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Design and Development of a Vertical Pool Wall Cleaning Device for Improving Public Hygiene and Reducing Manual Labor

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Abstract— *Maintaining hygiene in public swimming pools is essential for safeguarding public health; however, cleaning vertical pool walls is still largely carried out using manual methods. This approach is time-consuming, physically demanding, and exposes maintenance workers to health risks caused by prolonged water contact and chemical usage. To address these limitations, this project presents the design and development of an automated Vertical Pool Wall Cleaning Device that enhances cleaning efficiency while reducing human effort.*

The proposed system is controlled by an Arduino UNO microcontroller and employs rotating brushes to mechanically scrub pool walls, effectively removing algae, dirt, and biofilm deposits. A motorized vertical movement mechanism enables the device to travel uniformly along the wall surface, ensuring complete coverage and consistent cleaning performance. For sustainable operation, the system is powered by a solar panel integrated with a rechargeable battery, minimizing reliance on external electrical supplies. In addition, a built-in filtration system collects loosened debris during the cleaning process, preventing water recontamination.

By replacing traditional manual scrubbing with an automated mechanical solution, the device improves worker safety, reduces labor requirements, lowers operational costs, and supports the long-term maintenance of a cleaner, healthier swimming environment for public pools worldwide.

Keywords— Arduino UNO, Automated cleaning, Public sanitation, Solar-powered system, Swimming pool hygiene, Vertical wall cleaner.

I. INTRODUCTION

Public swimming pools are widely used facilities where maintaining proper hygiene is essential to protect public health. While pool floors are regularly cleaned using available equipment, the vertical walls of swimming pools often receive less attention and become major areas for the growth of algae, bacteria, biofilms, and organic deposits. These contaminants not only reduce water quality but can also cause skin infections and waterborne diseases if not removed effectively.

At present, cleaning pool walls is mostly carried out using manual methods. Maintenance workers are required to physically scrub the walls while being exposed to chemically treated water for long durations. This process is physically exhausting, time-consuming, and poses health risks to workers. In addition, manual cleaning often leads to uneven results, higher labor costs, and frequent partial or complete draining of pool water, which increases operational expenses and water wastage.

Although robotic pool cleaners are available, most existing systems are designed to clean horizontal surfaces and are expensive, leaving limited practical solutions for vertical wall cleaning. To overcome these limitations, this project focuses on the development of an automated Vertical Pool Wall Cleaning Device. The proposed system uses an Arduino UNO-based control unit to manage motorized vertical movement and rotating brushes for effective wall scrubbing. A solar-powered energy system supports eco-friendly operation, while an integrated filtration mechanism collects loosened debris to prevent water recontamination.

By automating the cleaning process, the device reduces human effort, improves cleaning consistency, enhances worker safety, and offers a cost-effective and sustainable solution for maintaining hygiene in public swimming pools.

II. LITERATURE REVIEW

Liyanage et al. (2024) presented a critical analysis of wall-climbing robots (WCRs), focusing on locomotion and adhesion technologies. The review compares high-quality research to evaluate performance, efficiency, and surface adaptability of different designs, examining the strengths and limitations of major adhesion mechanisms and highlighting key challenges for future research.

Noorazman and Ibrahim (2022) critically analyzed the design and performance of an autonomous swimming pool cleaning robot targeting up to 80% hygiene efficiency. The study evaluated navigation algorithms, debris collection mechanisms, and cleaning consistency, demonstrating reduced labor dependency and improved maintenance effectiveness.

Tang et al. (2023) presented a bio-inspired amphibious soft climbing robot modeled after tree frogs and starfishes, emphasizing advanced suction-based adhesion. Experimental analysis confirmed strong adaptability, surface conformity, and vertical climbing stability in complex environments.

Elsevier (2019) offered a detailed evaluation of energy-efficient water cleaning devices developed through optimized motor design, brush configuration, and water flow control. Experimental findings demonstrated measurable reductions in power and water usage while maintaining cleaning effectiveness.

