP32

```
/*
 * Program ID: aquaponicsIOT-PIDESP32.ino
 * Program By:
 * Date Start:
 *   Date End:
 *
 *   Revision: Ver. 1.0
 *
 *    Modules: ESP32
 *
 *       Note: Requires the Arduino Mega.
 *
 */

//=================================================================
//
// Load libraries.
//
//=================================================================
//
#include <HardwareSerial.h>
#include <WiFi.h>
#include <WiFiClient.h>
#include <Firebase_ESP_Client.h>
#include "addons/TokenHelper.h"
#include "addons/RTDBHelper.h"


//=================================================================
//
// Macros.
//
//=================================================================
//
#define debug(x)      Serial.print(x)
#define debugln(x)    Serial.println(x)
#define debugfl(x,y)  Serial.print(x,y)


//=================================================================
//
// GPIO pin assigment.
```

```
//
//==================================================================
//
const int WiFiLED = 33;


//==================================================================
//
// Class/Object creation.
//
//==================================================================
//
TaskHandle_t Task2;
FirebaseData fbdo;
FirebaseAuth auth;
FirebaseConfig config;
HardwareSerial fromMega(1);


//==================================================================
//
// Firebase data and credentials.
//
//==================================================================
//
const char* DATABASE_URL = "https://aquaponics-data-project-
default-rtdb.firebaseio.com/";
const char* API_KEY = "AIzaSyABJLUeCY0rOAzF9Nbb2SQ7ujA7pOf8IAY";


//==================================================================
//
// WiFi credentials.
//
//==================================================================
//
const char* ssid = "aquaponics";
const char* password = "aquaponics1234";


//==================================================================
//
// Constant variables.
//
//==================================================================
//


//==================================================================
//
// Global variables.
//
```

```
//=================================================================
//
bool signupOK = false;


void setup(){
  Serial.begin(115200);
  fromMega.begin(9600, SERIAL_8N1, 18, 19);

  debugln("Setup starts.");

  delay(500);

  pinMode(WiFiLED, OUTPUT);

  digitalWrite(WiFiLED, LOW);

  // Connect to WiFi, nothing will happen if not connected.
  WiFi.mode(WIFI_STA);
  WiFi.begin(ssid, password);
  debugln("Connecting to WiFi ..");
  while (WiFi.status() != WL_CONNECTED) {
    debug('.');
    delay(500);
  }

  debugln(WiFi.localIP());
  digitalWrite(WiFiLED, HIGH);

  if (WiFi.status() == WL_CONNECTED){
    config.api_key = API_KEY;   // Assign the api key.
    config.database_url = DATABASE_URL;   // Assign the RTDB URL.

    /* Sign up */
    if (Firebase.signUp(&config, &auth, "", "")){
      debugln("Ok, database conneted.");
      signupOK = true;
    }
    else{
      debug("%s\n");
      debug(config.signer.signupError.message.c_str());
    }

    /* Assign the callback function for the long running token
generation task */
    config.token_status_callback = tokenStatusCallback; //see
addons/TokenHelper.h

    Firebase.begin(&config, &auth);
    Firebase.reconnectWiFi(true);
  }
```

```
  /*
   * Create a task that will be executed in the Task2code()
function,
   * with priority 1 and executed on core 1.
   */
  xTaskCreatePinnedToCore(
                    Task2code,   /* Task function. */
                    "Task2",     /* name of task. */
                    10000,       /* Stack size of task */
                    NULL,        /* parameter of the task */
                    1,           /* priority of the task */
                    &Task2,      /* Task handle to keep track of
created task */
                    0);          /* pin task to core 1 */
  delay(500);

  debugln("Setup ends.");
}


void loop(){

  String MyS = "35.5,5.5,7,40.5";
  String array[10];
  String token = "";
  int MyP = 0;
  int MyI = 0;
  int index = 0;
  bool isOnline = false;

  // Wait for mega to send us a string of values.
  while (true){
    // Tell mega that we are ready to receive data. Just send
numbeer 1.
    fromMega.println(1);

    if (fromMega.available() > 0){
      MyS = fromMega.readString();
      break;
    }

    delay(1000);
  }

  // Process incoming string.
  while (true){
    if(MyI>=0){
      MyI = MyS.indexOf(",", MyP);
      token = MyS.substring(MyP, MyI);
      MyP = MyI + 1;
      array[index] = token;
      Serial.println(array[index]);
```

```
      index = index + 1;
    }

    if (index >= 4){
      break;
    }
  }

  // Always check the internet connection.
  if (WiFi.status() != WL_CONNECTED){
    debugln("Disconnected");
  }
  else{
    isOnline = true;
  }


//================================================================
//
  // Update on-line database.
//

//================================================================
//
  if (Firebase.ready() && signupOK && isOnline){

    // Write water temperature.
    token = array[0];
    if (Firebase.RTDB.setString(&fbdo,
"aquaponics/waterTemperature", token)){
      debugln("h2o Okay");
    }
    else{
      debugln(fbdo.errorReason());
      isOnline = false;
    }

    // Write dissolved oxygen.
    token = array[1];
    if (Firebase.RTDB.setString(&fbdo,
"aquaponics/dissolvedOxygen", token)){
      debugln("Oxygen Okay");
    }
    else{
      debugln(fbdo.errorReason());
      isOnline = false;
    }

    // Write pH.
    token = array[2];
    if (Firebase.RTDB.setString(&fbdo, "aquaponics/phValue",
token)){
```

```
      debugln("pH Okay");
    }
    else{
      debugln(fbdo.errorReason());
      isOnline = false;
    }

    // Write air temperature.
    token = array[3];
    if (Firebase.RTDB.setString(&fbdo,
"aquaponics/airTemperature", token)){
      debugln("air Okay");
    }
    else{
      debugln(fbdo.errorReason());
      isOnline = false;
    }
  }



//=================================================================
//
  // For displaying to tne serial monitor fr debugging.
//

//=================================================================
//

  debug("H2O Temp: "); debug(array[0]);
  debug('\t');
  debug("Oxygen: "); debug(array[1]);
  debug('\t');
  debug("pH: "); debug(array[2]);
  debug('\t');
  debug("air Temp: "); debugln(array[3]);

  delay(2000);

}


/*
 * Task2code: WiFi and data connection indicator.
 */
void Task2code(void * pvParameters ){
  while(true){

    if (WiFi.status() != WL_CONNECTED) {
      digitalWrite(WiFiLED, LOW);
      debugln("Connection lost, reconnecting...");
```

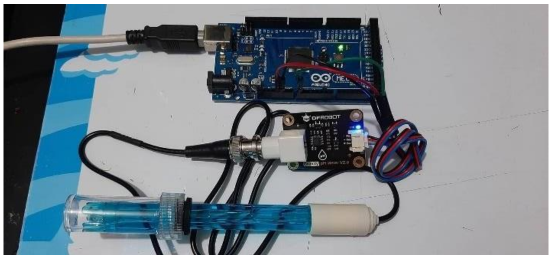
```
      WiFi.begin(ssid, password);
      while (WiFi.status() != WL_CONNECTED) {
        delay(1000);
        debugln("Connecting to WiFi...");
      }
    }
    else{
      digitalWrite(WiFiLED, HIGH);
    }

    delay(100);
  }
}
```

