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# The Smart Aquaponic System Integrated with Internet of Things Technology

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**Abstract**

Aquaponics is a sustainable plant method that combines aquaculture (fish life) and hydroponics (soilless plants) in a closed cycle. To achieve optimal results, aquaponics requires a robust water cycle and meticulous maintenance, including monitoring temperature, environmental air humidity, and plant media humidity, among other factors. The current aquaponics system still relies on manual methods for monitoring, lacking an integrated system to handle this care function. Therefore, we developed this product to address these issues by concentrating on creating intelligent aquaponic systems that integrate the Internet of Things, enabling users to track necessary parameters. Additionally, the system automates tasks like irrigation and fish feeding schedules. In this development, the researcher employed the 7-phase Engineering Design Process (EDP) model, which includes the following stages: (1) defining the problem, (2) conducting research, (3) developing a solution concept, (4) constructing a prototype, (5) constructing a product, (6) conducting a product analysis, and (7) improving the product. he BBC micro:bit microcontroller as the main controller and the ESP01s WiFi module as the component that allows interaction with ThingSpeak. Next, the researcher used several types of sensors, such as DHT11, HC-SR04, capacitive soil moisture sensor v1.2, DS18B20, and actuators such as a DC water pump motor and a FS90 180-degree servo motor. As a result, the researcher successfully met the set objectives, including the design, development, and testing of the product's functionality, and the product performed as expected. Finally, according to experts, this product's weakness is that it requires the addition of a humidity sensor installed on each plant pot, which is recommended for further study due to limitations on the microcontroller's I/O pins.

## 1. Introduction

Aquaponics is a sustainable and innovative farming method that integrates plant cultivation and fish in a closed system. This system utilises a symbiotic relationship between aquaculture organisms and hydroponic plants. In addition, in this interconnected ecosystem, fish waste is used in a cycle as nutrients for plants, while plants clean and filter water and create a repeating cycle between aquaculture or fish and hydroponics or plants. Furthermore, according to Sumeth Wongkiew et al., aquaponics has the ability to produce both edible and organic results [1]. Furthermore, modern agriculture has begun to turn to Internet of Things (IoT) applications in an effort to increase productivity and crop yields. The agricultural sector has widely adopted this IoT application, which includes the use of robots, drones, sensors, computer imaging, monitoring, and data analysis. Therefore, to achieve optimal results from any method, it is necessary to incorporate IoT elements [2]. IoT applications in agriculture have also been widely used in various methods with their own concepts such as in Newark, USA (Aero Farm), Paris, France (Agricool), Phoenix, USA (Bites), London, United Kingdom (GrowUp Urban Farm) and Singapore (Sustainable Agriculture)[3].

## 1.1 Background Research

Aquaponics is generally a simple and easy-to-operate system, but there are some common problems with this system, such as poor water cycles. The aquaponic system is highly dependent on a good water cycle and is important in distributing oxygen, nutrients, and good bacteria in the system to help the growth and survival of plants and fish [4].

Furthermore, water is one of the most important elements in an aquaponics system because it is the foundation for plant and fish life. Aspects such as water pH, temperature, oxygen level, and nutrient level reveal low water quality. Those aspects must always be in optimal conditions to get successful aquaponics results [5]. In addition, it is seen from the aspect of fish care that when there are too many fish in a fish tank, it will disturb the whole system. Aquaponic systems rely on fish to provide water with nitrifying substances [6].

Aquaponics requires hydroponic elements to complete the system. To achieve optimal results, the plants used must be suitable. Vegetables, fruit plants, herbs, and flowers are among the plants available for planting. Among them are tomatoes, lettuce, pepper, cucumber, water spinach, cabbage, strawberries, and others [7]. Aquaculture or farmed fish can consist of edible fish or ornamental fish. This aquaponic system can rear a variety of fish, including spiny fish, catfish, seabass, and more. You can rear ornamental fish such as Koi fish, Goldfish, or Anabas testudines [7].

## 1.2 Problem Statement

Nevertheless, researchers have identified several issues inherent in this aquaponic system, notably its reliance on a robust water circulation mechanism. An interruption in this hydrological cycle might result in inadequate nutrient circulation [8].

Subsequently, this aquaponic plant technique necessitates meticulous attention to details such as illumination, pH supervision, soil dampness, and temperature regulation, along with the establishment of a feeding schedule for the aquaculture animals inside the aquaponic system. Aquaponic plants that get little or excessive sunlight will have stunted growth [8]. Moreover, the time of feeding aquaculture animals is crucial for assuring the fish's development rate and maintaining their health under ideal circumstances. Overfeeding aquaculture cattle may result in a deterioration of water quality and harm fish as a result of leftover surplus food [9].

