Aquatic Robot for Trash Removal and Water Quality Monitoring Built from Recycled Materials

Abstract— **This paper presents the design and development of an aquatic robot for trash removal and water quality monitoring, built using recycled materials for a cost-effective and sustainable solution to water pollution. The robot is equipped with paddle wheels for improved control, a detachable waste collection bin, and sensors for real-time monitoring of key water quality parameters such as temperature. The system's architecture is controlled via a mobile interface, which allows remote operation and live data transmission. Performance tests were conducted to evaluate waste collection efficiency at different speeds and the robot's ability to monitor water conditions. Results show that the robot can effectively collect waste and provide valuable water quality data, making it a viable solution for environmental conservation in polluted water bodies. While the current version of the robot is remote-operated, our ongoing research aims to incorporate automated trash detection and collection capabilities.**

Keywords— Aquatic Robot, Water Quality Monitoring, Recycled Materials, Environmental Sensors, Real-Time Monitoring

I. INTRODUCTION

Bangladesh, a riverine country with more than 230 rivers crisscrossing the land, is home to one of the most complex river systems in the world.[1] These rivers are deeply intertwined with the nation's social, cultural, and economic life. However, river pollution has become a significant problem, with industrial and household waste being discharged into rivers through canals, drains, and sewers, eventually flowing into the Bay of Bengal. According to recent estimates, approximately 2 lakh tons of plastic are dumped into the Bay of Bengal via Bangladesh's rivers[2]. In response, the Bangladesh government has developed a master plan to combat pollution in six major rivers[3]. Our project aims to contribute to these efforts by constructing an affordable boat using recycled materials, providing a low-cost solution that can be scaled to deploy multiple boats along rivers, helping prevent further pollution.

Previous work on water surface cleaning robots has provided a variety of approaches to trash removal, but these solutions either focus on buoyancy, waste detection, or water quality monitoring without exploring cost-effective designs using recycled materials.

M. Amarnath et al. described a "Waterbin" that floats on the water surface and efficiently collects about 13 kg of garbage. The design incorporates buoyancy simulations using ANSYS 19.2 to ensure stability[4]. E. Rahmawati et al. developed a waterbot with low hydrodynamic resistance and weight, reducing the risk of drowning due to leakage. Their boat maintained symmetry regardless of whether the waste container was empty or full [5]. Siti Farina Hidayah Zabidi et al. designed a boat with a real-time monitoring system, enabling manual control and reducing the risk of loss, especially in larger rivers.[6]

Siddhanna Janai et al. proposed a waterbot equipped with a PIR sensor for detecting living or non-living objects and an ultrasonic sensor to measure distance.[7] They also built a robotic arm for garbage collection, which was simulated using Tinkercad. Desmond Dunggat et al. introduced an unmanned surface vehicle (USV) with a conveyor belt for garbage collection, featuring real-time monitoring and object detection capabilities.[8] Pei Wang et al. employed a dual-camera system on a dual-hull boat to detect objects and accurately measure the distance from the boat.[9] Vasundhara L et al. developed a boat that combined garbage collection with water quality monitoring using a temperature sensor and Total Dissolved Solids (TDS) meter.[10]

While these previous designs show advancements in buoyancy, detection, and monitoring, none of the systems have been constructed from recycled materials to reduce costs. Moreover, all these boats rely on propellers for movement, which can be difficult to control. Propellers with sharp metal blades can have a detrimental impact on aquatic ecosystems. In contrast, our project uses paddle wheels without sharp blades for boat propulsion, ensuring that the aquatic ecosystem is not harmed while improving control and simplifying operation. Additionally, after collecting more garbage, the weight in traditional garbage tanks increases hydrodynamic resistance, raising the risk of the boat sinking. To address this, our boat uses a net basket that hovers just above the water, stabilizing the boat as it accumulates more garbage.

II. METHODOLOGY

This section outlines the water surface trash cleaner bot's design, development, and testing processes. The methodology is divided into three stages: mechanical design, system architecture, and robot control system.

A. Mechanical Design

The proposed system is designed to be cost-effective, environmentally friendly, and suitable for usage in polluted water bodies like lakes and rivers. The design of the robot focuses on ensuring superior stability and maneuverability, allowing it to gather all the floating waste in its vicinity efficiently.

