Smart Aquaponics Systems for Urban Farming

Muhammad Suzaril Shah bin Zakaria
Universiti Kuala Lumpur, MIIT
Jalan Sultan Ismail City Campus, Malaysia
suzarilshah@gmail.com

Ts Dr. Amna binti Saad
Universiti Kuala Lumpur, MIIT
Jalan Sultan Ismail City Campus, Malaysia
amna@unikl.edu.my

***Abstract*— This project presents the applications of Internet of Things (IoT) as instrumentations to automate traditional aquaponics environment. Presently, the economic situation in Malaysia during COVID19, resulting in a significant amount of demand for food production. Correlating to that, research has shown that Aquaponics can help to solve this problem by increasing efficiencies in conventional farming and consequently, increasing food production to the local community in Malaysia. However, extensive and arduous labours have made Aquaponics be costly disadvantageous, especially for small farmers and hobbyists hence making it to be inaccessible to particular group 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. Using the aforementioned parameter data, the tendencies and trends in Aquaponics systemscan be analyzed. The project features the use of sensors like two water level sensors, liquid temperature sensor, and humidity sensor to collect parameters wirelessly by using an ESP 8266 thatwill trigger the actuators when certain events are met. The actuator will 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 lastly analyzing data that comes from the sensor of the prototype. Therefore, this solution isexpected to increase efficiencies in the Aquaponics environment without needing human intervention hence reducing the cost of labour in Aquaponics and consequently producing more yield that is organic and healthy. The project will serve a significant impact on the local community, especially during this pandemic outbreak wherefood production is significantly demanded. In addition, the yield from Aquaponics is unquestionably nutritious, and health enthusiasts willsurely benefit from this project.

KEYWORDS: Internet of Things, Automations, Microcontroller, Sensors, Wireless Network, Aquaponics, crop yield Introduction (*Heading 1*)

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 will integrate an Aquaponics farming method with smart sensors IoT components. The Aquaponics farming method was introduced by the ancient Aztec Civilization for a sustainable fish farm and growing plants in its era. This concept is suitable for this civilization, as well, especially in urban living where the soil is scarce. At the same time, indirectly improve the standard of living as described in SDG goals set by UNICEF. 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 andProduction (SDG number 12) [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 [2]. Business owners are struggling to manage their expenses and contemplating to relinquish their employees to cut costs. 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 procurement of the food source as well as its supply chain. The demand for food was never this high since the Malaysian government enforced the Restricted Movement Order (RMO) to its citizens. Furthermore, paterfamilias is the only ones that are allowed to buy foods in the supermarkets, which is very limited and finite. This project featured growing foods from home, which is organic and healthy, not to mention the needless to go out from thehome to find food sources.

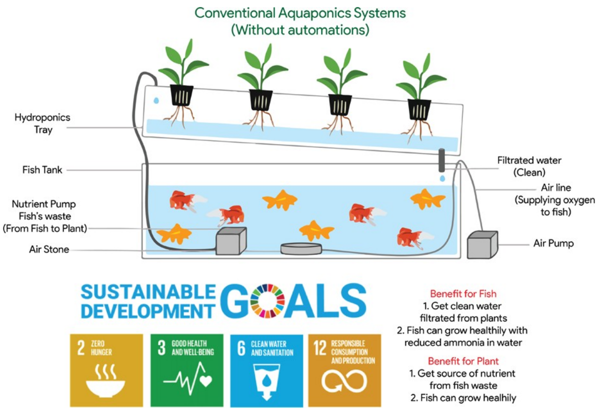

Figure 1 Conventional Aquaponics Systems

Conventional Aquaponics needs arduous and constant monitoring to ensure balanced symbiotic environment between aquaculture and plants. Also, even a small amount of parameter imbalance will 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 taken into account to avoid disproportionate in symbiotic ecology, which can lead to waste of resources. To combat this problem, effortless labour and minimal workforce are required to monitor the resource's utilization. With the development of this project, strenuous yet continuous manual monitoring and excessive labours are not required anymore hence reducing the cost of maintaining Aquaponics.

