Internet of Things (IOT)-Based Mobile Application for Monitoring of Automated Aquaponics System

Flordeliza L. Valiente, Ramon G. Garcia, Ellaine Joy A. Domingo, Scott Martin T. Estante, Erika Joanna L. Ochaves, Julian Clement C. Villanueva, Jessie R. Balbin

Mapúa University
Manila, Philippines

Abstract– **Traditional farming and fishkeeping have enabled human populations to produce foods, but as communities grow though, less and less agricultural and farm land is available. In addition, due to climate change, producing crops progressively is a difficult thing to do. Aquaponics address these concerns. Aquaponics is the integration of aquaculture and hydroponics in one system. The purpose of this study is to create an automated aquaponics system using Nile Tilapia and Romaine Lettuce with access and control of pH level and temperature through Internet of Things (IoT). Intel Edison is used as the microprocessor which continuously sends information of the aquaponics' status and adjusts them if the parameters falls below their optimal levels. The system can be monitored with the use of an Internet Protocol (IP) camera. Weekly comparison of the growth of the plant and fish in automated aquaponics, and traditional fishkeeping and hydroponics are done and growth in the automated aquapponics is significantly greater than its traditional counterpart.**

Index Terms— Automated Aquaponics, Intel Edison, Internet of Things (IoT)

I. INTRODUCTION

A. *Background of the Topic*

Food and Agriculture Organization of the United Nations defined aquaponics as "the integration of aquaculture and hydroponics in one system". In aquaculture, water must be treated to control ammonia, which is from fish waste, and in hydroponics, water must be added with nutrients for the plants. In aquaponics, the fish waste serves as nutrients for the plants which in turn cleans the water for the fish. Aquaponics is a closed-loop, recirculating water system in which plants and fish grow together symbiotically. Aquaponics is a sustainable technology that will become even more valuable as resources become limited [3]. The viability of aquaponics must be examined in detail though if the researchers are going to rely on something so radically different to provide something as essential as food. [5]

B. *Statement of the Problem*

Aquaponics is time consuming where daily management is mandatory which includes feeding of fish, ensuring the water cycle from fish tank to grow bed and vice versa, and maintaining temperature and pH level. Oversight and negligence of the owner can cause a collapse of the system. Thus, lack of Internet of Things (IoT) makes the maintenance burdensome wherein it is difficult to leave the system unattended for a long period of time Automating the aquaponic system and integrating it with the Internet of Things (IoT) will address these concerns.

C. *Objectives*

The purpose of this study is to create an automated aquaponics system using Nile Tilapia and Romaine Lettuce with access and control of pH level and temperature through internet of things with the use of Intel Edison and study the growth of Nile Tilapia and Romaine Lettuce in it. The study specifically aims (1) to construct an automated aquaponics system that should maintain the pH level of the water, temperature of the plant and water, automatically turn ON/OFF the light for the plant and automatic feeder for the fish and automatically refills water of the system (2) to implement an Internet of Things (IoT) interfacing and access to the automated aquaponic system through a web and mobile application that displays the aquaponics' status, with live streaming of the fish, and allows manual control of the pH level of the water, temperature of the plant and water, light for the plant, and automatic feeder for the fish, (3) to determine the difference of the growth in length of Nile Tilapia in the automated aquaponic system and in the traditional fishkeeping, and (4) to determine the difference of the growth in plant height of the Romaine Lettuce in the automated aquaponic system and in the hydroponics.

D. *Significance of the Study*

Using Internet of Things (IoT) in aquaponics can help save time since the system can be supervised and controlled at home or in any place with the use of internet. With a controlled environment in the automated aquaponics, the fish and plant can be grown in their optimum condition. In addition, using Aquaponics, problems about depletion of agricultural lands reserved for leafy green vegetables and fresh water fish is addressed. It decreases the amount of space needed to produce two products at once. Aquaponics extends the growing season to 365 days per year, regardless of the weather. Since it is an indoor aquaponics, it is a favoured solution for unpredictable climate conditions [1]. Aquaponics also conserves 90% of the water that conventional farming loses to runoff and evaporation [2].