APPENDIX E

PROGRESS DOCUMENTATION

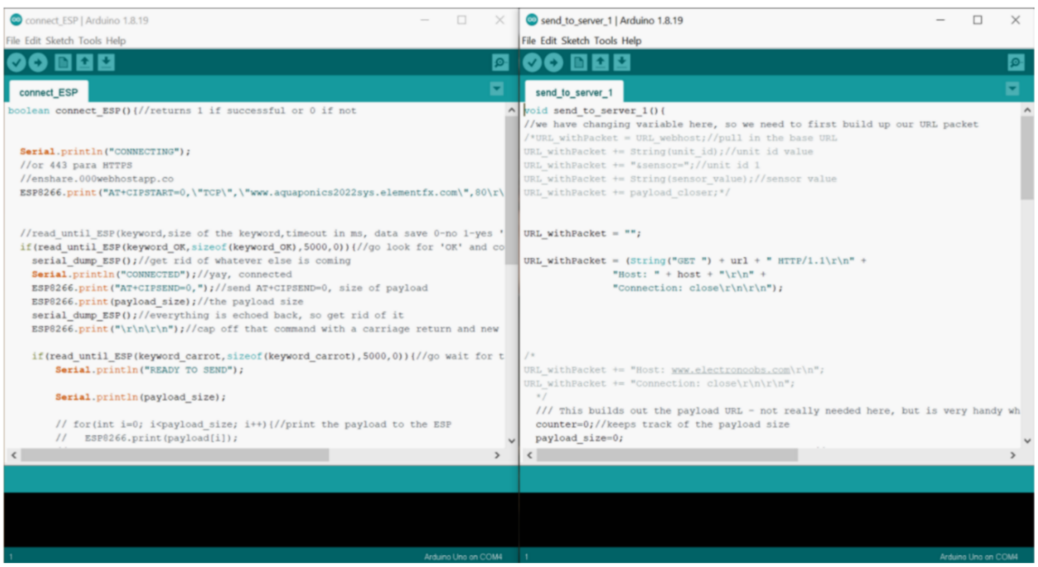
Canvassing and Acquiring Materials

pH sensor calibration

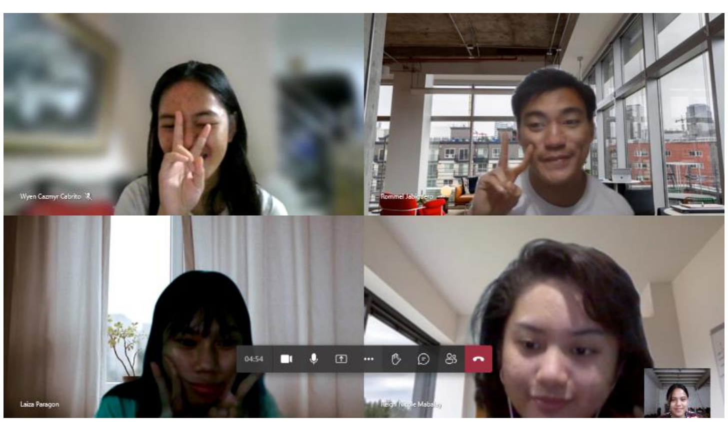


DO sensor calibration

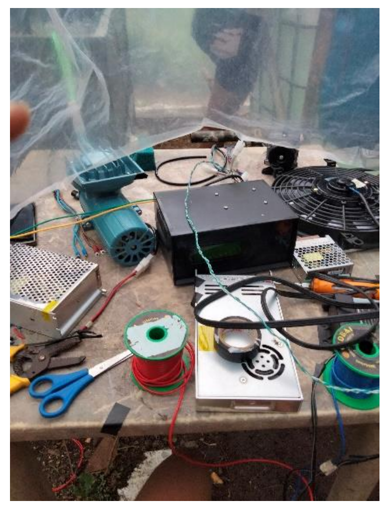
The Arduino Mega to ESP 32 connection is stable.



Group Meetings



Construction of the Whole system



Measuring the sizes of Tilapia and Lettuce

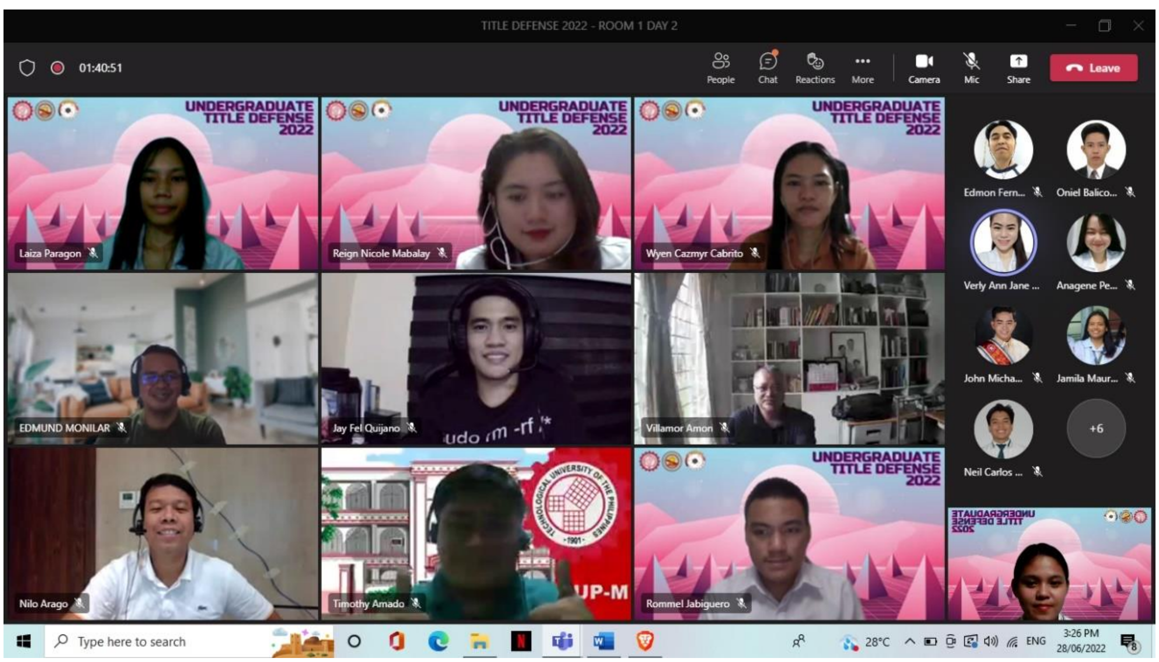
Enclosing the wirings inside the chassis

Installed waterproof LED strips for the plants.

The whole setup of Smart Aquaponics System


Topic Defense

Title Defense



Progress Presentation

Pre-Final Defense

Appreciate

Final Defense

APPENDIX F

PROPONENT'S INFORMATION

WYEN CAZMYR C. CABRITO

ELECTRONICS ENGINEERING STUDENT

Contact

Phone

09472320180

Email

wyencazmyr.cabrito@tup.edu.ph

Address

Blk 83 lot 16 Mabuhay Homes 2000
Salawag Dasmarinas Cavite

Personal Profile Statement

A passionate and hardworking Electronics Engineering student who believes everything can be achieved by working on it with enthusiasm. Can adapt with the environment and easy to get along with.

Education

2019 - Present

Technological University of the Philippines - Manila

Bachelor of Science in Electronics Engineering

- Member of Organization of Electronics Engineering Students (2019-Present)

2017 - 2019

University of Perpetual Health System Dalta - Molino Campus

- Studied under Academic track: Science, Technology, Engineering and Mathematics (STEM)

2013-2017

Bacoor National High School - Villa Maria Annex

Conferences and Trainings Attended

- **ECE Fields Seminar 2019 - "Amplify the Future"**
- **Arduino Day 2021!**
- **Webinar (from DICT) - Discover the new trends: Video Conferencing Tools to Increase Productivity**
  Webinar: Real-Life Application of Mathematics and Physics
- **Master IP Addressing and Subnetting for CCNA (Free Course Training)**
- **MNET: Cisco Routing Basics MNET (Free Course Training)**

ROMMEL A. JABIGUERO

ELECTRONICS ENGINEERING STUDENT

Contact

Phone

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Email

rommeljabiguero7@gmail.com

Address

9 Sisa St. Acacia Malabon City

Skills

- **Fast learner** and eager to learn new things
- **Open-minded** and accepts criticism
- Good in written and verbal communication
- Able to work **independently** or as part of a team
- Proficient in **Microsoft Office**
  - Word
  - Excel
  - Powerpoint
  - Internet
  - etc.

Personal Profile Statement

An Electronics Engineer in the making, Loves challenging and healthy environment where I can maximize and be able to utilize my skills, knowledge and educational background efficiently for organizational, personal and professional growth.