This project will feature the usage of four sensors; one for fish; three for the plant. Hence there will be four parameters that will 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. As for the sensors used for plant, liquid temperature sensor, water level sensor, and humidity sensor will be used as parameters for this project. The readings for the parameter will be transmitted wirelessly through a Wi-Fi module via microcontrollers; thus, further action can be taken through actuators if certain events occurred. As an example, if the water level in the fish tanks exceeds the water level threshold, the water pump will pump the water to the plant tray. Subsequently, it will notify aquaponics systems owner to look after their plants and fishes if specific parameters are violated.

II. LITERATURE REVIEW

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

A. Aquaponics Farming Method

Aquaponics is one of the efficient farming methods developed by ancient Aztec civilization featuring the hybrid combination of Hydroponics and Aquaculture. Aquaponics has the potential to solve at least four of Sustainable Development Goals (SDG) under UNICEF's objective to provide a sustainable way of life; 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) [1]. There are many benefits of implementing this farming method rather than relying on the conventional method of farming, such as reducing land and water usage by 90%. In Aquaponics, excretory waste from fish will provide enough nutrition to the plants. In return, the plants will clean the water for the fish to stay alive in a conducive ecology. To achieve perfect symbiotic ecology, certain factors need to be taken into consideration to increase productivity as well as cutting cost to 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 important to maintain a good environment for aquaculture in Aquaponics. Fishes may die if the water they are living is not treated. There are a lot of factors that 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 the increase of ammonia concentrations in water hence making the water to intoxicate the fish as well as any other aquaculture in the water [1].

In addition, 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. By applying RAS, it will incorporate the treatment and reuse of water with less than 10% of total water volume replaced per day [1]. Furthermore, we may observe the reduction of water usage and fertilizer since plants can nourish its nutritional diet through fish waste itself, also reducing the cost of fertilizer. Combining adequate aquaculture and fertilized hydroponics will eventually make up perfect ecology for Aquaponics.

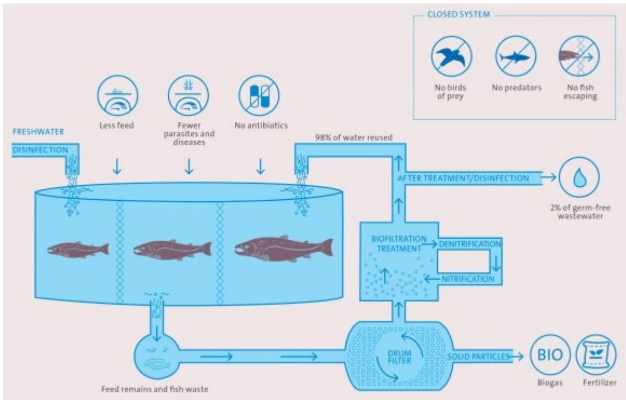

Figure 2.1 Example of Recirculation Aquaculture Systems (RAS)

As an addition to RAS, farmers can also rely on the microbial organism to cleanse the water for fish. The ammonium nitrate infested water can be treated by breaking up Ammonium Nitrates by using nitrification process. The breaking up process is carried out by unicellular microorganism such as Nitrosomonas sp. and Nitrobacter sp. The Nitrification process involves Nitrosomonas sp. breaking down Ammonia into Nitrites and Nitrobacter sp. breaking down Nitrites into Nitrates [2]. While Nitrites is more toxic than Nitrates, fish can tolerate a more significant number of Nitrates than Nitrites [2]. These microorganism biofilters can be found in a pond or lake as they undergo nitrification naturally in their respective ecology [3]. The full nitrification process can be depicted in the diagram below:

