Innovative Aquabot Design for Sustainable and Efficient Aquarium Care

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ABSTRACT

Fishkeeping is one of the traditional hobbies that remains popular today, involving maintaining various species of fish and beautifying their habitat. This hobby not only provides personal enjoyment but also can attract sustenance, according to the specific beliefs of the Chinese community. Research shows that fishkeeping provides numerous benefits for human well-being, especially for enthusiasts. However, the significant time and effort required to maintain an aquarium, especially its cleanliness, can be challenging for busy individuals. To address this problem, research has been undertaken that focuses

Keywords: Sustainability, aquabot, aquarium, development model

INTRODUCTION

Aquarium maintenance plays a vital role in sustaining healthy aquatic environments, whether in household aquaria, research facilities, or public exhibits. Stable water quality conditions—such as dissolved oxygen, temperature, pH, turbidity, and ammonia concentration—are essential for preventing stress, disease, and mortality among aquatic organisms. Traditionally, aquarium upkeep relies heavily on manual activities including scrubbing algae, vacuuming substrate, performing water changes, monitoring filtration, and measuring water chemistry. These labour-intensive practices not only demand significant time and expertise but also contribute to unnecessary water consumption and inconsistent maintenance schedules, which can compromise ecosystem stability. Recent technological advancements have enabled the integration of Internet of Things (IoT) systems and low-cost sensors into aquatic environments to facilitate real-time water quality monitoring (Nordin et al., 2024; Shinde et al., 2024). Such systems provide continuous measurement of key parameters, supporting early detection of fluctuations that may harm aquatic life. In aquaculture and aquarium-scale systems, IoT-based platforms have demonstrated strong potential for reducing manual intervention by applying automated data logging, wireless connectivity, and cloud-based analytics (Ahamed et al., 2025; Sapna & Aswathy, 2024). These technologies, combined with decision-support methods such as fuzzy-logic control, have been adopted to enhance water quality regulation and resource efficiency (Kuriakose et al., 2024).

Parallel to developments in sensing and automation, robotic solutions for underwater maintenance have advanced rapidly, particularly in algae cleaning, sediment removal, and structural inspection. Smart cleaning robots and autonomous aquatic platforms have shown promise in biofouling control, energy-efficient mobility, and modular maintenance tasks (Rahman et al., 2023). However, most of these systems are designed for industrial aquaculture ponds or large marine environments rather than confined aquarium spaces. Research specifically addressing compact, multi-functional “aquabots” suitable for home or medium-scale aquaria remains limited. Sustainability considerations further emphasize the need for improved aquarium-maintenance technologies. Excessive water changes, high electricity consumption, and over-use of chemical treatments contribute to environmental waste and long-term operational costs. Integrating an aquabot with IoT-enabled water-quality monitoring offers a promising solution by combining autonomous cleaning, scheduled operation, and data-driven maintenance decisions. Such systems can stabilize water conditions, reduce manual labour, optimize resource use, and promote long-term ecosystem health. Given these emerging opportunities, this study aims to develop and evaluate an improved aquabot design tailored for sustainable aquarium maintenance. The proposed system integrates low-energy propulsion, modular cleaning mechanisms, multi-parameter water-quality sensing, and real-time data connectivity. This paper presents the system design, operational workflow, and performance evaluation, providing a pathway for sustainable and automated aquarium management.

METHODOLOGY

Research design

The research design serves as a structured framework that guides the development of the aquarium cleaning robot, ensuring a systematic and coherent research process. It encompasses key components that direct the project from initiation to completion. The process begins with the formulation of clear research objectives and questions, which set the overall direction and focus of the study. To visually represent the sequence of tasks, the process is typically illustrated using a flowchart, highlighting the logical progression from start to finish. Fig.1 below illustrates the flowchart outlining the preparation stages for developing the aquarium cleaning robot.

