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Smart Aquaponics

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Abstract

Living in space-limited environments and tight working schedules makes modern societies difficult to plant and take care of their aquariums. Smart aquaponics systems offer a sustainable solution for urban farming by integrating fish cultivation and plant production in a single automated ecosystem. This study aims to design, develop, and validate a smart aquaponics system equipped with an automatic fish feeder, water circulation system, and pH monitoring sensor to reduce manual maintenance while improving system efficiency. The methodology involved concept generation and evaluation of three preliminary designs, material selection, system fabrication, and functional testing of key components. Testing was conducted to validate the performance of water pump operation, automatic feeder, and pH monitoring. The results showed that the water pump successfully maintained continuous nutrient-rich water circulation and supported healthy plant root development within seven days. The automatic feeder consistently dispensed six servings per day according to the programmed schedule throughout the testing period, while the pH sensor successfully detected changes in water quality, recording a decrease from pH 7.0 to pH 6.3. In conclusion, smart aquaponics system provides a cost-effective, portable, and low-maintenance solution for small-scale sustainable farming, with potential for future enhancement through Internet of Things (IoT)-based remote monitoring and additional water quality sensing capabilities.

1. Introduction

Smart Aquaponics is a tool that can do two jobs at one time. Based on our project this time, smart aquaponics can provide food for fish automatically and can supply water to plants [1], [2], [3]. Therefore, our project is highly recommended for people who are busy working and have difficulty managing plants and pet fish because this tool can work automatically according to the time that has been set [2]. In addition, this product can be used in places without land such as apartments, condominiums, flats and so on. This is said to be because this product is very suitable for use in places without soil [4]. Smart aquaponics is a sustainable and convenient solution for managing aquaponic systems [5]. By automating the feeding process for aquatic organisms, it ensures a consistent supply of nutrients to the water, supporting healthy aquatic life and optimal plant growth [1], [6]. This system reduces the

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need for manual intervention, making it ideal for individuals with busy schedules or limited experience in managing such setups [3]. The feeder enhances sustainability by maintaining a closed-loop ecosystem where fish waste nourishes plants and plants purify the water [2], [6]. This minimizes waste, reduces water usage, and decreases dependence on chemical fertilizers [5], [7]. Additionally, its eco-friendly and cost-effective design requires minimal maintenance, making it a practical choice for urban settings where space and resources are limited [8]. By integrating automation with environmental stewardship, smart aquaponics promote modern, sustainable agriculture [5], [9]. It supports year-round food production, contributing to food security while empowering individuals and communities to adopt efficient and innovative farming technologies [7], [10].

2. Literature Review

Smart Aquaponics systems, including the Deep Flow Technique (DFT), Nutrient Film Technique (NFT), and aeroponics, are crucial technologies employed in modern plant factories [11]. Effective management of hydroponic environments requires continuous monitoring of electrical conductivity (EC), pH, dissolved oxygen, and temperature to ensure optimal plant growth [12]. In closed-loop hydroponic systems, the concentrations in nutrient solutions change over time, often leading to nutrient imbalances [13]. Although real-time monitoring of individual nutrient ions is ideal, current limitations in sensor technology hinder its commercial application [14]. As a practical alternative, most commercial farms rely on EC-based control systems, coupled with periodic nutrient solution analysis and manual adjustment to maintain nutrient balance [12]. Advanced solutions, such as ion-selective electrodes combined with artificial neural networks, offer promising approaches for estimating specific ion concentrations, while disinfection technologies—including filtration, thermal treatment, ozone, and UV radiation—are implemented to maintain hygienic and stable crop production conditions [15].

2.1 History of Aquaponics

By the l6th century, Belgian Jan van Helmont recorded the earliest known science-based research on aquaponics. He noted that water delivered nutrients to plants. Building Jan van Helmont's previous work, in 1699, John Woodward created the world's first aquaponics nutrient solution after concluding that plant growth benefited by nutrients in water was more accessible than soil [16].