Megalingam (2018) critically reviewed advancements in autonomous robotic surface cleaners for hygiene maintenance in public and commercial environments, comparing automation technologies based on cleaning efficiency, operational cost, and scalability. The study concluded that autonomous systems significantly reduce maintenance costs.

I. Summary of Literature Gaps

Existing research has demonstrated the feasibility of wall-climbing robots and automated pool cleaners. However, most systems focus on horizontal surface cleaning or are designed for specialized applications. There remains a need for a low-cost, solar-powered, vertical wall cleaning device specifically designed for public swimming pool hygiene maintenance, which this research addresses.

III. METHODOLOGY

The design methodology of the Vertical Pool Wall Cleaning Device focuses on developing an automated system that replaces manual wall scrubbing with a reliable mechanical and electronic solution. The approach combines electronic control, mechanical cleaning, and sustainable power management.

3.1 System Architecture

The overall system is based on a modular architecture with the **Arduino UNO** serving as the central control unit, processing user inputs and controlling motor operations. Electrical power is generated using a **12V solar panel**, regulated through a charge controller, and stored in a rechargeable battery for continuous operation even when sunlight is unavailable.

The Arduino generates control signals using **Pulse Width Modulation (PWM)** to manage motor speed and direction. Since the motors require higher power than the Arduino can supply, **L298N motor driver modules** are used to safely interface the controller with the motors.

3.2 Mechanical Cleaning and Vertical Movement

Effective cleaning is achieved through two coordinated motorized actions:

Component	Function
High-torque DC gear motor	Drives rotating nylon/plastic brush to scrub pool wall surface
Second geared motor	Enables vertical movement using pulley/linear motion mechanism
Fine mesh filtration unit	Captures loosened debris to prevent water recontamination

3.3 Control Logic and Circuit Design

The control system is designed for ease of operation and reliability. Users can adjust cleaning speed using push buttons for preset speed levels or a throttle for precise control. Directional movement of the vertical motor is controlled using H-bridge logic, enabling upward and downward motion. Safety features such as flyback diodes and decoupling capacitors protect electronic components from voltage spikes and electrical noise.

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3.4 Mathematical Validation and Component Selection

To ensure reliable real-world performance, mathematical calculations were carried out during the design stage:

Parameter	Calculated Value
Total system power demand	~30W
Battery capacity	4Ah to 7Ah
Solar panel capacity	~20W
Expected continuous operation	≥1 hour

These calculations ensure efficient energy usage and dependable system performance.