To summarise, the statement implies that developing a smart aquaponic system using Internet of Things technology requires combining microcontrollers, sensors, actuators, and WiFi modules for IoT connectivity. This technique seeks to tackle crucial concerns such as ambient temperature and humidity parameters, soil humidity, automated feed scheduling, and automatic watering for aquaculture animals in aquaponic systems.

## 1.3 Research Objectives

The project developed is to fulfil the objectives:

- Design an automated aquaponics system equipped with IoT features and Thingspeak application.
- Develop an automated aquaponics system equipped with IoT features and the Thingspeak application.
- Testing the functionality of an automated aquaponics system equipped with IoT features and the Thingspeak app.

## 2. Literature Review

Aquaponics systems depend on the type of plants and fish used in this system to ensure the effectiveness of a successful ecosystem. In addition, the combination of electronic components and sensors is also the hardware that forms the basis of the system's functionality in performing data collection functions for monitoring for IoT capabilities.

## 2.1 Effectiveness of Existing Aquaponic Systems

Aquaponics The effectiveness of aquaponics in general is based on the plants and fish used in this system. These plants and fish integrate to form a complete ecosystem which is aquaponics. The fish farm that is the choice in aquaponics generally consists of small fish that do not eat plants such as guppy fish, platy and molly, but large fish such as spiny fish, anabas, snakehead fish and catfish can also be used as livestock to obtain meat products as well in this aquaponic system [10].

Next, the plants planted can also consist of various types of green vegetables such as water spinach, cabbage and lettuce. Plants grown in this aquaponic system will absorb nutrients from the water produced from fish waste [10]. In addition, the aquaponic system is also effective if the type of plants and fish chosen are appropriate. Therefore, based on the researchers' findings, water spinach is a plant that has high $NO_3$ removal efficiency and can directly function as a natural biofilter in this aquaponic system [11].

In addition, fish such as Anabas testudines are also suitable fish for aquaponic systems because of their ability to live in a closed system such as aquaponics [12]. Finally, based on this finding, the researcher took into account the combination of plants and fish to be used in the development of this product.

## 2.2 Sensors and Components Used Based on Past Studies

Sensors are hardware that work together with other electronic components to carry out various functions. Based on previous research, in this aquaponics and IoT system, several components and sensors are needed to ensure that the built system can function as a complete system [13].

Additionally, in the context of the title of this study, which is the aquaponic plant method, there are several sensors that are compatible with the aquaponic system as in the findings of the study that has designed an IoT-based aquaponic monitoring system that measures and controls parameters such as oxygen levels, PH sensors, temperature sensors and so on by recording various parameters in a real-time setting [14]. As in agriculture, various configurations of sensors and components used especially in some past studies related to agriculture such as Table 1.

**Table 1** *Components and sensors used based on previous studies*

| No | Research | Description |
|---|---|---|
| 1 | Khaoula, T., Ait Abdelouahid, R., Ezzahoui, I., & Marzak, A. (2021). Architecture design of monitoring and controlling of IoT-based aquaponics system powered by solar energy. *Procedia Computer Science*, 191, 493–498. https://doi.org/10.1016/j.procs.2021.07.063 | This project focuses on the development of solutions based on IoT in controlling and monitoring water quality and environmental parameters.<br>Components and sensors used such as:<br>- Node MCU<br>- Water level sensor<br>- Temperature sensor<br>- CO2 sensor<br>- Humidity sensor |
| 2 | Kodali, R. K., & Sabu, A. C. (2022). Aqua Monitoring System using AWS. 2022 *International Conference on Computer Communication and Informatics (ICCCI)*, 1–5. https://doi.org/10.1109/ICCCI54379.2022.9740798 | This project focuses on developing a monitoring system with AWS technology and providing notifications to users with the medium of email.<br>Components and sensors used such as:<br>- ESP32<br>- DHT11<br>- Relay<br>- Feeding system |
| 3 | Menon, P. C. (2020). IoT enabled Aquaponics with wireless sensor smart monitoring. *2020 Fourth International Conference on I-SMAC (IoT in Social, Mobile, Analytics and Cloud) (I-SMAC)*, 171–176. https://doi.org/10.1109/I-SMAC49090.2020.9243368 | This project focuses on discussing approaches to solving the problems that occur among gardeners who use aquaponic methods by using a technical approach which is the development of aquaponic systems with wireless sensors.<br>Components and sensors used such as:<br>- Arduino Mega<br>- ESP8266<br>- PH sensor |

