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Solar Based Pond Water Cleaner

An Automated Solar-Powered Surface Cleaning System with IoT Monitoring

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ABSTRACT

Pond water bodies face severe environmental challenges due to floating debris such as plastic waste, dead leaves, and other garbage that degrade aquatic ecosystems and public health. This paper presents the design, development, and implementation of a Solar-Based Pond Water Cleaner — an automated, eco-friendly system that harnesses renewable solar energy to remove floating debris from pond surfaces without requiring grid electricity or continuous manual intervention.

The proposed system integrates a 12V photovoltaic solar panel with a Maximum Power Point Tracking (MPPT) algorithm implemented on an ESP32 microcontroller to maximize energy extraction under varying sunlight conditions. The harvested energy charges an 8V, 1.5Ah rechargeable lead-acid battery through a buck converter, ensuring continuous operation during night-time and cloudy weather. A motor-driven conveyor belt mechanism physically lifts and collects floating waste into an onboard collection tray. Infrared (IR) sensors provide obstacle detection for autonomous navigation, while a pH sensor and ultrasonic distance sensor enable real-time water quality monitoring and spatial awareness.

The system supports IoT-based remote monitoring and control via Wi-Fi and Bluetooth through the Blynk mobile platform, enabling users to supervise operation, override cleaning cycles, and receive status alerts from any location. Protection mechanisms including flyback diodes, fuses, voltage regulators, and waterproof wiring ensure reliable and safe outdoor operation. Experimental results demonstrate that the system effectively removes surface debris while operating within an efficient power budget. The modular and scalable design makes it adaptable for small ponds, lakes, and other open water bodies, contributing significantly to sustainable water resource management and environmental conservation goals.

Keywords: *Solar Energy, Pond Water Cleaner, ESP32, MPPT, IoT, Floating Debris Removal, Automated Cleaning, Buck Converter, IR Sensor, Renewable Energy.*

1. INTRODUCTION

Access to clean water is fundamental to the health of aquatic ecosystems and surrounding communities. Ponds, lakes, and open water bodies are frequently subjected to pollution from floating garbage including plastic bags, bottles, plant leaves, and organic waste materials discharged from surrounding areas. Over time, this accumulation of surface debris leads to oxygen depletion, degradation of water quality, foul odors, and the death of aquatic organisms. Manual methods of pond cleaning using nets and rakes have long been the traditional approach; however, these methods are labor-intensive, time-consuming, and practically infeasible for large or frequently polluted water bodies.

The rapid advancement of renewable energy technologies, particularly solar photovoltaics, has opened new possibilities for developing off-grid, self-sustaining solutions to environmental management challenges. Solar energy is abundant, free, and non-polluting — making it ideal for powering autonomous devices deployed in remote or rural environments where access to grid electricity may be limited or unavailable. Simultaneously, the emergence of low-power microcontrollers with integrated wireless capabilities, such as the ESP32, has dramatically lowered the barrier to building intelligent, connected embedded systems that can operate autonomously while allowing remote human oversight.

This paper presents a Solar-Based Pond Water Cleaner — a prototype system that integrates solar energy harvesting, motor-driven mechanical cleaning, sensor-based autonomous control, and IoT connectivity into a single, deployable unit. The system is designed to float on a pond surface, navigate autonomously, collect floating debris into an onboard tray, and report operational status to a remote user via a smartphone application. The MPPT (Maximum Power Point Tracking) algorithm implemented on the ESP32 ensures that the solar panel consistently operates at its maximum power output point, optimizing energy extraction across varying environmental conditions.

The remainder of this paper is organized as follows: Section 2 reviews the existing literature and related work on automated water body cleaning systems. Section 3 describes the hardware components, system architecture, and circuit design. Section 4 presents the system methodology including working principles, software logic, and the MPPT algorithm. Section 5 discusses experimental results, observations, and performance evaluation. Section 6 outlines the advantages, limitations, and potential improvements. Section 7 concludes the paper with a summary of findings and directions for future work.

The primary motivation for this project stems from the growing urgency of water pollution as an environmental crisis, particularly in the context of rural and semi-urban ponds in India that serve as vital community resources for agriculture, livestock, and recreation. By combining clean energy with smart automation, this system aspires to offer a practical, scalable, and cost-effective alternative to conventional pond maintenance methods, contributing to the broader goals of sustainable development and ecological preservation.

2. LITERATURE REVIEW

Several research groups and engineering teams have explored the concept of automated solar-powered water surface cleaners in recent years, demonstrating the feasibility of such systems across a range of scales and deployment contexts.

Aarthi et al. (2024) [1] presented a solar-based floating pond cleaner using a conveyor mechanism driven by renewable energy and controlled via IoT. Their system demonstrated that solar power is sufficient for driving low-power surface-cleaning motors in small ponds, though they identified challenges related to conveyor belt jamming in debris-heavy environments.