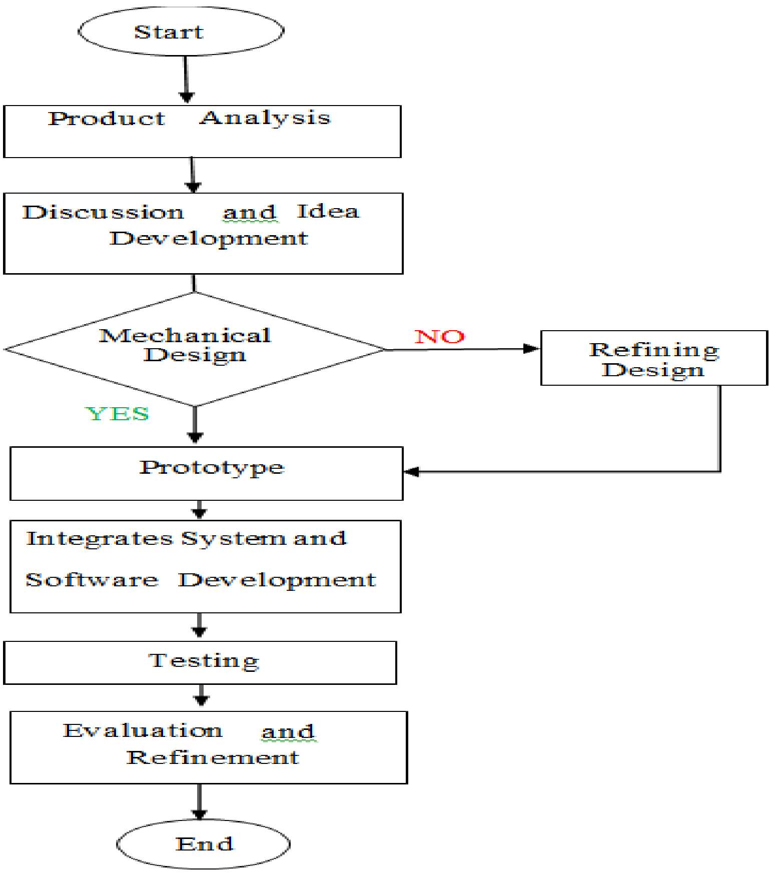

Fig. 1 Process flow for development aquabot.

Second design (design 2)

The second design introduced a larger and more spacious compartment for the electrical components, allowing for proper installation and testing of all necessary systems. This revision aimed to address the limitations of the initial design while focusing on the core objective: developing a robot capable of submerging in water and efficiently cleaning waste from the bottom of an aquarium. Buoyancy was initially estimated to be adequate

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based on general design principles. A detailed 3D model was created using CAD. software and prepared for prototyping. Figure 3.4 presents the second 2D design, while Figure 3.5 shows a screenshot of the 3D model.

RESULTS AND DISCUSSION

First design (design 1)

The design concept for the aquarium cleaning robot emphasizes creating a durable, efficient, and user-friendly device. The initial design featured a compact structure; however, this led to difficulties in accommodating all the necessary electrical components. The allocated space for the electrical system was too limited, making it impossible to fit the required parts. As a result, the electrical system could not be properly integrated, preventing effective testing of the robot. Figures 3.2 and 3.3 illustrate the initial 2D and 3D design, respective

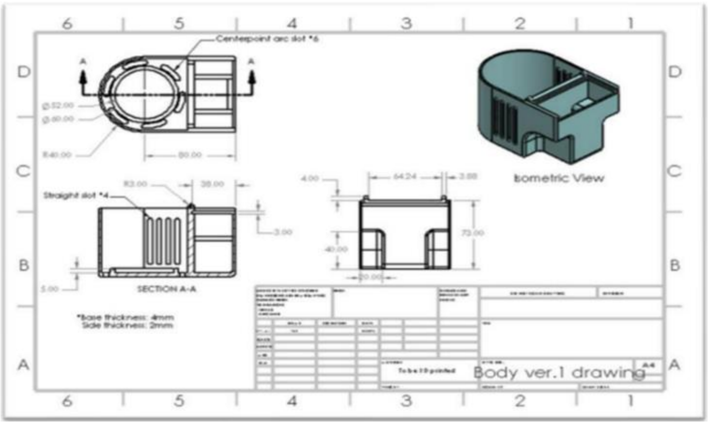

Fig.2 Initial 2D design

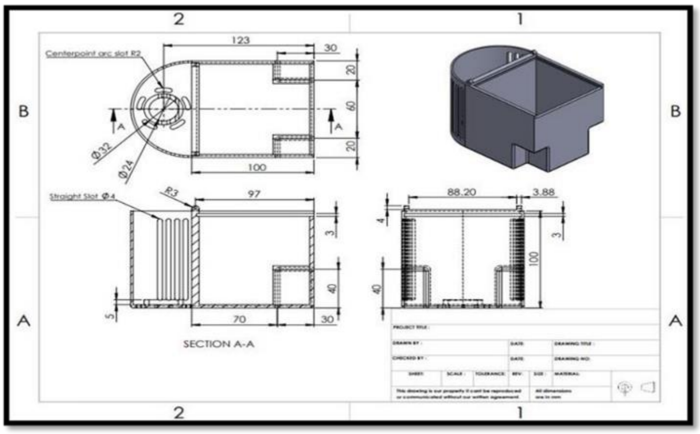

Fig.4 2nd 2D design

Fig.3 1st design prototype

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Fig.5 2nd design prototype

Third design (design 3)

The third design iteration added weight plates evenly spaced throughout the robot to solve the immersion problem noted in the second version. This change was made primarily to address the issue of high buoyancy and allow the robot to stay completely submerged, which was necessary for cleaning the aquarium's bottom. For the robot to remain balanced and be able to move efficiently underwater, the distribution of these weights was carefully thought out. Figure 3.5 show the third 2D design attached with a weight plate.

