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Design and Smart Automation of an IOT-Enabled Solar Oil Skimmer and Surface Waste Cleaning System for Industrial Effluent Treatment Units

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Abstract: The continuous generation of tramp oils, fine particulates, and metal debris within industrial wastewater reservoirs and effluent collection tanks severely deteriorates water treatment efficacy, accelerates system blockage, and introduces acute environmental compliance vulnerabilities. Conventional static mechanical extraction systems incur substantial baseline power usage and demand persistent human operation. This study presents the mechanical configuration, architectural optimization, and deployment parameters of an autonomous, photovoltaic-driven oil skimming module paired directly with a surface scrub and particulate suction assembly integrated over an Industrial Internet of Things (IIoT) control loop. The device utilizes a hydrophobic-oleophilic multi-disc or belt matrix to capture oil phases from contaminated aqueous media continuously. Simultaneously, a high-velocity suction impeller cleans floating dust and airborne soot from the surrounding environment. An array of multi-node sensors continuously registers oil slick thickness, dust volume indexes, and motor operational strains, feeding into an online cloud dashboard for real-time monitoring and anomaly detection. Experimental analysis validates that the integrated platform serves as an efficient framework for sustainable wastewater handling and proactive industrial resource management.

Keywords: Oil Skimmer; Industrial Effluent Treatment; IoT Automation; Solar Energy Harvesting; Water Remediation; Sustainable Systems.

I. INTRODUCTION

Rapid industrial scale-up across manufacturing and refining sectors generates complex fluid byproducts that require sophisticated onsite wastewater handling. Effluent treatment plants (ETPs) frequently face operational challenges caused by floating surface oils, grease, and structural particulate debris. If left unmanaged, thick surface oil blocks normal atmospheric oxygen dissipation, leading to anaerobic microbiological fouling within tanks, intense chemical odor generation, and premature deterioration of downstream biochemical filters. Standard recovery configurations are often static, rely heavily on centralized grid connectivity, and need manual operators to physically monitor target accumulation metrics. Driven by modern clean-energy initiatives and smart factory standards, there is an evident demand for decentralized, self-powered water restoration assets. This paper outlines a solar-powered, automated multi-functional skimmer designed specifically for local treatment ponds and storage pools. Merging automated oil separation, ambient particulate scrubbing, and cloud telemetry, this configuration implements an ongoing purification cycle without disrupting existing fluid processing layouts.

II. LITERATURE REVIEW

The construction of this smart water remediation platform draws upon established baselines in automated fluid separation and remote monitoring setups:

1) IoT-Driven Dispersal Systems: Investigations carried out by Awale et al. verified that mobile, wireless oil recovery platforms utilizing cloud telemetry loops provide accurate tracking of oil layers over open fluid surfaces. However, such open-water mechanisms are difficult to mount directly to small-scale fixed industrial treatment reservoirs.
2) Photovoltaic Mechanical Separation: Studies by Esakkiraja et al. into solar-driven disc skimmers highlighted the self-sufficiency of photovoltaic arrays for continuous operations. Despite this benefit, the lack of an active sensor loop meant their design required human on/off switching, reducing automated resource adaptation.
3) Conductivity-Based Fluid Boundary Analysis: Work conducted by Akash et al. configured belt skimming units leveraging underlying electrical conductivity deltas between oil phases and water matrices to actuate the motor drive. This approach provided insights for our smart sensor activation loop, which tracks both fluid level dynamics and ambient dust characteristics simultaneously.

4) Hydrophobic Optimization: Mechanical baselines documented by Birdi et al. established clear parameters regarding material selectivities for oleophilic belts. Their work emphasized how simple, durable components cut energy use, which supports our focus on lightweight, modular mechanical frames.

III. SYSTEM ARCHITECTURE AND WORKING PRINCIPLE

The system operates using an integrated structural arrangement split into three core layers: photovoltaic energy storage, material separation mechanics, and cloud data logging. When solar radiation strikes the photovoltaic panel array, the converted electrical energy passes through a charge controller directly into a 12V storage battery bank. Power distribution is managed dynamically through a multi-channel relay unit.