| | | |
|---|---|---|
| | | - Nitrate sensor<br>- Ammonia sensor |
| 4 | Riansyah, A., Mardiati, R., Effendi, M. R., & Ismail, N. (2020). Fish Feeding Automation and Aquaponics Monitoring System Base on IoT. *2020 6th International Conference on Wireless and Telematics (ICWT),* 1–4. https://doi.org/10.1109/ICWT50448.2020.9243620 | This project focuses on the development of a monitoring system for pH and TDS in aquaponic systems and automatic feeding of fish.<br>Components and sensors used such as:<br>- Arduino Uno R3<br>- ESP8266<br>- pH sensor<br>- TDS sensor |

Based on Table 1, there are various past studies that have been carried out for this aquaponics system that emphasize several aspects such as monitoring systems, automatic feeding systems and notification systems. Additionally, the microcontroller for the existing system in this chapter also uses Node MCU [14], ESP32 [13], Arduino Mega [15] and Arduino Uno R3 [16]. Therefore, researchers take into account functionality such as monitoring, automatic feeding systems for fish and notification interface systems to be developed in addition to using appropriate hardware and sensors.

## 3. Methodology

The methodology section explained about the model that has been used in this product development. This chapter also discussed the research design that used, research procedure that involved and research instrument that applied into the development of Smart Aquaponic System Equipped with Internet of Things Technology.

### 3.1 Research Design

The Engineering design process (EDP) model was used throughout the development process of the project. This model firstly used in the writing of literature studies by researchers who focus on the application of the EDP model in capstone courses that are oriented towards project development and among the earliest researchers who use this EDP model in research. EDP model used consist of seven phases, namely:

- Define The Problem
- Conduct Research
- Develop Concept of Solution
- Create Prototype
- Develop Product
- Product Analysis
- Improvement

### 3.2 Research Procedure

The development of this product involves a procedure based on the seven phases of EDP model that used. The procedure involves as in Table 2.

#### 3.2.1 Define the Problem

The problem found in the existing aquaponic system includes aquaponics that requires detailed care as it requires a consistent water cycle so that the flow of nutrients is not interrupted and remains optimal [8]. In addition, the problem that occurs is that it requires close care by monitoring data parameters such as environmental temperature, water temperature, environmental humidity, soil moisture, water level and including feeding scheduling for aquaculture [9].

#### 3.2.2 Conduct Research

Research is done based on the problems that occur with reference to the previous phase. The problem focuses on the need for aquaponics in meticulous care in the aspect of consistent water cycle care, monitoring the humidity of plant media and feeding scheduling for aquaculture livestock.

In addition, there is also an aquaponics system with an IoT system, but in the project, it only focuses on real-time data monitoring and only notifies users of the status [15]. Next, there is also a project that focuses on the scheduling of aquaculture feeding, but this project only focuses on the feeding scheduler [16].

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Therefore, an aquaponics project that integrates the BBC micro:Bit microcontroller and data monitoring functions such as temperature, humidity, water level and control such as fish feeding scheduling and irrigation cycle control is still missing and the problem that occurs is solved with the development of a Smart Aquaponic System project with Equipped Internet of Things Technology.

**Table 2** *Operational project framework Engineering Design Process (EDP)*

| Phase | Step (EDP) | Procedure |
|---|---|---|
| 1 | Define The Problem | Problems exist are identified by looking at information related to the problems that arise. |
| 2 | Conduct Research | Research on problems that occur such as projects with the same concept are searched for and collected. |
| 3 | Develop Concept of Solution | Through research, problem solving concepts are built. |
| 4 | Create Prototype | Preparation of components and materials, then building a prototype model of the project to test the design of the project. |
| 5 | Develop Product | Build a functional final product based on the input from the previous phase. |
| 6 | Product Analysis | Improvements are made based on the findings of evaluation and testing including functional evaluation by experts. |
| 7 | Improvement | Improvements are made based on the findings of the previous phase. |

### 3.2.3 Develop Concept of Solution

The solution concept built is to develop an aquaponic system equipped with a microcontroller, WiFi module, several types of sensors and actuators. The concept of closed-loop control theoretically involves data parameters that are compared with current parameters and appropriate control is performed to correct the parameter value to the desired level [17]. This solution concept allows an aquaponic system to function with a closed-loop control concept as shown in Fig. 1.

