Smart Aquaponics Systems for Urban Farming

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***Abstract*— This project presents the Internet of Things (IoT) applications as instrumentations to automate traditional aquaponics environment. Presently, Malaysia's economic situation during COVID19 is facing a significant amount of demand for food production. Research has shown that Aquaponics can help solve this problem by increasing conventional farming efficiencies and increasing food production to Malaysia's local community. However, extensive and arduous labours have made Aquaponics costly, especially for small farmers and hobbyists, making it inaccessible to specific groups or individuals. This study aims to provide automation to the Aquaponicsenvironment by developing an IoT based prototype to monitor and gather parameter data involving water level, humidity and temperature in the Aquaponics ecology. The tendencies and trends in Aquaponics systems can be analysed using the parameter mentioned. The project features sensors like two water level sensors, liquid temperature sensor, and humidity sensor to collect parameters wirelessly by using an ESP 8266 that would trigger the actuators when certain events are met. The actuator would serve as the balance check for the symbiotic ecology and accommodating parameter it lacks based on the sensor data. Moreover, the project is divided into three different development phases: setting up normal aquaponics ecology; implementing automation in aquaponics systems; and analysing data from the prototype's sensor. Therefore, this solution is expected to increase efficiencies in the Aquaponics environment with less human intervention, reducing labour costs in Aquaponics and producing more organic and healthy yield. The project would significantly impact the local community, especially during this pandemic outbreak wherefood production is considerably on demand. The yield from Aquaponics is unquestionably nutritious, and health enthusiasts will surely benefit from this project.**

KEYWORDS: Internet of Things, Automations, Microcontroller, Sensors, Wireless Network, Aquaponics, crop yield, Blynk, Arduino, Aquaculture

I. INTRODUCTION

Aquaponics comes from two words: '*aqua*' + '*ponics*'. 'Aqua' is related to aquaculture, that is to raise fish in a controlled environment. '*Ponics*' is Latin '*to work'*, refer to growing plant in soil-less media. This project integrates an Aquaponics farming method with smart sensors IoT components. The ancient Aztec Civilisation introduced the Aquaponics farming method for a sustainable fish farm and growing plants in its era. This concept is suitable for this civilisation,especially in urban living where the soil is scarce. Simultaneously, it indirectly improves living standards, as described in UNICEF's Sustainable Development Goals (SDG) as in [7]. By implementing the project following SDG, it accomplishes four goals: Zero Hunger (SDG number 2), Good Health and Well-being (SDG number 3), Clean Water and Sanitation (SDG number 6) and Responsible Consumption and Production (SDG number 12), refer to Figure 1.

In this dire situation, considering the COVID19 virus pandemic outbreak, the economy plummeted significantly following the close of multiple businesses which experienced a dramatic economic downturn that records up to RM63 billion loss as reported by World Bank Blogs in [8]. Business owners are struggling to manage their expenses and contemplating to relinquish their employees to cutcosts. Amidst the situation, the most critical sector that is affected is the food sector. Although the government assured that the food supplies are sufficient, there are inevitable adversities in the food source procurement and supply chain. The demand for food was never this high since the Malaysian government enforced the Restricted Movement Order (RMO). Furthermore, paterfamilias is the only ones allowed to buy foods in very limited and finite supermarkets. This project featured growing foods from home that is organic and healthy, not to mention the need to go out fromhome to find food sources.