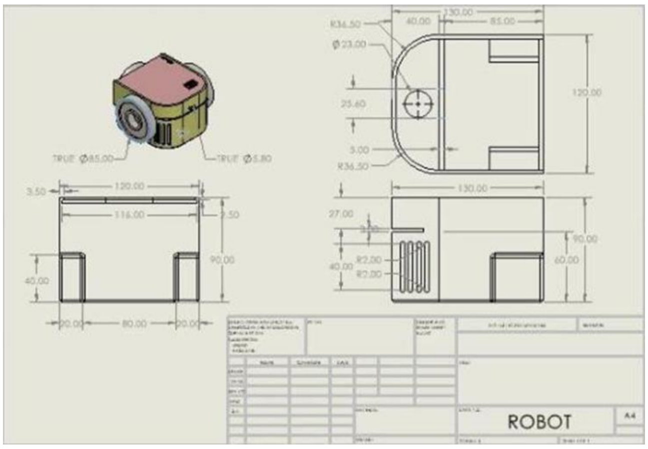

Fig.6 3rd 2D design

Fig.7 3rd prototype

Fourth design (design 4)

The fourth prototype maintained the original 3D design but introduced several modifications to achieve neutral buoyancy and enhance the robot’s ability to efficiently remove debris from the aquarium floor while staying afloat on the water’s surface. To provide buoyancy and ensure stability, polystyrene foam was attached to the underside of the robot's body. Additionally, a suction tube connected to a pump was integrated, enabling the robot to effectively extract waste from the aquarium bottom without requiring full submersion. To enhance mobility, a compact propeller system was installed, allowing the robot to navigate smoothly through the water. This lightweight setup helped maintain balance and support during operation. Figure 3.13 shows the improved design featuring the propeller system and buoyancy enhancements.

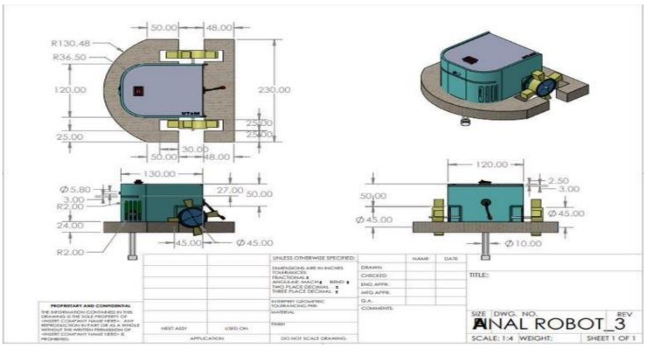

Fig.8 4th 2D design

Fig.9 4th Prototype

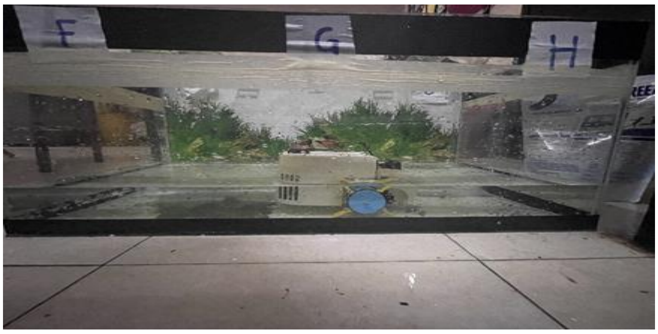

Fig.10 Aquabot in aquarium

Budget Plan

During the prototype making, there are some expenses made in preparing materials and the internal structure of the system. The price and cost used in making the prototype are listed as shown. Total expenses are around RM65.19 as recorded in Table 3.1.

Table I Breakdown cost for aquaria robot development

No	Item	Single price	Quantity	Total amount
1.	ESP 8266	9.68	1	9.68
2.	IR Infrared Obstacle Avoidance Sensor	2.09	1	2.09
3.	3V-6V 130 Mini DC Motor	2.80	2	5.60

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4.	Motor Driver	5.99	1	5.99
5.	DC 12V wire/ 5V USB Water Pump	3.50	1	3.50
6.	Relay Module 5V	3.50	1	3.50
7.	Polystrene Foam	2.8	1	2.80
8.	2000mAh Rechargeable Battery 4.8V	15.50	1	15.50
9.	Aquarium Sponge Filter	1.90	1	1.90
10.	Metal Shaft	0.80	1	0.80
11.	Tube	1.00	1	1.00
12.	PLA Filament (347g)	20.0	1	20.00
13.	Cardboard	2.50	1	2.50
14.	Switch	7.70	1	7.70
	Total (RM)			65.19

CONCLUSION

The final aquabot design demonstrated its ability to efficiently clean the bottom of aquariums using components such as the ESP8266 microcontroller, water pump, and suction tube. The robot's functionality was supported by a compact and functional design that effectively addressed the primary challenge of debris removal. Moreover, the project adhered to sustainable development goals by utilizing PLA+ material and a rechargeable power source, minimizing its environmental impact. However, limitations, such as the inability to access hard-to-reach corners and a relatively simple aesthetic, suggest room for improvement. Addressing these areas can further enhance the aquabot's performance, appeal, and user satisfaction.

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