The 20th century was a flurry of studies and advancements in how we grow. In the late 1920s, Dr. William F. Gericke of the University of California extended laboratory experiments to further studies on nutrition in practical, commercial crops growing outside. He coined the term "aquaponics"; a word derived from the Greek words, hydro, meaning water and ponos meaning labor, or "water-working." His work is the basis for modern aquaponic growth [16].

2.2 Types of Aquaponics

There are various types of aquaponics system such as deep-water culture systems, nutrient film technique systems, Wicks system, ebb and flow systems, drip systems as well as aeroponics systems [17], [18], [19].

2.2.1 Deep-water Culture Systems

Deep water culture aquaponics are simply plants suspended in aerated water. Deep water culture systems, also known as DWC system, are one of the easiest and most popular methods of hydroponics on the market.

2.2.2 Nutrient Film Technique Systems

Nutrient film technique systems are best suited for lightweight plants, like mustard greens, kale, lettuce, spinach as well as fruits like strawberries. Nutrient film technique (NFT) systems suspend plants above a stream of continuously flowing nutrient solution that washes over the ends of the plant's root systems.

2.2.3 Wick Systems

Wick systems are by far the simplest form of aquaponics. Wick systems are passive aquaponics - meaning they don't require mechanical parts like pumps to function. Wicks systems work by a process called capillary action. The wick absorbs the water it's immersed in like a sponge, and when it meets the porous growing media, it transfers the nutrient solution to the plants.

2.2.4 Ebb and Flow Systems

Ebb and flow systems (also called flood and drain systems) are one of the most popular aquaponic growing methods. Ebb and flow hydroponics work by flooding a grow bed with a nutrient solution from a reservoir below. The submersible pump in the reservoir is equipped with a timer.

2.2.5 Drip Systems

Drip systems are a popular and widespread method of aquaponics among commercial growers. In an aquaponics drip system, the aerated and nutrient-rich reservoir pumps solution through a network of tubes to individual plants. This solution is dripped slowly into the growing media surrounding the root system, keeping the plants moist and well-nourished.

2.2.6 Aeroponics Systems

Aeroponics systems suspend plants in the air and expose the naked roots to nutrients filled with mist. Water and nutrients are stored in a reservoir and then pumped to a nozzle that atomizes the solution and distributes it as a fine mist. The mist is usually released from the top of the tower, allowing it to cascade down the chamber. Aeroponics do not need substrate media to survive. The root's constant exposure to air allows them to drink oxygen and grow at an accelerated rate.

2.3 Aquaponics Benefit

In an aquaponics system, the plants in aquaponics tank are the primary tools for water quality and balance because they use fertilizer coming from fish waste. The waste output by fish is a good source of nutrients and micronutrients which are helpful in growing vegetation but do not require the addition of chemicals. Healthy plants also assist in absorbing these nutrients odd the liquids, decreasing the chance of harming the fish and formation of unwanted compounds [20]. The plants develop in the water filled solution, following the Nutrient Film Technique (NFT) or Deep-Water Culture (DWC). In NFT, a thin film of nutrient affluent water is always flowing over the roots of the plant, and at the same time giving oxygen [21]. In DWC, the plants roots are immersed in nutrient solution making nutrient uptake high for the plant [22]. Both the systems are very efficient because they convey the nutrients straight to the plant roots reducing wastage of water besides water. This is a mutually beneficial relationship between the prawn and the water, plants and the fish in a manner that recycling of water and nutrients is persistent, leading to the preservation of the environment and increase in output of the system.

