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Remote Controlled Floating Waste Cleanup System

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Abstract: This paper introduces an innovative solution to water pollution through the development of a remote-controlled floating waste cleanup system. Designed to autonomously collect floating waste from water bodies, the system minimizes human intervention while ensuring safe and efficient operations. It incorporates a belt-driven waste collection mechanism that continuously gathers debris into a designated collector bin, powered by a battery charged via a solar panel to promote sustainable energy use. The cleanup vessel is equipped with an ESP32-CAM module that enables live video streaming for real-time remote monitoring, allowing operators to oversee the cleaning process effectively. An integrated ultrasonic sensor measures the fill level of the collector bin, providing essential feedback to ensure timely waste disposal. Additionally, a web-based dashboard offers wireless control, enabling operators to manoeuvre the vessel in multiple directions—forward, reverse, left, and right, while managing the activation of the conveyor belt. Overall, this system not only improves the efficiency of water surface cleaning but also reduces the risks and labor associated with manual cleanup operations. It demonstrates a scalable, environmentally friendly solution for maintaining cleaner aquatic environments through the integration of automated control, renewable energy, and real-time monitoring technologies
Keywords: Floating Waste Cleanup, ESP32-CAM, Conveyor Belt, Water Pollution, Renewable Energy.

1. Introduction

In today's rapidly evolving landscape of Internet of Things (IoT) technologies, the integration of smart systems into marine environments presents exciting opportunities for enhanced control and monitoring. This project focuses on the development of an IoT-based marine dashboard that not only allows for real-time control of essential boat functions but also integrates automated sensor monitoring and live video streaming. By leveraging affordable hardware, such as the ESP32 microcontroller and camera module, the system provides a comprehensive solution that is both scalable and adaptable to diverse marine applications. The core of the project is built around a dual-component framework. On one side, a Wi-Fi enabled web server facilitates intuitive remote control of various motorized functions—including directional movement and conveyor belt operations—via a user-friendly interface. This interface also displays critical real-time data, such as the bin fill level, measured using ultrasonic sensors. On the other side, a dedicated camera server powered by an ESP32 module provides live streaming capabilities. This setup not only captures high-quality visual data but also supports additional functionalities like enhanced situational awareness and potential future implementations in surveillance or environmental monitoring. By combining robust network connectivity with real-time data acquisition and multimedia streaming, the project demonstrates a practical application of IoT in marine automation. The integrated system is designed to operate reliably in challenging environments, ensuring that users can monitor and control marine devices remotely with minimal latency. Moreover, the modularity of the design paves the way for future enhancements, including advanced sensor integration and machine learning-driven analytics. Overall, this project represents a significant step towards smarter, more efficient marine operations. It lays the foundation for further research into IoT applications in harsh and dynamic environments, emphasizing both innovation and practical usability in real-world scenarios.

2. Literature Review

The evolution of the Internet of Things (IoT) over the past decade has fundamentally reshaped how researchers and practitioners approach remote monitoring and control systems. Early studies in IoT laid the essential groundwork by demonstrating the benefits of networked sensor arrays and actuators, which enabled data collection and remote interaction in a variety of environments. These pioneering efforts revealed that integrating sensors with communication networks could provide timely insights into system performance, even from remote locations—a concept that remains central to modern IoT applications.

More recent research has expanded on these early findings, particularly in the context of marine and industrial applications. In these domains, the challenge has always been to develop systems that are not only cost-effective but also robust enough to handle the dynamic and often harsh conditions encountered in real-world settings. Low-cost microcontrollers like the ESP32 have emerged as a preferred choice in this regard. The ESP32 is celebrated for its built-in Wi-Fi capabilities, low power consumption, and impressive processing power. Researchers have shown that such microcontrollers can effectively bridge the gap between complex sensor networks and user-friendly control interfaces. This dual capability has been especially valuable in projects that require both automated data collection and real-time remote control.

Another key area of focus in the literature is the application of ultrasonic sensors for precise, non-contact measurement tasks. Ultrasonic sensors have been widely documented for their ability to accurately measure distance and detect object levels, which is particularly beneficial in settings where direct measurement is impractical. Multiple studies have confirmed that these sensors offer reliable performance under varying conditions, making them an integral component in systems that monitor fill levels, water levels, or even the presence of obstacles. The validation of ultrasonic sensor technology through various comparative studies further supports their integration into automated systems such as marine dashboards.