Education

2019 - Present

Technological University of the Philippines - Manila

Bachelor of Science in Electronics Engineering

- Member of Organization of Electronics Engineering Students (2019-Present)
- Qualified Dean's lister (2019-Present)
- **Dost Scholar -** R.A. 7687 (2019-Present)

2017 - 2019

Arellano University Jose Rizal Campus - Senior High School

- Academic excellence award, with honors (2017-2019)
- Best in Research - Science Investigatory Project (2019)
- S.T.E.M. Club External Vice President (2018-2019)

2013-2017

Tinajeros National High School - Junior High School

- Graduated with Academic excellence award, with honors
- MTAP mathematics quizzer
- Participated on UP rocket launching contest (2017)
- Student Teacher Counterpart (2015-2016)

Work Experience

2022

TRI-POWER Sales and Electrical Services - Quezon City
Internship

2019

SJM Air Conditioning and Refrigeration Maintenance - Malabon City
Air Condition maintenance Helper

Trainings and Certifications

- Certified and Completed ten (10) Seminars for Graduating Class Students of TUP-Manila ECE department:
  - Next Generation Qualification: The Role of Physics of Failure and Artificial Intelligence in Electronics
  - Unleashing the Power of Data: SAP Analytics Cloud Workshop
  - STEP UP: Paradigmatic in Today's Semiconductor Industry
  - Accessing New Avenues: Exploring the Role of Open RAN in Today's Communication Technology
  - The data Revolution: Navigating the Importance of Data Science in Today's world
  - APP Dev Insider: Behind the Scenes of Application Development Using Flutter
  - Connecting the Unconnected: Exploring the Potential of "Lorawan" for a Smarter World
  - Unlocking the Limitless: Getting Cloud Powered with Google Cloud Platform
  - Hack-Proof your Digital Life : A Beginners Guide to Information Security
  - Building Blocks of IC Design: A Primer for Graduating Electronics Engineering Students
- Master IP addressing & Subnetting for CCNA - MNET IT(May 2022)
- Telecommunications looking for future ECEs - OECES TUP Manila Branch Webinar (January 2022)
- Intro to Arduino Programming - IEEE TUP Manila Branch Webinar (December 2022)

REIGN NICOLE G. MABALAY

ELECTRONICS ENGINEERING STUDENT

Contact

Phone

09760310833

Email

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Address

454 Purok 7, Hulo St., Brgy. Sinasajan, Peñaranda, Nueva Ecija

Skills

- Basic Knowledge on Matlab , NI Multisim, Phyton Programming Languages
- Basic Knowledge in Web Development
- Work under pressure
- Fast learner and eager to learn new things
- Critical thinking skills
- Open-minded and accepts criticism
- Able to work independently or as a part of a team
- Communication skills
- Proficient in Microsoft Office

Personal Profile Statement

Soon-to-be Electronics Engineering Graduate, I am an independent and self-motivated student driven by a passion for problem-solving and project management. Seeking hands-on experience to apply my skills, knowledge, and organizational abilities to enhance quality, cost, and time metrics. Committed to making a meaningful impact, I am dedicated to continuous learning and growth in the field of electronics engineering.

Education

2019 - Present

Technological University of the Philippines - Manila

Bachelor of Science in Electronics Engineering
- Member of Organization of Electronics Engineering Students (2019-Present)

2017 - 2019

Village Montessori School - Senior High School

- Class Valedictorian (with Honors, 2017-2019)
- Work Immersion at LGU Rural Health Center Gapan City
- Best in Math
- Outstanding Performance in Research Innovation
- 2nd Place in DSSPC Collaborative and Desktop Publishing (2018 - 2019)
- 5th Place in DSSPC Photojournalism (2017 - 2018)
- 4th Place in DSSPC Collaborative and Desktop Publishing (2017 - 2018)

2013-2017

Westside Montessori Centrum - Junior High School

- Graduated with High Honors and Outstanding Award in Science
- 3rd Honors (2014 - 2016)
- 2nd Honors (2013 - 2014)
- 2nd Place in Science Quiz Bee (2013 - 2014)

Work Experience

2022 — Radix Telecom Phils., Ind., Inc.
Internship

2018 - 2019 — LGU Rural Health Center Gapan City
Immersion

Honors / Certifications

- Outstanding Performance in Research Innovation (2018-2019)
- Graduated with High Honors and Outstanding Award in Science (2016-2017)
- TechEX: Fundamentals of Cloud Computing & Exploring Azure DevOps
- Discover the New Trends: Video Conferencing Tools to Increase Productivity
- A Research Paper Writing Seminar
- Real-life Application of Mathematics and Physics
- Within Biomedical Engineering and Biosafety
- 5G and Its Spectrum
- MNET: Cisco Routing Basics
- MNET: Master IP Addressing and Subnetting for CCNA
- 2023 CSE - PPT Subprofessional Level Passer
- Certified and Completed ten (10) Seminars for Graduating Class Students of TUP-Manila ECE department:

\- Next Generation Qualification: The Role of Physics of Failure and Artificial Intelligence in Electronics
\- Unleashing the Power of Data: SAP Analytics Cloud Workshop
\- STEP UP: Paradigmatic in Today's Semiconductor Industry
\- Accessing New Avenues: Exploring the Role of Open RAN in Today's Communication Technology
\- The data Revolution: Navigating the Importance of Data Science in Today's world
\- APP Dev Insider: Behind the Scenes of Application Development Using Flutter
\- Connecting the Unconnected: Exploring the Potential of "Lorawan" for a Smarter World
\- Unlocking the Limitless: Getting Cloud Powered with Google Cloud Platform
\- Hack-Proof your Digital Life : A Beginners Guide to Information Security
\- Building Blocks of IC Design: A Primer for Graduating Electronics Engineering Students

LAIZA F. PARAGON

ELECTRONICS ENGINEERING STUDENT

Contact

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Email

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Address

126 P. Manahan St., Brgy. 31, Pasay City

Skills

- Computer Skills: Microsoft Office Applications
- Technical Skills: Basic Electronics and Communication; Troubleshooting; Soldering
- Hard-working, Fast Learner, Active listener and Flexible
- Organized and Efficient

Personal Profile Statement

Electronics engineering student with a passion for applying knowledge and skills. Strong foundation in electronics principles, hands-on project experience, and problem-solving abilities. Seeking a role to contribute to real-world challenges and make a meaningful impact in the field. Motivated, quick learner, and eager to collaborate in a dynamic environment for technological advancements.

Education

2019 - Present

Technological University of the Philippines - Manila - College

Bachelor of Science in Electronics Engineering

- Member of Organization of Electronics Engineering Students (2019-Present)
- **Dost Scholar -** R.A. 7687 (2019-Present)

2017 - 2019

Philippine Christian University - Manila

Senior High School

- Graduated with High honors

2013-2017

Camiling School for Home Industries - Junior High School

- Graduated with honors
- Supreme Student Government Officer (PIO) (2015-2016)
- Contributor to the School Newspaper (2015-2017)

Work Experience

2022

Radix Telecom Phils., Ind., Inc.
Internship

Trainings and Certifications

- Certified and Completed ten (10) Seminars for Graduating Class Students of TUP-Manila ECE department:
  - Next Generation Qualification: The Role of Physics of Failure and Artificial Intelligence in Electronics
  - Unleashing the Power of Data: SAP Analytics Cloud Workshop
  - STEP UP: Paradigmatic in Today's Semiconductor Industry
  - Accessing New Avenues: Exploring the Role of Open RAN in Today's Communication Technology
  - The data Revolution: Navigating the Importance of Data Science in Today's world
  - APP Dev Insider: Behind the Scenes of Application Development Using Flutter
  - Connecting the Unconnected: Exploring the Potential of "Lorawan" for a Smarter World
  - Unlocking the Limitless: Getting Cloud Powered with Google Cloud Platform
  - Hack-Proof your Digital Life : A Beginners Guide to Information Security
  - Building Blocks of IC Design: A Primer for Graduating Electronics Engineering Students
- Master IP addressing & Subnetting for CCNA
- MNET: Cisco Routing Basic MNET
- A Research Paper Writing Seminar
- Discover the New Trends: Video Conferencing Tools to Increase Productivity
- How to Find Your Market Craft an Irresistible Offer for Aspiring Freelancers
- 5G and Its Spectrum
- TechEx: Exploring Philippine Space Technology
- Real-Life Application of Mathematics and Physics

LARIELYN J. RUAZOL

ELECTRONICS ENGINEERING STUDENT

Contact

Phone
09657782279

Email
ruazollarielyn32@gmail.com

Address
Cavinti, Laguna

Skills

- Arts, Crafts and Design
- Basic knowledge in SketchUp, Tinkercad, Cadense Virtuoso, and Verilog
- Computer Literacy
- Strong Communication
- Fast Learner

Personal Profile Statement

Soon to be a BS Electronics Engineering graduate. A person who is driven by excellence and possesses an outstanding ability for coming up with creative and practical ideas that will help the operations of the company succeed. I am looking for a job opportunity that will take advantage of this ability.