3. Methodology

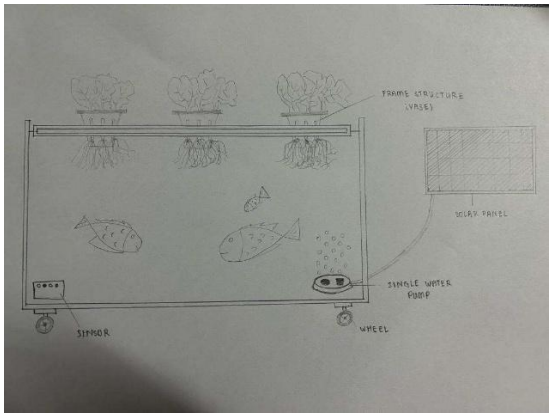
The methodology focuses on the process of generating concepts in preliminary design, where three design options, based on previous studies, are evaluated. The strengths and weaknesses of each design will be assessed by comparing the main components such as the feeding medium, water circulation system, sensors, frame structure, and power supply system. Next is material selection to ensure the most suitable materials and parts are utilized in building the project. Following this, the project will proceed with an analysis of the structural design to confirm its efficiency and functionality. Additionally, a detailed cost of components used in this project will be carried out to estimate the overall expenses and ensure the project remains cost-effective.

3.1 Preliminary Designs

Design A as shown in Fig. 1(a) is a design that integrates fish and plants in the same tank, where fish live in the water and plants grow above the surface with their roots submerged. An automatic feeder is used to provide food for the fish at set intervals. The main advantages of this design are its cost-effectiveness and efficient use of space. However, maintaining ecological balance requires frequent monitoring of water quality, making it less suitable for users seeking low- maintenance systems.

Design B as shown in Fig. 1(b) is a design that fish and plants are kept in separate tanks. Water from the fish tank is pumped into the plant tank, where the plants absorb nutrients before being filtered and returned to the fish tank. An automatic feeder ensures the fish are regularly fed. This system offers better control over water quality and plant growth, reduces the risk of disease, and ensures a more stable ecosystem. However, it requires more space and higher setup costs compared to the single-tank system.

Design C as shown in Fig. 1(c) is a design that completely separates fish and plants, with plants grown hydroponically in a layered pipe system while fish are kept in a separate tank. An automated nutrient delivery system ensures the plants receive the necessary nutrients, and an automatic feeder handles fish feeding. This setup provides precise control over the nutrition of both plants and fish but comes with more complex maintenance requirements and higher operational costs.



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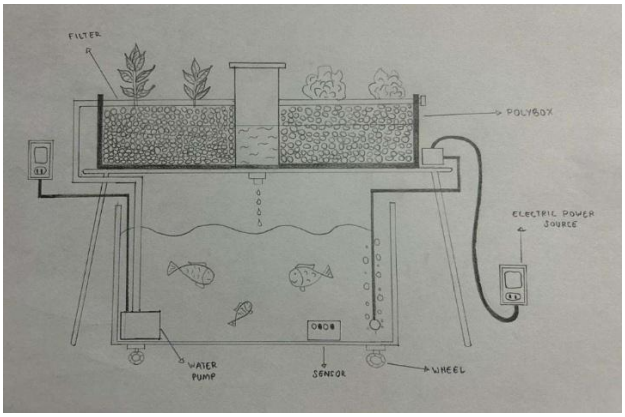

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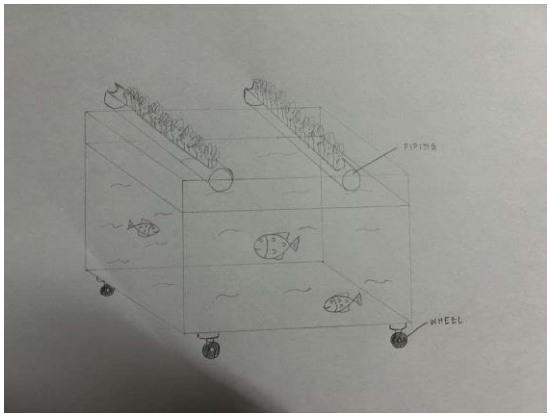
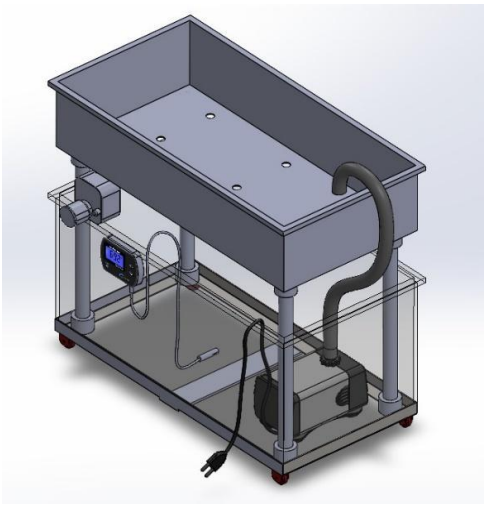