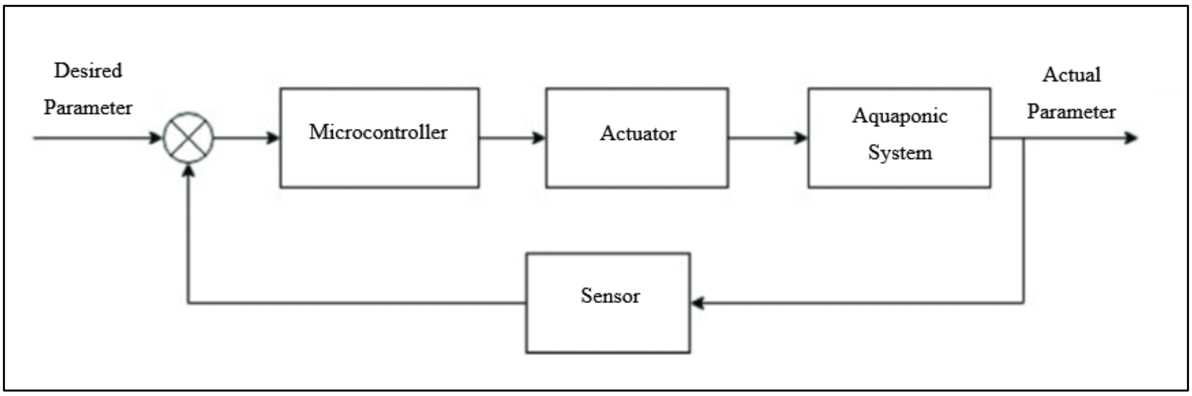


**Fig. 1** *Block diagram of closed-loop control concept*

Addition, using this concept, the BBC Micro:Bit microcontroller used as a processing unit and the ESP01s WiFi module as an IoT communication unit for connecting the aquaponics system to the web-based software platform. In addition, sensors are also used to focus on monitoring and collecting data such as environmental temperature and humidity, plant media humidity, water level and water temperature that help in the functionality of the actuator. Block diagram for this product as Fig. 2.

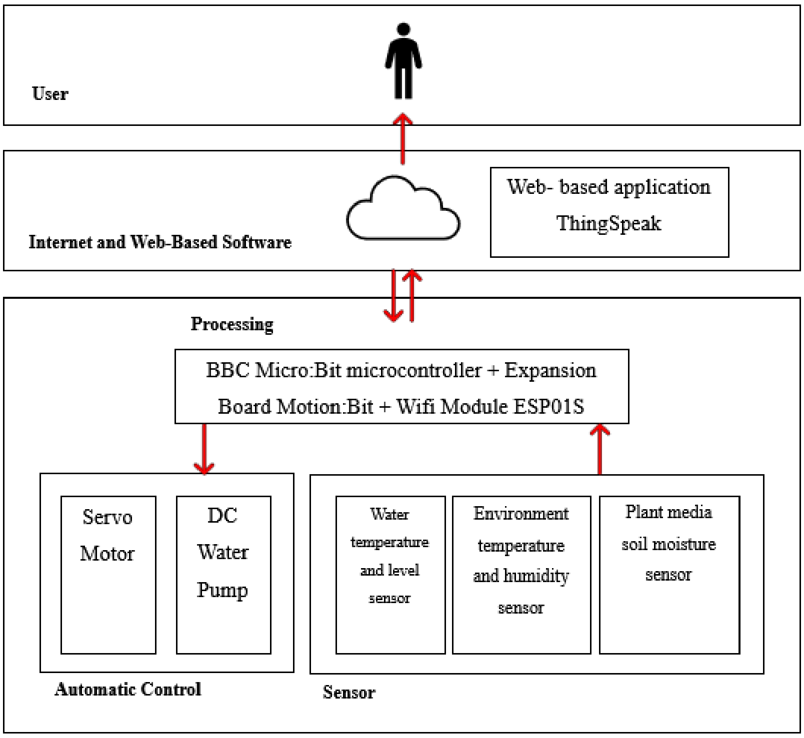


**Fig. 2** *Product block diagram for smart aquaponic system equipped with internet of things technology*

### 3.2.4 Create Prototype

This phase focuses on prototype development, this development involves the selection of electronic hardware, aquaponic hardware and software that has been used. The selection of hardware and software has become the basis for the schematic construction of the electronic circuit for this prototype. In addition, after the selection of hardware and software is done, design development such as circuit design, aquaponic hardware system design and software design are done. Once the hardware identified, the schematic circuit develops based on the hardware used. The schematic diagram is in Fig. 3.

