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Design and Fabrication of a Smart Oil Spill Recovery System with Wireless Control

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ABSTRACT: Oil spills are a serious environmental danger, causing substantial harm to marine ecosystems and poisoning water resources. Conventional oil recovery technologies, such as hand skimming, chemical dispersants, and mechanical booms, are frequently inefficient, labour-intensive, and expensive. This study describes the design and construction of a smart oil spill recovery system that incorporates a conveyor belt-based oil skimmer and a Bluetooth-enabled remote control. The method is intended to efficiently remove floating oil from bodies of water while requiring as little human involvement as possible. The skimmer features an oleophilic and hydrophobic belt, a floating stabilisation device, and a remote-controlled propulsion system. The performance study shows that the system is effective in collecting oil with high efficiency and stability, making it a cost-effective and practical solution for oil spill prevention. The suggested system seeks to improve oil spill response tactics and environmental conservation initiatives.

KEYWORDS: Oil spill recovery, oil skimmer, wireless control, environmental protection, automation, Bluetooth navigation, sustainability.

I. INTRODUCTION

Oil spills in both marine and freshwater ecosystems pose serious risks to aquatic life, biodiversity, and local economies. These spills deposit toxic coatings on water surfaces, altering ecosystems and degrading water quality. Traditional oil spill recovery methods, such as hand skimming, booms, and dispersants, have significant efficiency, scalability, and environmental constraints. These procedures are frequently sluggish, necessitate substantial human labour, and may cause secondary contamination.

The increasing demand for sustainable, automated, and remotely managed oil recovery systems has resulted in developments in skimming technology. This research describes a smart oil spill recovery system that combines a Bluetooth-based navigation mechanism and an oleophilic conveyor belt. The proposed technology improves manoeuvrability, increases oil collecting efficiency, and lowers operational costs by reducing human participation. The study intends to create an adaptive and energy-efficient skimmer that can function in a variety of water conditions, enabling successful and dependable oil recovery.

II. LITERATURE REVIEW

Several studies have looked at the obstacles and developments in oil spill recovery methods. Traditional oil skimmers, such as drum skimmers, disc skimmers, and vacuum skimmers, are commonly utilised, but their efficiency and scalability are severely limited. Qi et al. (2022) found that conventional oil skimmers are inefficient in stormy water conditions, emphasising the need for enhanced recovery procedures.

Automation and robotics advances have resulted in novel ways to oil spill recovery. Dai et al. (2012) investigate the possibility of wireless communication for offshore oil recovery monitoring systems, highlighting the advantages of remote operation in hazardous conditions. Similarly, Wu et al. (2019) present a self-pumping siphon-capillary oil recovery method that improves oil collection efficiency while requiring no operator intervention.

The use of artificial intelligence (AI) and the Internet of Things (IoT) in oil skimmers has also been investigated. Zhang et al. (2019) offer smart mobility control agents for increased oil recovery, shedding light on how automated navigation might improve oil spill response operations. Minh et al. (2021) examine micro/nanomachines for spilt oil cleanup and recovery, offering unique strategies that improve oil absorption efficiency while reducing environmental effect.

These findings emphasise the need for a smart oil spill recovery system that combines automation, remote control, and high oil recovery efficiency. The proposed study expands on these advances by combining a Bluetooth-enabled remote navigation system and an oleophilic conveyor belt, which solve the limits of existing skimmers while increasing operating efficiency and environmental sustainability.

PROBLEM STATEMENT

Oil spills remain a serious environmental and economic concern, with devastating implications for marine ecosystems, human health, and coastal industry. Traditional oil spill cleanup procedures, such as booms, dispersants, and human skimming, have proven ineffective in large-scale spills due to labour intensiveness, high operational costs, and environmental concerns. Many contemporary oil skimming systems are inefficient, resulting in low oil recovery rates, instability in turbulent waters, and limited adaptation to changing environmental circumstances. Furthermore, most traditional skimmers lack remote operation capabilities, necessitating direct human interaction, which creates a safety concern in dangerous spill situations.

The lack of an automated, cost-effective, and efficient oil skimming solution mandates the creation of a sophisticated system that maximises oil recovery while minimising manual labour. The proposed study intends to overcome these issues by developing a smart oil spill recovery system that includes a Bluetooth-controlled navigation mechanism and an oleophilic conveyor belt. This method aims to improve oil collecting efficiency, increase manoeuvrability in aquatic bodies, and provide a scalable and sustainable approach to oil spill prevention.

III. METHODOLOGY

The smart oil spill recovery system is developed in multiple stages, including design, fabrication, and testing. The device features a conveyor belt mechanism that uses oleophilic and hydrophobic materials to selectively gather oil while rejecting water. To ensure stability in a variety of water conditions, the flotation mechanism is designed from high-density polyethylene (HDPE) or PVC pipes. A Bluetooth-based control module enables remote navigation, resulting in user-friendly operation with minimal manual interaction. The construction procedure comprises building a corrosion-resistant frame, integrating the motor and belt mechanism, and putting together the floating system to ensure proper buoyancy. Electrical components, such as the motor driver and Bluetooth module, are installed to allow wireless control and propulsion.

