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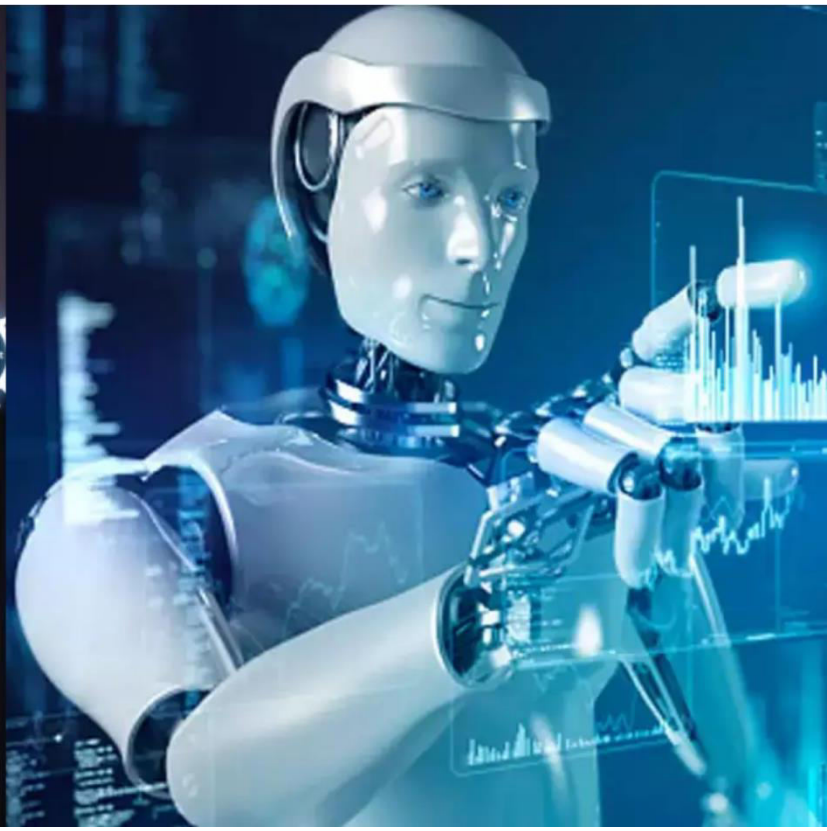

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Smart Autonomous Marine Waste Collector

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ABSTRACT: In recent years, aquatic debris accumulation in marine and freshwater bodies has posed a critical threat to aquatic ecosystems and water quality. Traditional manual surface cleaning methods are labour-intensive, inefficient, and often lack real-time monitoring capabilities. This project presents the design and implementation of an automated, fully autonomous smart water-filtration bin ("Aqua Cleaner") controlled by a NodeMCU-32S (ESP32) microcontroller and powered by an advanced renewable solar energy system comprising a 5W monocrystalline solar panel, an intelligent solar charge controller, and a high-capacity LiFePO4 backup battery pack ensuring continuous 24/7 off-grid operation. The system utilizes an ultrasonic distance sensor (HC-SR04 / IP67 waterproof JSN-SR04T probe) to dynamically monitor debris accumulation depth (calibrated at 24.0 cm for empty, 18.0 cm for 50% capacity, and 13.5 cm for 100% capacity). Upon detecting a 'Full' state, the ESP32 initiates a timed 44.50-second water pumping cycle via an active-LOW relay module to drive water filtration and surface debris intake. A built-in 'Debris Full' locking mechanism halts pumping if the bin remains clogged post-cycle, preventing motor burnout and overflow. Furthermore, an integrated I2C LCD provides real-time local status updates, while an embedded asynchronous web server hosted on the ESP32 (SoftAP mode) delivers a real-time web dashboard displaying live fill percentages, color-coded status alerts, and motor operation. Crucially, when the bin reaches full capacity, harbour crews and operators receive immediate visual and status notifications directly via the responsive web dashboard interface, enabling proactive maintenance scheduling and eliminating unexpected spills. Hardened hardware isolation—including noise-resilient 10 kΩ I2C pull-up resistors, regulated solar power management with backup battery storage, and dedicated power routing—ensures robust, off-grid, and noise-free operation in aquatic environments.