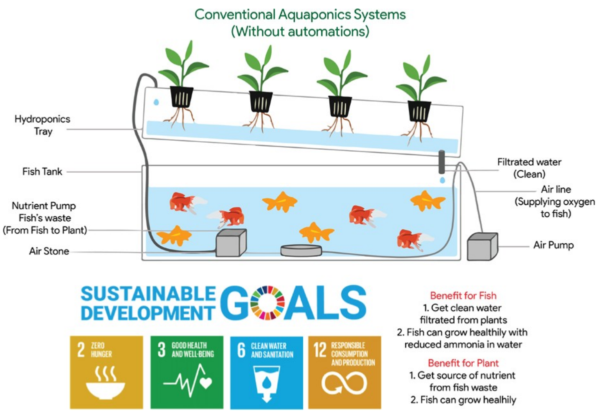

Figure 1 Conventional Aquaponics Systems

Conventional Aquaponics needs arduous and constant monitoring to ensure balanced symbiotic environment between aquaculture and plants. Besides, even a small amount of parameter imbalance would cause harm to both symbiotic living ecology. As large amounts of capital need to be invested in incorporating Aquaponics, proper care for both plants and aquaculture should be considered to avoid disproportionate in symbiotic ecology, leading to a waste of resources. In order to combat this problem, effortless labour and minimal workforce are required to monitor the resource's utilisation. With this project development, strenuous yet continuous manual monitoring and excessive labours are no longer needed. Hence, reducing the cost of maintaining Aquaponics.

This project features the usage of four sensors; one for fish; three for the plant. Hence, four parameters would be used to monitor the water quality and other conditions to ensure the balanced symbiosis between fishes and plants. The sensors used for fish include a water level sensor. The sensors used for plant, liquid temperature sensor, water level sensor and humidity sensor would be used as parameters for this project. The readings for the parameter would be transmitted wirelessly through a Wi-Fi module via microcontrollers. Thus, further action can be taken through actuators if certain events occurred. For example, if the water level in the fish tanks exceeds the water level threshold, the water pump pumps the water to the plant tray. Subsequently, it would notify aquaponics systems owner to look after their plants and fishes if specific parameters are violated.

II. LITERATURE REVIEW

This section consists of a few discussions on several subjects that relate to the project. The review starts with a definition and the background concept of Aquaponics and its benefits to farmers. Moreover, a comparison of Aquaponics with the conventional farming method would also be discussed to highlight the significance of automating Aquaponics ecology. Furthermore, the present issues relating to Aquaponics would also be focused on this chapter to answer research questions on the farming method, how to maintain water quality, how to reduce labour and comparison of Aquaponic to conventional farming. On top of that, the literature review includes some work by previous researchers that researched the Aquaponics automation field of study.

A. Aquaponics Farming Method

Aquaponics is an efficient farming method developed by ancient Aztec civilisation, featuring Hydroponics and Aquaculture's hybrid combination. Aquaponics has the potential to solve four out of seventeen SDG under UNICEF in [7]: Zero Hunger (SDG number 2); Good Health and Well-being (SDG number 3); Clean Water and Sanitation (SDG number 6) and Responsible Consumption and Production (SDG number 12). In [1] Badiola et al. with their RAS model shown that there are many benefits of implementing this farming method rather than relying on the conventional farming method, such as reducing land and water usage by 90%. In Aquaponics, excretory waste from fish provides enough nutrition to the plants. In return, the plants clean the water for the fish to stay alive in a conducive ecology, refer to Figure 2.1. In order to achieve perfect symbiotic ecology, certain factors need to be considered to increase productivity and cut the cost of the affected farmers that implement Aquaponics in their plantations.

B. Water Quality Control

Water is an essential requirement for any fish to live and grow. Thus, it is necessary to maintain a suitable environment for aquaculture in Aquaponics. Fishes may die if the water they are living in is not treated. Many factors can contribute to the decrease in water quality in an enclosed ecology such as an aquarium or fish tanks. Excessive fish waste and decomposing uneaten fish food can contribute to increased ammonia concentrations in water, hence making the water intoxicate the fish and any other aquaculture in the water [1].

In order to mitigate this problem, a water recirculation technique, namely Recirculating Aquaculture System (RAS), was invented to keep the cycle of water flow from fish tanks to plants. Applying RAS in [1] Badiola et al. incorporate the treatment and reuse of water with less than 10% of total water volume replaced per day. Furthermore, we may observe water usage and fertiliser reduction since plants can nourish its nutritional diet through fish waste and reduce fertiliser costs. Combining adequate aquaculture and fertilised hydroponics would eventually be made up perfect ecologyfor Aquaponics.