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E. Scope and Delimitations

This study shall only take into consideration the examination of the growth of Nile Tilapia fish and Romaine Lettuce vegetable using aquaponics with deep water culture (DWC) method or raft method or floating on a small scale system. This study only uses Romaine Lettuce Seedling with initial height of 4 to 5cm and Nile Tilapia Fingerlings with initial length 5.5 to 5.7 cm for the experimentation. Moreover, testing has been done only in a span of four weeks. This study is only focused on maintaining certain parameter of the system that includes pH level and temperature of the system and using supported technology such as Internet of Things (IoT) to do so. This study also does not observe the matter on nitrification and supervision of the other parameters aside from pH level and temperature.

II. METHODOLOGY

A. Aquaponics

In the production of vegetables, plants, and herbs in an aquaponics, it made use of the nutrients from the effluent water from the aquaculture. Channeling the nutrient rich waste water into secondary crops is an alternative treatment of water that is both cost-effective and environmental friendly [3].

In aquaponics the farmer feeds the fish. The fish produce waste and ammonia, which are harmful for the fish in larger quantities. The water from fish is guided to plants where beneficial bacteria break ammonia first into Nitrites and then into Nitrates. Plants feed on the Nitrates and other nutrients, thus cleaning the water. Solid waste can be filtered out of water by either grow beds, in a media bed system, or by an additional filter. Clean, oxygenated water is returned to the fish tank [4].

According to Food and Agriculture Organization of the United Nations, the production of plants and fishes in an aquaponics is comparable with hydroponics and aquaculture systems. This integration removes the problems of running aquaculture and hydroponics systems independently wherein the nutrient rich waste water by product of aquaculture which must be either treated or disposed is diverted through the hydroponics which sets as the fertilizer for the plants [5].

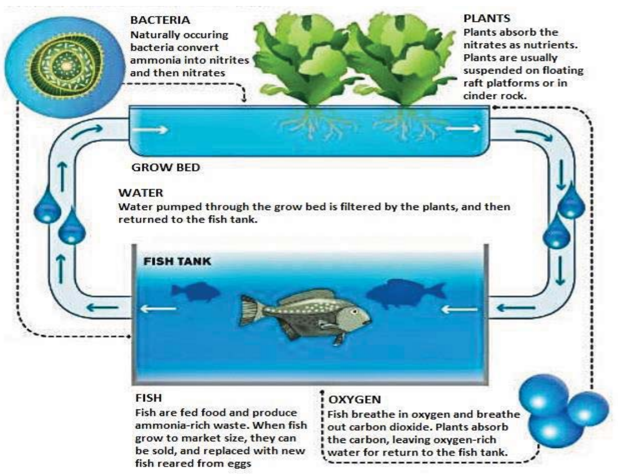

Fig. 1 Aquaponics System

Deep Water Culture (DWC) / Floating Raft System

In the Raft system, plants are grown in a floating polystyrene board that has holes just for the plants to fit in, with their roots hanging down into the water [5]. There are beneficial bacteria in the whole system which also circulates when the process is happening.

Ideal parameters and requirements for: Romaine Lettuce

Romaine Lettuce also known as cos forms an upright, elongated head and can grow best in cool areas since it is a winter crop. Typical temperature of lettuces ranges from 15-27 degrees Celsius. Silty clay loam, loam, clay loam soils are the soil requirement for best growing of lettuce with a pH of 6 to 6.8 [6].

Nile Tilapia

Tilapia is widely grown in warm countries. It can reach on an average weight of 200 to 350 grams in four months with at least 80 % survival rate. It is a fast growing fish that eats various food and can undergo low protein diet though they are herbivorous [7]. Nile tilapia has an optimal temperature range of 27-30 degrees Celsius. For the pH level, the optimum range for primary reproduction is from 6.5 to 9 [8].

Growing of Romaine Lettuce

- Lettuce requires a long days' worth of sunlight or it must be exposed in a good hydroponic lightning system for 12 hours to be able to get good results [5].
- Every gallon of water, add a concentration of roughly one teaspoon of any appropriate fertilizer with a small amount of Epson salt and calcium nitrate [5].
- Lettuce can be cultivated year-round in a hydroponics system with a temperature on the cooler side, which is optimum at 13-24 degrees Celsius [5]

Feeding of Nile Tilapia

In growing Nile Tilapia the amount of feeds is very essential. Nile Tilapia grew faster if fed 4 times daily than 2 times but it won't grow faster when fed 8 times. The quantity of feed to be given to a pond or cage each day should normally be based on a percentage of the biomass present [5].

