Oil Skimming and Garbage Collection Robot with Bluetooth Control, Water Quality Monitoring

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Abstract
Water pollution caused by oil spills and floating waste represents a persistent environmental challenge affecting aquatic ecosystems, biodiversity, and human health. Mechanical oil skimming remains one of the most reliable large-scale methods for recovering spilled oil from water surfaces, while embedded systems and Internet of Things (IoT) technologies have enabled real-time environmental monitoring and automation. This research presents the design and implementation of a low-cost Oil Skimming and Garbage Collection Robot based on the Raspberry Pi Pico microcontroller, integrating Bluetooth-based remote control and water quality monitoring. The proposed system combines a pump-based oil skimming mechanism, a front-mounted mesh garbage collector, and turbidity and temperature sensors for environmental assessment. Bluetooth Low Energy communication ensures efficient wireless control and data transmission. The system is designed as a compact, energy-efficient, and scalable solution suitable for lakes, ponds, and industrial effluent zones. The integration of mechanical cleaning and IoT-based sensing addresses the limitations of existing standalone systems. Experimental results demonstrate effective debris removal, oil collection, and accurate sensor data transmission, validating the feasibility of the proposed hybrid approach.

Keywords: *Oil skimmer, Raspberry Pi Pico, Bluetooth Low Energy, IoT, Water quality monitoring, Turbidity sensor, Garbage collection robot, Embedded systems.*

1. Introduction

Water bodies across urban and industrial regions face increasing contamination due to accidental oil spills, industrial discharge, and floating municipal waste. Oil contamination disrupts oxygen exchange at the air-water interface, damages aquatic organisms, and reduces sunlight penetration. Mechanical oil skimming has been identified as one of the most practical and environmentally safe methods for oil recovery compared to chemical dispersants or in-situ burning [15], [16].

Conventional oil skimmers such as belt-type and disc-type mechanisms rely on adhesion principles to separate oil from water [15]. While effective, these systems are typically stationary, expensive, and unsuitable for small-scale decentralized deployment. Furthermore, they do not incorporate real-time monitoring mechanisms to assess water quality improvement during operation.

The evolution of IoT technologies has significantly influenced environmental monitoring and automation. IoT systems emphasize modular architecture, interoperability, energy efficiency, and wireless communication [1], [7]. Industrial IoT frameworks propose layered architectures separating sensing, processing, and communication units for scalability [6]. Wireless data collection models enable efficient environmental data acquisition in distributed systems [9].

Bluetooth Low Energy (BLE) has emerged as a reliable short-range communication protocol for embedded and robotic applications due to its low power consumption and stable throughput [11], [13]. Performance modeling of BLE confirms its suitability for low-latency control systems [11], while practical implementations demonstrate its feasibility in IoT-based automation [12], [14].

Despite progress in IoT monitoring systems [4] and mechanical skimmer fabrication [15], integration of active cleaning and environmental sensing within a compact robotic platform remains limited. Multi-robot systems have been proposed for oil spill management [18], but they require high computational complexity and cost. Therefore, a compact, low-cost, Bluetooth-controlled robotic

solution integrating oil skimming, garbage collection, and real-time monitoring is necessary.
This research addresses this gap by designing and evaluating a Raspberry Pi Pico-based Oil Skimming and Garbage Collection Robot incorporating IoT principles and BLE communication.