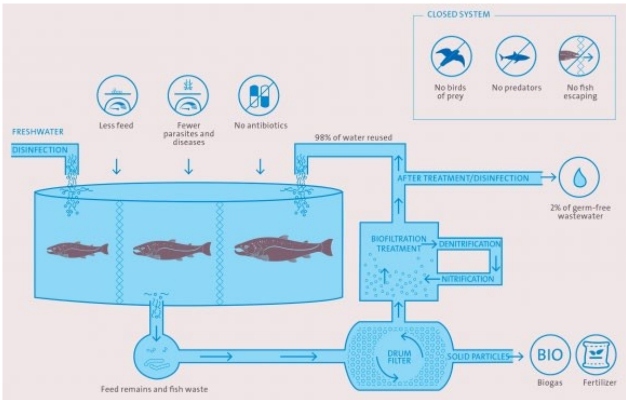

Figure 2 Example of Recirculation Aquaculture Systems (RAS) [1]

As an addition to RAS, farmers can also rely on microbial organisms to cleanse the fish's water tank. Breaking up Ammonium Nitrates by using nitrification process can treat the ammonium nitrate infested water. The process is carried out by unicellular microorganism such as Nitrosomonas sp. and Nitrobacter sp. In [2], Eding et al. studied the Nitrification process that involves Nitrosomonas sp. breaking down Ammonia into Nitrites and Nitrobacter sp. breaking down Nitrites into Nitrates. The study showed that While Nitrites is more toxic than Nitrates, fish can tolerate many Nitrates than Nitrites. In [3], Tyson et al. in agreeable that the microorganism biofilters can be found in a pond or lake as they undergo nitrification naturally in their respective ecology. The full nitrification process can be depicted in the diagram below, refer to Figure 2.

C. Manual Labour

One of the main issues that are discussed in Aquaponics is manual labour, as it increases the farming cost as suggested by Palm et al. in [4], ended up devouring many resources and as a consequence, decreases productivity for farmers. Specific controlled parameters need to be taken care of, including

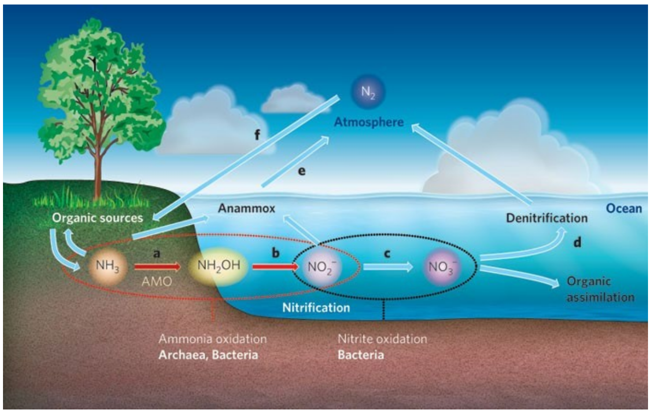

Figure 3 Nitrification process in a pond

feeding food for fish regularly, maintaining water quality by draining and replacing clean water once a month, and maintaining symbiosis of aquaculture and agriculture. These intricate labours eventually consume many resources by hiring workers to care for the symbiotic environment [4]. This situation might not be an issue to small scale Aquaponic farmers but imagine having a large-scale Aquaponic Plantations with thousands of plants to maintain. The cost itself drags the farmers to their feet while the productivities efficiencies plummet.

As a solution to these problems, researchers (Palm et al., Murali et al., and Kori et al.) had done a lot of Internet of Things (IoT) based projects with Aquaponics as implemented in [4][5][6]. The next topic features the mitigations for this problem in-detail to exemplify how far researchers and engineers had helped in this field. Most of these solutions involve electronics elements between sensor nodes, controller as well as actuators. This solution's basic concept is to have sensors to monitor parameters such as water level, temperature, pH level, and humidity of their respective symbiotic ecology. Then, after certain events trigger, the controller would send an electrical signal to the actuator to raise the fish tanks' water level to lower Ammonia and pH concentration, turning on the light bulbs to raise temperature humidity. In an interesting case, they even spend their effort building real-time aquaponics monitoring accessible through smartphones.