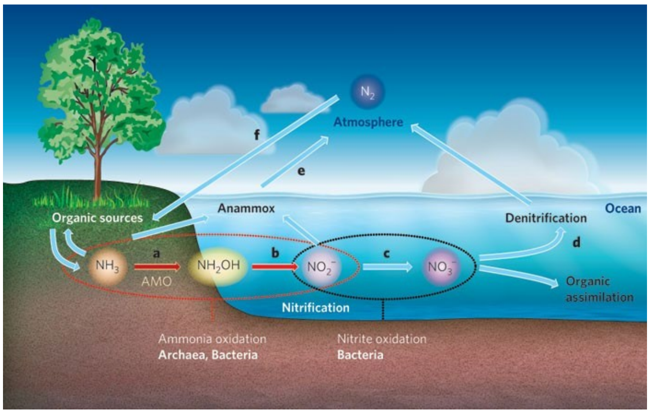

Figure 2.2 Nitrification process in a pond

C. Manual Labour

One of the main issues that are discussed in Aquaponics is manual labour, as it will increase the farming cost [4], ended up devouring a lot of resources and as a consequence, decreases productivity for farmers. The specific controlled parameter needs tobe taken care of including feeding food for fish regularly, maintaining water quality by draining and replacing clean water once a month, and also maintaining symbiosis of both aquaculture and agriculture. These intricate labours will eventually consume a lot of resources by hiring workers to take care of the symbiotic environment [4]. This might not be an issue to small scale aquaponics farmers but imagine having a large- scale Aquaponics Plantations with thousands of plants to maintain, the cost itself will drag the farmers to their feet while the productivities and efficiencies plummet.

As a solution to these problems, researchers had done a lot of Internet of Things (IoT) based projects with Aquaponics [4][5][6]. The next topic will feature the mitigations for these problems in-detail to exemplifies how far researchers and engineers had helped in regards to this field. Most of these solutions involve electronics elements between sensor nodes, controller as well as actuators. The basic concept of this solution is, having sensors to monitor parameters such as water level, temperature, pH level as well as humidity of their respective symbiotic ecology. Then, after certain events trigger, the controller will send an electrical signal to the actuator to take actions such as raising the water level of the fish tanks to lower the concentration of Ammonia and pH, turning on the light bulbs to increase temperature and humidity. In an interesting case, they evenspend their effort to build a real-time aquaponics monitoring that is accessible through smartphones.

D. Comparison between various farming method with Aquaponics

Aquaponics is the most effective of another farming method. This is because Aquaponics can produce both fish and plants outputs effectively without the need for any chemical fertilizers. Furthermore, Aquaponics does not dependent on soil;hence less pesticide is expected to visit aquaponics plants. Therefore, aquaponics owners will not need to procure pesticides toget rid of the invasive insects. The other benefit of Aquaponics includes requiring less water to nurture aquaponics environment, and it does conserve space too. On top of that, compared to thedifferent farming methods, Aquaponics is the most cost-friendly as well as not harmful to the environment.

The plants in Aquaponicsrely on natural fertilizer supplied by aquaculture's waste in theecology for its nutritional needs, and consequently, it will cut the cost for fertilizer. Conversely, to leverage the benefits Aquaponics has to offer, it does rely on arduous labours and rigorous monitoring to ensure healthy ecology for both of the 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. Besides, the model defines a combination of sequential and prototyping models since it is best used for large projects which involve continuous enhancements, especially when doing the prototyping project. A well-defined activity will be decided upon every iteration of the model until the 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 objective is achieved or not. On top of that, this can be solved by 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 4 elemental phases, such as Planning, Risk Analysis, Development, and Evaluation.