The water surface trash cleaner bot was constructed using recyclable materials. Four recycled plastic bottles (Polyethylene terephthalate -PET) formed the buoyant base, reinforced with a PVC board for durability. To minimize disruption to aquatic life, the water wheels were designed without sharp blades and crafted from environmentally friendly PVC. Powered by 100 rpm 12v DC gear motors, these wheels propelled the bot. A detachable trash bin was positioned at the center of the robot, while a high-torque servo motor (MG-996R, Max torque-9.4Kg-cm) operated a trash collector arm (made of iron net and PVC) gathered floating debris and deposited it into the bin. After the trash is collected, the bin is manually emptied for disposal. The robot's dimensions are approximately 68 cm in length, 50 cm in width, and 22 cm in height (excluding the camera stand), with a total weight of 2.75 kg. **Figure 1** illustrates the proposed 3D design of the robot.

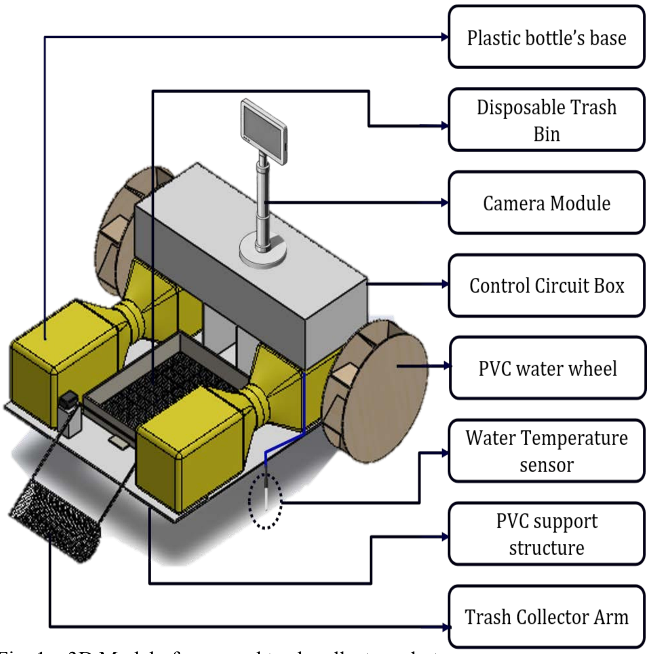

Fig. 1. 3D Model of proposed trash collector robot

The key benefits of our aquatic cleaning robot include its lightweight and corrosion-resistant design, making it durable and well-suited for long-term use in water environments. Additionally, the robot is designed to be aquatic ecosystem-friendly, ensuring minimal disturbance to marine life during operation. Using recyclable materials makes the robot's construction sustainable and environmentally conscious. The components are cost-effective, enabling the production of multiple units at a lower price. The robot can also properly dispose of collected trash, promoting effective waste management. Finally, its design allows for easy maintenance, ensuring long-term operational efficiency.

B. System Architecture

The proposed water surface trash cleaner system is controlled by an Arduino Mega, which serves as the central processing unit. The system architecture is depicted in **Figure 2.**
A sealed control box mounted on the bottle structure safeguards the sensitive circuitry from water splashes. Two 100 RPM DC motors are connected to an L298N motor drive, which uses a dual H-bridge mechanism to control motor speed and rotation direction. The robot utilizes a differential drive mechanism for its propulsion. A DS18B20 – waterproof thermal sensor measures water temperature, a fundamental water quality parameter. The robot is remotely operated from a control room via a Bluetooth connection. An HC-05 Bluetooth module, with an approximate range of 10 meters, enables the transmission of remote commands to the robot and the reception of water quality data in the control room. A repurposed smartphone captures real-time video footage, which is then streamed to the control room using a mobile hotspot. The servo motor is powered by a 20V DC source through an LM2596 buck converter module to step down at 7V.