(c)

Fig. 1 *Preliminary design (a) Design A; (b) Design B; (c) Design C*

3.2 Final Design

Fig. 2(a) illustrates the final design of the Smart Aquaponics created using SolidWorks. The design features a multipurposed aquarium with planting area equipped with a caster wheel mounted on a moveable platform. Key components include an aquarium for fish and sources of water, a polybox above it for planting area, and a platform that supports this Smart Aquaponics with caster wheel make it easy to move everywhere as shown in Fig. 2(b). The model was developed to ensure ergonomic design, and improved management for users.



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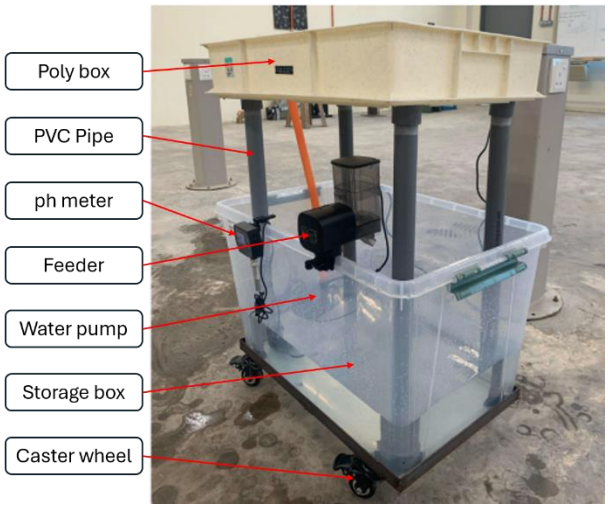

(b)

Fig. 2 *Final design (a) 3D model of the Smart Aquaponics designed using SolidWorks; (b) Smart Aquaponics*

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3.3 Material Selection

The materials chosen for the Smart Aquaponics System were selected based on their durability, water resistance, ease of assembly, and cost-effectiveness. These factors are crucial for ensuring sustainability and efficiency in small-scale agricultural applications. Polypropylene planting boxes (polybox) were used for the grow beds due to their lightweight nature, high resistance to moisture, and non-toxic properties, making them ideal for holding plants and growing media. To support the polybox above the fish tank, PVC pipes were used because they are strong, waterproof, easy to cut and assemble, and resistant to corrosion, making them suitable for both indoor and outdoor use. For the fish tank, a clear plastic storage box made from transparent polypropylene or polycarbonate was selected. This material allows easy visual monitoring of the fish and water quality, is impact-resistant, and safe for aquatic life.

3.4 Costing

This part explains the estimated cost of materials used to build the Smart Aquaponics System. The items listed in Table 1 were bought from local hardware and farming supply shops, and the prices are based on current market value. Every material was chosen to give a good mix of low cost, usefulness, and suitability for the system's design. The total cost gives a clear view of the project's spending and helps with proper planning and budgeting.

Table 1 *Material cost*

No.	Component	Quantity	Cost (RM)
1	Storage Box	1	39.00
2	Water Pump	1	40.09
3	Feeder	1	52.56
4	Polybox	1	18.40
5	PH Meter	1	66.69
6	Casterwheel Platform	1	0.00
7	PVC Pipe	4	0.00
8	PVC Connecter	3	0.00
9	Water Pipe	1	0.00
10	Hose Clamp	3	1.60

4. Testing and Validation

The Smart Aquaponics system integrates three main components that were tested for functionality and reliability: the water pump system, the automatic feeder (AF-250), and the pH sensor. Each of these plays a crucial role in maintaining a self-sustaining environment for both fish and plants. The water pump system is responsible for circulating nutrient-rich water from the fish tank into the plant-growing polybox, which uses hydroballs as a growing medium. As water flows through the system, nutrients from fish waste are absorbed by the plant roots, and excess water returns to the fish tank through a drainage hole in the polybox, completing the cycle.

