Oil Spillage Detection and Recovery System

Pratik Sawant[1], Aniruddha Phadte[2], Ghanashri Nipanikar[3], Melison Vaz[4], Dr. Sonali Pandit[5]

[1,2,3,4] Bachelor of Engineering Student, [5]Associate Professor
Department of Electrical and Electronics Engineering, Goa college of Engineering, Farmagudi, Ponda-Goa, India

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Abstract - *Oil spillages in marine environments pose severe ecological and economic threats, while traditional cleanup methods remain slow, labor-intensive, and costly. This paper presents an automated, low-cost, 3D-printed robotic boat integrated with IoT monitoring for localized oil spill detection and recovery. The system utilizes plastic oleophilic disks coupled with high-torque DC motors to selectively adhere and lift surface oil into an onboard storage tank. An intelligent onboard controller activates the skimming mechanism upon oil detection, navigates autonomously via obstacle avoidance, and monitors tank capacity to prevent overflow. Real-time system telemetry and recovery progress are managed remotely using the Blynk IoT platform. The proposed prototype offers a scalable, efficient solution for hazardous spill management in harbors and industrial waterways.*

Keywords: *3D-printed Boat, Oleophilic Disk Skimming, Obstacle Avoidance System, IoT.*

1. INTRODUCTION

Global petroleum consumption continues to rise, with major economies relying heavily on oil transport via maritime and offshore infrastructure. Consequently, oil spills frequently occur due to tanker leakages, pipeline ruptures, natural disasters, illegal operational discharges, and infrastructure sabotage. When released into aquatic environments, lower-density oil rapidly forms thin surface sheens that disrupt marine ecosystems. Spills severely impact wildlife by destroying the thermal insulation of marine mammals, causing hypothermia in birds, disrupting fish reproduction, and blocking sunlight necessary for phytoplankton photosynthesis. Additionally, bioaccumulation of toxins threatens seafood safety and human health.

Conventional spill response relies on physical containment (booms and skimmers), in-situ burning, and chemical dispersants. Among mechanical methods, skimmers offer an efficient, eco-friendly solution for direct oil removal. This paper presents an automated disc-type skimmer utilizing oleophilic plastic rotating discs to efficiently collect and separate surface oil without chemical contamination, providing a scalable and cost-effective solution for environmental protection.

2. METHODOLOGY

The project methodology is divided into two primary phases:

Phase I: Foundational Research and Domain Analysis.

The initial phase involved a comprehensive literature review focusing on modern oil detection and recovery technologies, Machine Learning integration, and IoT-based environmental monitoring systems. Relevant research papers were analyzed to evaluate optimal sensor configurations and hardware-software communication protocols. Additionally, historical real-world oil spill case studies were examined to identify operational risks, define core functional requirements, and establish the system design architecture.

Phase II: System Implementation and Experimental Validation.

The second phase focused on prototype construction, software integration, and experimental testing. An ESP32 microcontroller served as the primary control unit, interfacing with an IR sensor and camera module for oil detection, alongside HC-SR04 ultrasonic sensors for obstacle avoidance and tank volume monitoring. The software architecture structured sensor data and transmitted live telemetry over Wi-Fi to a Blynk IoT dashboard for real-time remote monitoring. Upon oil detection, the system automatically triggers the skimmer and propulsion motors to initiate recovery. Controlled aquatic field trials using engine oil validated the prototype, demonstrating low detection latency, accurate spill identification, and reliable recovery performance.

3. DESIGN

3.1 BLOCK DIAGRAM

The proposed oil spill skimmer boat operates on a centralized control architecture powered by an ESP32-S3 microcontroller, which coordinates data processing, sensor inputs, and motor driving logic. An ultrasonic sensor provides obstacle detection for autonomous navigation, while a camera module and an IR sensor handle live visual monitoring and surface liquid classification based on light reflection properties. Actuation is managed via an L298N motor driver controlling the DC gear motor for skimming operations and a Cytron MDD3A driver controlling dual DC motors for boat propulsion. The system is powered by a central power supply unit and interfaces wirelessly with the

Blynk IoT mobile application over Wi-Fi for real-time monitoring and user control.