Education

2019 - Present

Technological University of the Philippines - Manila

Bachelor of Science in Electronics Engineering

- Member of Organization of Electronics Engineering Students (2019-Present)

2017 - 2019

AMA Computer College Sta Cruz Campus

- Studied under Academic track: Science, Technology, Engineering and Mathematics (STEM)

2013-2017

Liceo de Cavinti

Work Experience

2018 - present

SANGGUNIANG KABATAAN
Barangay Labayo - Cavinti, Laguna
SK Secretary

2022

On-The-Job Training at Municipality of Cavinti
Municipal Engineering Office

2017 - 2019

PESO Management and TESDA: Municipal Hall of Cavinti, Laguna
SPES Worker
Special Program for Employment of Students

2018

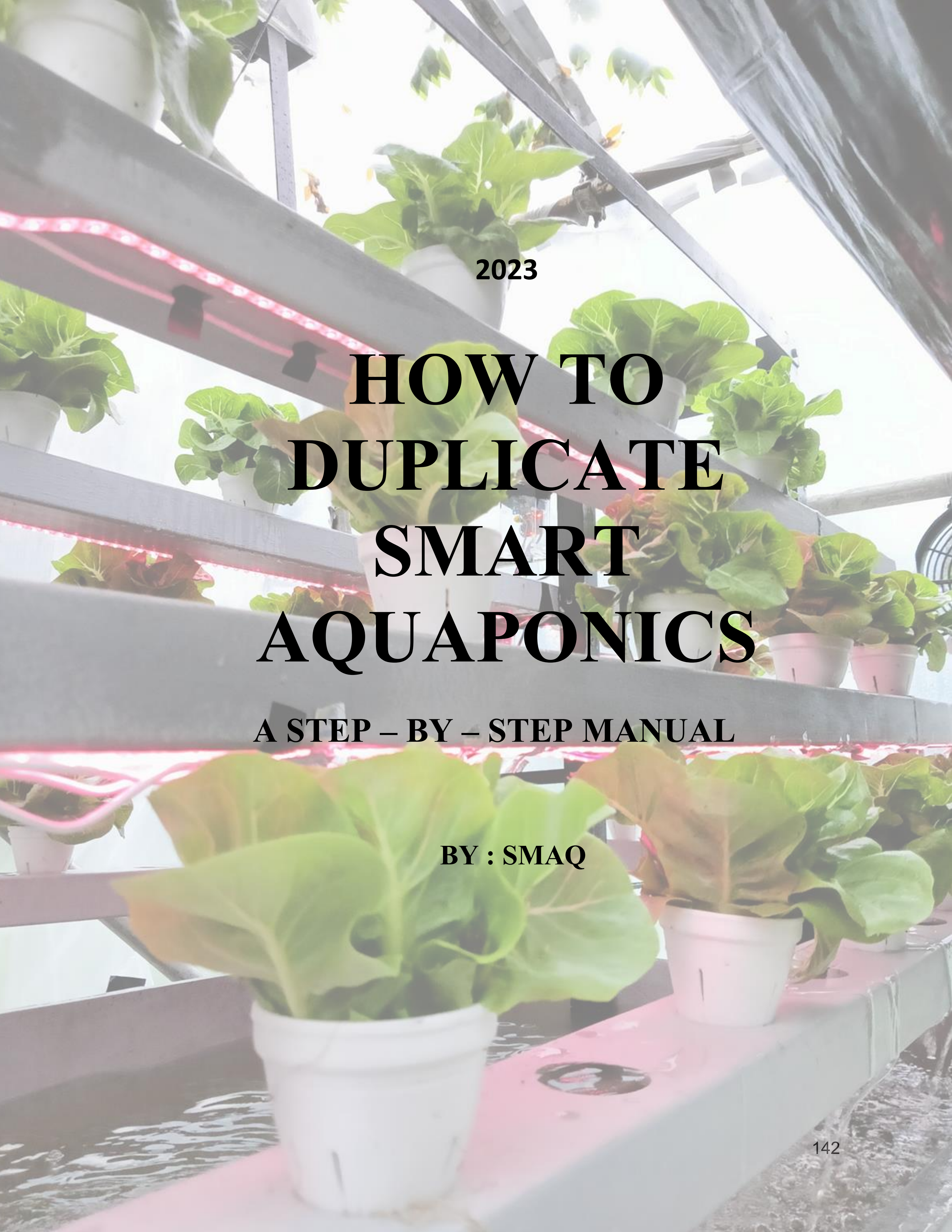
WORK IMMERSION at Municipality of Cavinti
Municipal Accounting Office

Honors / Trainings / Certifications

- ECE Fields Seminar 2019 - "Amplify the Future"
- Webinar (from DICT) - Discover the new trends: Video Conferencing Tools to Increase Productivity
- Webinar: Real-Life Application of Mathematics and Physics
- Master IP Addressing and Subnetting for CCNA (Free Course Training)
- MNET: Cisco Routing Basics MNET (Free Course Training)
- Diving into the Depths of Understanding Circuits: Exploring and Designing a Novel Dual Edge Trigger Flip-flop 2023
- SK Orientation Seminar on Financial Management and Updating of the Comprehensive Youth Development (Baguio City) 2022
- Gawad Parangal 2018 - 2022 (Outstanding Sangguniang Kabataan)
- Gawad Parangal 2022 (Best in Committee Project in Health)
- Iskolar ng Laguna (Gov. Ramil L. Hernandez) 2019 - 2023
- Iskolar ng Bayan (Mayor Arrantlee Arroyo) 2019 - 2023

ANNEX I

HOW TO DUPLICATE THE SYSTEM



2023

HOW TO DUPLICATE SMART AQUAPONICS

A STEP – BY – STEP MANUAL

BY : SMAQ

Manual on How to Duplicate the SMART AQUAPONICS SYSTEM

To make Smart Aquaponics System, it is first necessary to know what materials will be needed to be able to achieve a good functioning product. These are the materials to consider:

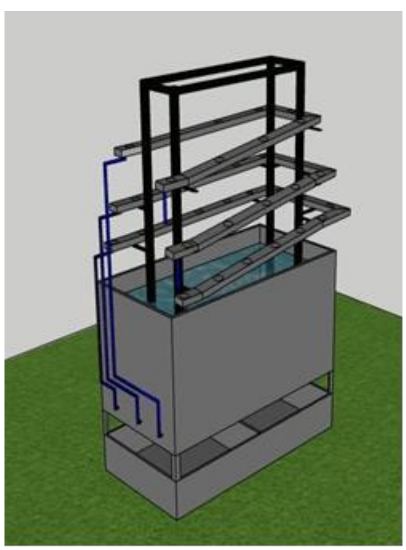
Automation	Unit	Quantity
Arduino Mega R3 w/ cable	pcs	1
DF Robot Gravity: Analog PH	pcs	1
Waterproof Temperature	pcs	1
AM2320 Digital Temperature	pcs	1
DF Robot Gravity: Analog	pcs	1
MOD-LM393	pcs	1
ESP32 38pins	pcs	1
4 channel relay module	pcs	1
DS3231 RTC module	pcs	1
Hi Link 12V 220 VAC - 12	pcs	1
LM25965	pcs	1
2 Channel relay 5V	pcs	1
Power Supply 5A/12V	pcs	1
Power Supply 29A/12V	pcs	1
Power Supply	pcs	1
Arduino Nano unsoldered	pcs	1
Nano unsoldered w/o cable	pcs	1
MPQ 904	pcs	1
Raspberry Pi 4B (4 GB)	pcs	1
Raspberry Pi Peripherals	pcs	1
Motor Driver 43A BTS7960	pcs	1
ODSCN Webcam	pcs	1
Rapoo Camera 1	pcs	1
Monitor	pcs	1
Ultrasonic Sensors	pcs	3
Grow lights (12m)	pcs	4
Float switch	pcs	1