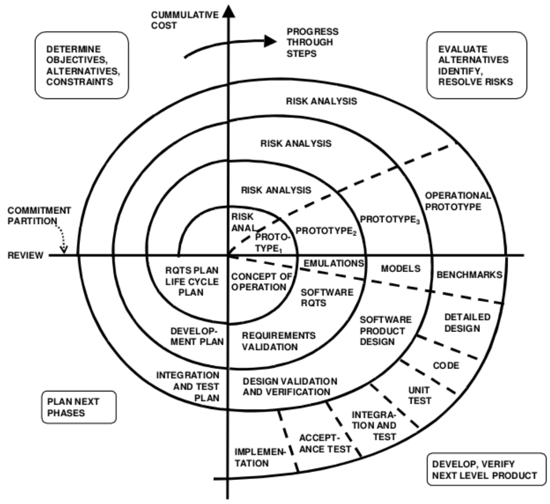

Figure 3.1 Spiral Model Methodology

The Spiral model is designed to enhance the prototyping modelas it iterates the four elemental cycles until completion of the project. This will allow tremendous improvement for the results since risk monitoring, and regular expertise is the core characteristics of this approach, the overall project becomes more transparent. Furthermore, it will eliminate 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. In recapitulation, the spiral model enables incremental releases of the product and gradual refinementthrough each iteration around the spiral.

1. Identifications

The model starts with the Identification Process, which will clarify problems, goals and objectives by using the six questions of 5W and 1H (What, Who, Where, When, Why and How). In the first iteration, a feasibility study will be carried out after the ideas for the project had been approved by FYP supervisor. This activity will gather all findings relating to the project, such as research gaps, previous work, related methodology, et cetera. Besides, these findings can be found using all sources of information from research and conference Journal, encyclopedia, internet, books, articles and previous study that were carried out by previous researchers that investigate 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 is proposed in this project.

2. Risk Analysis

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

In addition, the functionality of the prototype was carefully planned and determined to match the objective and goals of the project. At the same time, a step-by-step block diagram can visualize it. Then, the design process for the project takes place, in which it will identify parameters that need to be measured as well as accommodating insufficiency in the Aquaponics ecology and consequently recognizing possible risks in developing the prototype. After that, a list of hardware and software required to instigate the prototype will be listed. Substantially, by planning ahead and identifying risk in this project, it could reduce error and eliminate unpredictable predicaments when the end-product of the project is developed.

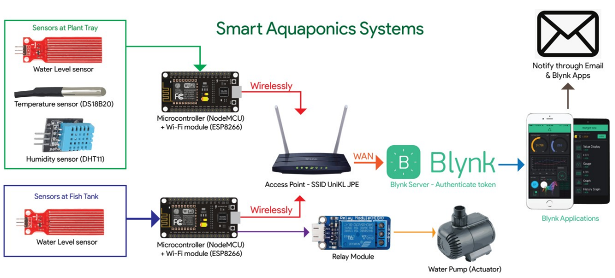

Figure 3.2 Block Diagram of Automated Aquaponics Systems

3. Development

This phase will feature 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, as there is a total of 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, will be measured by implementing hardware sensors such as water level sensor, temperature sensor, humidity level sensor. These sensors will be implemented in aquaponics ecology to act as receptors for the symbiotic environment.

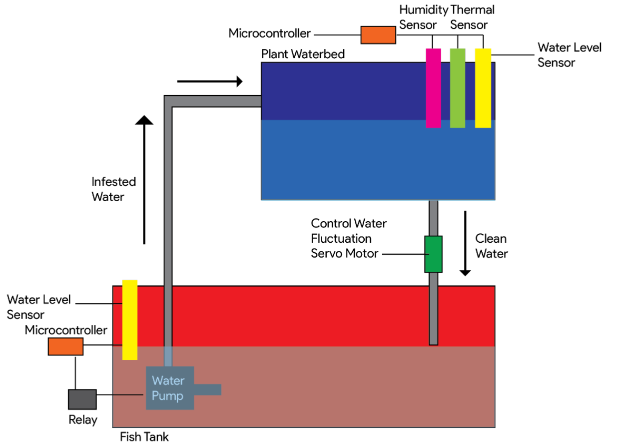

Figure 3.3 Automated Aquaponics System Concept Plan

To monitor these parameters, sensors will 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 will display the monitored parameters as well as options to regulate the insufficient parameter that can disrupt the balanced aquaponics ecology. Associating this into the equation, actuators are needed to restore balance to the aquaponics environment.

Moreover, the actuators incorporate the use of a water pump in which it will be installed in the ecology to regulate the parameters. Likewise, the water pump will serve to increase 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, by increasing water level, it will make the alkaline yet ammonium infested water to dilute its properties while supplying clean water to the fish to reside in the fish tank.