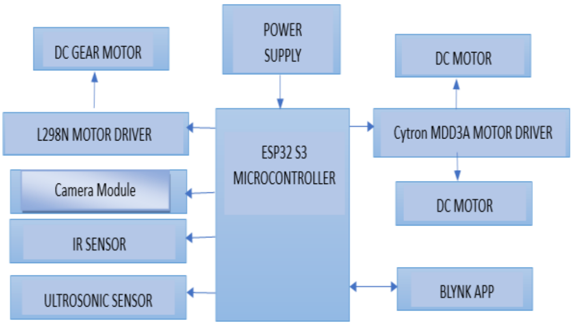

Fig - 1: Block Diagram

3.2 FLOWCHART

The operational logic of the system begins with the ESP32 initializing forward propulsion via the Cytron motor driver. During navigation, the system continuously monitors for obstacles and surface oil; if an obstacle is detected, the boat adjusts its movement trajectory accordingly. When oil is detected by the combined IR sensor and camera module, the ESP32 reduces vessel speed and activates the skimming motor. The skimmer continues operation until the collection tank reaches capacity, at which point the system automatically stops the skimming motor and allows manual movement adjustments via the Blynk application interface.

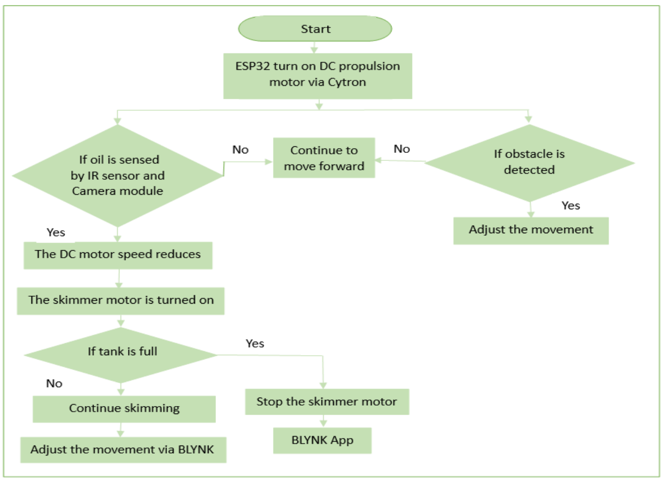

Fig - 2: Flowchart

4. SCHEMATIC LAYOUT

The oil skimmer boat integrates sensing, control, power management, and actuation subsystems for surface oil recovery. Main navigation logic and multi-sensor telemetry are managed by an ESP32 microcontroller, supported by an ESP32-CAM module dedicated to vision-based oil spill identification.

- Power Distribution System

A 12V battery powers the system using a dual-voltage layout. High-draw Cytron MDD3A and L298N motor drivers draw directly from the 12V rail, while a buck converter steps the voltage down to a regulated 5V rail to power the microcontrollers and sensors.

- Propulsion and Steering

Vessel movement relies on a differential steering configuration driven by two DC propulsion motors. Interfaced through a Cytron MDD3A driver, the main ESP32 regulates speed, direction.

- Oil Skimming Mechanism

Surface oil collection is driven by a dedicated DC gear motor connected to an L298N H-Bridge driver. The driver supplies 12V power to maintain necessary torque for the skimming disk, managed directly by control signals from the central microcontroller.

- Navigation and Environment Sensors

Three HC-SR04 ultrasonic sensors provide environmental feedback: two side-mounted sensors detect obstacles , while a third monitors the onboard tank liquid level. Additionally, an infrared (IR) sensor measures surface reflection changes to detect liquid spillage.

- Microcontrollers and Vision

Processing is divided between two modules: the central ESP32 aggregates sensor data and executes movement commands, while the ESP32-CAM captures images for real-time oil spillage detection over a shared power and ground framework.

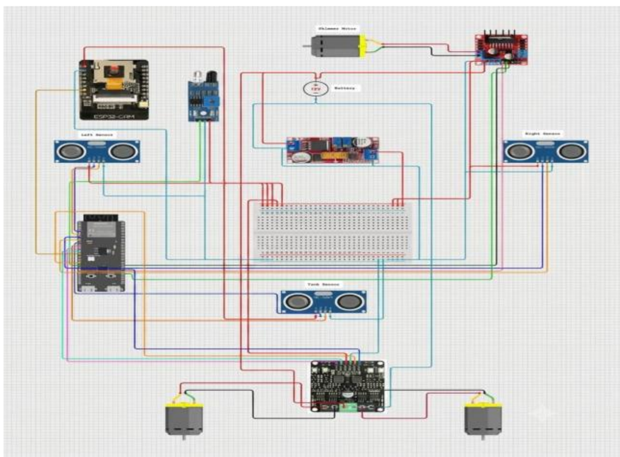

Fig -3: Schematic Layout

5. DESIGN AND FABRICATION OF 3D BOAT

The oil skimmer boat housing was designed in Autodesk Fusion 360 using a modular layout to isolate electrical and chemical hazards. The chassis was fabricated from Polyethylene Terephthalate Glycol (PETG) due to its high durability, water resistance, and chemical compatibility with corrosive oils. To maintain stability and component safety, the internal hull is segregated into three functional compartments:

- Oil Storage Tank: A central, sealed reservoir that collects skimmed oil from the water surface.
- Battery Compartment: Located at the lowest point of the hull to serve as a functional ballast to protect Lithium-ion batteries from water and oil exposure.
- Electronics Compartment: An elevated, walled-off bay that houses sensitive microcontrollers (ESP32), motor drivers, and RC receivers to prevent short circuits and chemical degradation.