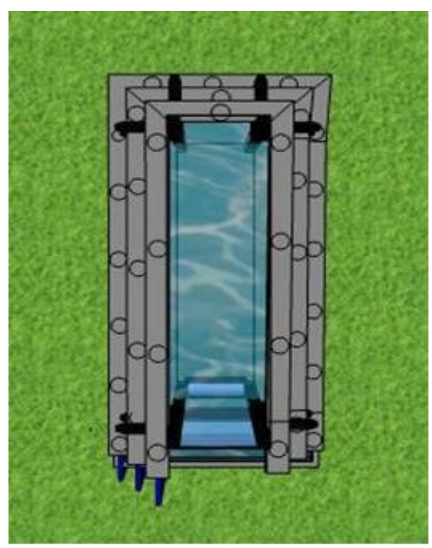
Hardware	Unit	Quantity
Fish tank (Fiber Glass)	pcs	1
1L Sodium Hydroxide	pcs	1
Aux Fan 10 PVC 12V	pcs	4
Bilge Pump	pcs	4
Net Cups	pcs	35
Automatic Fish Feeder	pcs	1
Acrylic Case (Camera)	pcs	1
Acrylic Board	pcs	1
Hose for aerator	pcs	3
Acrylic Case (Filter)	pcs	1
Brush Filter	pcs	12
Waterproof Anti fog Film	pcs	1
Duracon with holes	pcs	15
Duracon Endcap	pcs	3
PVC pipes 1/2	pcs	2
PVC elbow 1/2	pcs	15
Standard L-Shape Shelf	pcs	18
Tubular Steel 2x2	pcs	2
5/16 x 3 1/2 w/ washer	pcs	10
5/16 x 3 w/ washer	pcs	10
Auto wire #18	pcs	4
Flat Cord #14	pcs	2
Coupling 1/2	pcs	3
R. Plug	pcs	1
hinges 1x2	pcs	3
Automotive wires (120m)	pcs	4

A Smart Aquaponics system combines aquaculture (fish farming) with hydroponics (plant growth without soil) in a symbiotic environment. The system monitors and optimizes numerous aspects using technology and automation, resulting in efficient and sustainable food production. Here's how to build a Smart Aquaponics system step by step:

1. Planning and Design:

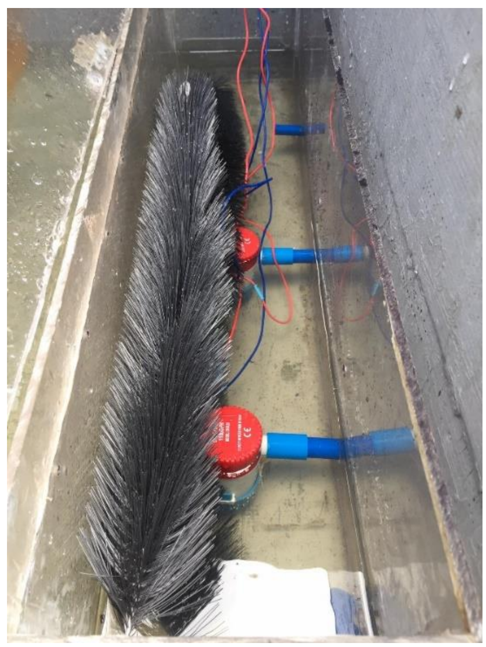
- Determine the scale and size of Aquaponics system based on available space, resources, and goals.
- Nile Tilapia and Romaine Lettuce are the best suitable fish and plant for the system.
- Design the system's layout, considering how the fish tanks, grow beds, piping, and electrical connections will be placed.
- Find a better place to deploy Smart Aquaponics System that provides access to water, sunlight, and electricity, and consider who will benefit from it.





2. Construction of Fish Tank:

- The fish tank is customized in Paete Laguna and it is made of fiber glass with a dimension of 1x2 meters and a height of 2.79 ft.
- Build a box made from acrylic glass and put it inside the aquarium. Inside the acrylic casing is the brush filter and the three water pumps.



3. Hydroponic Setup:

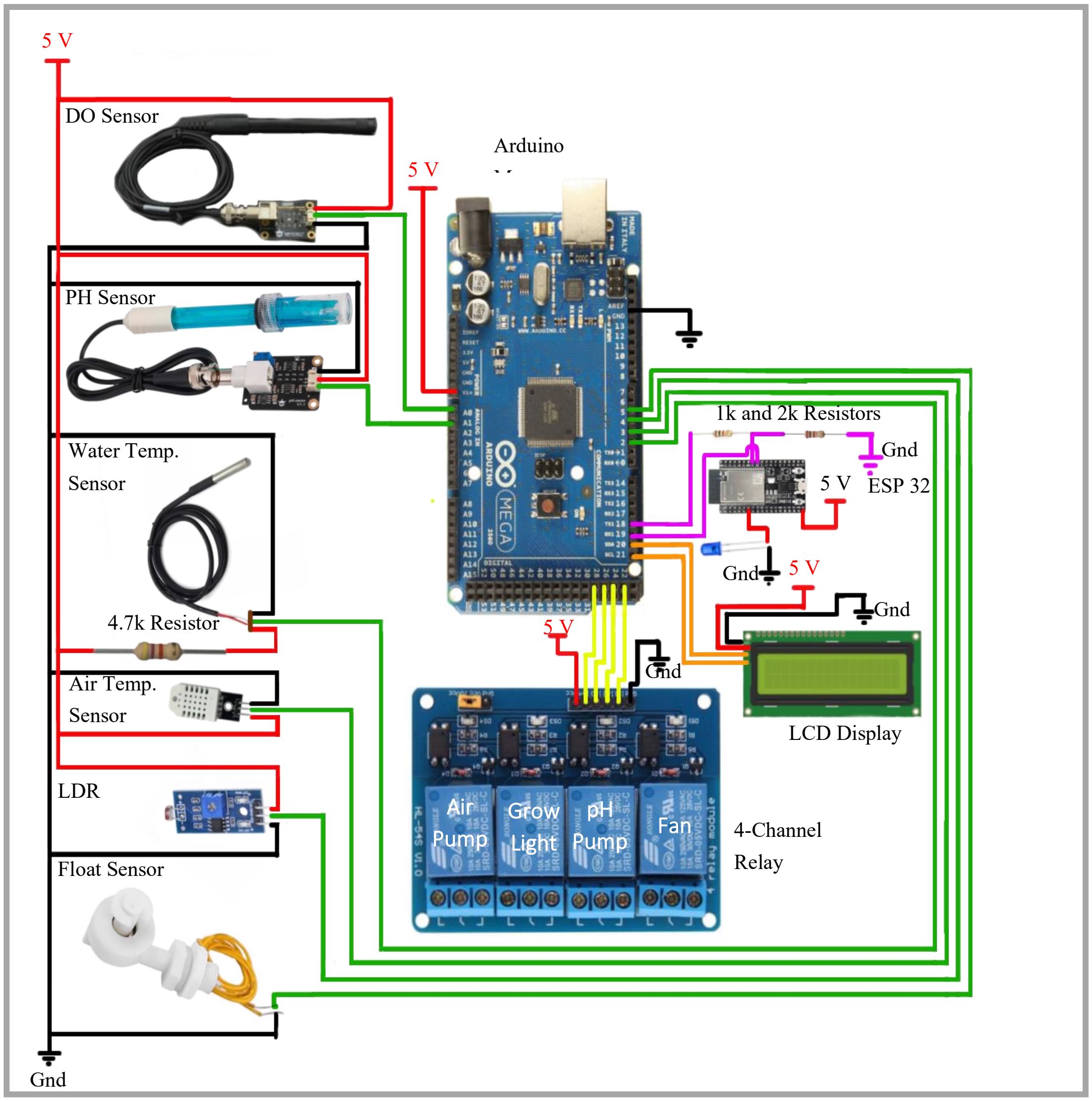
- For the plants, used 15 Tubular Downspout PVC pipes placed horizontally with holes which will hold the net pots of the plants and it measures 3”x4”. At the end of the downspout in each level, there are open pipes which lets the water to flow back to the tank.
- To place the 3 layers of Tubular Downspout, make a support, which is 2x2 tubular steel and 18 pieces of standard L-Shape Shelf Alloy steel.
- Blue PVC pipes are installed and connected to the pumps inside the fish tank. It serves as a way for the water from the tank to travel to the three levels of downspout.