The automatic feeder, model AF-250, is used to automate the feeding process for the fish. It allows for customizable feeding times and portions, supporting between 1 to 6 feedings per day and 1 to 9 servings each time. This reduces the need for manual feeding and ensures the fish receive food consistently, improving system reliability and user convenience. The feeder's operation is fully programmable and supports manual feeding if needed.

Lastly, the pH sensor is used to monitor the water quality, which is essential for both fish health and nutrient absorption by the plants. The sensor provides real-time data on pH levels, allowing the user to detect any shifts in water acidity caused by fish waste or other factors. By observing pH trends over time, adjustments can be made to maintain a balanced environment within the aquaponics system. Overall, these three components work together to create an efficient, automated, and low-maintenance solution for sustainable aquaponics farming.

4.1 Testing Parameter

1. Water Pump

i) Objective : To maintain continuous water flow between tank and grow bed
ii) Medium Used : Hydroball in polybox

iii) Nutrient Flow : Fish tank -> Polybox -> Overflow -> Return to fish tank
iv) Test Duration : 7 days continuous operation

2. Automatic Feeder

i) Objective : To automate fish feeding on a scheduled basis
ii) Feeder Setting : 3 times/day, 2 servings/time
iii) Feed Type : Fish pallets (<3mm)
iv) Capacity : 250ml
v) Test Duration : 4 days

3. pH Sensor

i) Objective : Monitor pH levels affected by fish waste
ii) Initial Water pH : 7.0
iii) Duration : 30 minutes with lived fish
iv) Measurement Interval : Every 10 minutes

4.2 Results

The results presented in this section are based on the testing parameters established in Subsection 4.1. The performance of the developed Smart Aquaponics system was assessed through the evaluation of its key operational components, namely the water pump, automatic feeder, and pH sensor. Each component was tested under predefined conditions to verify its functionality, consistency, and suitability for long-term aquaponics applications. The collected data were analysed to determine the effectiveness of the automated system in maintaining water circulation, providing scheduled fish feeding, and monitoring water quality. Overall, the results provide preliminary validation of the proposed system as a practical and low-maintenance solution for small-scale sustainable farming.

4.2.1 Water Pump Operation Over Time

Fig. 3 depicted graph shows that the water pump system in the Smart Aquaponics project effectively supports plant root growth over 7 days. Root development started on Day 2, continued to growth steadily from Day 3 and reached a healthy stage by Day 5, indicating good nutrient and water circulation. The system operated continuously without leaks or failure, ensuring a stable environment for both plants and fish. Overall, the water pump proved to be reliable, efficient, and suitable for low-maintenance use.