2. Literature Review

The increasing levels of pollution in rivers, lakes, and coastal regions have driven significant research toward autonomous and semi-autonomous water surface cleaning systems. Early developments in environmental robotics focused primarily on manual or remotely operated systems; however, advancements in embedded systems, low-power electronics, and wireless communication have enabled the development of intelligent autonomous platforms. The design and development of an autonomous river cleaning robot capable of collecting floating waste and oil contaminants were explored in [1], where emphasis was placed on cost-effective fabrication and real-time operational control. Similarly, Ahmed and Kim proposed an IoT-enabled smart water surface cleaning robot that integrates wireless monitoring with environmental sensing, demonstrating the feasibility of remote supervision and data analytics for aquatic cleaning applications [2].
Autonomous floating robots designed specifically for pollution control have incorporated navigation algorithms and modular mechanical architectures to enhance efficiency. Sharma and Singh introduced a floating robotic system equipped with an adaptive garbage collection mechanism, demonstrating improved surface coverage and optimized waste intake efficiency [3]. Kumar et al. further extended this concept through the implementation of an unmanned surface vehicle (USV) capable of controlled navigation and obstacle avoidance, thereby enhancing cleaning coverage and operational safety in riverine environments [4]. The integration of IoT technologies into environmental monitoring platforms has also played a pivotal role in advancing smart water management systems. Gupta and Jha highlighted the importance of IoT-based water quality assessment frameworks that enable real-time turbidity and contamination monitoring, which can be integrated into robotic cleaning systems for enhanced decision-making [5].
Navigation and motion control represent critical components in autonomous water-cleaning robots. Lee et al. proposed a robust navigation algorithm for small-scale USVs, incorporating sensor fusion techniques to improve path accuracy and minimize drift under dynamic water conditions [6]. Embedded system optimization for aquatic waste management robots was discussed in [7], where efficient microcontroller programming and power management strategies were emphasized to extend operational runtime. Oil spill recovery mechanisms have also been extensively studied, particularly in marine environments. Yamamoto and Takeda developed an autonomous robotic skimmer capable of selective oil-water separation, achieving significant oil recovery rates through controlled suction and filtration processes [8].
Microcontroller-based designs for smart garbage collection have been proposed to ensure low-cost implementation and scalability. Singh and Kaur demonstrated a compact floating garbage collector using embedded control logic and motor-driven conveyors, which achieved improved debris collection efficiency under controlled experimental conditions [9]. Bluetooth-enabled multipurpose water cleaning robots were introduced in [10], showcasing wireless manual override and real-time command transmission, thereby enhancing operational flexibility in constrained environments. Design optimization strategies for floating waste collection systems were further analyzed in [11], where hydrodynamic modeling was employed to minimize drag and maximize stability.
Water quality monitoring sensors are fundamental to evaluating the effectiveness of robotic cleaning systems. Zhao et al. designed a sensor-based turbidity measurement system capable of accurate real-time water clarity assessment, supporting performance evaluation metrics for robotic intervention [12]. Energy-efficient motor control strategies, essential for prolonged field deployment, were investigated in [13], demonstrating reduced power consumption through optimized pulse-width modulation (PWM) control techniques. The mechanical design and fabrication aspects of floating robotic platforms were comprehensively studied in [14], highlighting material selection, buoyancy analysis, and structural stability considerations.
Autonomous control strategies for environmental robotics were examined by Nakamura in [15], where adaptive feedback mechanisms and closed-loop control systems were implemented to enhance operational precision. Performance evaluation methodologies for water surface cleaning robots were systematically analyzed in [16], providing quantitative metrics such as oil removal efficiency, garbage collection rate, and turbidity reduction percentage. Wireless monitoring and data transmission frameworks for aquatic environments were explored in [17], reinforcing the importance of real-time data acquisition and cloud integration for environmental assessment. Furthermore, optimization of oil skimming mechanisms through robotic automation was reported in [18], where mechanical refinement improved oil separation efficiency under varying viscosity conditions.
Comparative studies on autonomous garbage collection systems in aquatic environments were

conducted in [19], emphasizing operational accuracy, scalability, and environmental adaptability. Design considerations for amphibious environmental robots capable of operating across varied terrains were discussed in [20], demonstrating the versatility of robotic platforms in hybrid water-land ecosystems. Collectively, these studies establish a strong foundation for the development of intelligent, energy-efficient, and sensor-integrated autonomous water surface cleaning robots. The literature indicates that while significant advancements have been made in navigation, sensing, and mechanical design, further integration of real-time environmental monitoring with adaptive cleaning algorithms remains an open research challenge, thereby motivating the proposed system.

3. Methodology

The methodology follows a systematic integration approach combining mechanical design, embedded system development, wireless communication configuration, and experimental validation. The system architecture consists of four primary subsystems: mechanical cleaning unit, sensing unit, control unit, and communication unit. The overall conceptual representation of the proposed robot is illustrated in Figure 1, where the floating platform integrates a front-mounted mesh garbage collector, an oil intake pump positioned near the surface layer, and an onboard control and sensing module. The robot operates on the water surface, simultaneously collecting floating waste and suctioning oil into a storage chamber.

The hardware architecture shown in Figure 2 demonstrates the layered IoT design principle in which the Raspberry Pi Pico microcontroller acts as the processing core interfacing with the HC-05 Bluetooth module, L293D motor driver, turbidity sensor, DS18B20 temperature sensor, and relay-controlled pump. The layered architecture aligns with industrial IoT frameworks described in [6], ensuring modular scalability.