4. Plumbing and Circulation:

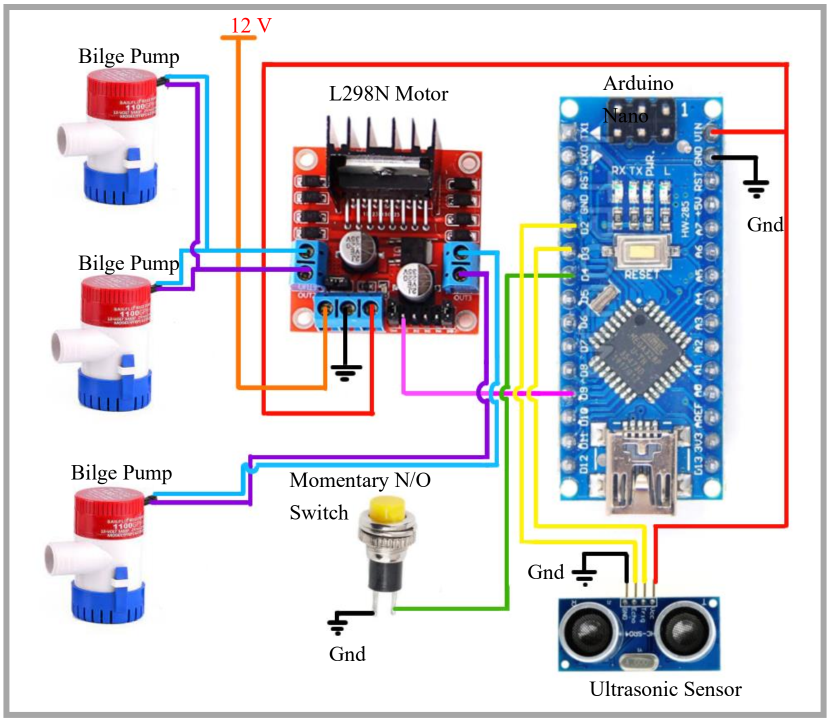
- Blue PVC pipes are installed and connected to the pumps inside the fish tank. It serves as a way for the water from the tank to travel to the three levels of downspout.
- Installing three water pumps and aerators to keep the fish tanks' oxygen levels stable and encourage the transfer of nutrients to the plants.

5. Monitoring and Automation:

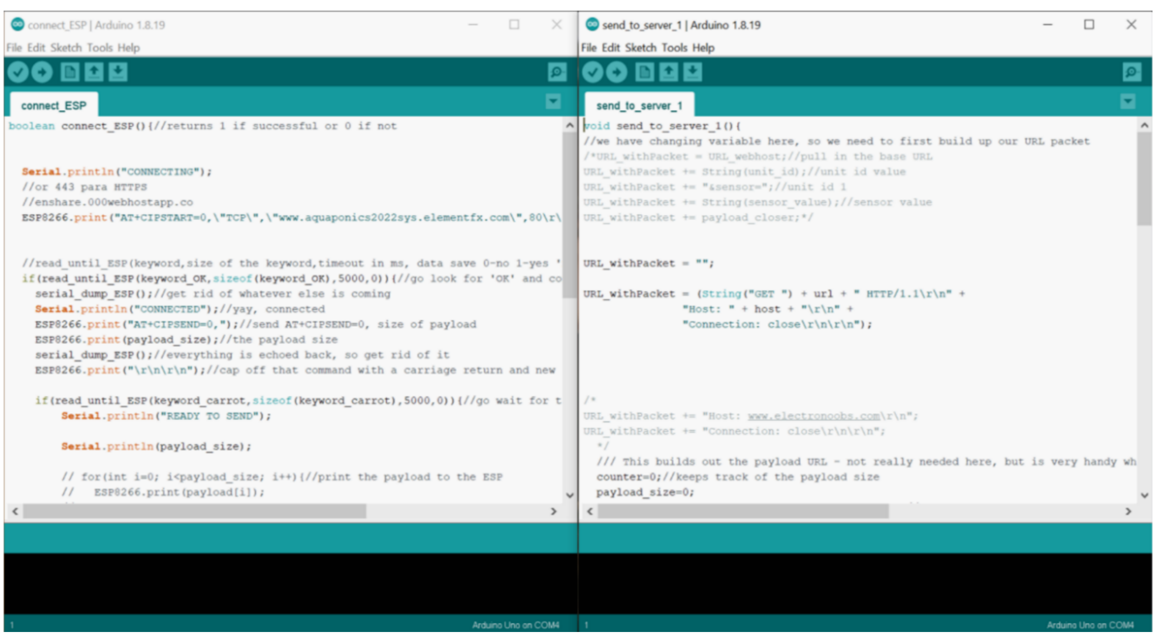
- Integrate sensors and correcting devices to maintain critical parameters like the pH level, dissolved oxygen level, water temperature, fans, air pump, automatic fish feeder, and grow lights.
- As the system's main controller, the Arduino Board is in charge of overseeing numerous functions. The sensors are linked to the Arduino Board, including those for detecting the DO level, pH level, water temperature, air temperature, and light intensity.
- The Arduino Board is also linked to a 4-Channel relay, which serves as a switch to manage the power supply to the correcting devices. The Arduino Board is attached to an LCD display to give on-site observers real-time viewing of the collected data for convenient monitoring.
- Implementing a PID Control Algorithm to control the water flow in the downspout down to the fish tank.



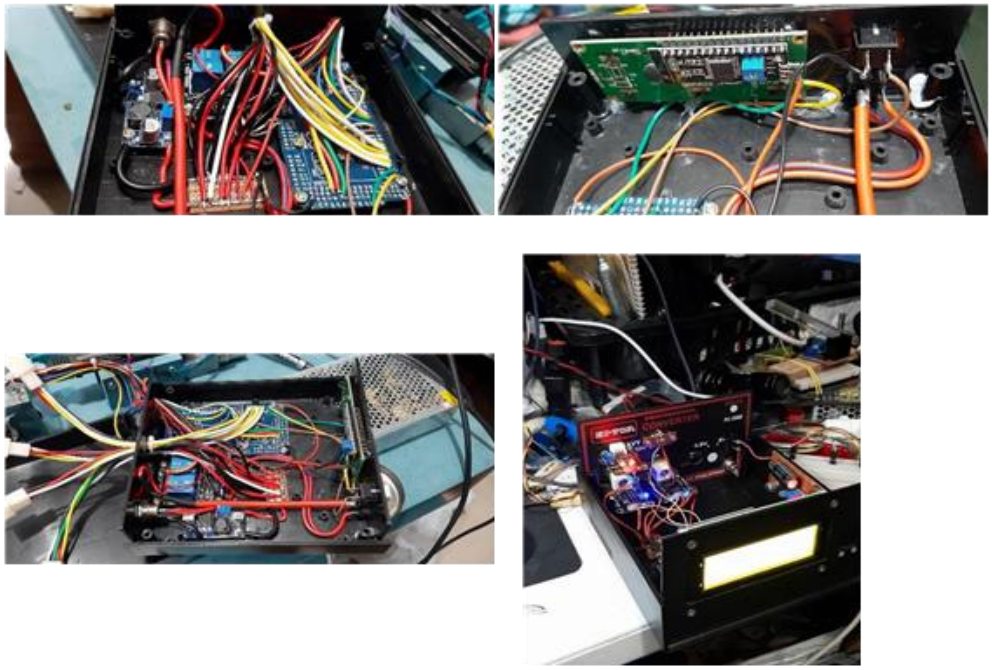
Setup of Sensors, Correcting Devices and IoT Connection