KEYWORDS: 5w solar panel with solar charging controller and LiFePO4, ESP32(NodeMCU-32S), Ultrasonic Distance Sensor (HC-SR04), I2C LCD Display, Water Pump

I. INTRODUCTION

Marine debris accumulation across commercial marinas, public ports, protected bays, and private waterfront amenities presents a severe threat to aquatic biodiversity, where floating plastics, bags, and micro plastics alter water chemistry and harm marine life. To address these challenges, the Smart Autonomous Marine Waste Collector has been developed as an IoT-enabled surface water filtration bin designed to automate floating trash capture, provide real-time level telemetry, and prevent bin overflow. Conventional sea bins function via continuous suction pumps that trap debris in an underwater mesh bag; however, these systems lack automated fill monitoring, forcing harbour crews to conduct daily manual patrol visits regardless of actual garbage volume and incurring high labour and fuel costs.

Furthermore, when bins fill up unexpectedly between scheduled checks, captured plastics spill back into the marina water, causing secondary pollution, while continuous pump execution in clogged bins leads to excessive energy consumption and motor overheating. To solve these limitations, the project integrates acoustic depth telemetry using HC-SR04 or JSN-SR04T sensors calibrated to empty (24 cm = 0%), half (18 cm = 50%), and full (13.5 cm = 100%) thresholds, an automated 44.50-seconds water pumping cycle triggered upon 100% capacity detection to pull debris into the mesh basket, and a 'Debris Full' lockout mechanism that halts the pump if the bin remains clogged post-cycle to protect the motor.

Additional features include a dual telemetry interface providing local visual status via a 16x2 I2C LCD and remote telemetry through an embedded ESP32 web server in Access Point mode, alongside hardware stabilization that hardens I2C lines against motor-induced EMI using 10 kΩ pull-up resistors and software auto-recovery routines. This system is versatile across numerous applications and use cases, making it ideal for commercial marinas in multi-dock debris collection across boat slips and yacht basins, protected bays and marine reserves in eco-sensitive wildlife zones, private resorts and waterfront lakes for high-end amenity maintenance, and ports and harbour terminals for automated surface

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trash extraction. Additionally, it can be installed in municipal urban ponds and parks for low-maintenance waste management, utilized in hydroponic and agricultural irrigation canal keepers to protect agricultural water intake channels from floating debris, deployed in gamified eco-tourism and resort docks to engage visitors, and utilized as automated environmental research sampling stations for autonomous field data collection by marine biology and water pollution researchers.

II. RELATED WORKS

Ashok et al. [1] presented an autonomous watercraft for the cleanup of floating waste in water bodies, utilizing computer vision frameworks such as YOLO object detection models to identify and collect surface debris. Chen and Wang [2] introduced autonomous marine debris collection vessels for sustainable aquaculture and irrigation canal maintenance, analyzing the critical operational needs of managing floating waste accumulation in commercial water channels and agricultural intake systems. Intiadi [3] devised an IoT-based smart waste bin featuring automated level detection and control protocols to monitor container fill status and reduce manual inspection frequencies. Patel and Sharma [4] presented hardware stabilization and electromagnetic interference (EMI) mitigation techniques for microcontroller-driven aquatic robotic systems operating in electrically noisy environments near high-current pumps and motors. Ramson et al. [5] introduced identification and sensor networks-based bin level monitoring systems as a review, studying the relationship between basic sensor networks and manual data logging parameters for tracking container waste accumulation over time.