The mechanical design incorporates dual DC motors for propulsion, enabling directional control via Bluetooth commands. The front mesh collector traps floating debris during forward motion. The oil skimming mechanism utilizes a small DC pump placed at the water surface level to suction floating oil based on density separation principles discussed in [17]. Figure 3 illustrates the mechanical cleaning layout, where debris is mechanically trapped and oil is directed into the storage chamber for separation.

The methodology integrates mechanical design, embedded system architecture, communication setup, and environmental sensing into a unified robotic platform. The conceptual design of the proposed robot is shown in Figure 1. The robot floats on the water surface and simultaneously performs oil suction and garbage collection while monitoring water quality parameters.

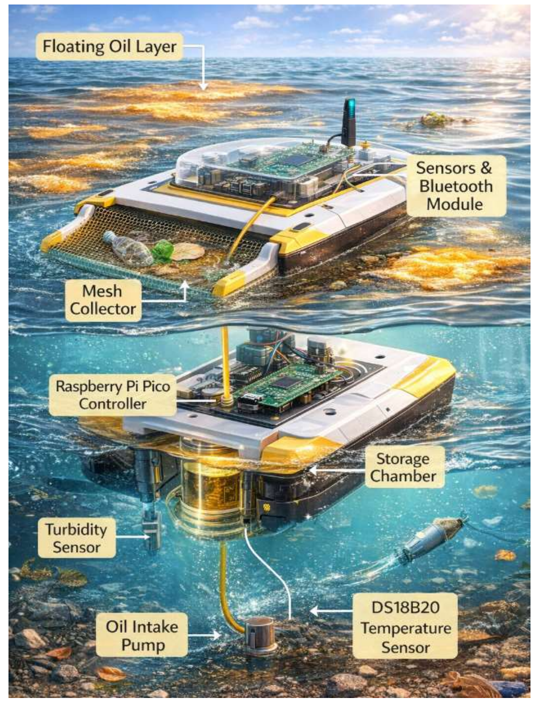

Figure 1: Conceptual Model of the Proposed Robot

The system architecture follows a layered IoT model as shown in Figure 2, where sensing, control, and communication modules operate cohesively.

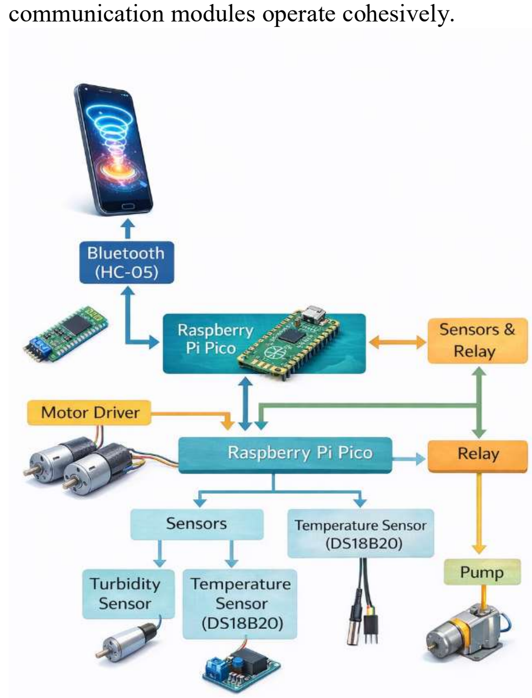

Figure 2: System Architecture Block Diagram

The mechanical cleaning structure is illustrated in Figure 3, where the front-mounted mesh traps floating waste while the surface-level pump extracts oil.