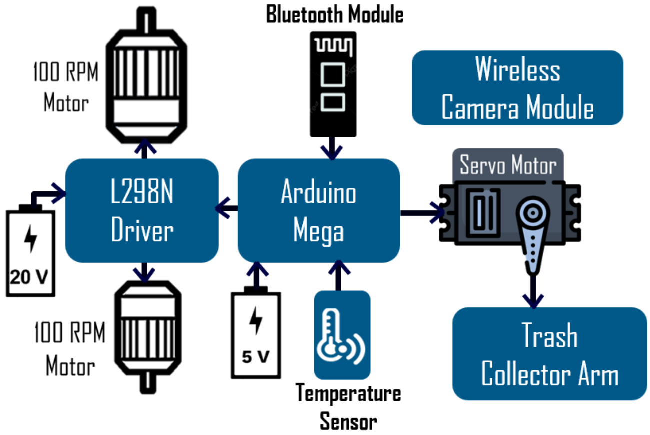

Fig. 2. Overall system architecture

C. Control System Design

The control system used in the proposed trash cleaner robot is discussed in this section. The overall control system design involves Arduino IDE, Bluetooth RC controller app, and Bluetooth terminal Hc-05 app. The interface is depicted in **Figure 3**.

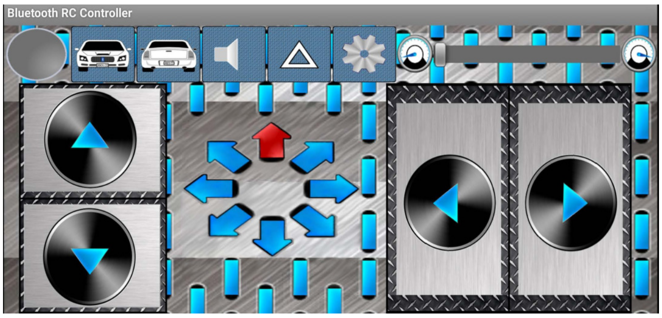

Fig. 3. Controller interface of the Aquatic robot

The flowchart of **Figure 4** illustrates the operational flow of an autonomous water-cleaning robot controlled through a remote controller (RC) app. It begins with the initialization of the system, which establishes communication between the robot and the RC controller app. Once connected, the robot transmits real-time water quality data to a remote application while receiving movement and trash collection commands. If the remote user decides to continue trash collection, the robot sends the real-time footage to the remote user. The user detects the waste location and manually navigates the robot toward the identified trash. The Arduino microcontroller controls the robot's navigation and trash collection arm, relaying remote commands to the L298N motor driver and servo motor. Simultaneously, the water quality sensor provides feedback on water conditions to the Arduino. The system loops until the user commands it to stop. After collecting sufficient trash, the remote operator guides the robot for trash disposal, ensuring an efficient and continuous cleaning operation. The controller flow diagram of the robot is provided in **Figure 4.**

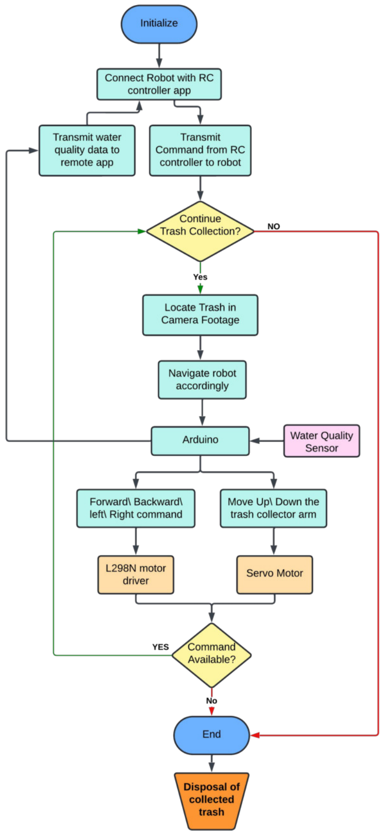

Fig. 4. Control flow of the proposed system

Figure 5 illustrates the water surface cleaning robot from multiple perspectives.

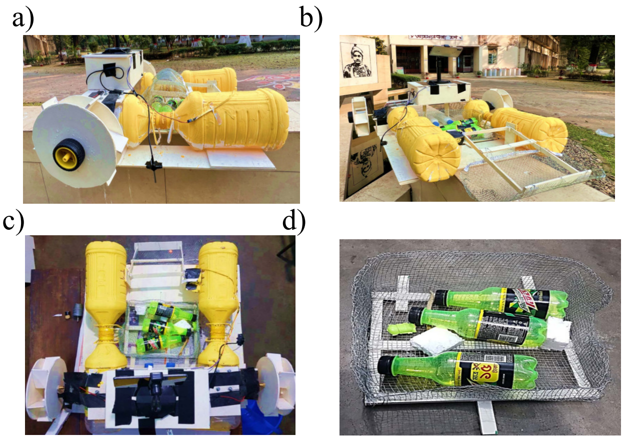

Fig. 5. (a) Side view, (b) front view, and (c) top view of the water surface cleaning robot. (d) Displays the detachable waste bin.