In addition to sensor technologies, the role of live video streaming has gained considerable attention in recent years. Live video not only enhances situational awareness but also facilitates real-time decision-making in remote operations. The integration of multimedia streaming with IoT devices represents a significant step forward in creating immersive and responsive control systems. Researchers have explored various techniques to optimize video transmission, including advanced compression algorithms and adaptive streaming protocols that can handle bandwidth fluctuations and reduce latency. Although challenges such as power consumption and data transmission efficiency persist, ongoing innovations continue to improve the feasibility of high-quality live video in remote monitoring systems.

Moreover, the literature increasingly emphasizes the importance of system integration and user-centric design. As IoT systems evolve, there is a growing consensus that the ultimate success of these technologies depends on their ability to deliver intuitive and reliable user experiences. Studies have illustrated that an effective system must not only incorporate state-of-the-art hardware components but also provide a seamless interface that allows end users to interact with and control complex systems effortlessly. This user-focused approach ensures that technological advancements translate into practical benefits for operations in sectors such as marine technology, where timely and accurate control can have significant operational impacts.

Overall, the body of literature on IoT, sensor integration, and multimedia streaming provides a comprehensive foundation for the design of modern remote-control systems. By synthesizing insights from early conceptual research with the latest developments in microcontroller and sensor technologies, the current project leverages established methodologies while also pushing the boundaries of innovation. This integrated approach not only enhances the operational efficiency of marine systems but also opens new avenues for future research, including advanced analytics and machine learning applications that promise to further revolutionize remote monitoring and control.

2.1. Objectives and Methodology

The project is designed to efficiently remove debris from water bodies and deposit it into a dedicated collection container. It aims to send immediate alerts when the container nears capacity, allow wireless control of the vessel's movements (including forward, backward, left, and right) via a web server, and provide real-time visual monitoring through an ESP32-CAM module. Additionally, the system leverages a solar panel to harness renewable energy, emphasizing eco-friendly operation.

Debris Collection System: A conveyor belt is mounted at the front of the boat, designed as a continuous loop rotating around two pulleys and driven by a 12V DC motor. As the boat moves forward, the belt collects floating debris from the water surface and transports it into an adjacent waste collection bin.

Waste Level Monitoring and Alerts: An ultrasonic sensor is positioned above the collection bin to continuously monitor the waste level. The sensor measures the distance from the sensor to the accumulated waste, and when the waste reaches a preset level, it triggers an alert to notify the operator that the bin is full.

Wireless Navigation Control via Web Server : The system integrates wireless control through a web server, allowing the operator to remotely manoeuvre the boat. The control interface, accessible via a web browser or dedicated web application, enables directional

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commands—forward, backward, left, and right. The boat's movement is primarily driven by a rear-mounted propeller that facilitates both forward and reverse motion.

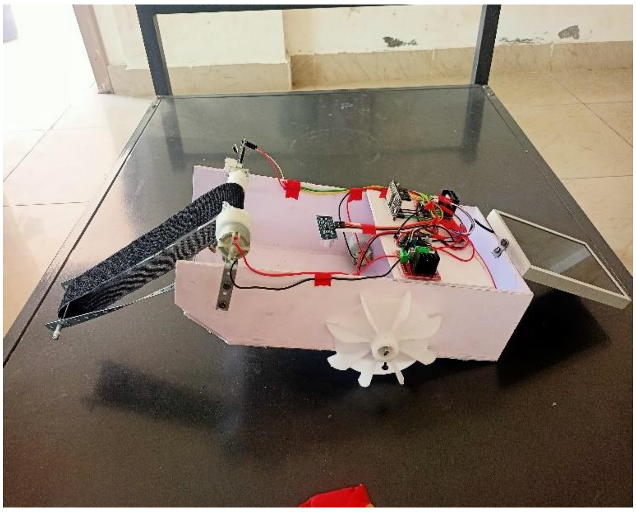

Figure.1 Proposed idea

Real-Time Video Streaming : An ESP32-CAM module is installed on the boat to provide live video streaming. This feature enables the operator to monitor the area in front of the boat in real time, ensuring precise navigation towards debris and efficient waste collection.

Solar-Powered Operation: To ensure eco-friendly and sustainable functionality, the boat is equipped with a solar panel. The panel is strategically positioned to maximize sunlight exposure, while an LM2596 voltage regulator maintains a stable voltage output, thereby powering the system reliably using renewable energy.