D. Comparison between various farming method with Aquaponics

Aquaponics is the most effective out of another farming method. Aquaponics can produce both fish andplants outputs effectively without any chemical fertilisers. Furthermore, Aquaponics are independent on soil; hence less pesticide is expected to visit aquaponics plants. Therefore, aquaponics owners are not needed to procure pesticides to get rid of invasive insects. Aquaponics' other benefit includes requiring less water to nurture the aquaponics environment, and it does conserve space.

On top of that, compared to thedifferent farming methods, Aquaponics is the most cost-friendly and not harmful to the environment. The plants in Aquaponicsrely on natural fertiliser supplied by aquaculture's waste in theecology for its nutritional needs, and consequently, it cuts the cost for fertiliser. Conversely, to leverage the benefitsAquaponics offers, it relies on arduous labour and rigorous monitoring to ensure healthy ecology for both aquaponics cultures, which can be costly and tedious.

III METHODOLOGY

A. Spiral Model Methodology

Spiral Model was selected to be implemented as the methodology model because it has a flexible nature that is quite detrimental to the project. The model also defines a combination of sequential and prototyping models since it is best used for large projects that involve continuous enhancements, especially when doing the prototyping project. A well-defined activity would be decided upon each iteration of the model until a full prototype is developed. Considering this project involves a lot of parameters, comparing existing data with the data gathered at the end of the project should be carried out to determine whether the objectives are achieved or not. .

On top of that, this can be solved using a spiral model since it has a recurring cycle and enhancing prototype for every process iterated that can make data analysis and prototyping improvement easier to carry out. This model consists of four elemental phases, such as Planning, Risk Analysis, Development, and Evaluation.

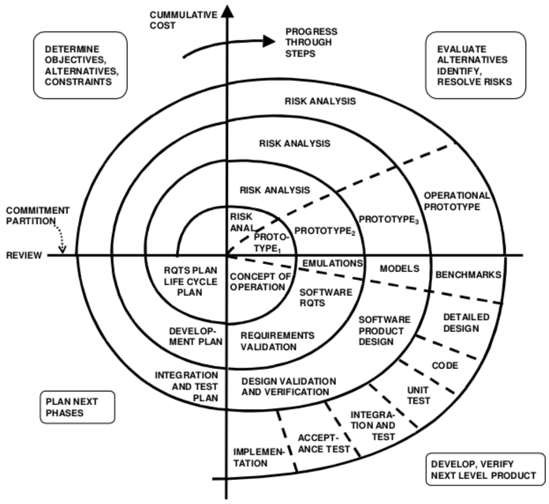

Figure 4 Spiral Model Methodology

The Spiral model, refer to Figure 4, is designed to enhance the prototyping model as it iterates the four elemental cycles until completion of the project. The iteration allows tremendous improvement for the results since risk monitoring, and regular expertise is the core characteristics of this approach, the overall task becomes more transparent. Furthermore, it eliminates risks while developing a fully stable prototype after the cycle ends. Each spiral can be termed as a loop, and each loop is a separate development process in a spiral model. The four activities form the intermediary phases of a spiral model and are repeated for each loop. The spiral model enables incremental releases of the product and gradual refinementthrough each iteration around the spiral in recapitulation.

1. Identification

The Spiral methodology model starts with the Identification Process, which would clarify problems, goals, and objectives using the six questions of 5W and 1H (i.e. What, Who, Where, When, Why and How). A feasibility study would be carried out in the first iteration after the FYP supervisor had approved the project's ideas. This activity gathers all findings relating to the project, such as research gaps, previous work and related methodology.

These findings can be found using all sources of information from research and conference Journal, encyclopedia, internet, books, articles, and previous study carried out by previous researchers investigating similar findings to the project. Based on the literature review process, various research gaps can be spotted, which eventually incites research questions concurrently identifying which problems to solve and what solution should be proposed in this project.