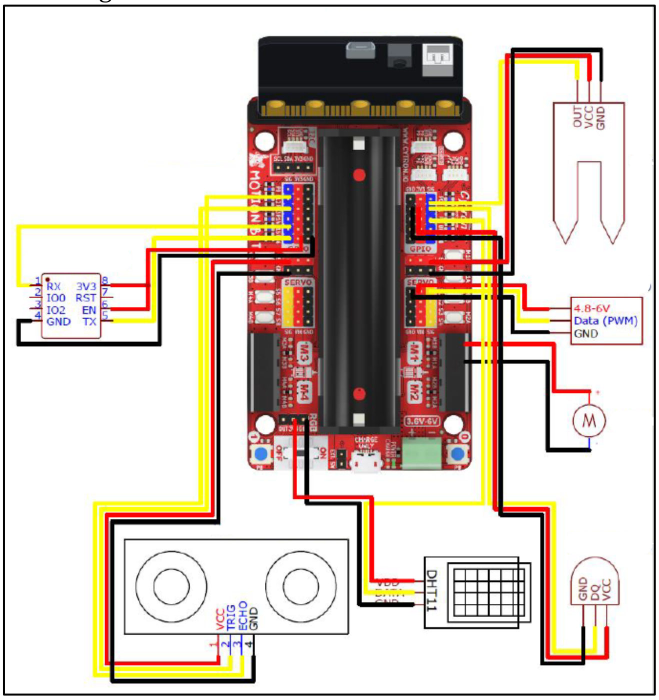


**Fig. 3** *Schematic diagram for smart aquaponic system equipped with internet of things technology*

### 3.2.5 Develop Product

Results product development involves the use of input from creating prototype from previous phase. The development includes the circuit development for the product based on schematic in Figure 3. Next, the development covers the building of hardware and software such as the aquaponic structure for plant media pot location and water tank for fish, while for software is the development of interface using graph, widget, and number on ThingSpeak. The final product was built as in Fig. 4 and Fig.5 is the actual photo of the product.

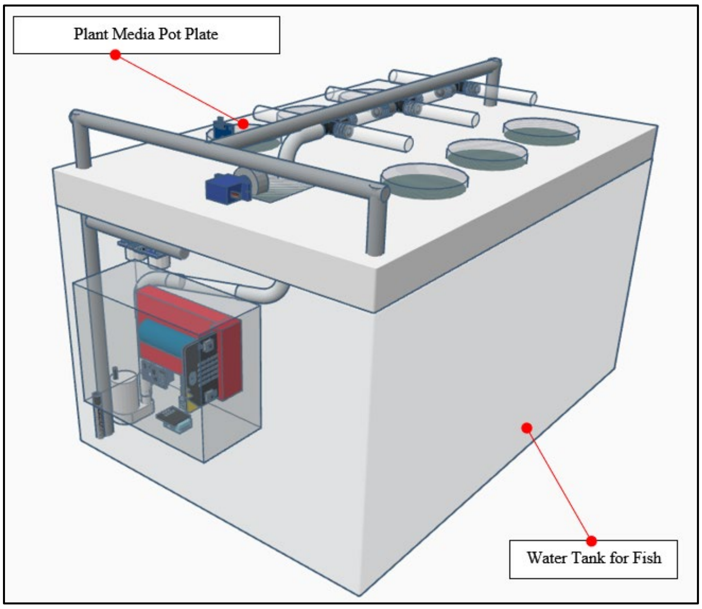


**Fig. 4** *3D design of the product*

The interface for web-based monitoring system was set up the interface on the ThingSpeak software showing the information such as environment temperature and humidity, water temperature and water level, fish feeding frequency meter, soil moisture percent and water pump status. Addition, in this software and programming design development also take a consideration based on type of plant and fish that used in this system. In this development, the type of plant used is water spinach which requires an optimal plant media humidity of around 55% - 70% for aquaponic growth to be successful [18].

While the suitable environmental temperature for the care of water spinach is also between 20 - 27 Celsius [19]. Next, for the fish used in this system Anabas Testudines it requires temperature around 25 - 32 Celsius [20]. In addition, in terms of fish nutrition, researchers set feeding four times a day or every six hours based on recommendations from previous studies regarding the optimal feeding frequency for Anabas Testudines [21]. The designed interface in ThingSpeak as in Fig. 6

### 3.2.6 Product Analysis

Results Analysis done in this project covering the circuit analysis that carry out using multimeter to measure the output voltage on the physical circuit while comparing the data to the data sheet of the specific electronic components. Next, the analysis also covers the test for product functionality based on the programming that developed. This test analyses the functions such as plant care functionality, fish care functionality and functionality of the WiFi module that runs the IoT functions. Finally, water spinach and Anabas testudines were used in the testing of this product.