B. Internet of Things

Internet of Things (IoT) is a construction that combines information and energy processes to control very large collections of different objects [9]. To extend the internet into the real world is the IoTs' target and vision [10].

Internet of Things is a new revolution of the Internet. Objects make themselves recognizable and they obtain intelligence by making or enabling context related decisions through communicating information about themselves. They can access information that have been aggregated by other things, or they can be components of complex services [11].

C. Intel EDISON

The Intel® Edison development platform is designed to rapidly produce and prototype Internet of Things (IoT) and wearable devices. It is created to lower the barriers to entry for consumer product designers, entrepreneurs, and investors [12].

III. DATA GATHERING

A. *Conceptual Framework*

Figure 2 shows the conceptual framework of the study. Nile Tilapia Fingerlings and Romaine Lettuce Plant Seedling was used in the automated aquaponics. Automating the system, certain parameters of water like pH level and temperature, as well as the system for feeding of the fish and light exposure provided for the plants can now be controlled either automatically or manually. Using a camera for the overall view of the aquaponics system, the aquaponics can be viewed if the automatic control is working and if the fishes are still alive. Obtaining all the data needed from the sensors, it will be transmitted by the Intel Edison through the internet to the Thingspeak site to store the data and the created application will then access these data.

B. *Hardware Development*

Construct the aquaponics system and assemble the hardware to automate the aquaponics. Place the temperature sensors in the growbed and in the fish tank, and the pH sensor in the fish tank. Actuators are also placed to give corrective actions in temperature and pH level. Heater and fan to correct the temperature and peristaltic pumps in correcting the pH level. An automatic feeder was also placed and an IP camera. An ultrasonic sensor was also placed to know when to activate the pump for water refilling. The microcontroller used was Intel Edison.