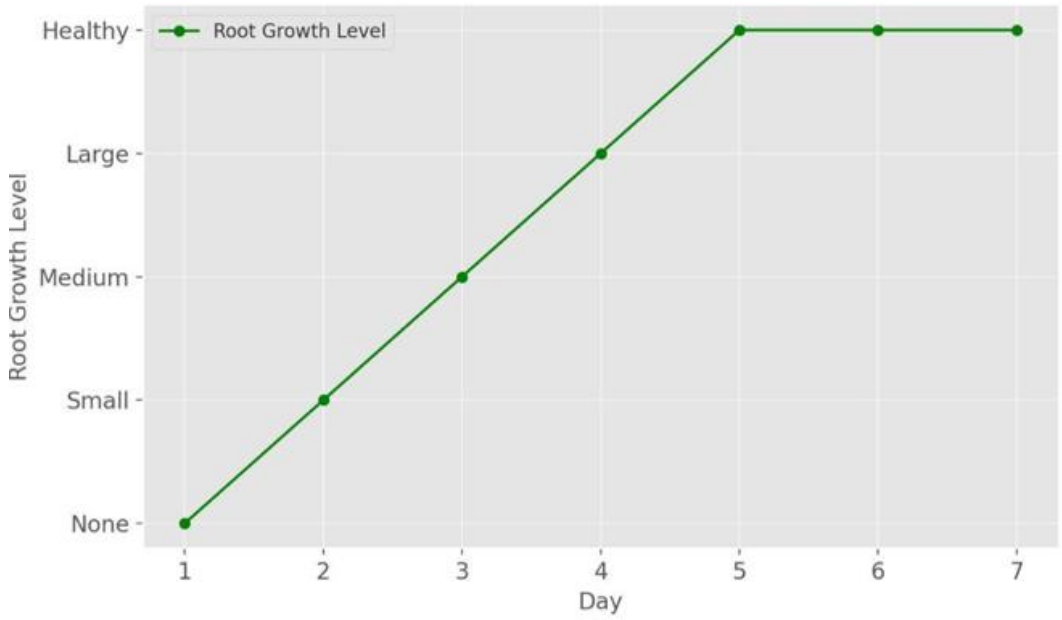

Fig. 3 *Graph of plant root growth over 7 days (water pump test)*

4.2.2 Auto Feeder Performance

Fig. 4 illustrated auto feeder graph shows a consistent six servings per day over four days, confirming the feeder operated reliably without issues. It dispensed food accurately at scheduled times, and the manual function worked well. Fish responded normally, indicating the feeding system was effective. Overall, the feeder is dependable and reduces manual work, making it ideal for automated fish care in the aquaponics system.

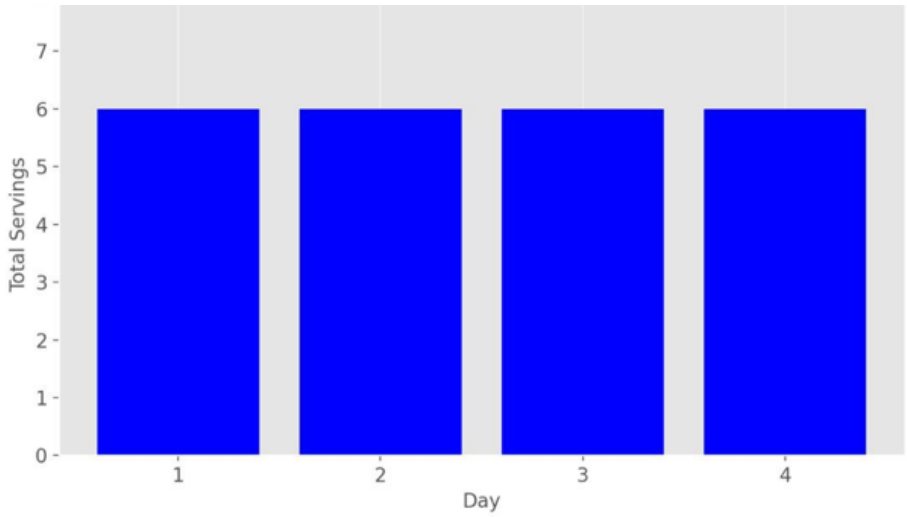

Fig. 4 *Graph of total serving dispensed per day (auto feeder test)*

4.2.3 pH Sensor Reading Over Time

Fig. 5 illustrated pH sensor graph shows a gradual drop in pH from 7.0 to 6.3 over 30 minutes, indicating the sensor accurately detected changes caused by fish waste. This confirms the sensor is responsive and reliable for monitoring water quality, helping maintain a healthy balance for both fish and plants in the aquaponics system.