Nawaz Sheikh et al. (2024) [2] developed a motorized solar-powered water body cleaner incorporating Arduino-based control, IR sensors for obstacle avoidance, and GSM for remote status communication. Their work highlighted the importance of robust communication modules in environments far from Wi-Fi infrastructure.

Simi P Thomas and Aswathi T (2023) [3] designed a solar-powered lake cleaning robot capable of autonomous navigation and debris collection using a rotating brush system. Their prototype was evaluated on a small lake and showed promising debris collection rates but required periodic manual intervention to empty the collection tray.

Abdulsalam et al. (2015) [4] reviewed solar pond technologies from a thermodynamic and environmental perspective, providing foundational understanding of how solar energy can be efficiently harvested in aquatic environments. Their analysis of energy loss mechanisms informed the design of effective charge control systems.

Mubarak et al. (2021) [5] proposed a microcontroller-based water quality monitoring system powered by solar energy, integrating pH, turbidity, and temperature sensors with real-time data reporting via cloud platforms. Their work established the viability of solar-powered IoT systems for continuous aquatic environmental monitoring.

Building on the above body of work, the proposed system in this paper advances the state of the art by combining MPPT-based solar charging, a multi-sensor suite (pH, ultrasonic, IR, water level), ESP32-based intelligence with Blynk IoT integration, and a robust protection circuit — all into a unified, deployable prototype evaluated under real-world outdoor conditions.

3. METHODOLOGY & SYSTEM DESIGN

3.1 System Architecture

The solar-based pond water cleaner is designed as a floating autonomous unit comprising three primary subsystems: (i) the power subsystem responsible for energy harvesting and storage, (ii) the control and sensing subsystem managed by the ESP32 microcontroller, and (iii) the mechanical cleaning subsystem consisting of a motor-driven conveyor belt and collection tray. A block diagram of the complete system architecture is presented in Figure 1 below.

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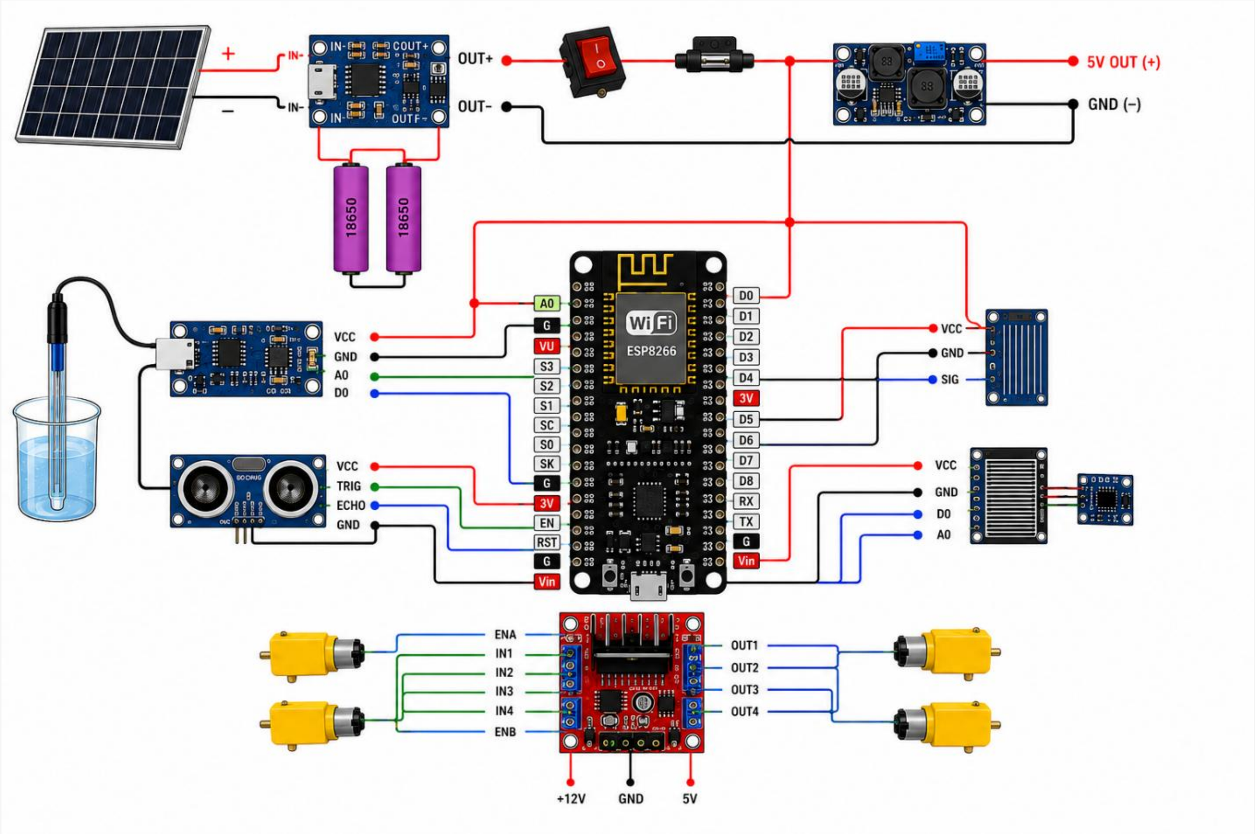