III. Result and Discussion

In this section, we first outline the overall performance of the aquatic robot under various testing conditions. The tests were conducted to evaluate the robot's ability to collect waste effectively and monitor water quality, as described in the methodology**.**

Figure 6 shows the test environment where the aquatic robot was deployed, providing a controlled setting to assess its waste collection capabilities and water quality monitoring functions. The robot successfully detected and collected a variety of water surface trash, including plastic bottles, plastic bags, styrofoam and small cans.

A. Maximum Load Capacity

The robot employs four empty five-liter plastic bottles to provide buoyancy, allowing it to float on the water's surface. Each bottle can displace approximately 5 kilograms of water. According to Archimedes' principle, the robot can support a maximum total weight of 20 kilograms before submerging.

Considering the robot's own weight of 2.75 kilograms, it can carry a maximum payload of approximately 17 kilograms of trash. Currently, as a prototype, the disposable trash bin is designed to hold 500 g of trash. This capacity can be scaled by adjusting the dimensions of the bin to accommodate larger loads.

B. Performance Test

Performance analysis is a critical aspect of evaluating the efficiency and effectiveness of any system or device. It involves measuring various parameters to understand how well the system operates under different conditions. **Table 1** presents the results of the waste collection efficiency of the aquatic robot at various driving speeds, measured in meters per second (m/s). The table illustrates the mass of waste collected, recorded in grams (gm), at each speed over three trials, followed by the average waste collected. The data show a general trend of increasing waste collection efficiency with higher speeds, peaking at 0.350 m/s, where the robot collected an average of 68.64 gm of waste. However, the efficiency slightly decreased at the highest tested speed of 0.400 m/s.

TABLE I. Result of waste collecting operating at different speeds

Driving Speed (ms^{-1})	**Collected Waste (gm)**	**Average (gm)**
0.125	51.87	51.5
	51.65	
	50.98	
0.220	66.87	63.32
	62.99	
	60.12	
0.350	68.64	68.64
	62.40	
	74.88	
0.400	66.59	65.05
	62.12	
	66.44	

Fig. 6. Test environment

C. Water Quality Test

Water quality testing is crucial for assessing the health and safety of aquatic environments. Monitoring key parameters, such as temperature, ensures that water remains suitable for marine life. By integrating water quality sensors into the aquatic robot, the system not only collects waste but also provides real-time data on water conditions, enabling timely interventions to prevent environmental degradation.

Figure 7 illustrates the mobile interface where the Bluetooth module transmits data from the water quality sensors to a connected mobile device. This interface allows operators to remotely monitor water temperature and control the robot's movements and trash collection operations.

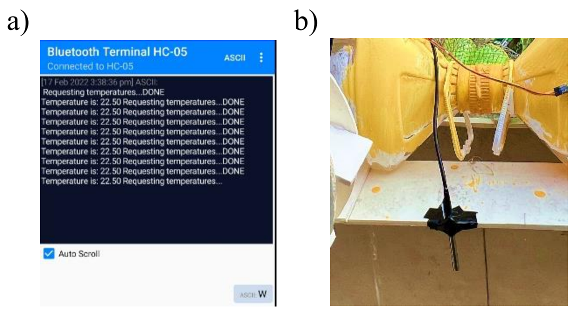

Fig. 7. (a) Temperature data of the water received through Bluetooth module, (b) temperature sensor attached to the robot

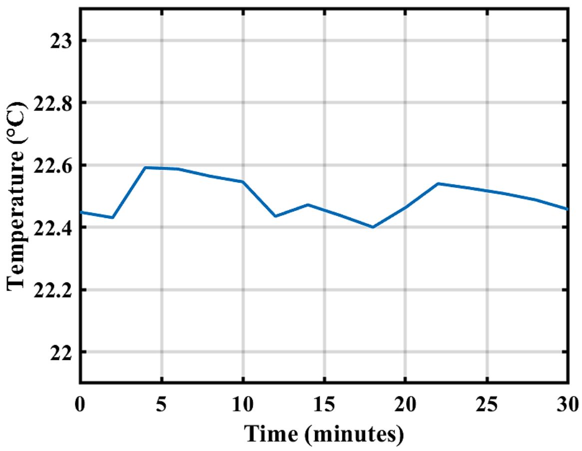

Fig. 8. (a) Temperature vs time data received from the Bluetooth module

The graphical representation of temperature vs. time depicts how the water temperature fluctuates in our test environment, as shown in **Figure 8.** This real-time monitoring helps assess environmental factors affecting water quality and aquatic life, providing valuable insights for timely intervention.