3. Related Work

The figure 2 shows the block diagram of the proposed model. The components used here are solar panel, battery, DC motors, motor driver, ESP32 module, ESP32-CAM module, ultrasonic sensor, LM2596 voltage regulator, conveyor belt and propellers. The working functionality of each component is described below:

ESP32 Microcontroller Unit: The ESP32 microcontroller serves as the primary processing hub, coordinating the operation of all integrated components. This module facilitates wireless communication, processes sensor data, and transmits control signals. It is powered through a stabilized voltage supply derived from a battery via a voltage regulation circuit.

Solar Energy Harvesting and Power Storage: A photovoltaic panel is employed to harness solar energy, ensuring continuous charging of the onboard battery. This stored energy acts as the primary power source for the entire system, eliminating dependence on external electrical supplies. Instead of directly distributing this power, it is first conditioned through a voltage regulator to ensure stable operation of sensitive electronics.

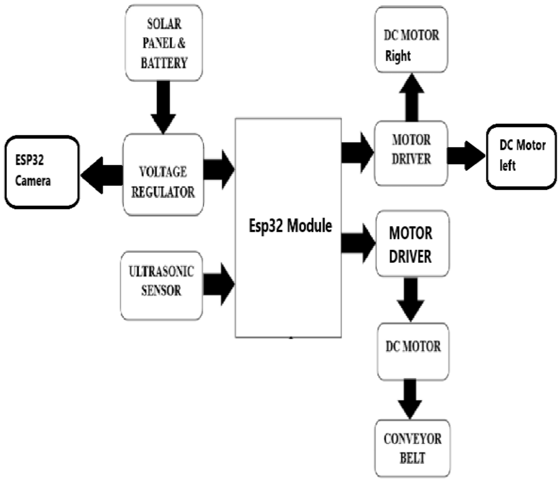

Figure.2 General Block Diagram

Voltage Regulation System: To prevent damage due to voltage fluctuations, an adjustable voltage regulator (such as the LM2596) is utilized. This regulator fine-tunes the electrical output before supplying power to various components, ensuring that each receives the required voltage without the risk of overloading.

Distance Monitoring Sensor: An ultrasonic sensor is incorporated to monitor the waste accumulation within the collection bin. This sensor continuously emits ultrasonic waves, which bounce back upon encountering an obstacle (waste). When the bin reaches its maximum capacity, the reflected signal triggers an alert, notifying the control system.

Live Streaming Module (ESP32-CAM): To provide real-time surveillance of the system's operational area, an ESP32-CAM module is used. Equipped with an integrated camera, this module captures live visuals, transmitting the feed wirelessly to an IoT dashboard. Each user is assigned a unique IP address for secure access to the video stream.

Motor Control System: A motor driver is responsible for translating the control signals from the ESP32 into precise movements of the DC motors. These motors regulate the motion of the floating vessel, allowing forward, backward, and directional adjustments. The speed and direction of movement are remotely controlled via an IoT interface.

Waste Collection Mechanism: A conveyor belt system, powered by a dedicated DC motor, is integrated to scoop floating debris from the water surface and deposit it into the onboard collection bin. The motor's operation is synchronized with the control module to optimize energy efficiency and waste collection efficiency.

3.1. Flowchart And Description

The flowchart illustrates the operational sequence of the proposed water surface waste collection system. The

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process follows a structured approach, ensuring smooth operation and real-time monitoring.

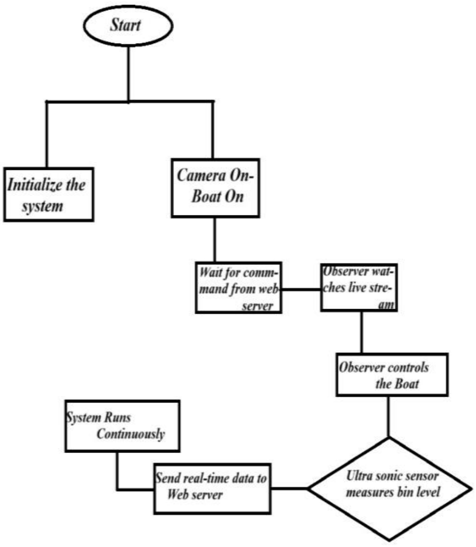

Figure.3 Process Flowchart

System Initialization: The process begins with the initialization of all hardware components, including the power system, control unit, and sensors. This ensures that all modules are functioning correctly before the system proceeds further.