### 3.2.7 Improvement

Improvement phase involving three experts' validation done on completed product. The validation was done by the experts through a comment and recommendation for product improvements. Upon validation, researchers receive inputs and recommendations such as giving easy access to monitoring software, adding indicator on the electronic box and add labelling for ease user to navigate the product. The input gives the researchers guidelines on improvement and improvement was done by researcher add QR code to the monitoring system for user to easily scan. Besides, researchers also add indicators such as status light and labelling on the electronic box to the final product design. Finally, improvements were made to this product according to expert recommendations.

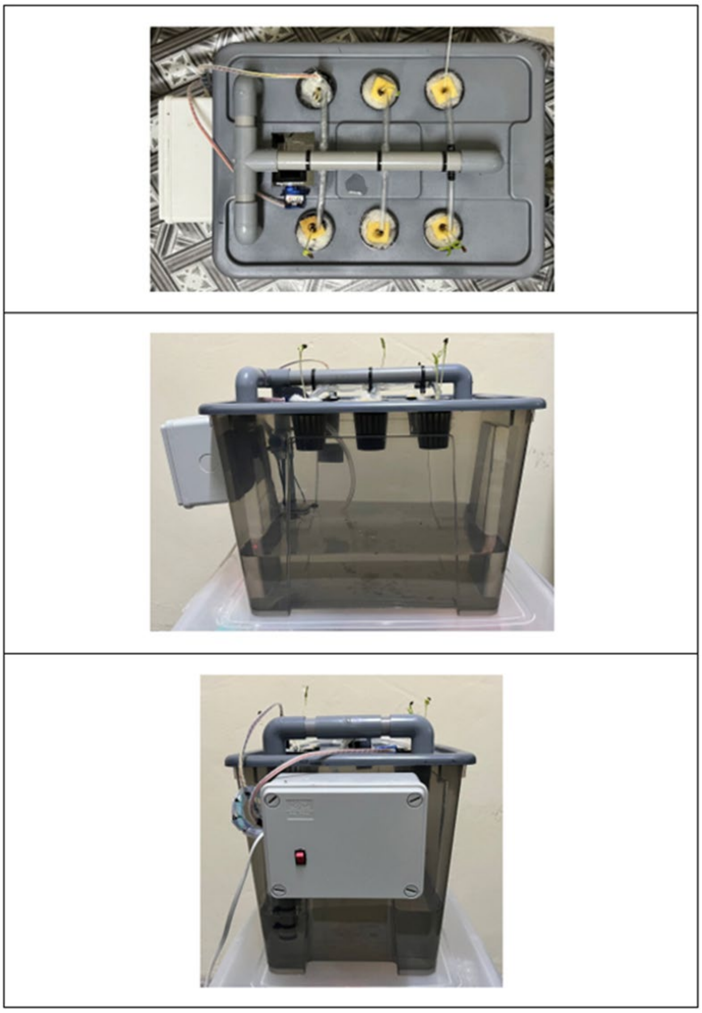

**Fig. 5** *Actual product*

## 3.3 Research Instrument

The product was evaluated through expert validation that focuses on design and testing aspects to the functionality of the Smart Aquaponic System Equipped with Internet of Things Technology. The recommendation from an expert is one of the instruments used for product improvement. Next, the research was also done by doing the analysis on the circuit using the multimeter to measure physically the built circuit as it compared to the data sheet for the specific component. Next, research is also done by analysing output from the log that is retrieved from ThingSpeak and the data can be translated into the functionality of the product. Furthermore, this method of analysis was done to three types of tests such as plant care functionality, fish care functionality and functionality of the WiFi module that runs the IoT functions.