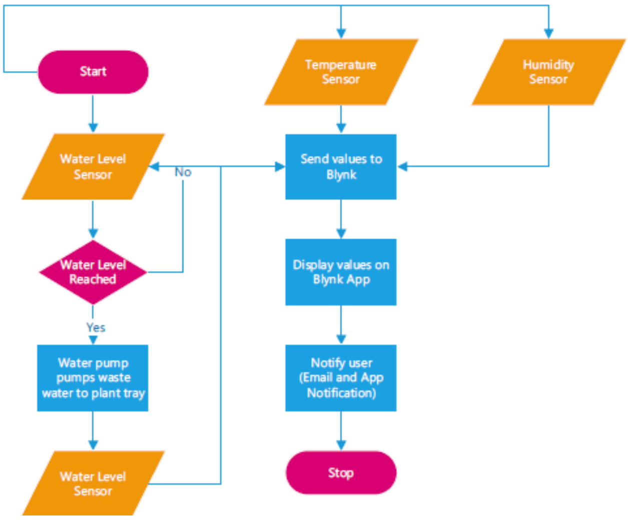

Figure 3.4 Flowchart for Automated Aquaponics Systems

4. Evaluation

In this iteration, the data from the parameters measured will then be analyzed to observe the trends in the automated aquaponics systems. After that, a deduction will be made to identify the effectiveness of the proposed solution in the development stage. These deductions and data results will be documented in the form of a final report. They can be used to 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.

IV. TESTINGS AND RESULTS

A. Prototype Implementation

After the development phase ends, the prototype was assembled based on the components discussed in the methodology section and should match project objectives. Figure 4.1 below shows the fully-implemented prototype of Smart Aquaponics systems which includes Sensors, Microcontrollers, and Actuators.

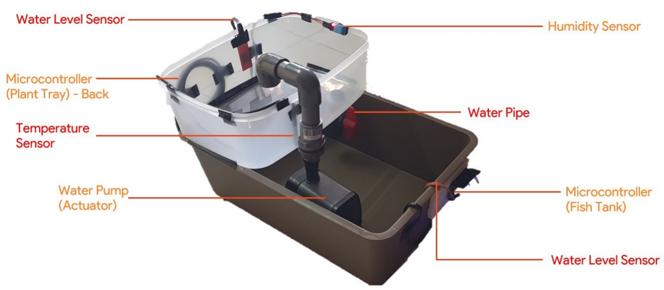

Figure 4.1 Fully Implemented prototype of Smart Aquaponics Systems

Testing and Results

The testing and result sections determine whether the project ective is achieved or not. There are two main components for ; section which includes hardware and system testing as ;erved in the following table. The table below shows the ectives of this project relative to its result.

Table 4.1 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 for both tanks collect data and visualize 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 will correctly test both microcontrollers, sensors, relay and actuators to ensure they are well-functioned for the next testing phase.

Table 4.2 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

To evaluate and verify the features of the prototype, testings are done to ensure the objectives of the project are achieved. The table below describes the system tests and its outputs during the testing. The prototype passed all aspect of testing's criteria hence achieving all project objectives stated earlier.

Table 4.3 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 4.2 Water is pumped when water level readings exceed8 litres at Fish Tank

Figure 4.3 Blynk Dashboards displaying sensor data for Fish Tanks and Plant tray

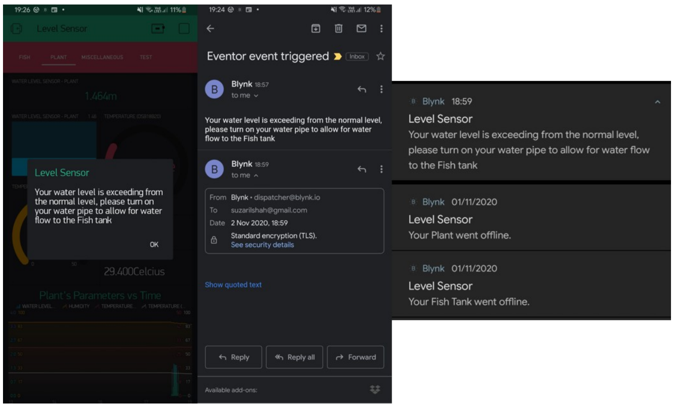

Figure 4.4 Email and App Notifications when the water level exceeds 1 litre at Plant Tray