D. Economic Analysis

In this section, we present a comprehensive cost analysis to evaluate the economic feasibility of the water surface cleaning robot. Material costs are provided in **Table 2.**

TABLE II. Materials costs

Material name	Quantity	Approximate Cost (USD) *[2023]*
Polyethylene terephthalate bottle	4	Repurposed
Camera	1	Repurposed
5mm PVC sheet (4ft x 4ft)	1	7
Arduino Mega	1	15
100rpm12v DC gear motor	2	20
Servo Motor (MG996R)	1	5
Temperature Sensor (DS18b20)	1	2
2200mAh 12v LiPo Battery	2	36
Others		10
Total Cost		95

E. Energy Consumption Analysis

Table 3 presents the energy consumption by each element. On average, the robot consumes 13 W of power. To estimate the operational duration on a single charge with a 2200mAh battery, we can apply the following formula:

$$Backup\ Time\ (h) = \frac{Battery\ Capacity(Ah) \times Input\ Voltage(v)}{Total\ Load(w)}$$

using this formula, the theoretical backup time is calculated to be approximately 2.03 hours. However, accounting for system inefficiencies and variations in motor speed, the robot is expected to operate for approximately 1.5 hours on a full charge with the 2200 mAh battery.

F. Minimum turning radius

The turning radius is critical to a vehicle's maneuverability in confined spaces. For an aquatic robot, it represents the minimum radius of the circular path that the robot can achieve during a turn. Unlike terrestrial vehicles, watercraft cannot execute immediate turns due to the presence of water resistance. A differential drive robot can ideally perform a perfect turn around the center of its axle, achieving a theoretical zero-turning radius.[11] However, in aquatic environments, the proposed robot encounters water drags, which affects its performance. Through experimental evaluation, we determined the turning radius of the proposed robot to be approximately 0.45 meters, indicating favorable maneuverability for the robot.

TABLE III. Energy consumption of each piece of equipment

Equipment	Voltage(V)	Current	Qty	Wattage(w)
Motor	12	0.3A	2	7.2
Servo	7	0.6A	1	4.2
Thermal Sensor	5	1.5mA	1	0.0075
Arduino	5	.3	1	1.5
	Total			12.91W

IV. CONCLUSION

In conclusion, the aquatic robot designed for trash removal and water quality monitoring demonstrates a cost-effective and environmentally friendly solution for tackling water pollution. Constructed from recycled materials, the robot effectively collects floating waste while providing real-time water quality data, making it a comprehensive tool for environmental management. The use of paddle wheels enhances control, and the system's modular design allows for easy maintenance and scalability. The proposed system is also eco-friendly for aquatic ecosystems, as it does not utilize metal propeller blades. The integration of sensors for water quality monitoring further adds value, ensuring timely data collection to help protect aquatic ecosystems. Although the robot monitors water temperature, adding sensors for other crucial parameters like pH levels, dissolved oxygen (DO), or turbidity would make the robot even more useful for comprehensive water quality monitoring. Future enhancements could focus on increasing overall efficiency, expanding its capabilities for water quality monitoring by adding more sensors, improving autonomous functions, and broadening its range of communication system for longer range control.

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To: Sadia Afrose <sadia.afrose1927@gmail.com>

Dear Sadia Afrose,

Congratulations!
It is our pleasure to inform you that your submission titled, "Aquatic Robot for Trash Removal and Water Quality Monitoring Built from Recycled Materials" has been ACCEPTED for presentation at the 13th International Conference on Electrical and Computer Engineering (ICECE). Following careful consideration by a group of expert reviewers and the conference's Technical Committee, your submission has been accepted for presentation at this conference. We received a high volume of submissions this year but could only accept a limited number of papers for presentation at ICECE 2024.

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