Setup for Water Level Correction of Downspout with the implementation of PID Algorithm



Arduino Mega to ESP 32 connection



Actual Setup inside the Black Box

AquaPID_mar20a | Arduino 1.8.19

File Edit Sketch Tools Help

Upload

AquaPID_mar20a §

```
}

// Main loop of the program
void loop() {
  // Calculate the time since the last sample
  unsigned long now = millis();
  unsigned long timeChange = now - lastTime;

  // Check if it is time to update the PID output
  if (timeChange >= sampleTime) {
    // Read the input from the ultrasonic sensor
    digitalWrite(trigPin, LOW);
    delayMicroseconds(2);
    digitalWrite(trigPin, HIGH);
    delayMicroseconds(10);
    digitalWrite(trigPin, LOW);
    long duration = pulseIn(echoPin, HIGH);
    input = duration * 0.034 / 2.0; // in cm

    // Calculate the error
    error = setpoint - input;

    // Calculate the integral and derivative terms
    integral += error * timeChange;
    derivative = (error - lastError) / timeChange;

    // Calculate the PID output
    output = kp * error + ki * integral + kd * derivative;

    // Limit the output to the specified range
    if (output < minOutput) {
      output = minOutput;
    } else if (output > maxOutput) {
      output = maxOutput;
    }
```

AquaPID_mar20a | Arduino 1.8.19

File Edit Sketch Tools Help

Verify

AquaPID_mar20a §

```
// Define the pin connections for the ultrasonic sensor and the pump
const int trigPin = 2;
const int echoPin = 3;
const int pumpPin = 9;

// Define the PID constants
double kp = 1.0;
double ki = 0.0;
double kd = 0.0;

// Define the setpoint and other PID variables
double setpoint = 50.0; // in cm
double input = 0.0;
double output = 0.0;
double error = 0.0;
double lastError = 0.0;
double integral = 0.0;
double derivative = 0.0;

// Define the sample time and the PID limits
unsigned long lastTime = 0;
unsigned long sampleTime = 1000;
double minOutput = 0.0;
double maxOutput = 255.0;


void setup() {
  // Set the pin modes
  pinMode(trigPin, OUTPUT);
  pinMode(echoPin, INPUT);
  pinMode(pumpPin, OUTPUT);

  // Initialize the LCD display
  lcd.begin(16, 2);
  lcd.print("Water Level: ");
}
```

PID Trial and Error code

6. Energy and Lighting:

- Install a waterproof LED grow lights at the bottom of the downspout to provide sufficient illumination for the plants.

7. Stocking the System:

- Nile Tilapia is the compatible fish species for the fish tank.
- Make sure the fish are well suited to the water's conditions and keep appropriate stocking densities.
- 150–200 pieces of tilapia can be placed into the 1000-liter fish tank.

8. Balancing the Ecosystem:

- Monitor and adjust the nutrient levels in the water by using the automatic fish feeder.
- To keep pH, ammonia, nitrate, and nitrite levels at their ideal ranges, water quality should be frequently tested and adjusted as needed.
- By cycling the water and developing a healthy nitrogen cycle, you may encourage the growth of microorganisms in the system.

9. Planting and Harvesting:

- Consider the Romaine lettuce's individual nutritional needs and compatibility with the aquaponic environment before planting it in the hydroponic system.
- Maintain adequate maintenance for the plant, including trimming, trellising, and insect control.
- Harvest the mature plants after 35 days and replant as required to keep the cycle of growth and harvesting going.

10. Continuous Monitoring and Maintenance:

- Regularly monitor the system's performance.

In conclusion, developing a smart aquaponics system involves a step-by-step process that integrates hydroponics and aquaculture in a mutually beneficial setting. You may create, build,

ANNEX II

USER'S MANUAL

USER'S MANUAL

Empowering Your Green Thumb: A Practical Guide to the Smart Aquaponics System

INTRODUCTION

This comprehensive guide for the Smart Aquaponics system is designed to assist you in understanding and utilizing the functionalities of our advanced aquaponics system. Whether you are a novice enthusiast or an experienced grower, this manual will provide you with the necessary information and instructions to maximize the potential of your aquaponics setup.

Aquaponics is a sustainable farming method that combines aquaculture (fish farming) and hydroponics (soil-less plant cultivation) in a symbiotic environment. The Smart Aquaponics system takes this concept to the next level by integrating cutting-edge IoT (Internet of Things) technology, enabling precise monitoring and automated control of key variables. By leveraging sensor data and smart algorithms, our system creates an optimized environment for the growth of both fish and plants.

We encourage you to read through this manual thoroughly before getting started. By familiarizing yourself with the system's functionalities and following the recommended practices, you will be able to cultivate healthy fish and vibrant plants in a sustainable and efficient manner.

So, let's dive in and unlock the full potential of the Smart Aquaponics system!

SYSTEM OVERVIEW

The Smart Aquaponics system revolutionizes the way we cultivate fish and plants by integrating IoT (Internet of Things) technology with traditional aquaponics principles. This advanced system offers a range of features and benefits that enhance the efficiency, control, and productivity of your aquaponics setup.

Note: This user's manual provides detailed instructions for the setup, operation, and maintenance of the hardware components and the automated features of the Smart Aquaponics system. Please note that the website where the data is displayed and analyzed is developed and maintained by the AqCloud Team, who specialize in the software aspects of the system. For any inquiries or support related to the website functionality, please reach out to the AqCloud Team. The SMAQ Team is responsible for assisting you with all aspects of the Smart Aquaponics system covered in this manual.

Key Features:

IoT Integration: The Smart Aquaponics system harnesses the power of IoT technology to monitor and control crucial parameters such as pH levels, dissolved oxygen, water temperature, and more. By seamlessly collecting and analyzing data in real-time, the system ensures optimal conditions for fish and plant growth.

Automated Control: With the Smart Aquaponics system, manual adjustments and monitoring are a thing of the past. The system's smart algorithms and automated controls maintain optimal environmental conditions, such as nutrient levels, lighting schedules, and water flow, allowing you to focus on other important aspects of your aquaponics operation.

SYSTEM SETUP

To ensure a successful setup of your Smart Aquaponics system, follow the steps outlined below:

Equipment and Components:

- Arduino Mega Board (Quantity: 1)
- Power Supply (12V DC)
- Miscellaneous tools (screwdriver, wrench, etc.)

For Aqaculture Setup

- Fish Tank (Capacity: 1000 liters)
- Water Pumps (Quantity: 3)
- Plumbing Materials (PVC pipes, connectors, valves)
- Fish Feeder
- Correcting Devices
  - water pump
  - air pump
- Sensors
  - pH
  - dissolved oxygen

- water temperature

For Hydroponic Setup

- Grow Pipes (Quantity: 3 layers)
- Sensors
  - air temperature
  - light dependent resistor (LDR)
- Correcting Devices
  - grow lights
  - fans (inlet and exhaust)
- Water Level Corrector (Quantity: 3)
  - This one is already assembled. It contains arduino nano programmed using PID Algorithm and it uses ultrasonic sensor to detect the water level.

Physical Installation:

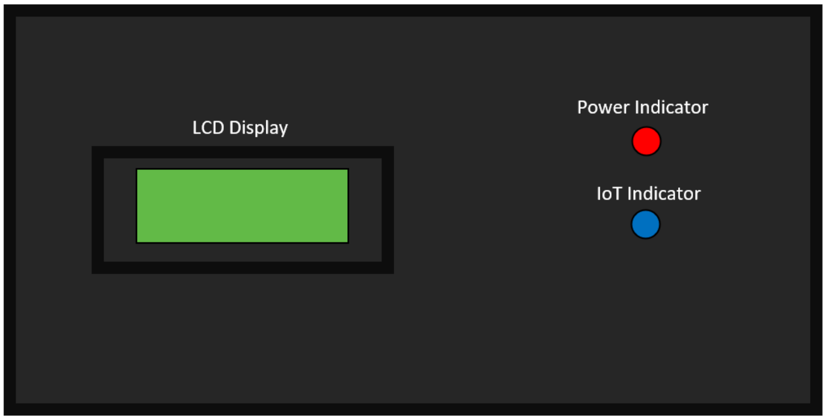
- Position the fish tank in a suitable location, ensuring stability and access to power outlets. The space should be greater than 1x2 meters which is the systems measurement.
- Install the grow pipes by placing it on the metal stand. You can base on the picture given below.