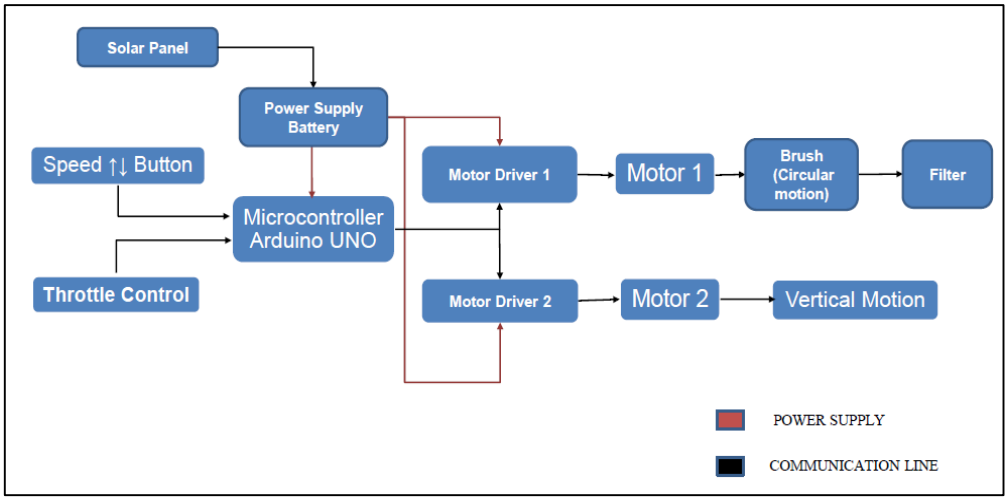

Figure 1: Block Diagram of Vertical Pool Wall Cleaning Device

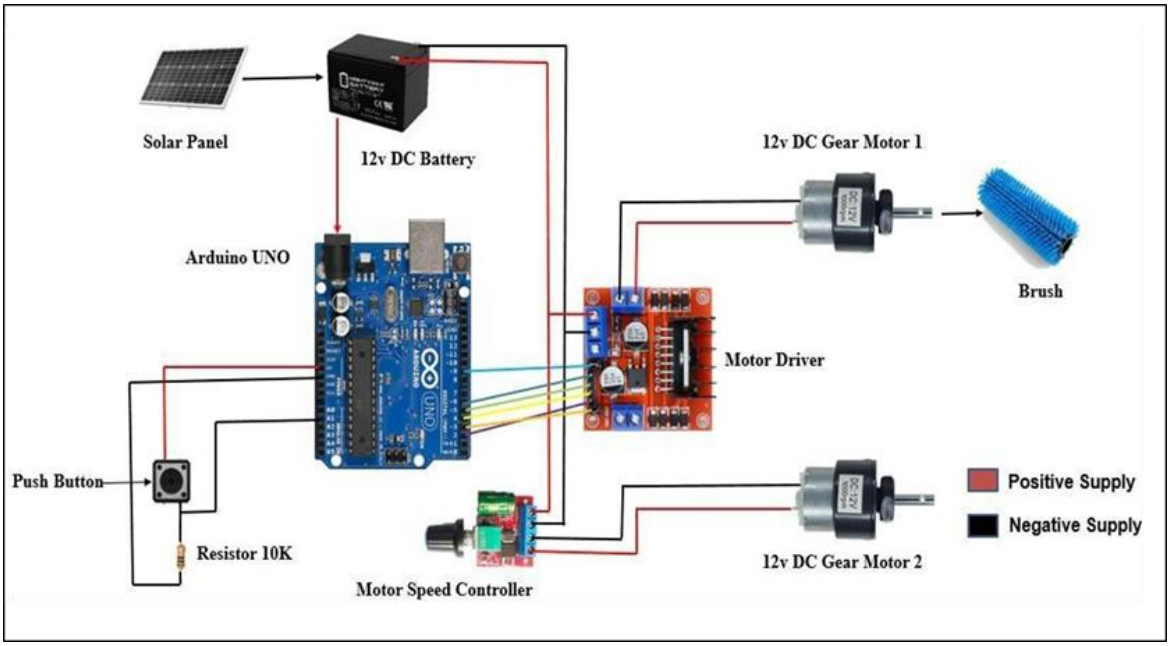

Figure 2: Circuit Diagram of Vertical Pool Wall Cleaning Device

IV. RESULTS AND DISCUSSION

The study on the Vertical Pool Wall Cleaning Device highlights a promising solution for addressing hygiene maintenance challenges in public swimming pools. Analysis of existing literature and current manual cleaning practices indicates that traditional methods are labor-intensive, time-consuming, and dependent on skilled workers for consistent performance.

The reviewed mechanical and automated cleaning approaches demonstrate that a vertically operating wall-cleaning mechanism can effectively enhance accessibility to underwater and vertical surfaces that are typically difficult to clean manually.

4.1 Expected Performance Benefits

Aspect	Expected Improvement
Cleaning consistency	Uniform coverage without human error
Worker safety	Reduced direct contact with chemicals and contaminated water
Operational cost	Lower labor requirements and reduced water wastage
Environmental impact	Solar-powered operation reduces grid electricity dependence

The proposed concept integrates compact mechanical brushing, suction, and mobility features, which are expected to significantly reduce manual involvement while improving cleaning efficiency and uniformity. Review findings suggest that such devices can potentially remove algae formation, biofilm deposits, and microbial contaminants more thoroughly compared to conventional scrubbing techniques.