2. Risk Analysis

In this iteration, risk analysis would be carried out to determine possible detrimental factors that can affect the project massively. Aside from that, hardware and software requirements would also be listed in this phase to determine thefinancial risk as well as the resources needed to complete theproject.

Initially, a research model is determined to formulate a project plan in outlining the activities, tasks, dependencies and timeframe required to complete the project hence determining the estimation for the project cost. As a result, the cost of expenditures can be controlled and monitored during project implementation according to the plan devised earlier in this phase.

The prototype's functionality was carefully planned and determined to match the project's objectives and goals while a step-by-step block diagram, refer to Figure 5, visualises it. Then, the design process for the project takes place. It identifies parameters that need to be measuredand accommodate insufficiency in the Aquaponics ecology and, consequently, recognise possible risks in developing the prototype.

After that, a list of hardware and software required to instigate the prototype would be listed. Substantially, by planning and identifying risk in thisproject, it could reduce error and eliminate unpredictable predicaments when the project's end-product is developed.

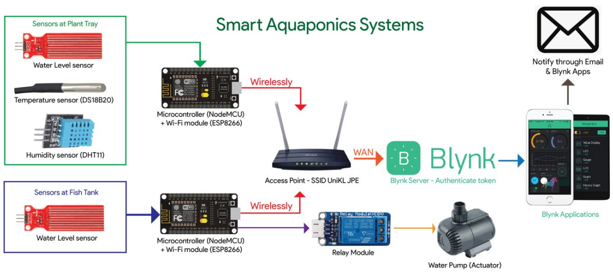

Figure 5 Block Diagram of Automated Aquaponics Systems

3. Development

This phase features the development stages of Automated Aquaponics Systems. The development stages consist of three main elements; sensors, monitoring, and actuators. Before deciding which sensor to use, parameter identification is detrimental. There are four parameters determined to be included in this project; three for plants and the other one was reserved exclusively for the fish. In addition, the parameters that need to be monitored include water level, temperature, and humidity level. Subsequently, the parameters decided from prior, would be measured by implementing hardware sensors such as water level sensor, temperature sensor, humidity level sensor. These sensors would be implemented in aquaponics ecology to act as receptors for the symbiotic environment, refer to Figure 6 for the system concept plan.

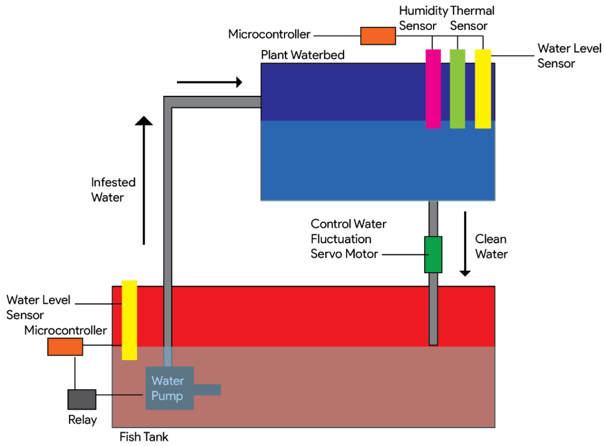

Figure 6 Automated Aquaponics System Concept Plan

To monitor these parameters, sensors need to send updates to the microcontroller and push the data as it forwards it to the Blynk server. A mobile application developed by using Blynk services displays the monitored parameters and options to regulate the insufficient parameter that can disrupt the balanced aquaponics ecology. Refer to Figure 7 for the Blynk dashboard that helped a user to monitor the parameters. In which case, actuators are needed to restore balance to the aquaponics environment.

Moreover, the actuators incorporate the use of a water pump in which it would be installed in the ecology to regulate the parameters. Likewise, the water pump increases water level if the pH level started to turn excessively alkaline, indicating that there are abundant of Ammonia in the water that is bad for the fishes. On top of that, increasing the water level makes the alkaline yet ammonium infested water to dilute its properties while supplying clean water to the fish to reside in the fish tank.