Below is the final design of the project

Fig – 4: Final Design

6. TESTING AND RESULT

The integrated 3D-printed oil spillage detection and recovery system was evaluated under controlled experimental conditions. Surface oil detection was accomplished using an infrared (IR) sensor grid, triggering an onboard mechanical skimmer to deposit recovered oil into a localized storage tank. Controlled testing evaluated the influence of skimmer material types (Plastic, PVC, and Aluminum) and rotational speeds (RPM) on overall oil collection efficiency. Real-time telemetry and remote operational control were enabled via a Blynk IoT dashboard.

6.1 EXPERIMENTAL DATA AND RESULTS

The trials were conducted under strictly uniform environmental conditions to ensure comparative validity: a total of 50 mL of surface oil was introduced initially, and each trial run was fixed for a duration of 1 minute. Efficiency is calculated based on the volume of pure oil recovered relative to the initial 50 mL fluid volume

Trial 1: Plastic Skimmer

Material: Plastic
Initial Oil Volume: 50ml
Time: 1 min

Table 4.1: Oil skimmed by Plastic Skimmer

Sr. No.	Speed (RPM)	Oil Collected (ml)	Water Collected (ml)	Total Liquid (ml)	Efficiency (%)
1.	240rpm	38 ml	16 ml	54 ml	76 %
2.	255rpm	32 ml	28 ml	60 ml	64 %
3.	270rpm	20 ml	48 ml	68 ml	40 %
4.	285rpm	10 ml	120 ml	130 ml	20 %
5.	300rpm	10 ml	195 ml	205 ml	20 %

Trial 2: PVC Skimmer

Material: PVC
Initial Oil Volume: 50ml
Time: 1 min

Table 4.2: Oil skimmed by PVC Skimmer

Sr. No.	Speed (RPM)	Oil Collected (ml)	Water Collected (ml)	Total Liquid (ml)	Efficiency (%)
1.	240rpm	30 ml	23 ml	53 ml	60 %
2.	255rpm	26 ml	35 ml	61 ml	52 %
3.	270rpm	17 ml	55 ml	72 ml	34 %
4.	285rpm	8 ml	115 ml	123 ml	16 %
5.	300rpm	7 ml	130 ml	137 ml	14 %

Trial 3: Aluminum Skimmer

Material: Aluminum
Initial Oil Volume: 50ml
Time: 1 min

Table 4.3: Oil skimmed by Aluminum Skimmer

Sr. No.	Speed (RPM)	Oil Collected (ml)	Water Collected (ml)	Total Liquid (ml)	Efficiency (%)
1.	240rpm	20 ml	10 ml	30 ml	40 %
2.	255rpm	14 ml	12 ml	26 ml	28 %
3.	270rpm	8 ml	15 ml	23 ml	16 %
4.	285rpm	4 ml	20 ml	24 ml	8 %
5.	300rpm	4 ml	23 ml	27 ml	8 %

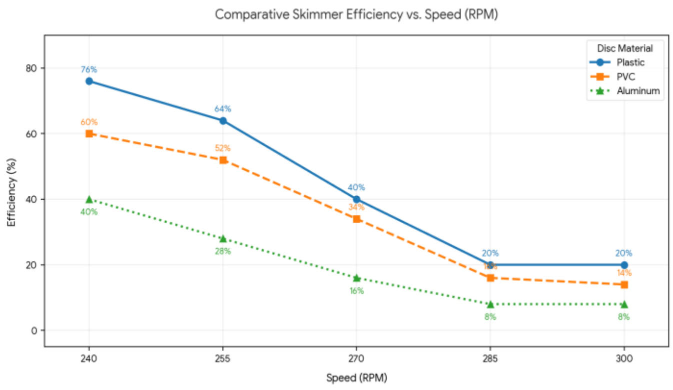

Chart – 1: Skimmer Efficiency vs Speed (rpm)