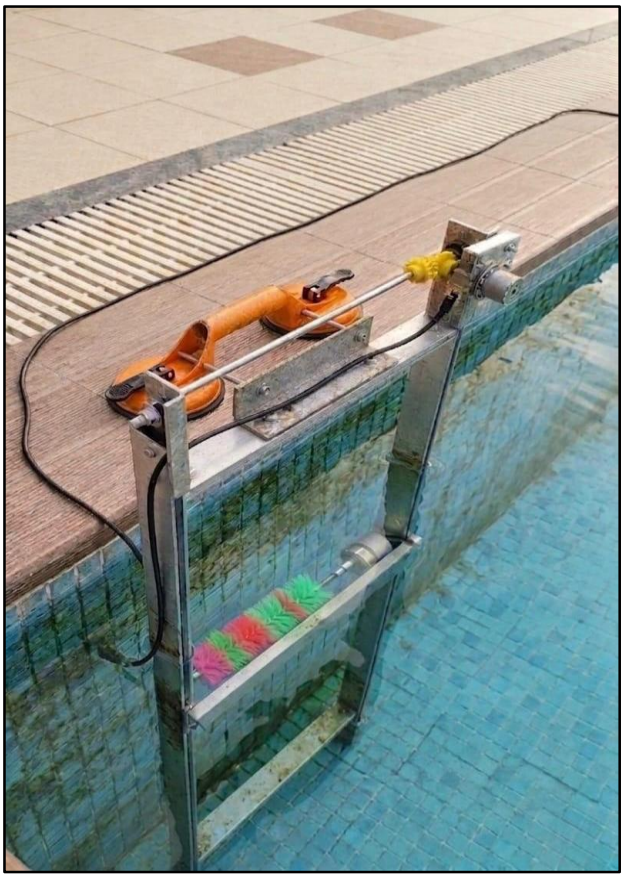

Figure 3: Working Model of Vertical Pool Wall Cleaning Device

V. COMPARATIVE ANALYSIS

Feature	Manual Cleaning	Existing Robotic Cleaners	Proposed Device
Vertical wall cleaning capability	Yes (labor-intensive)	Limited	Yes (automated)
Power source	Manual labor	Grid electricity	Solar + battery
Worker exposure	High	Low	Minimal
Cleaning consistency	Variable	High	High
Cost	Low labor (but recurring)	High	Medium (one-time)
Water wastage	High (draining required)	Low	Minimal
Portability	N/A	Low	High

VI. CONCLUSION

The Vertical Pool Wall Cleaning Device successfully addresses the major hygiene and labor-related problems involved in traditional swimming pool maintenance. By automating the wall cleaning process, the system eliminates the need for continuous manual scrubbing, which often leads to uneven cleaning, physical exhaustion, and health risks for workers due to prolonged exposure to chemicals and contaminated water. This automated approach ensures consistent and effective cleaning while improving worker safety.

The use of an Arduino UNO controller along with high-torque DC gear motors allows the device to move accurately along the pool walls and perform thorough mechanical scrubbing. The addition of a filtration system further improves hygiene by collecting loosened algae and debris, preventing them from mixing back into the pool water. Moreover, the integration of a solar-powered energy system with a rechargeable battery supports eco-friendly operation by reducing dependence on grid electricity and lowering overall maintenance costs.

Overall, this project demonstrates that replacing manual cleaning methods with a technology-based solution can significantly improve sanitation standards in public swimming pools while reducing operational effort and cost. With future upgrades such as IoT-based monitoring and AI-driven dirt detection, the device has strong potential to become a reliable and standard solution for modern pool maintenance.

VII. FUTURE SCOPE

Several enhancements can further improve the device:

Enhancement	Description
IoT-based monitoring	Remote performance tracking and maintenance alerts
AI-driven dirt detection	Intelligent cleaning based on contamination levels
Battery capacity increase	Extended operation time for larger pools
Multi-pool compatibility	Adaptable design for various pool sizes and shapes
Autonomous navigation	Sensor-based path planning for complete coverage

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CONFLICT OF INTEREST

The authors declare that there are no conflicts of interest related to this research. This work has been carried out as part of an academic study and is based entirely on publicly available research papers, journals, and technical resources. The authors confirm that they do not have any financial, commercial, or personal relationships that could influence the content or conclusions of this review. No external funding or industry support has been received.

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