Activation of Boat and Camera Module: Once initialized, the boat and the onboard ESP32-CAM module are powered on. The camera module starts capturing live video footage, which is then transmitted to a remote web server for monitoring purposes

Awaiting Remote Command: The system enters a standby mode, waiting to receive operational instructions from the remote user via an IoT-based web server. During this phase, the observer gains access to the live feed and assesses the environment before sending control commands.

Remote Monitoring and Navigation Control: The observer continuously monitors the boat's movement and surroundings using the live-streamed footage. Based on the real-time visuals, the observer remotely directs the boat's navigation, adjusting its direction as needed to optimize waste collections

Waste Collection Monitoring: As the boat navigates through the water, an ultrasonic sensor constantly measures the waste accumulation inside the collection bin. If the bin reaches its maximum capacity, a notification is sent to the remote user, prompting necessary actions.

Continuous Operation and Data Transmission: The system operates in a continuous loop, ensuring uninterrupted waste collection. Simultaneously, real-time data, including bin status and boat position, is transmitted to the web server, allowing the observer to make informed decisions.

4. Results and Discussion

The boat was designed following established floating conditions, as depicted in Figure 4. The following parameters were systematically evaluated:

Figure.4 Boat Floating on the Water

Manoeuvrability Testing: The boat was subjected to a series of test runs to assess its manoeuvrability in various water conditions. Key aspects such as turning, acceleration, and deceleration were evaluated to determine the responsiveness to control inputs.

Equipment Verification: All integrated features and equipment, including sensors, propulsion motors, and communication systems, were rigorously tested to verify their functional performance and seamless integration with the boat's control systems.

Stability Assessment: The stability of the boat was examined under diverse environmental conditions, including calm water, wave disturbances, and wind exposure, to ensure consistent balance and stability throughout the operation.

Figure 5 Collection of Waste into the Bin.

The boat incorporates a conveyor belt mechanism at the front section, designed to facilitate surface waste collection. A conveyor belt typically consists of a continuous loop of material that rotates around two pulleys, enabling the movement of objects from one location to another.

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In this setup, the pulleys rotate in the same direction and at a consistent speed, propelling the belt and the material carried on it. To ensure efficient operation, the belt is driven by a 12V DC motor.

As the boat moves forward, the conveyor belt collects floating debris from the surface of water bodies. Directly behind the conveyor system is a waste collection bin, where the accumulated waste from the belt is deposited.

This prototype is capable of collecting lightweight objects such as leaves, small plastic waste, and other floating debris. Figure 5 illustrates the process of leaf collection into the bin, which is positioned inside the boat.

This surface waste collection mechanism contributes to reducing water pollution by efficiently gathering contaminants from the water's surface

Wireless Control Using Web Server:

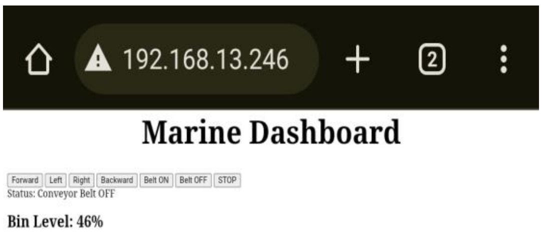

Figure.6 Operating buttons in webserver

The boat operates entirely in a wireless mode, utilizing the ESP32 microcontroller with an integrated Wi-Fi module. The control system is accessed through the user's mobile device via a web server application.

The web server, hosted on the ESP32, assigns a unique IP address to each user device, enabling wireless communication. The ESP32 connects to the user's mobile hotspot using its built-in Wi-Fi capability, allowing the operator to control the boat's movement and conveyor belt functions remotely.

The primary propulsion system of the boat relies on a propeller mounted at the rear, which generates thrust for forward and reverse motion.

The operator can control the movement of the boat in multiple directions, including forward, backward, left, and right, by interacting with the control switches on the web-based interface. The control interface provides the following functional switches, as illustrated in Figure 6:

(a). **Conveyor Belt ON/OFF:** Activates or deactivates the waste collection conveyor belt.

(b). **Forward ON/OFF:** Controls the forward movement of the boat by activating the propeller.

(c). **Reverse ON/OFF:** Engages the reverse motion of the boat.

(d). **Left Rotate ON/OFF:** Controls the leftward rotation for directional adjustments.

(e). **Right Rotate ON/OFF:** Controls the rightward rotation for manoeuvring.

This wireless control mechanism offers flexibility and ease of operation, allowing efficient surface waste collection in aquatic environments.