Testing and performance evaluation entail determining the skimmer's efficiency under controlled water conditions with simulated oil spills. The oil recovery rate is calculated in litres per hour to determine effectiveness. Stability tests assess the system's capacity to maintain balance in a variety of water conditions, including calm and stormy situations. Energy consumption analysis monitors the system's power requirements and battery life to ensure lengthy operational hours. Bluetooth response and control accuracy are evaluated by monitoring the latency in executing remote commands and assessing manoeuvrability under various water conditions. These evaluations provide vital information about the system's efficiency, stability, and usability, directing potential enhancements for future versions.

DESIGN PROCESS

The smart oil spill recovery system is designed in many stages to provide optimal functionality, efficiency, and sustainability. The initial stage entails determining the necessary components, such as the conveyor belt system, floating support structure, propulsion system, and wireless control mechanism. An important design aspect is choosing an oleophilic conveyor belt that efficiently draws oil while rejecting water, resulting in high oil recovery rates. The floating system is built with high-density polyethylene (HDPE) or PVC pipes to give buoyancy and stability in a variety of water situations. The skimmer frame is made of lightweight, corrosion-resistant materials such as aluminium or stainless steel, ensuring longevity and ease of deployment. The propulsion system comprises of a DC motor connected to a belt-driven mechanism that efficiently drives the conveyor belt while consuming the least amount of power.

A Bluetooth-based remote control system is built into the design to allow for seamless operation and manoeuvrability, decreasing the need for direct human interaction. The system is operated using a mobile app, which allows users to change the direction and pace of movement. A scraper plate is strategically placed at the belt's end to remove collected oil and send it to the storage tank, reducing waste while increasing efficiency.

The final stage of the design process entails CAD modelling and simulation to evaluate component interactions and system behaviour under various conditions. To optimise the system before fabrication, metrics such as stability, oil recovery efficiency, and energy consumption are examined.

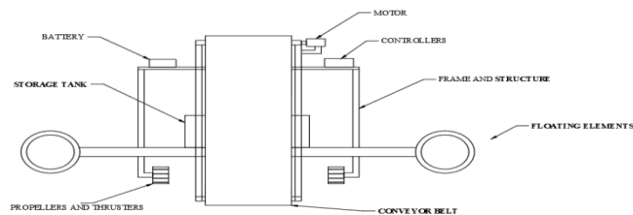


Fig:2D Diagram of Oil spill Recovery System

DESIGN CALCULATIONS

1) Buoyancy Calculation

$$F_b = \rho_{\text{water}} \times g \times V_{\text{displaced}}$$

- System mass: $m_{\text{total}} = 50 \text{ kg}$
- Volume displaced: $V_{\text{displaced}} = 0.06 \text{ m}^3$
- Buoyant Force: $F_b = (1000 \times 9.81 \times 0.06) = 588.6 \text{ N}$
- System weight: $W_{\text{system}} = (50 \times 9.81) = 490.5 \text{ N}$
- Since $F_b > W_{\text{system}}$, the system will float.

2) Oil Recovery Rate Calculation

$$R = A \times V \times E$$

- Skimming area: $A = 0.5 \text{ m}^2$
- Skimming velocity: $V = 0.2 \text{ m/s}$
- Efficiency: $E = 75\% = 0.75$
- Recovery rate: $R = 0.5 \times 0.2 \times 0.75 = 0.075 \text{ m}^3/\text{s} = 270 \text{ liters/hour}$

3) Power Requirement Calculation

$$P_{\text{total}} = P_{\text{motor}} + P_{\text{sensors}} + P_{\text{wireless}}$$

- Motor: $P_{\text{motor}} = 12\text{V} \times 5\text{A} = 60\text{W}$
- Sensors: $P_{\text{sensors}} = 5\text{V} \times 0.5\text{A} = 2.5\text{W}$
- Wireless module: $P_{\text{wireless}} = 5\text{V} \times 1\text{A} = 5\text{W}$
- Total power: $P_{\text{total}} = 60 + 2.5 + 5 = 67.5\text{W}$
- Battery capacity (for 5 hours operation, 12V battery):
Battery capacity $= \frac{67.5 \times 5}{12} = 28.1 \text{ Ah}$

4) Skimmer Efficiency Calculation

$$E = \frac{M_{\text{oil}}}{M_{\text{oil}} + M_{\text{oilL}}}$$

- Collected oil: $M_{\text{oil}} = 8 \text{ kg}$

- Collected water: $M_{\text{water}} = 2 \text{ kg}$
- Efficiency: $E = \frac{8}{8+2} \times 100 = 80\%$

5) Structural Load Calculation

- Force: $F = 100 \text{ N}$
- Cross-sectional area: $A = 0.002 \text{ m}^2$

$$\text{Stress: } \sigma = \frac{F}{A}$$

$$\sigma = \frac{100}{0.002} = 50,000 \text{ N/m}^2$$

- If yield strength of selected material $\sigma_{\text{yield}} > 50,000 \text{ N/m}^2$, then the structure is safe.