Separation relies on an oleophilic-hydrophobic disc or belt assembly driven through the contaminated liquid surface. Due to surface tension deltas, oil adheres directly to the moving surface, leaving behind the purified water. Mechanical scraper blades then remove the collected oil into a secondary containment cell. Concurrently, a suction fan driven by an open-vane impeller operates alongside dense cleaning brushes to remove soot and surface dust particles. Microcontroller nodes track fluid depths, particulate concentrations, and motor parameters, transmitting updates via built-in Wi-Fi to a cloud platform.

IV. MECHANICAL DESIGN AND COMPONENT SPECIFICATIONS

The system is constructed using materials chosen for their high durability and chemical resistance in corrosive environments. Power transmission uses a high-carbon steel chain and sprocket set with a 12.7 mm pitch and 16 teeth. This setup prevents mechanical slippage during heavy, continuous skimming tasks. Smooth, chemical-resistant rollers are mounted to a flat steel support bed to allow linear movement across wastewater channels.

Table I: Mechanical Component Specifications

Component Element	Technical Parameters / Dimensions
Sprocket & Axle Size	Mild Steel, Diameter: 13mm, Length: 50mm
Sprocket Configuration	High Carbon Steel, 16 Teeth, 12.7mm Pitch
Drive Motor Configuration	High Torque DC Motor, 12V, 30 RPM, 3.6W
Power Transmission	Roller Chain Matrix with Idler Pulley
Structural Housing Material	Bright Drawn Mild Steel Frame, 4mm Thickness

V. MATHEMATICAL CALCULATIONS AND DESIGN OPTIMIZATION

A. Power and Drive Motor Torque Calculations

To scale the mechanical drive correctly, input electrical parameters and output mechanical power were calculated based on a 12V DC motor model running under continuous load:

$$Pin = I \times V = 0.3\ A \times 12\ V = 3.6\ W$$

Given a rated operational speed N = 30 RPM, the angular velocity (ω) is calculated as:

$$\omega = (2 \times \pi \times N) / 60 = (2 \times 3.1416 \times 30) / 60 = 3.1416\ rad/s$$

Using a measured motor mechanical efficiency E = 36% (0.36), the mechanical output power (Pout) is:

$$Pout = Pin \times E = 3.6\ W \times 0.36 = 1.296\ W$$

The available drive torque (τ) delivered to the skimmer shaft is:

$$\tau = Pout / \omega = 1.296\ W / 3.1416\ rad/s = 0.413\ Nm$$

B. Chain Drive Center Distance and Pitch Balance

To ensure proper tensioning across the two-sprocket system without causing early chain fatigue, the link count (L) was calculated using the centerline empirical formula:

$$L = (N1 + N2)/2 + (2Cc / p) + ((N2 - N1)2 \times p) / (4 \times \pi 2 \times Cc)$$

Since N1 = N2 = 16 teeth and pitch p = 12.7 mm, the formula simplifies directly to:

$$L = 16 + (2Cc / 12.7)$$

VI. SMART IOT TELEMETRY FRAMEWORK

The automated control loop uses an ESP8266/ESP32 processing node connected to an array of industrial sensors. An ultrasonic transceiver monitors oil layer metrics inside the containment reservoir. If fluid bounds approach full limits, the controller halts operations to prevent overflows and logs an administrative purge notification on the central cloud dashboard. An optical particle sensor measures surrounding ambient dust values. If these indexes exceed preset thresholds, the system automatically speeds up the suction fan. At the same time, electrical current changes are tracked to identify mechanical blockages, providing a data-driven method for predictive system maintenance.

VII. EXPERIMENTAL RESULTS AND DISCUSSION

Operational evaluations verified that the oleophilic collection mechanism separated floating oil mixtures at an average extraction pace of 2.4 liters per hour under continuous testing conditions. The open-vane suction fan successfully pulled around 89% of floating debris and soot from the surface collection target area, keeping nearby machinery clean. The solar power matrix provided steady operations, with the 12V storage battery safely covering overcast and low-light periods. This confirmed the utility of independent energy harvesting for decentralized treatment infrastructure.