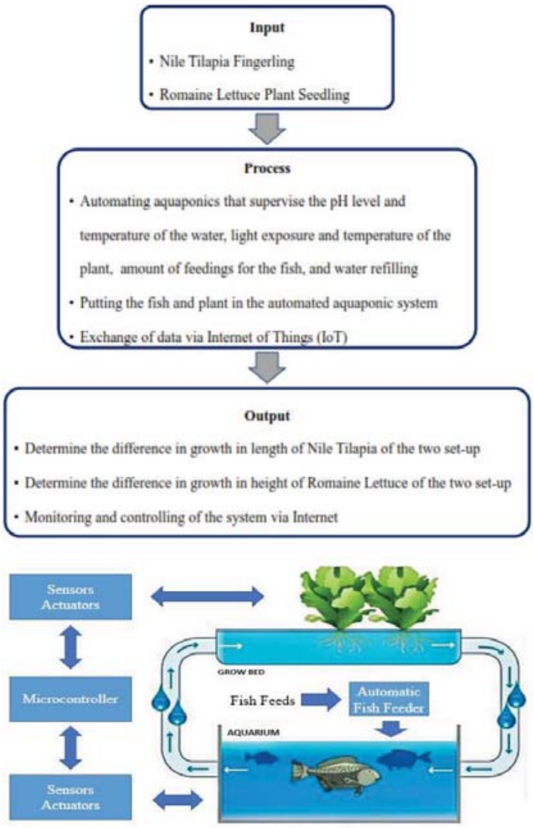

Fig. 2 Conceptual Framework

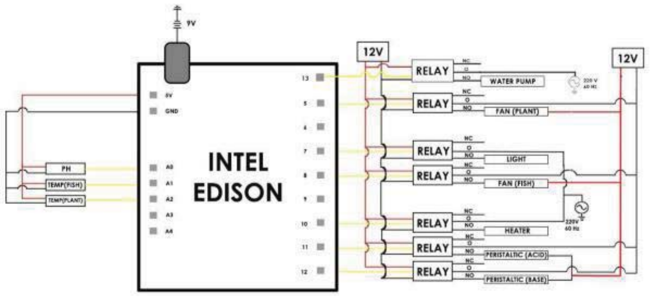

Fig.4 Wiring Diagram of Sensors and Actuators

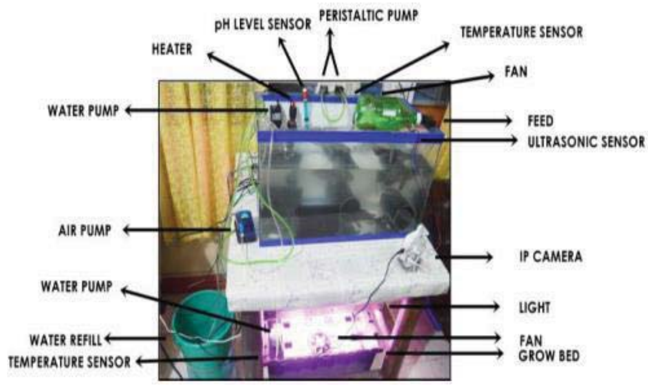

Fig. 5 Actual Automated Aquaponic System

C. *Software Development*

The research also involves integrating the aquaponics system with Internet of Things (IoT) wherein the entire structure is powered by the Intel Edison which collects data from the sensors installed and stores these data in the Internet of Things (IoT) enabled cloud which is the ThingSpeak. The Intel Edison is programmed to monitor the environmental variables of the automated aquaponics and maintain these to the preferred conditions. The system also comprises a web application shown in Figure 7 and mobile application shown in Figure 8 that has real-time sensor data monitoring of the automatic system but also allows manual control to the system.

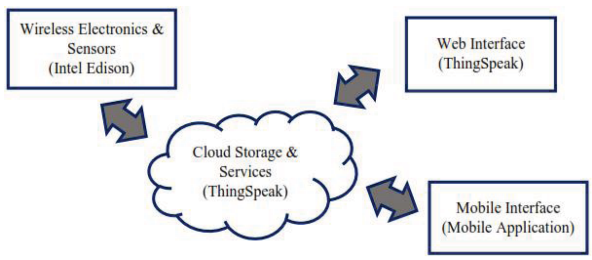

Fig. 6 Internet of Things System Diagram

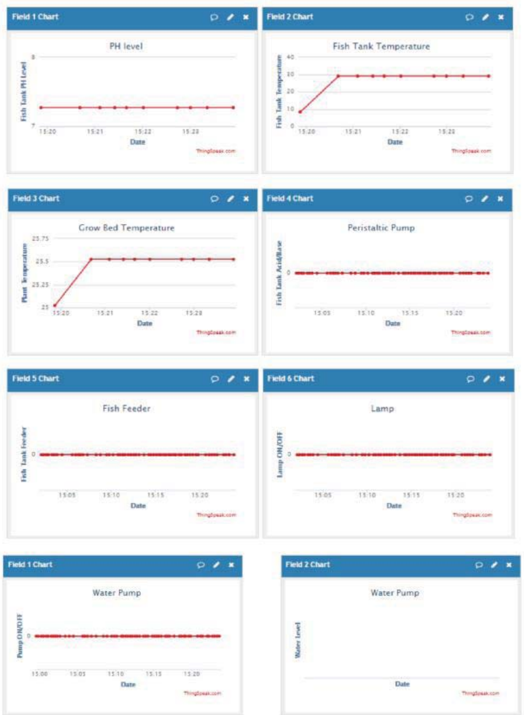

Fig. 7 Automated Aquaponics Web App

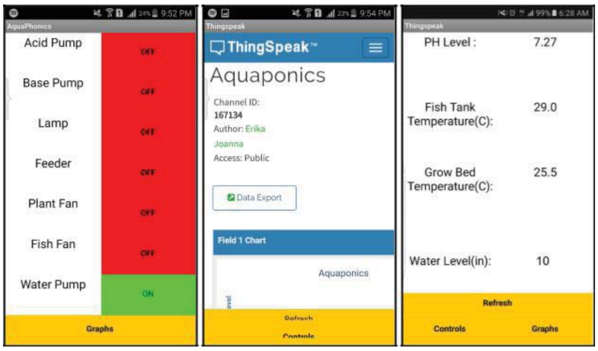

Fig. 8 Automated Aquaponics Mobile App

The Arduino software was used to develop on the Edison. The Edison was coded to connect to the internet to give and get information in the ThingSpeak.