Here, an effective technological solution for a smart autonomous marine waste collector utilizing IoT and acoustic telemetry is proposed, and the ESP32 microcontroller is connected to get the depth data from ultrasonic sensors (HC-SR04 / JSN-SR04T). Acoustic depth monitoring is used for calibrating empty, half, and full thresholds for real-time fill detection during aquatic surface operation. The automation protocol is executed for triggering a 44.50-second water pumping cycle upon 100% capacity detection to pull debris into the mesh basket, along with a 'Debris Full' lockout mechanism to protect the motor if the bin remains clogged. After threshold evaluation, the prediction of bin capacity and telemetry status is updated via an embedded web server and 16x2 I2C LCD.

Designing and performing automated telemetry and motor protection algorithms, which analyze water surface depth data quickly and accurately using calibrated sensor thresholds with the highest reliability for marinas and irrigation channels, is the major contribution of this study. The hardware stabilization's inclusion assists in hardening I2C lines against motor-induced electromagnetic interference (EMI) and provides reliable real-time waste monitoring. The remaining paper is structured as: the proposed system together with the experimental protocol is described in Section III.

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III. METHODOLOGY

A. Block Diagram of Proposed System:

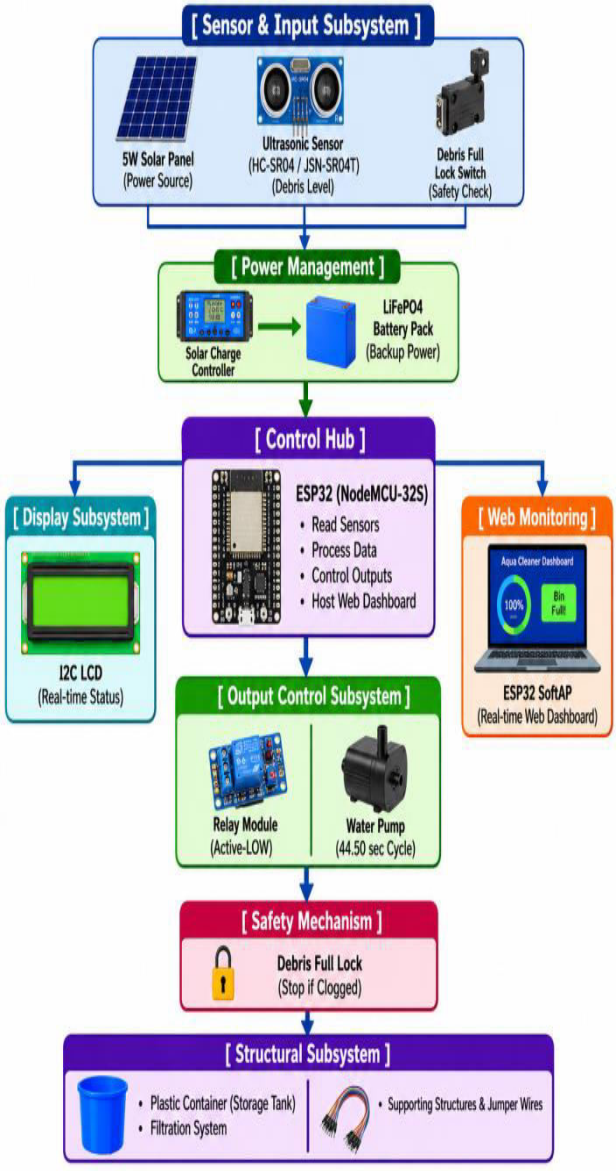

Figure 1 Block Diagram

The proposed Smart Autonomous Marine Waste Collector ("Aqua Cleaner") integrates local acoustic sensing, automated pump timing control, safety lockouts, and web telemetry into a unified, resilient IoT architecture. The structural design features a static mechanical funnel guide positioned above an underwater net basket to direct floating debris inward efficiently. Distance telemetry monitors the internal fill state and triggers an active-LOW relay module that powers the water filtration pump for a precisely calibrated 44.50-second cycle. Real-time operational data and fill metrics are displayed locally via a 16x2 I2C LCD and broadcast remotely through an embedded ESP32 web dashboard hosted in Software Access Point (SoftAP) mode.