3. Data Collections

The Blynk Applications allows for data collection and visualization via graph vs time for further data analytics for the project. Figure 4.5 and Figure 4.6 below shows the data collected in both fish tanks and plant trays, respectively. Thisdata can be used for analytics to determine the trends and tendencies in an aquaponics system.

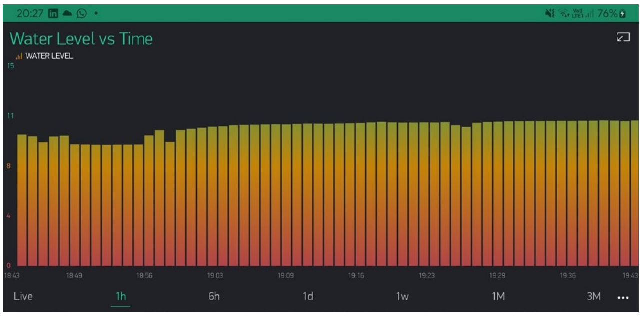

Figure 4.5 Data Collections at Fish Tank depicted by a graph vs time

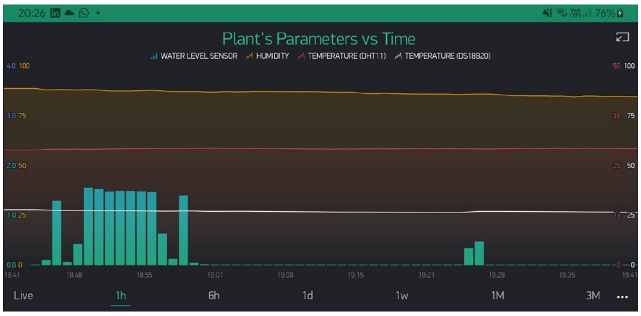

Figure 4.6 Data Collections at Plant Tray depicted by a graph vs time

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 the graph below, the water level from the fish tanks are decreasing as remaining waters were pumped into the plant the tray at the end of each day. On Friday, the water pipe at the plant trays was opened, enabling for clean water to flow back into the fish tank. However, the initial water level in the fishtanks is also decreasing by 0.21 litre from the initial water level of 8 litres in the fish tanks on Monday. This might be caused by the plants absorbing water for photosynthesis process earlier during the water traverse at the plant tray. Referring to the graph, farmers should maybe add or replacewater at both tanks to potentially enhance the water quality for the fish and plant to inhabit the ecosystem adequately.

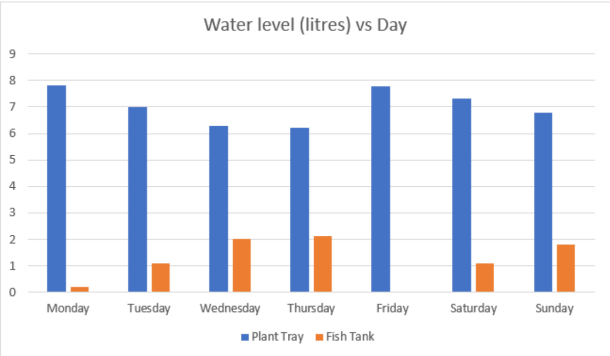

Figure 4.7 Reading from the water level sensors in a week graph vs day

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

In addition, the project 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 canbenefit from its nutrient and simultaneously clean the water for the fish. The prototype also provides notifications, specifically email and apps notifications to farmers if the water level exceeds a certain level in the plant tray, eliminating the need for constantmonitoring to the aquaponics systems.

Referring to previous works during literature studies phase, there are many researchers that 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 commercialized in the future.

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