The following parameters are what the microcontroller was programmed to maintain:

1. pH Level
   if pH < 6.2 then peristaltic pump will actuate to add acid if
   pH > 7.5 then peristaltic pump will actuate to add base
2. Temperature of water
   if temp < 27°C then the heater will turn on if temp > 30°C then the fan will turn on
3. Temperature of plant
   if temp > 27°C then the fan will turn on
4. Light duration
   from 0 to 12 hours, the Fluorescent lamp is on
   from 12 to 24 hours, the Flourescent lamp is off
5. Automatic feeder
   Every 8 hours, the automatic feeder will turn on
6. Automatic water refilling
   if the water is > 2in from the sensor, the water pump is on

D. Experimental Procedures for Data Gathering

The data collection method used by the researchers for the study is experimentation. It was used to prove or disapprove the stability of the study and to study the growth of Nile Tilapia and Romaine Lettuce in an automated aquaponics as compared to the traditional hydroponics and fishkeeping. The following data gathering procedures were used to obtain the data presented.

1. Calibrate the pH sensor through the use of pH meter. If the values do not match, the difference between the theoretical and actual behavior of a pH probe must be compensated for. A calibration is required to match the pH meter to the current characteristics of the used pH sensor.
2. Calibrate the temperature sensor by using a thermometer to measure the temperature of the system. If the reading from the submerged temperature sensor does not match the reading from the thermometer, the difference between the reading of the sensor and thermometer were regulated with the use of Arduino,
3. Submerge the pH sensor and temperature sensor in the system. The reading should be automatically displayed on the web and mobile application.
4. If the reading does not satisfy the optimal values of the parameters, the system automatically adjusts the pH through the use of peristaltic pump and the temperature through the use of fan cooler and heater.
5. If the level of the water is below the set level, it will be automatically refilled with water be the water pump.
6. Record the pH and temperature of the system at 7:00 am, 3:00 pm and 11:00 pm daily for 4 weeks.
7. Compute for the daily average for pH and temperature of the system.
8. Subsequently, measure the plant length from the bottom of the stem until the longest leaf.
9. Record the height of the Romaine Lettuce in aquaponics and in hydroponics every 7 days and compute for the average plant height.
10. Using a fish net, bring the fish close to the wall of the fish tank and measure its length using a measuring device.
11. Record the length of the fish in aquaponics and in traditional fishkeeping every 7 days and compute for the average length.
12. Do the data gathering procedure for 28 days.

IV. Results and Discussion

Test Subject

The growth of Nile Tilapia and Romaine Lettuce was closely observed, while the pH level and temperature of the automated aquaponics were maintained in their optimum value. The water was also automatically refilled when needed. The pH level and temperature were monitored real time through the use of a web and mobile application.

Testing Duration

The test lasted for 28 days. The testing begun when the plant has grown a little and for the fish, the test started when the fish are already fingerling. Measurements were taken three (3) times a day for the whole 4 weeks. Testing is done every 7:00 AM, 3:00 PM and 11:00 PM.

Test Variables

The Nile Tilapia and Romaine Lettuce was incorporated with the automated system created for 28 days. The pH level and temperature was controlled and monitored. There should be no human intervention for the maintenance of the aquaponic for the study to be valid. Table 1 shows the average pH level and temperature per day measured by the sensors during the duration of the testing. The amount of food for the fish was varied according to its growth.