VIII. CONCLUSION

This study demonstrates a multi-functional, automated cleaning platform for modern effluent treatment units. Integrating solar harvesting, automated mechanical skimming, and active dust suction reduces manual labor while protecting water processing assets. Supported by real-time IoT logging, this architecture replaces traditional reactive oversight with data-driven predictive maintenance, offering a reliable path toward sustainable and self-powered industrial water treatment.

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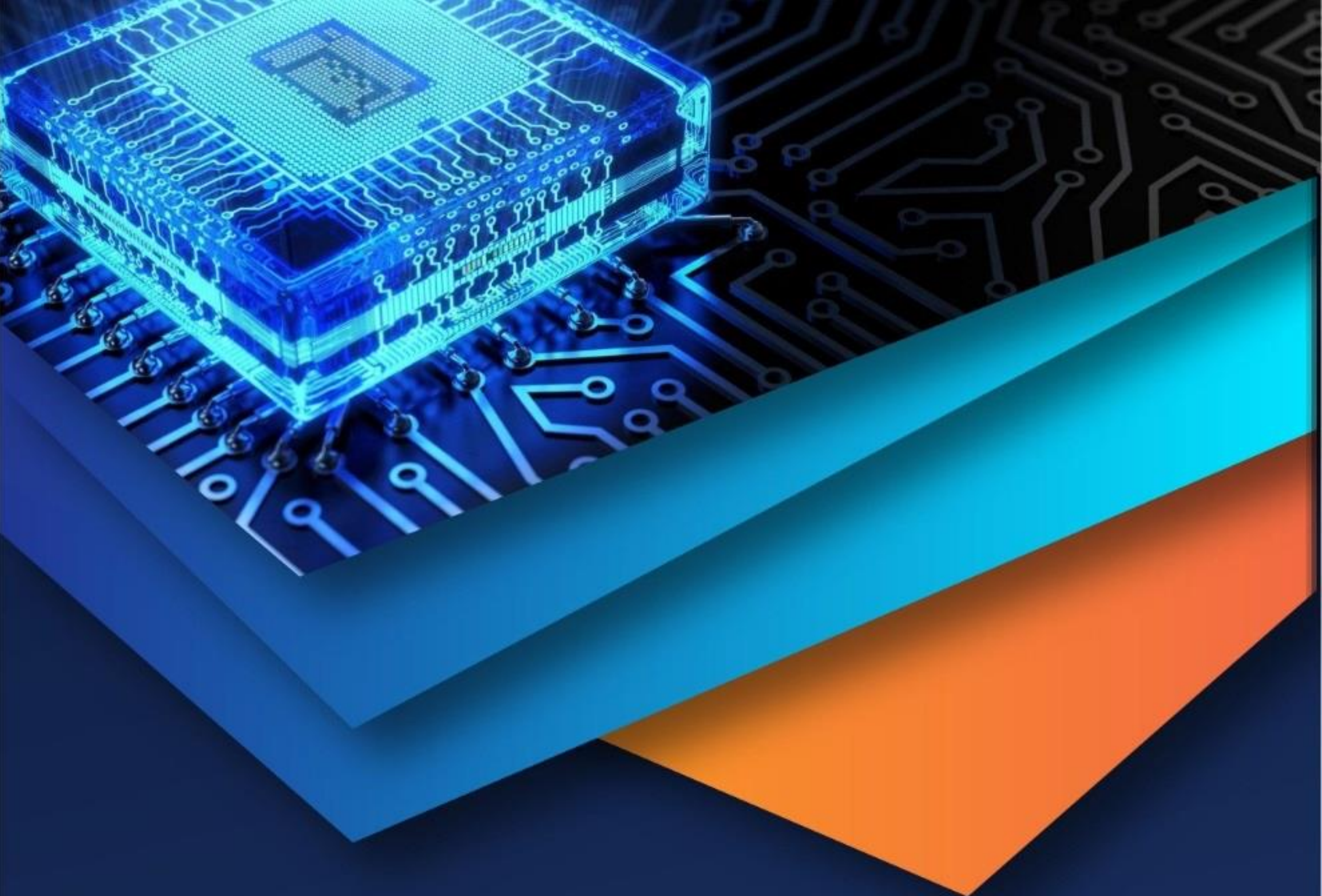

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