- Effect of Rotational Speed (RPM): Higher skimmer rotational speeds caused a sharp decline in oil recovery efficiency alongside an increase in water collection across all materials. This performance degradation occurs because elevated speeds induce localized surface turbulence, disrupting the oil's surface tension and causing non-selective fluid intake.
- Effect of Material Selection: Plastic yielded the highest performance, achieving a peak efficiency of 76% at 240 RPM due to its superior oleophilic and hydrophobic surface characteristics. In comparison, PVC reached a maximum efficiency of 60%, while Aluminum performed worst at 40% peak efficiency due to lower oil-adhesion properties.
- Optimal System Configuration: To maximize oil recovery while minimizing water intake, the system should deploy a plastic skimmer operating at a lower rotational speed threshold of 240 RPM.

6.2 BLYNK IOT DASHBOARD

To facilitate remote management, telemetry data is routed to a customized Blynk IoT Web Dashboard, allowing operators real-time monitoring and manual manipulation capability over the deployed vessel.

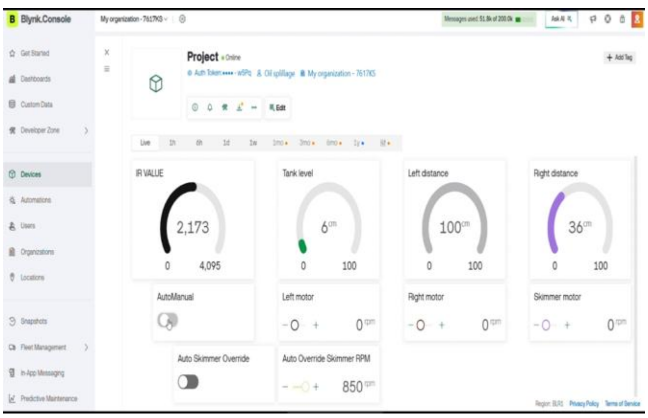

Fig - 5: Initial State of skimming process

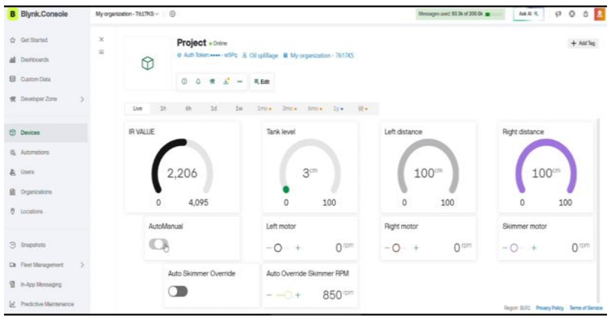

Fig - 6: Final State of skimming process

6.4 COMPARATIVE ANALYSIS OF SYSTEM STATES

The system transitions adaptively between active oil detection (Fig - 5) and completed recovery (Fig - 6):

- IR Surface Detection: The IR sensor value increases slightly from 2,173 (active oil detection) to 2,206 (post-collection), indicating minor shifts in surface reflectivity due to varying fluid densities or baseline recalibration.
- Collection Tank Level: The tank sensor tracks operational progression, transitioning from an initial near-empty reading of 6 cm to a stable final state of 3 cm following successful skimming recovery.
- Proximity & Obstacle Avoidance: Spatial updates confirm clear navigation on the left side (constant 100 cm across both states), while the right distance sensor updates from 36 cm (initial boundary/obstacle detected) to 100 cm as the boat clears the path.
- Motor Control Feedback: Feedback displays for the left, right, and skimmer motors remain at 0 rpm in Automatic Mode due to suppressed real-time telemetry feedback loops; active RPM indicators register explicitly only when toggled to Manual Mode.

Table 4.4: Value of Initial and Final state of skimming process

Parameter Gauge	Fig - 5 value (Final state)	Fig - 6 Value (Initial State)	Interpretation
IR Sensor Value	2173	2206	Minor shift in surface reflectivity
Tank level	6 cm	3 cm	Tank completely filled (Maximum capacity reached)
Left Distance	100 cm	100 cm	Clear path on the left boundary
Right Distance	36 cm	100 cm	Obstacle detected within 0.36 meters

7. CONCLUSIONS

This paper successfully presented the development and implementation of a fast, cost-effective, automated Oil Spillage Detection and Recovery System. Driven by an ESP32-S3 microcontroller, the platform integrates IR fluid-detection sensors and ultrasonic obstacle-avoidance navigation with an oleophilic rotating disk and scraper mechanism for efficient oil recovery. Testing validates the system's overall efficiency, mobility, and real-time IoT monitoring via Blynk, demonstrating strong potential for scalable, automated maritime spill containment.

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