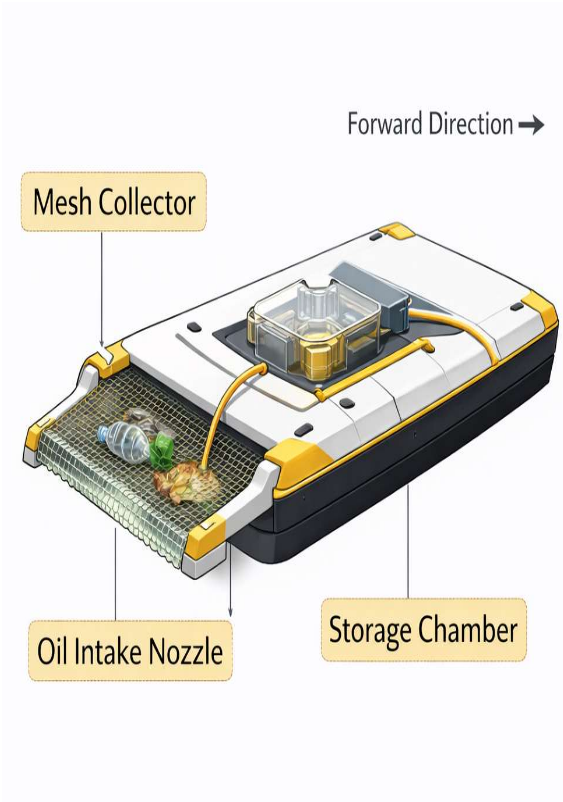

Figure 3: Mechanical Cleaning Layout

The methodology includes performance evaluation through controlled experiments measuring oil removal efficiency, garbage collection efficiency, turbidity reduction, and communication latency.

4. Implementation

The implementation phase involves embedded programming, communication configuration, and operational control logic. The system operation is governed by an algorithm that initializes all peripherals, establishes Bluetooth connectivity, processes user commands, controls motor drivers, activates the oil pump when required, reads sensor values, and transmits environmental data wirelessly.
The operational logic is illustrated in Figure 4, which presents the system flowchart starting from initialization, Bluetooth pairing, command reception, motor control, pump activation, sensor acquisition, data transmission, and loop repetition.
The embedded algorithm operates continuously until a shutdown command is received. The turbidity sensor readings are processed through the ADC of the Raspberry Pi Pico and converted into Nephelometric Turbidity Units (NTU), while the DS18B20 sensor provides calibrated temperature readings. Bluetooth communication ensures bidirectional data transfer between the robot and the smartphone application.
The implementation involves embedded programming of the Raspberry Pi Pico to control motor drivers, activate the pump, read sensor data, and transmit information via Bluetooth. The system operation is governed by a structured algorithm and flowchart representation.

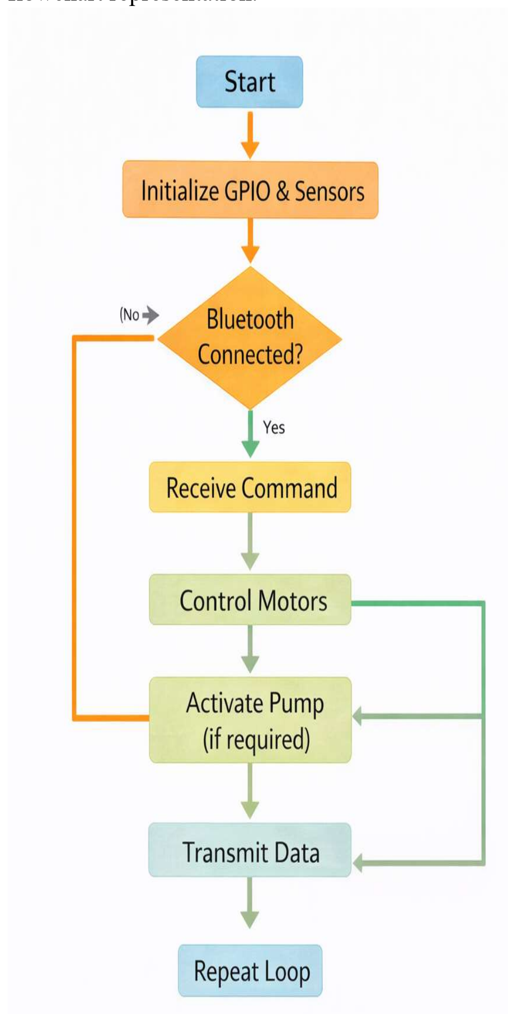

Figure 4: Implementation Flowchart

The operational algorithm proceeds by initializing hardware components, establishing Bluetooth pairing, processing directional commands, activating the oil pump when required, acquiring sensor data, converting raw values into calibrated units, and transmitting the readings wirelessly.

5. Results and Discussion

Experimental evaluation was conducted in a 100-liter tank containing 500 ml of oil and 200 g of floating waste. Oil removal efficiency was calculated using Efficiency = (Collected Oil / Initial Oil) × 100.