Alert Message

The floating waste collected from the water bodies is directed into a dedicated bin installed on the boat. The bin level is continuously monitored using an ultrasonic sensor positioned at the top of the bin. The sensor is configured with a predefined distance range to accurately detect the bin's fill level.

As waste accumulates and reaches the maximum level, it obstructs the ultrasonic waves and triggers a detection event. Upon identifying a full bin, the system promptly sends an alert message to the operator, indicating that the bin is full.

This notification enables the operator to navigate the boat back to the designated operating area for waste disposal and maintenance. This automated bin monitoring system ensures efficient waste collection management, minimizing manual intervention and enabling timely maintenance.

Live Streaming

Live streaming functionality is implemented using the ESP32-CAM module, allowing the operator to visually monitor the area in front of the boat in real time. This feature significantly reduces the time required to locate waste from a distance, as the operator can directly navigate toward visible debris.

To enable live streaming, a unique IP address is generated along with a username configuration. The ESP32-CAM module connects to the Wi-Fi network using the same credentials through the web server application. This setup facilitates seamless streaming and remote monitoring via a mobile device.

Figure7 illustrates the configuration of the CAM module, which offers various adjustable settings to suit individual preferences and operational requirements. The flexibility of these settings ensures optimal streaming quality and efficiency during waste collection operations.

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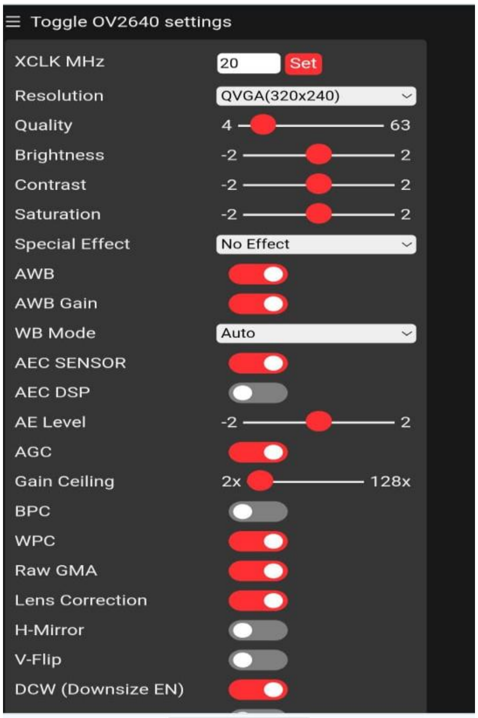

Figure.7 Settings of ESP CAM Module

5. Conclusion and Future Scope

The developed system effectively automates the collection of floating debris from water surfaces through a conveyor mechanism that continuously deposits the gathered waste into a designated container. An ultrasonic sensor positioned above the container continuously monitors the fill level, and when the container reaches its capacity, the system promptly generates a notification indicating that the bin is full.

The boat is designed to maintain buoyancy and stability while actively collecting waste. It achieves forward and backward motion using a propeller mounted at the rear, while directional control (left and right turns) is accomplished through the coordinated operation of DC motors installed on either side of the vessel.

To enhance operational efficiency, the system integrates real-time video streaming using the ESP32-CAM module, allowing the operator to visually monitor the waste collection process. Robust wireless communication, established via the ESP32 Wi-Fi module, facilitates reliable remote control of the boat through a web-based dashboard. Comprehensive testing in various aquatic environments has demonstrated the prototype's ability to perform all intended functions efficiently, confirming its practical applicability for surface waste management.

Scalability: The system can be scaled up to manage larger volumes of floating debris, thereby increasing overall waste collection capacity.

Mechanical Enhancements:

- Incorporate rotating cutting blades at the front of the vessel to trim aquatic vegetation, especially along lake edges, allowing the boat to navigate tight corners and densely vegetated areas.
- Attach trash nets to enhance the efficiency of capturing floating waste.

Smart Automation:

- Integrate machine vision with advanced image processing techniques to enable autonomous detection and collection of waste.
- Develop IoT-enabled smart robots to further automate the clean-up process.
- Environmental Monitoring:
- Incorporate advanced sensing and monitoring tools, such as:
- Remote sensing systems for detecting floating debris and pollution hotspots.
- Water quality analyzers to assess contamination levels and track improvements.
- Underwater drones to evaluate submerged waste and inspect underwater pollution sources.
- Performance Evaluation: Continuously assess the effectiveness of the system through data collection and analysis to optimize clean-up operations.

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