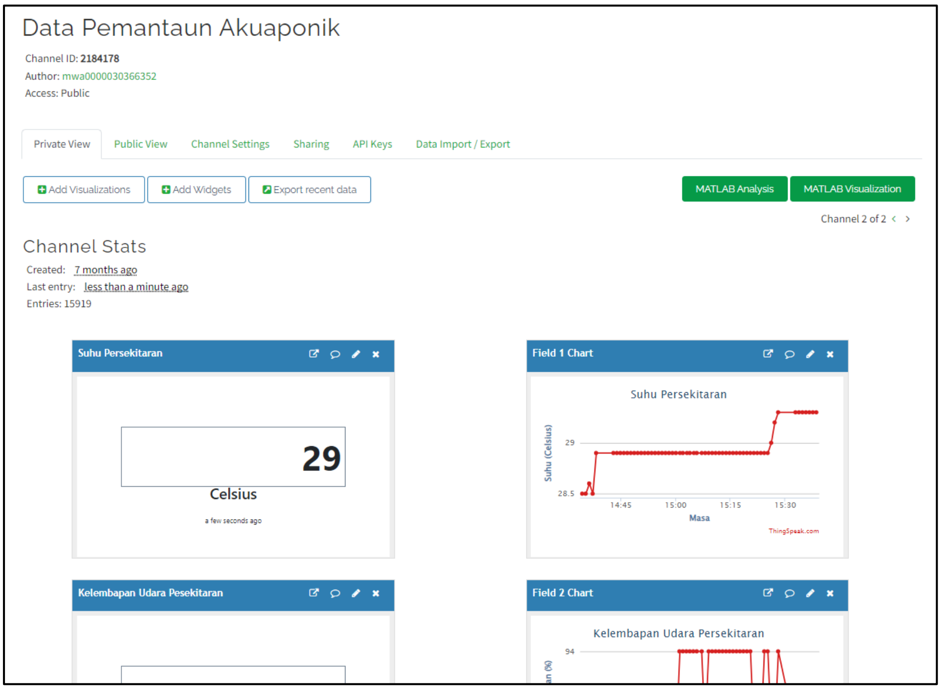


**Fig. 6** *The interface of monitoring software in ThingSpeak*

## 4. Result and Discussion

The results and discussion section presents data and analysis of the testing done. This section covers the result from the test such as circuit analysis and functionality testing.

### 4.1 Results

#### 4.1.1 Circuit Analysis

The circuit developed and built mainly to control the functionality of the whole system. The circuit consists of BBC micro:bit microcontroller, Motion:Bit expansion board, ESP01s WiFi module, DHT11 sensor, HC-SR04 sensor, capacitive soil moisture sensor, DB18B20 sensor, DC water pump and FS90 servo motor. All this component was analyses using the multimeter on the voltage output and data compared to the data sheet for the rated voltage for each component. Table 3 shows the result upon the circuit analysis.

#### 4.1.2 Testing of Components Involved in Plant Care Functions

Testing for the plant care function is to monitor the functionality to ensure it follows the parameters set according to the standard that found for an optimal water spinach plant care function. This parameter such as 55% - 70% soil moisture level for optimal growth moisture level [18]. Addition, environment temperature around 20 – 27 Celsius [19]. When the moisture parameter is below 55% as per set by researcher, the DC water pump will run and indicate status "1" on the output and for moisture above 55% the status shows vice versa at "0". Table 4 shows the result of the test for plant care function.

**Table 3** *Result for circuit analysis*

| Component | Signal pin | Voltage reading value based on data sheet (V) | The value of the voltage reading on the multimeter (V) |
|---|---|---|---|
| DHT11 | Pin 2 | 3V | 3.33V |
| HC-SR04 | Pin 12 (Trig)<br>Pin 13 (Echo) | 5V | 5.05V |
| Capacitive soil moisture sensor v1.2 | Pin 0 | 5V | 5.05V |
| DB18B20 | Pin 1 | 3V | 3.33V |
| DC water pump | M1 | 2.5 – 6V | 3.93V |

| | | | |
|---|---|---|---|
| FS90 servo motor | S1 | 4.8V | 3.94V |
| ESP01s | Pin 16 (Tx)<br>Pin 15 (Rx) | 3V | 3.33V |

**Table 4** *Result for plant care function analysis*

| Enviroment Temperature, Celsius | Plant Media Moisture, Percent % | Water Pump Status |
|---|---|---|
| 30.2 | 58 | 0 |
| 30.2 | 54 | 1 |
| 30.2 | 54 | 1 |
| 30.2 | 55 | 1 |
| 30.2 | 57 | 0 |
| 30.2 | 58 | 0 |

### 4.1.3 Testing of Components Involved in Fish Care Functions

Testing for the fish care function is to monitor the functionality to ensure it follows the parameters set according to the standard that found for an optimal Anabas testudines fish care function. The parameters that are optimal for this type of fish care function the temperatures must be around 25 - 32 Celsius [20]. Next, this fish also needs a feeding frequency four times a day or every six hours [21]. The analysis was done to see the functionality of the automatic fish feeding system to make sure it can function as standard that configured in the programming of this product. The result is in Table 5.