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B. Operational Work Flow:

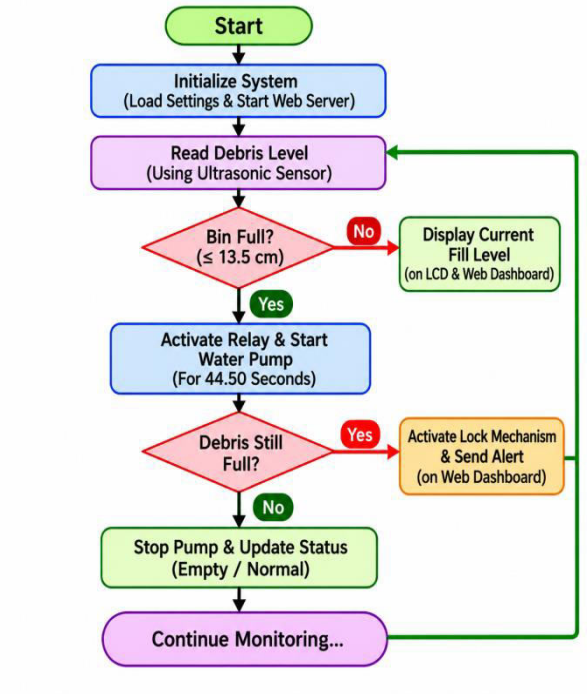

Figure 2 Operational Work Flow

The end-to-end operational workflow follows a structured sequence:
Initialization: The system powers on via the solar-charged LiFePO4 battery pack, initializing GPIO pins, the I2C LCD display, and launching the embedded SoftAP web server.

Continuous Monitoring: The ultrasonic sensor repeatedly measures the distance between the sensor mounting point and the top surface of the collected debris.

Threshold Evaluation: The ESP32 computes the corresponding fill percentage using calibrated distance parameters.
Automated Pumping Cycle: Upon detecting 100% capacity, the microcontroller activates the relay and runs the water pump for the pre-calibrated 44.50-second cycle.

Safety Lockout & Telemetry Update: Sustained clogging triggers the safety lockout mechanism, while real-time status updates are simultaneously refreshed on the local LCD screen and transmitted to the remote web monitoring dashboard.

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C. Circuit Diagram:

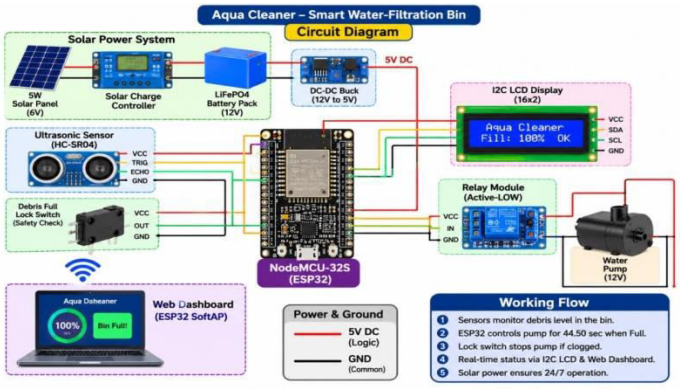

Figure 3 Circuit Diagram

D. Functions of Individual Blocks:
The system hardware and software architecture comprises several key functional blocks:
NodeMCU-32S (ESP32): Acts as the central processing unit, executing sensor acquisition logic, pump timing loops, web server hosting, and I2C LCD auto-recovery routines.

HC-SR04 / JSN-SR04T Ultrasonic Sensor: Measures the distance to the accumulated debris surface, calibrated at 24.0 cm (Empty / 0%), 18.0 cm (Half / 50%), and 13.5 cm (Full / 100%).