TABLE I
DATA LOG OF AVERAGE FISH FEED INTAKE, PH LEVEL, TEMPERATURE SENSOR VALUES, AND WATER LEVEL PER DAY

Day	Ave. Fish Feed Intake (mg)	Ave. pH Level	Ave. Temp. in Fish Tank (ºC)	Ave. Temp. in Grow Bed (ºC)	Ave. Water Level (in)
1	6	6.33	27.67	26	9
2	6	6.93	28	25.67	9
3	6	6.97	28.67	26.33	9
4	6	7.10	28	25.67	8.83
5	6	6.90	28.33	26	9
6	6	7.03	27.67	26	8.77
7	6	6.67	27.33	26	8.9
8	6	6.70	28	25.33	8.8
9	6	6.80	27.67	25.33	8.73
10	6	7	28	26	9
11	6	6.90	27.67	25	8.77
12	6	6.83	27.67	25.33	9
13	6	6.73	28.33	26	8.83
14	6	7	28.33	25.67	9
15	6	7.03	27.33	25.33	9
16	9	6.66	28.67	25.67	8.9
17	9	6.9	27.67	25.67	9
18	9	6.7	27.67	25.33	8.77
19	9	6.97	28	25.33	9
20	9	6.8	28.33	25.67	8.83
21	9	6.9	28.33	25	8.87
22	9	7.13	28	26	9
23	9	6.33	27.33	26.3	8.83
24	9	6.8	28.67	25	8.93
25	9	6.67	27.67	25.67	9
26	9	7.03	28.33	26	9
27	9	6.67	28	25.33	8.77
28	9	7.1	27.67	25.67	9

From the Table 1, it can be observed that the pH level and temperature of the automated aquaponics system was maintained on desired values.

Every 7 days for 4 weeks, the length of Nile Tilapia was determined. The average length of all fishes in aquaponic system shall be equal to the average length of all the fishes in the traditional fishkeeping for the initial set-up.

TABLE II
AVERAGE LENGTH AND GROWTH OF NILE TILAPIA IN AQUAPONICS AND TRADITIONAL FISHKEEPING

Week	Ave. Length of Nile Tilapia in Aquaponics (cm)	Growth of Nile Tilapia in Aquaponics (cm)	Ave. Length of Nile Tilapia in Traditional Fishkeeping (cm)	Growth of Nile Tilapia in Traditional Fishkeeping (cm)
1	4.2	-	4.2	-
2	6.1	1.9	5.3	1.1
3	8.2	2.1	7.3	2
4	11.2	3	9.3	2
Average Growth		2.33	Average Growth	1.70

To statistically compare the data for the two system, where the fish in automated aquaponics be the experimental group and the fish kept in traditional fishkeeping be the control group, every week, a one-tailed t-test was used with the following hypotheses:

Null Hypothesis, Ho: The growth in length of Nile Tilapia in automated aquaponics is equal or less than the growth in traditional fishkeeping.

Alternate Hypothesis, Ha: The growth in length of Nile Tilapia in automated aquaponics is greater than the growth in traditional fishkeeping.

$$Ho : u1-u2=0$$
$$Ha : u1-u2>0$$

TABLE III
T-TEST RESULT FOR THE GROWTH IN LENGTH OF NILE TILAPIA

Label	Week 1	Week 2	Week 3	Week 4
Number of samples in Experimental Group (n1)	5	5	5	5
Number of samples in Control Group (n2)	5	5	5	5
Mean of Experimental Group (x1)	4.2	6.1	8.2	11.2
Mean of Control Group (x2)	4.2	5.3	7.3	9.3
Standard deviation of Experimental Group (s1)	0.4472	0.2236	0.4472	.4472
Standard deviation of Control Group (s2)	0.4472	0.4472	0.4472	.4472
Degrees of freedom		6	8	8
Level of significance for directional test	.05	.05	.05	.05
Calculated t-value	0	3.5778	3.1825	6.7185
t-critical	0	1.943	1.86	1.86

For week 1, the computed t-value and t-critical is 0. The null hypothesis is accepted. This means that the growth in length of Nile Tilapia in automated aquaponics is equal or less than the growth in traditional fishkeeping for the first 7 days.

For week 2 to week 4, the calculated t-value is greater than the t-critical. The alternate hypothesis is accepted. Therefore, the growth in length of Nile Tilapia in automated aquaponics is greater than the growth in traditional fishkeeping for day 14 and up.

Every 7 days for 4 weeks, the plant height of Romaine Lettuce was determined. The average plant height was measured by taking the average length of all longest leaf of each lettuce. The average plant height of all the plants in aquaponic system shall be equal to the average plant height of all the plants in the hydroponics for the initial set-up.