**Table 5** *Result for fish care function analysis*

| Number of Data Collected by Hour | Water Temperature in the Fish Tank, Celsius | Water Level in the Fish Tank, % | Total Frequency of Fish Feeding |
|---|---|---|---|
| 6 | 29 | 75 | 1 |
| 12 | 29 | 75 | 2 |
| 18 | 25 | 75 | 3 |
| 24 | 29 | 75 | 4 |
| 30 | 29 | 75 | 5 |

### 4.1.4 Component Testing Involves Internet of Things Technology Connection Functionality

WiFi module functionality testing is to measure the max range of WiFi reception that can be reach by the ESP01s module that used in this product to enable the IoT communication. The test done by researcher moved the WiFi source away from the product by increasing the range. The status of WiFi connection indicates by color that set up by researcher into few statuses such as green WiFi and Thingspeak server connected, yellow either one of WiFi and ThingSpeak server connected, red neither WiFi and ThingSpeak server connected, and blue parameter sent to the ThingSpeak server. The test was done for a range of 30 meters to 150 meters. The result for the test is in Table 6.

**Table 6** *Distance (m) and WiFi connection status*

| Range (m) | Connection LED Light Status |
|---|---|
| 30 | Green (WiFi connected) |
| 60 | Green (WiFi connected) |
| 90 | Green (WiFi connected) |
| 120 | Yellow (WiFi disconnected) |
| 150 | Red (WiFi disconnected) |

## 4.2 Discussions

This section delves into the steps we took to implement the EDP model in this product development, as well as the outcomes of our analysis. The discussion aligns with the objectives of the product development, as outlined in section 1.2. The first objective is to design the system that covers the EDP model from phase one to phase four.

Researchers focused on issues that arise from the research, such as aquaponics, which requires a consistent water flow for optimal plant growth [8], and aquaponics, which requires close care to maintain optimal functionality [9]. In addition, the concept of a closed loop solution was incorporated into the product development process. In addition, the researcher conducted prototyping prior to the final product's construction. In addition, the discussion covers the system's development, which includes EDP model phase five. This phase commences with the construction of the product circuit, the assembly of hardware, the preparation of software, and the development of programming.

Phases six and seven of the EDP model encompass the functionality tests conducted on this product, including circuit analysis, tests for plant and fish care functions, and WiFi functionality for IoT communication. The results of the circuit analysis test differ slightly from the data sheet, possibly due to the manufacturer's tolerance of the electronic components. Next, for the water spinach plant care function, the DC water pump can function as configured in the programming. Despite the uncontrollable environment causing the temperature to exceed the standard, the test proceeds.

Furthermore, the fish care function operates as planned, thanks to the fish feeding system's ability to provide fish meals in accordance with the product's configured six-hour schedule. The temperature in the water tank is also in a good range for the fish care function, especially for the Anabas Testudines. Finally, for the WiFi function analysis, the product can connect to a WiFi source up to 90 meters in an open space.

## 5. Conclusions

In conclusion, the researcher's main objection (number 1.2) regarding the system's design, development, and testing has been addressed throughout the product development process using the seven-step EDP model. We have successfully developed this Smart Aquaponic System with Internet of Things Technology, utilizing a blend of microcontrollers, sensors, actuators, and WiFi modules. This product addresses user requirements by resolving issues with monitoring parameter data from the aquaponic environment and managing irrigation and automatic feeding through the system itself.

The developed product is also well-suited for the maintenance of water spinach and Anabas plants. This product also benefits users by enabling them to view the history of aquaponic parameter data, as well as to review and analyse their aquaponic conditions in detail. This project can also facilitate the aquaponic care process in a more systematic and intelligent manner for the benefit of users. Furthermore, the development of this product can offer users convenient access to monitoring information, such as historical graphs and numbers, enabling them to review and analyze the plants they cultivate. The researcher aspires for this product to not only enhance the user's experience, but also serve as a guide for future enhancements aimed at boosting efficiency and resolving challenges.

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## Conflict of Interest

Authors declare that there is no conflict of interests regarding the publication of the paper.

## Author Contribution

*The authors confirm contribution to the paper as follows:* ***study conception and design:*** *Muhammad Aiman Mohd Nor, Saifullizam Puteh;* ***data collection:*** *Muhammad Aiman Mohd Nor;* ***analysis and interpretation of results:*** *Muhammad Aiman Mohd Nor, Ellya Maisarah, Ikhwan Hafiz Bahrum, Nur Anis Aqilah, Nurhening Yuniarti;* ***draft manuscript preparation:*** *Saifullizam Puteh, Muhammad Aiman Mohd Nor. All authors reviewed the results and approved the final version of the manuscript.*

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