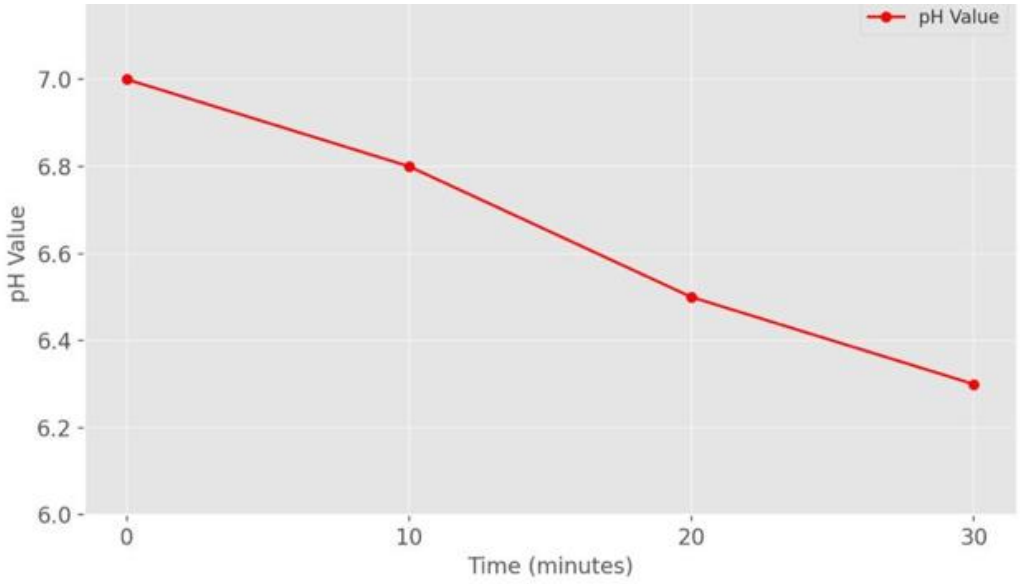

Fig. 5 *Graph of pH sensor readings over time (pH sensor test)*

5. Conclusion

The Smart Aquaponics system successfully demonstrated its capability to automate and simplify the management of a small-scale aquaponics environment. Experimental results showed that the integrated components, including the water pump, automatic feeder, and pH sensor, functioned reliably throughout the testing process. The water pump maintained continuous circulation of nutrient-rich water, the automatic feeder provided consistent and

timely feeding for the fish, and the pH sensor effectively monitored water quality, enabling early detection of changes that could affect the health of both plants and fish.

The main contribution of this project lies in the development of a portable, cost-effective, and low-maintenance smart aquaponics system that integrates automation with real-time water quality monitoring. By reducing manual intervention while maintaining stable operating conditions, the system offers a practical solution for home users, educational purposes, and small-scale sustainable farming. The integration of automated control and monitoring also demonstrates the potential of smart technologies to improve the efficiency and accessibility of aquaponics systems.

Although the proposed system achieved its intended objectives, further improvements can enhance its performance and applicability. Future work should focus on long-term system validation under different environmental conditions, integration of Internet of Things (IoT) technology for remote monitoring and control and the inclusion of additional water quality parameters such as dissolved oxygen, water temperature, and electrical conductivity. These enhancements would improve system reliability, scalability, and support wider adoption of smart aquaponics for sustainable food production.

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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:*** *Alif Hafizan Salleh, Adam Amrullah Mohd Pauzi, Muhammad Aqil Fikri Noor Azizan, Mohd Hadri Mohamed Nor;* ***data collection :*** *Alif Hafizan Salleh, Adam Amrullah Mohd Pauzi, Muhammad Aqil Fikri Noor Azizan;* ***analysis and interpretation of results:*** *Alif Hafizan Salleh, Adam Amrullah Mohd Pauzi, Muhammad Aqil Fikri Noor Azizan;* ***draft manuscript preparation:*** *Alif Hafizan Salleh, Adam Amrullah Mohd Pauzi, Muhammad Aqil Fikri Noor Azizan, Mohd Hadri Mohamed Nor. All authors reviewed the results and approved the final version of the manuscript*.

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