TABLE IV
AVERAGE PLANT HEIGHT OF ROMAINE LETTUCE IN AQUAPONICS AND HYDROPONICS

Week	Ave. Plant Height of Romaine Lettuce in Aquaponics (cm)	Growth of Romaine Lettuce in Aquaponics (cm)	Ave. Plant Height of Romaine Lettuce in Hydroponics (cm)	Growth of Romaine Lettuce in Hydroponics (cm)
1	5.58	-	5.55	-
2	6.55	0.97	6.5	0.95
3	7.13	0.58	6.9	0.40
4	8.08	0.95	7.58	0.68
Average Growth		0.83	Average Growth	0.67

To statistically compare the data of the two system, where the plant in automated aquaponics be the experimental group and the plant kept in hydroponics be the control group, every week, a one-tailed t-test was used with the following hypotheses:

Null Hypothesis, Ho: The growth in plant height of Romaine Lettuce in automated aquaponics is equal or less than the growth in hydroponics.

Alternate Hypothesis, Ha: The growth in plant height of Romaine Lettuce in automated aquaponics is greater than the growth in hydroponics.

$$Ho : u1-u2=0$$
$$Ha : u1-u2>0$$

TABLE II
T-TEST RESULT FOR THE GROWTH IN HEIGHT OF ROMAINE LETTUCE

Label	Week 1	Week 2	Week 3	Week 4
Number of samples in Experimental Group (n1)	4	4	4	4
Number of samples in Control Group (n2)	4	4	4	4
Mean of Experimental Group (x1)	5.58	6.55	7.13	8.08
Mean of Control Group (x2)	5.55	6.5	7.9	7.58
Standard deviation of Experimental Group (s1)	0.0959	.0574	0.15	0.15
Standard deviation of Control Group (s2)	0.1	0	0.0819	0.2987
Degrees of freedom	6	3	5	4
Level of significance for directional test	.05	.05	.05	.05
Calculated t-value	0.3608	1.7422	2.6347	2.9922
t-critical	2.447	2.353	2.015	2.132

For week 1 and week 2, the calculated t-value is less than the t-critical. The null hypothesis is accepted. This means that the growth in plant height of Romaine Lettuce in automated aquaponics is equal or less than the growth in hydroponics.

For week 3 to week 4, the calculated t-value is greater than the t-critical. The alternate hypothesis is accepted. Therefore, the growth in plant height of Romaine Lettuce in automated aquaponics is greater than the growth in hydroponics for day 21 and up.

V. CONCLUSION

The study entitled "Examination of Growth of Nile Tilapia and Romaine Lettuce in Automated Aquaponics System with Access and Control of pH Level and Temperature through Internet of Things with the Use of Intel Edison" utilizes the monitoring and controlling of the parameters to maximize the growth for the fish and plants using Intel Edison. The automation for the aquaponics system was done to make a simulated environment for the fish and plants programmed to maintain the parameters such as pH level (6.2 to 7.5) and temperature (<27ºC for Romaine Lettuce and 27ºC to 30ºC for Nile Tilapia) in their safe levels, and provided automated feeding system for the fish, light exposure for the plant and automatic refilling of the water.

For 28 days, the Intel Edison continuously sends the status of the automated aquaponics to the Thingspeak cloud. With Internet of Things (IoT), the automated aquaponics' pH level, temperature, light exposure, feeding and water refilling was controlled and monitored wirelessly through a web and phone application.

In the first week of the testing period of the Nile Tilapia, its growth in aquaponics is not significantly greater than its traditional counterpart but on the second to the fourth week of testing, the growth in length of Nile Tilapia in automated aquaponics is greater than the growth in traditional fishkeeping.

In the first and second week of testing of the Romaine Lettuce, growth in aquaponics is not significantly greater than its traditional counterpart but on the third and fourth week of testing, the growth in plant height of Romaine Lettuce in automated aquaponics is greater than the growth in hydroponics.

Based from the data acquired, the growth of the fish and plant depend on the maintenance of the pH level and temperature, and it is important to maintain these parameters for the fish and plant to attain a faster growth. In the first week of the testing period of the fish, and first and second week of the testing period of the plant, the growth of the Nile Tilapia and Romaine Lettuce is not significantly greater because it is its adjustment stage. For the following weeks, it can be seen in the t-test performed that the growth of Nile Tilapia and Romaine Lettuce is significantly greater in the automated aquaponics than in traditional fishkeeping and hydroponics which means that the fishes and plants can grow faster from their optimum environment used in the automated aquaponics.

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