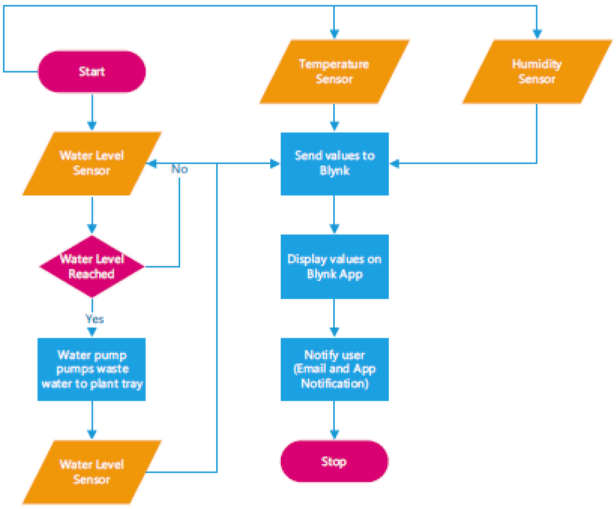

Figure 7 Flowchart for Automated Aquaponics Systems

4. Evaluation

The parameters measured would then be analysed to observe the automated aquaponics systems' trends in this iteration. After that, a deduction would be made to identify the proposed solution's effectiveness in the development stage, refer to Figure 7 for the automatic Aquaponics system's flowchart.

These deductions and data results would be documented in the form of the final report. They can create a highly adequate environment for both non-automated and automated aquaponics systems in the future. Furthermore, this iteration also involves thesis correction and amendments before report submission to the designated FYP supervisors and coordinators.

III. TESTINGS AND RESULTS

A. *Prototype Implementation*

After the development phase ends, the prototype was assembled based on the methodology section's components and should match project objectives. Figure 8 below shows the fully-implemented Smart Aquaponics systems prototype, including Sensors, Microcontrollers, and Actuators. Figure 9 demonstrated that the water is pumped out when the water threshold exceeded as sensed by the water level sensor.

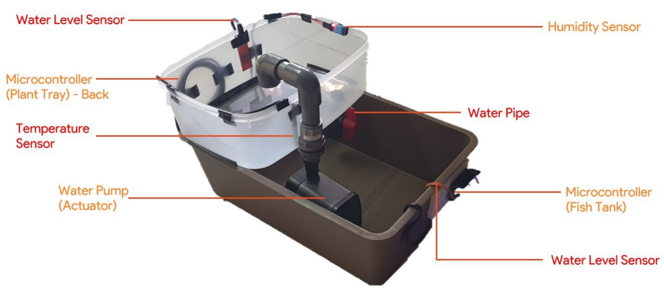

Figure 8 Fully Implemented prototype of Smart Aquaponics Systems

B. *Testing and Results*

The testing and result sections determine whether the project objective is achieved or not. This section has two main components: hardware and system testing, as observed in the following table. The Table 1 shows the objectives of this project relative to its result.

Table 1 project objectives and its results

Objective	Result
To develop a prototype of Aquaponics systems using the Internet of Things (IoT) framework.	The prototype has been developed successfully implementing Blynk Framework, one of IoT framework.
To monitor and gather data involving water level, humidity level, and temperature level in the Aquaponics environment between fish and plant.	The water level, humidity and temperature sensors forboth tanks collect data and visualise them in Blynk Applications Dashboard in real-time.

1. Hardware Testing

There are a few hardware testing that needs to be carried out to test the Smart Aquaponics Systems. The testing correctly tests microcontrollers, sensors, relay and actuators to ensure they are well-functioned for the next testing phase. Table 2 shows the Hardware testing, the expected output and the actual output.