5V Relay Module: An opto coupler-isolated relay module operating under active-LOW control logic (via GPIO 23) to safely interfaces the low-power microcontroller with the high-current water pump.

16x2 I2C LCD Display: Provides immediate local visualization of live fill status and percentage metrics, stabilized against electromagnetic interference (EMI) using 10 kΩ pull-up resistors on the SDA (GPIO 21) and SCL (GPIO 22) lines.

Embedded Web Server & SoftAP: Hosts an interactive, responsive web dashboard over a local Wi-Fi hotspot (Smart_Seabin_AP at IP address 192.168.4.1), enabling operators to monitor system status wirelessly without external internet dependency.

Static Funnel Guide: A passive physical structure mounted above the collection basket to funnel surface water and floating plastics directly into the entrapment zone.

State Machine Logic & Software Workflow
To ensure reliable autonomous operation, the firmware is programmed as a non-blocking state machine divided into three distinct operational states:

IDLE State: The system continuously samples distance every 2 seconds. Normal water filtration and monitoring continue as long as the fill level remains below full capacity. If the measured distance drops to $\le 13.5\text{ cm}$, the system transitions automatically to the PUMPING state.

PUMPING State: The relay module energizes the water pump ON for an exact duration of 44.50 seconds to extract trapped debris into the mesh basket. Upon completion of the timer, the system re-evaluates the distance. If the bin is cleared, it returns to the IDLE state; if the bin remains clogged ($\le 13.5\text{ cm}$), it transitions to the DEBRIS_FULL_LOCKED state.

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DEBRIS_FULL_LOCKED State: The pump is forced OFF to protect the motor from overheating or burnout. The local LCD displays "Debris Full!" and the web dashboard updates the status alert. The system remains locked until physical clearance is detected (distance $> 13.5\text{ cm}$), after which it safely resets back to the IDLE state.

IV. EXPERIMENTAL RESULTS

Calibration and Level Sensing:
The distance sensing logic was calibrated against the physical seabin prototype container:
Empty State: Distance ≥ 24.0 Cm ≥ LCD Shows Empty