- Connect the PVC pipes to create a water flow system, connecting the fish tank to the grow grow pipes.
- Place the fish feeder on the fishtank.
- Securely attach the sensors to the designated locations within the fish tank and grow pipes.

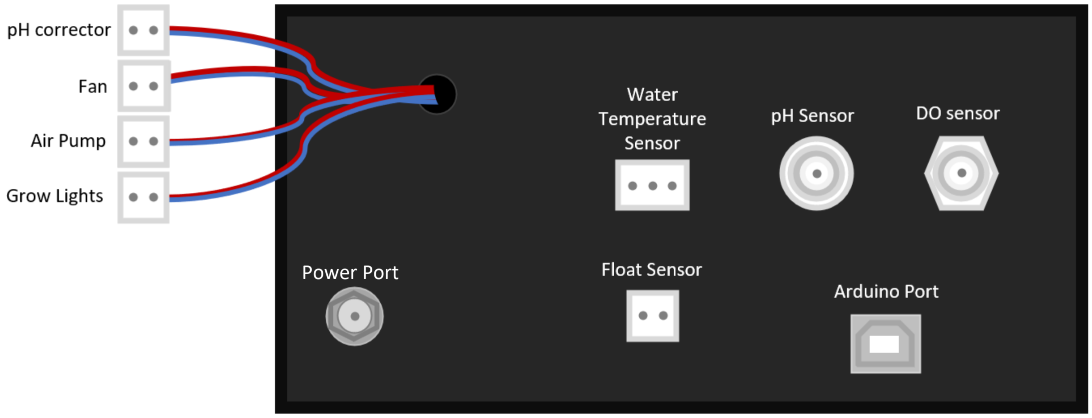
Electrical Connections:

- Connect the sensors to their respective Arduino boards according to the provided wiring diagram.
- Wire the water pumps to the power supply, ensuring proper polarity and secure connections.
- Double-check all electrical connections for any loose or exposed wires.

Front View of Black Box



Back of Black Box



Top View of Black Box

	Description
Front View	
LCD Display	- Displays the gathered data from the sensors
Power Indicator	- Indicates that the system is connected to power.
IoT Indicator	- Indicates that the system is sending data to cloud through WiFi connection or Hotspot.
Back View	
Power Port	- It is where the power is connected. It is the main input for supplying electrical power to the black box.
Sensors (Water Temperature Sensor, pH Sensor, DO Sensor, Float Sensor)	- It connects the Water Temperature sensor to the arduino board.
Arduino Port	- This port allows the user to connect the arduino board to outside devices like laptop when changing the codes.
Correcting devices (pH Corrector, Fanm,Air Pump, Grow Lights)	- These ports serves a connector to correcting devices which are used to mainatain the system.
Top View	
LDR Sensor	- This sensor monitors light intensity.

System Testing:

- Run test cycles to ensure proper functioning of the system.
- Monitor sensor readings on the LED display and verify against expected values.
- Check water flow through the plumbing system, ensuring proper circulation between the fish tank and grow beds.
- Note any issues or abnormalities observed during testing for troubleshooting purposes.

Troubleshooting:

- If you encounter any issues during the setup process, refer to the troubleshooting section of this manual for guidance.
- Contact the SMAQ Team for assistance if you are unable to resolve the issues independently.

Following these steps will help you set up your Smart Aquaponics system effectively. Ensure that you have all the necessary equipment and follow safety precautions throughout the setup process.

SYSTEM OPERATION

Once the Smart Aquaponics system is set up and ready, follow the steps below to operate the system efficiently:

- Power On:
  - Ensure that all electrical connections are secure and the power supply is connected to a reliable power source.
  - Switch on the power supply to provide electricity to the system.
- Monitoring:
  - Access the cloud database or the web application provided by the AqCloud Team.
  - Monitor the real-time sensor readings displayed on the interface, including pH, dissolved oxygen, and water temperature.
  - Check the status of the water pumps and ensure proper water circulation between the fish tank and grow beds
- Automated Correction:
  - The Smart Aquaponics system employs PID algorithms to automatically adjust water pumps and maintain optimal conditions.
  - The sensors continuously communicate with the Arduino boards, which, in turn, regulate water flow and nutrient distribution.
  - The system corrects any detected deviations from the predefined parameters to provide a stable environment for the fish and plants.
- Maintenance:
  - Regularly inspect the system for any signs of wear, leaks, or malfunctions.

- Clean the sensors and plumbing components periodically to ensure accurate readings and proper water flow.
- Replace any damaged or malfunctioning parts promptly.

- Safety Precautions:
  - Avoid exposing the electrical components to water or moisture.
  - Keep the system away from direct sunlight to prevent excessive temperature fluctuations.
- System Shutdown:
  - When necessary, safely power off the system by switching off the power supply.

By following these guidelines, you can effectively operate your Smart Aquaponics system and ensure the well-being and productivity of your Nile Tilapia fish and Romaine Lettuces.

MAINTENANCE

Regular maintenance is crucial to ensure the smooth operation and longevity of your Smart Aquaponics system. Follow these maintenance guidelines to keep the system in top condition:

- Clean Grow Beds: Periodically clean the grow beds to remove debris, excess waste, and dead plant matter. This helps maintain a healthy environment for plant growth.

- Inspect Water Pumps: Regularly inspect water pumps for any signs of wear, damage, or blockages. Clean or replace the pumps as needed to ensure proper water circulation.
- Check Sensors: Routinely check and calibrate sensors to ensure accurate readings. Clean the sensors to remove any buildup or contaminants that might affect their performance.
- Inspect Plumbing: Regularly inspect all plumbing connections for leaks or loose fittings. Address any issues promptly to prevent water loss or system malfunctions.
- Check Electrical Components: Ensure all electrical connections are secure and free from damage. Regularly inspect electrical components for any signs of wear or overheating.

SAFETY GUIDELINES

Ensuring the safety of users and the proper operation of the Smart Aquaponics system is of utmost importance. Please follow these safety guidelines at all times:

Electrical Safety:

- Only authorized personnel should handle electrical components and connections.
- Turn off the power supply before performing any maintenance or repairs on electrical parts.
- Use waterproof and properly insulated electrical connections in wet areas.

Water Safety:

- Avoid direct contact with the water in the fish tank and grow beds, especially if you have open cuts or wounds.
- Wash hands thoroughly after handling any components of the system.

Equipment Safety:

- Follow the manufacturer's instructions for the safe use and maintenance of all equipment, including pumps and sensors.
- Do not modify or tamper with the system's hardware components without proper knowledge and authorization.

Emergency Procedures:

- In case of an emergency, such as electrical shock or chemical exposure, seek immediate medical attention.
- Familiarize yourself with the location and operation of emergency shut-off switches or valves to quickly stop the system if necessary.

Secure the System:

- Keep the Smart Aquaponics system out of reach of unauthorized individuals or children.
- Ensure the system is securely mounted and stable to prevent accidental tipping or falling.

Regular Inspections:

- Conduct regular inspections of the entire system to identify and address any safety concerns or potential hazards.

Injury Reporting:

- Report any injuries or accidents related to the Smart Aquaponics system to the SMAQ Team promptly.

Remember, this user's manual is designed to provide guidance on using and maintaining the automated monitoring and correction aspects of the Smart Aquaponics system. For any inquiries or issues related to the website, data analysis, or software aspects, please contact the AqCloud Team. Always prioritize safety and take necessary precautions to ensure a safe and enjoyable experience with your Smart Aquaponics system.