Table 2 Hardware Testing and it's output

Hardware	Expected Output	Test	Output
Fish Tank's NodeMCU	Connect Wi-Fi module to Blynk Server and connect actuators and sensors to Microcontroller	✓	The microcontroller was connected to the Blynk server and all sensors and actuator are displayed in the Blynk Apps
Plant Tray's NodeMCU	Connect Wi-Fi module to Blynk Server and connect sensors to Microcontroller	✓	The microcontroller was connected to the Blynk server and all sensors are displayed in the Blynk Apps
Water Level Sensor at Fish Tank	Detect water level in the Fish Tank	✓	The water level sensor streams the sensor data at Blynk Dashboard via V3 pins.
Water Level Sensor at Plant Tray	Detect water level in the Plant Tray	✓	The water level sensor streams the sensor data at Blynk Dashboard via V7 pins.
Temperature sensor (DS18B20)	Detect the liquid temperature at the plant tray	✓	The temperature sensor streams the sensor data at Blynk Apps via V8 pins.
Humidity sensor (DHT11)	Detect humidity and environment's temperature at plant tray.	✓	The humidity sensor streams humidity sensor data at Blynk Apps via V5 pins and temperature data via V6 GPIO pins.
Relay	Close and Break circuit when "1" and "0" values are pushed respectively from Microcontroller.	✓	Relay circuit closes when microcontroller pushed "1" and break the circuit when "0" were pushed.
Water Pumps	Pump water to the Plant tray	✓	Water are pumped upon relay circuit closes.

2. Software Testing

In order to evaluate and verify the features of the prototype, testings are done to ensure that the project's objectives are achieved. Table 3 describes the system tests and their outputs during the testing. The prototype passed all aspect of testing's criteria, hence achieving all project objectives stated earlier.

Table 3 Software Testing and its output

System	Expected Output	Test	Output
Fish Tank sensor systems	Display sensor data in the Blynk Dashboard respective to its widgets	✓	All sensor data are displayed in the Blynk Applications
Plant Tray sensor systems	Display sensor data in the Blynk Dashboard respective to its widgets	✓	All sensor data are displayed in the Blynk Applications
Event Trigger	Water pump pumps water if water level reading exceeds 8 liters in the fish tanks	✓	The water in the fish tank is pumped to the plant when water level exceeded 8 liters
Notification systems	Blynk Server send an email and app notifications if water level reading exceeds 1 liter in the plant tray	✓	An email and app notifications were received when water level in the plant tray exceeds 1 liter.

Figure 9 Water is pumped when water level readings exceed 8 liters at Fish Tank

Figure 10 Blynk Dashboards displaying sensor data for Fish Tanks and Plant tray

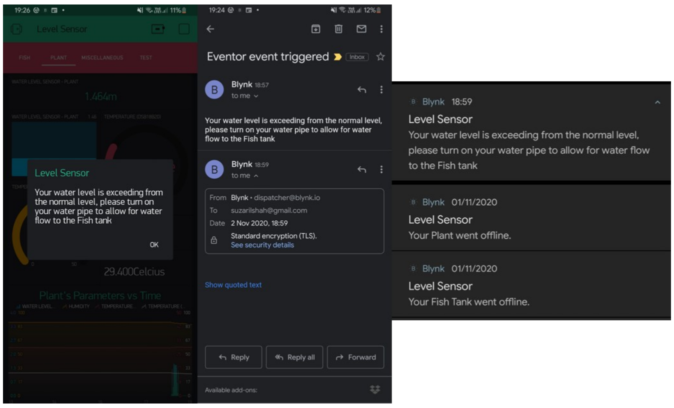

Figure 11 Email and App Notifications when the water level exceeds 1 liter at Plant Tray

3. Data Collections

The Blynk Applications allows for data collection and visualisation via graph vs time for other data analytics for the project. Figure 12 and Figure 13 below shows the data collected in both fish tanks and plant trays, respectively. This data can be used for analytics to determine the trends and tendencies in an aquaponics system.