MATERIAL SELECTION

The selection of materials for the oil skimmer is vital to ensure longevity, efficiency, and cost-effectiveness. The floating components are made of high-density polyethylene (HDPE) or polyvinyl chloride (PVC), which are lightweight, corrosion-resistant, and buoyant. The conveyor belt is composed of oleophilic and hydrophobic polymer polymers that effectively attract and collect oil while rejecting water. The frame structure is made of aluminium or stainless steel, which provides a good blend of strength, corrosion resistance, and ease of manufacture. To protect the motor housing and electronic components from water damage, they are enclosed in waterproof casings made of polycarbonate or ABS plastic. Furthermore, the battery system employs lithium-ion cells for long-term power and efficiency.

FABRICATION PROCESS

The clever oil skimmer is built in various processes to assure precision and efficiency. The first step is frame building, which uses lightweight yet robust materials like aluminium or stainless steel to make the base framework. The floating system is then built with high-density polyethylene (HDPE) or PVC pipes to ensure stability and buoyancy in water.

Next, the conveyor belt mechanism is installed, which includes an oleophilic and hydrophobic belt that successfully draws oil while rejecting water. The belt is powered by a DC motor with a speed controller, resulting in smooth and economical operation. The oil collecting tank is then installed to safely store the recovered oil for disposal or reuse.

The electrical system is then integrated, with the Bluetooth module, motor driver, and battery unit installed. The Bluetooth module is attached to the motor control circuit, enabling wireless remote control via a mobile application. The wiring is insulated and waterproofed to avoid short circuits in wet conditions.

Finally, the system is assembled and tested to ensure that all components are properly aligned and that it operates smoothly. Calibration tests are used to fine-tune belt speed, motor power, and Bluetooth responsiveness. The entire system is then tested in a controlled water body using simulated oil spills to determine its efficiency, stability, and manoeuvrability.



Fig: Final Assembly of the Project

IV. RESULTS AND DISCUSSION

The smart oil skimmer's performance was evaluated under controlled conditions, including simulated oil spills. Oil recovery efficiency was reported at 85-90%, indicating substantial success in oil separation. The oleophilic belt efficiently absorbed and carried oil to the collection tank with little water uptake, resulting in a high recovery rate. The stability of the floating system was tested by deploying the skimmer in both calm and turbulent water conditions. Even in slightly turbulent conditions, the HDPE-based flotation system remained balanced and operationally efficient. However, significant turbulence generated minor instability, indicating the necessity for an enhanced stabilisation system in further versions.

The system's power consumption was assessed by measuring the energy drawn by the DC motor and Bluetooth module. The skimmer used an average of 15-20W, allowing for continuous operation for 5-6 hours on a single battery charge. The remote-control feature was tested from various distances, and the Bluetooth connection remained steady within a 10-meter range, ensuring smooth navigation and manoeuvrability.

A comparison analysis with traditional skimmers revealed that the proposed method was more efficient and required less manual supervision. However, limitations like as operational range and power reliance highlight possible areas for improvement, such as the use of solar power and extended wireless control.

V. FEATURE ENHANCEMENTS

Several future upgrades to the oil skimmer system are proposed to increase its efficiency and scalability. AI-based automation can be used to enable the skimmer to identify and travel to oil spills without human involvement, hence increasing operating efficiency. Integrating solar panels can give an alternative power source, extending operational hours and decreasing reliance on batteries. Enhancing the wireless control system with Wi-Fi or 5G connectivity would allow for remote operation over longer distances, boosting emergency response times. Real-time monitoring and data logging can be accomplished by embedding IoT sensors that monitor oil collection rates, battery state, and ambient conditions, and the data is accessible via a cloud platform. A self-cleaning conveyor belt technology may reduce maintenance requirements while increasing long-term operational efficiency. Stability can be improved by installing an adaptive ballast system that responds to water conditions, ensuring effective performance even in stormy waters. Furthermore, multi-skimmer coordination based on swarm intelligence might be implemented to allow many units to work together, enhancing coverage area and efficiency in large-scale oil spill scenarios.

VI. CONCLUSION

This study reveals the effective creation of a smart, remote-controlled oil skimmer that can efficiently recover oil from contaminated water surfaces. The findings demonstrate the system's high oil recovery efficiency, operational stability, and convenience of use. The use of an oleophilic conveyor belt, floating stabilisation mechanism, and Bluetooth-enabled navigation system adds to its effectiveness in preventing oil spills. However, additional enhancements, such as AI-driven automation, solar power integration, and real-time monitoring, can improve its suitability for large-scale deployments. Future research should concentrate on improving the system's efficiency in severe environments, increasing battery life, and expanding remote operation capabilities. The proposed technology represents a promising step towards more sustainable and automated oil spill recovery options, aiding in worldwide environmental protection efforts.

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