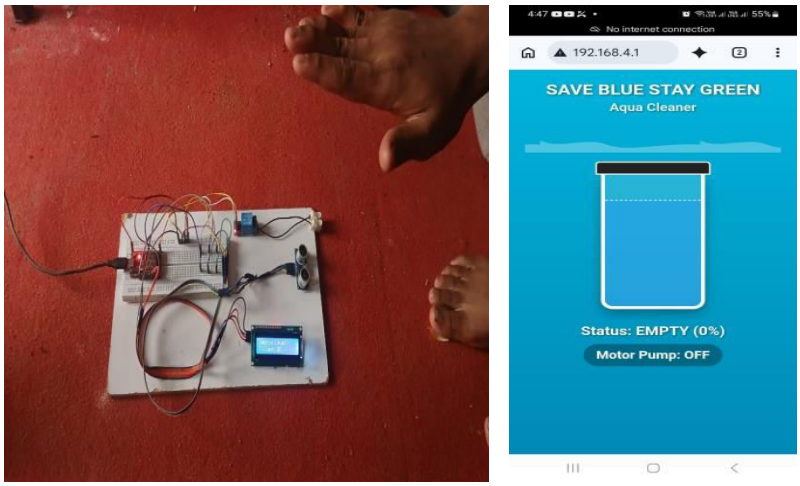

Figure 4 Empty State

Half State: 13.5 Cm < Distance ≤ 18.0 Cm ≥ LCD Shows Half-Filled

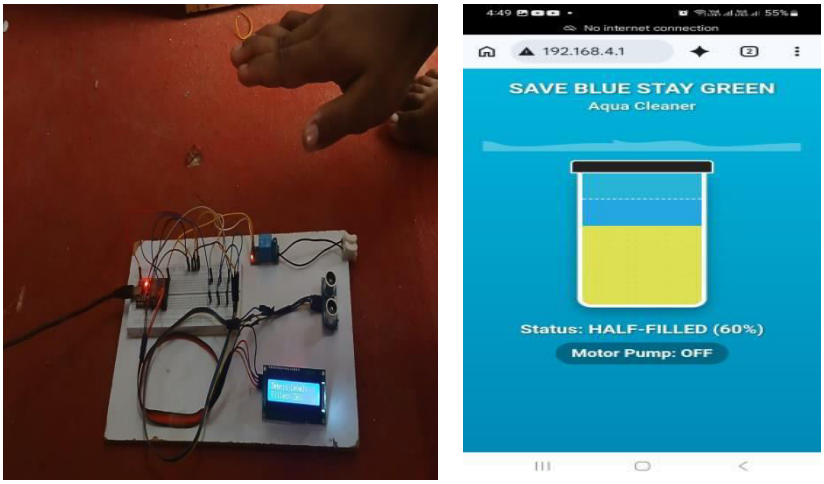

Figure 4 Half State

Full State: Distance ≤ 13.5 cm ≥ LCD shows Status: FULL (Pumping)

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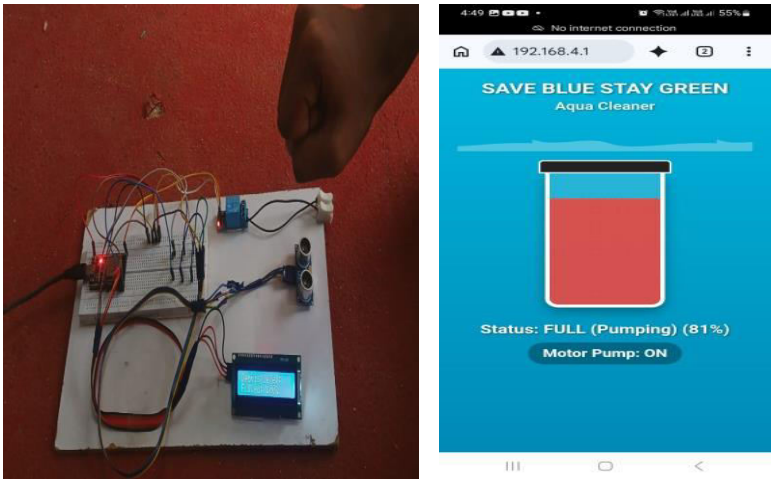

Figure 4 Full State

Automated Pumping & Locked State Recovery:
When fill capacity reached 100%, the relay activated the pump for exactly 44.50 seconds. If debris cleared, the system returned to IDLE. If the basket remained filled post-cycle, the system entered DEBRIS_FULL_LOCKED mode, powering off the relay and displaying 'Debris Full!' until cleared.

Hardware EMI Noise Stabilization
Adding 10 kΩ pull-up resistors between SDA (GPIO 21) to 3.3V and SCL (GPIO 22) to 3.3V, combined with a 2-second software `lcd.init ()` refresh routine, completely resolved I2C character corruption caused by pump motor surges.

V. CONCLUSION

Phase 1 of the Smart Autonomous Marine Waste Collector successfully delivers an automated, IoT-enabled aquatic cleaning solution. The ESP32 effectively coordinates distance telemetry, timed pump cycles, lockout safety routines, local LCD output, and remote web monitoring. Hardware hardening measures eliminated motor EMI issues, establishing a stable physical prototype.

Future Enhancements (Phase 2Vision Roadmap):
AI Computer Vision Integration: Mount an ESP32-CAM module running lightweight CNN object detection models to classify debris (plastics, cans, organic algae) prior to suction.

Solar Renewable Power: Deploy a 20W solar panel with a LiFePO4 battery pack and MPPT charge controller for off-grid marina operation.

LoRaWAN/Fleet Telemetry: Upgrade wireless telemetry from local Access Point Wi-Fi to cellular GSM/LoRaWAN for wide-area harbour fleet management.

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