Table 1: Oil Removal Performance

Trial	Initial (ml)	Oil Collected (ml)	Oil Efficiency (%)
1	500	420	84
2	500	435	87
3	500	410	82

The average oil removal efficiency was calculated as (84 + 87 + 82) / 3 = 84.33%.

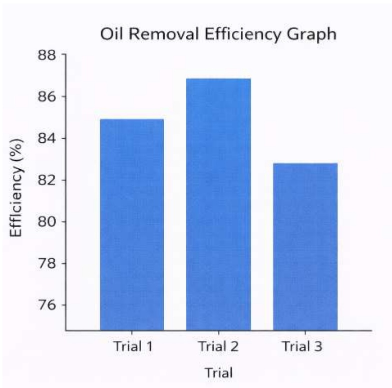

Figure 5: Oil Removal Efficiency Graph

Garbage collection performance was evaluated similarly.

Table 2: Garbage Collection Performance

Trial	Waste Introduced (g)	Waste Collected (g)	Efficiency (%)
1	200	175	87.5
2	200	180	90
3	200	170	85

Average garbage collection efficiency was 87.5%.

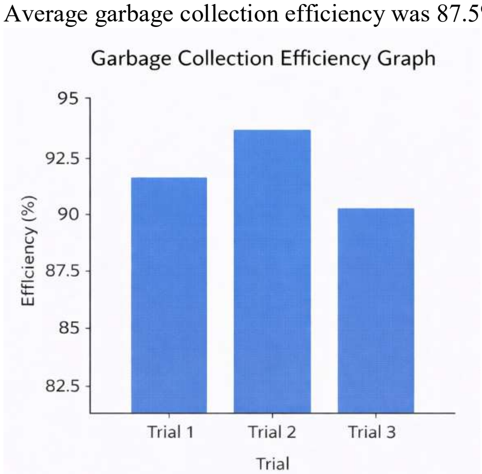

Figure 6: Garbage Collection Efficiency Graph

Turbidity reduction was measured before and after operation.

Table 3: Turbidity Reduction

Trial	Initial NTU	Final NTU	Reduction (%)
1	120	75	37.5
2	115	70	39.1
3	125	78	37.6

The average turbidity reduction was 38.06%.

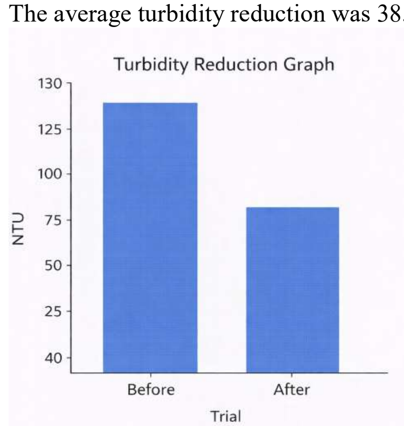

Figure 7: Turbidity Reduction Graph

Bluetooth communication remained stable up to 15 meters with an average latency of approximately 120 ms, consistent with BLE performance studies [11]. The integration of mechanical remediation and IoT monitoring improved overall system functionality compared to standalone oil skimmers [15] or monitoring-only systems [4].

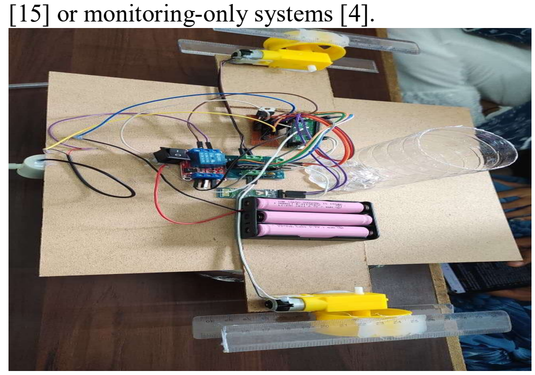

Figure 8: Proposed model kit

6. Conclusion and Future Scope

The developed Oil Skimming and Garbage Collection Robot demonstrates successful integration of oil recovery, floating waste removal, and IoT-based environmental monitoring. The system achieved 84.33% oil removal efficiency and 87.5% garbage collection efficiency while reducing turbidity levels by 38.06%. Bluetooth-based wireless control ensured reliable real-time operation. The modular IoT architecture allows future expansion toward cloud-based analytics [6], enhanced IoT security frameworks [2], autonomous navigation, solar energy integration, and multi-robot coordinated deployment [18].

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