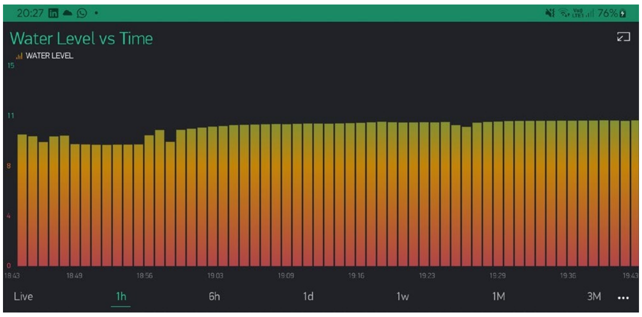

Figure 12 Data Collections at Fish Tank depicted by a graph vs time

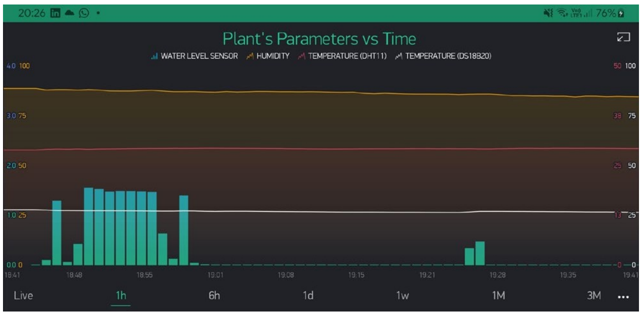

Figure 13 Data Collections at Plant Tray depicted by a graph vs time

4. Analysis

The readings from the sensors were taken daily for both plants tray and fish tanks. After that, the readings were then interpolated in a graph of Water level vs Days. Based on Figure 12, the water level from the fish tanks decreases as remaining waters were pumped into the plant tray at the end of each day. On Friday, the water pipe at the plant trays was opened, enabling clean water to flow back into the fish tank. However, the fish tanks' initial water level is also decreasing by 0.21 liter from the initial water level of 8 liters in the fish tanks on Monday.

The water quality and level change might be due to the plants absorbing water for photosynthesis process earlier during the water traverse at the plant tray. Hence by referring to such graph, farmers should consider to add or replace water at both tanks to potentially enhance the water quality for the fish and plant to inhabit the ecosystem adequately.

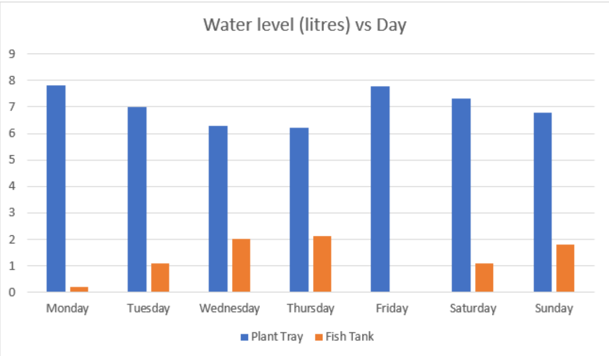

Figure 12 Reading from the water level sensors in a week graph vs day

IV. CONCLUSION

In conclusion, the Smart Aquaponics Systems are an SDG friendly project that can potentially solve the demand for food production, especially in this pandemic outbreak where people stayed indoors and confined from home.

Aquaponics enables the nurture of both plants and fishes to reduce time and costs for logistics, making it one of the most efficient farming methods. The recirculation of water in Aquaponics also reduce the waste of water usage among farmers.

The project also proves that technology can be assimilated with Aquaponics, automating tasks such as pumping fish's faeces-infested water into the plant tray so that the plant can benefit from its nutrient and simultaneously clean the water for the fish. The prototype also provides notifications, specifically email, and apps notifications, as depicted in Figure 4.4, to farmers if the water level exceeds a certain level in the plant tray, eliminating the need for constant monitoring to the aquaponics systems.

Based on the previous works during literature studies phase, many researchers are currently developing Aquaponics solutions to enhance food security and encouraging others to nurture food organically from home at their convenience. However, the project is still open to any future enhancements so that a robust and feature-rich prototype for this project can be commercialised in the future.

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