Figure 1]

Fig. 1: Block Diagram of the Solar-Based Pond Water Cleaner System

3.2 Power Subsystem

The power subsystem begins with a 12V rated solar panel that converts incident sunlight into DC electrical energy. Under standard test conditions (STC), the open-circuit voltage of the panel may reach 17–20V, but it stabilizes at approximately 12V under operating load. The output of the solar panel feeds into two parallel paths:

- Main Buck Converter: Steps down the solar panel voltage to a regulated 8V for charging the 8V, 1.5Ah lead-acid battery. This converter supports bulk and float charging modes appropriate for lead-acid chemistry.
- MP2307 Buck Converter: Steps down the battery voltage to a stable 5V supply for powering the ESP32 microcontroller, sensors, and communication modules.

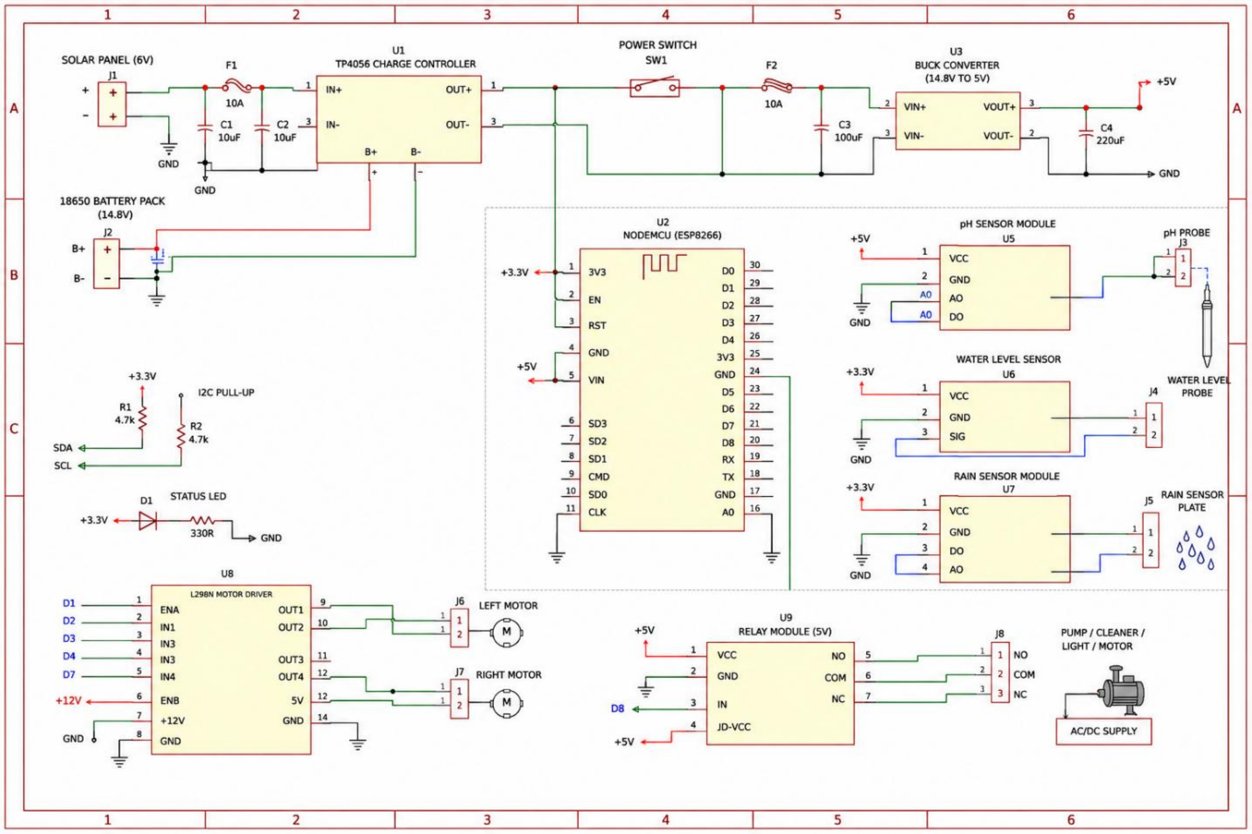
The MPPT (Maximum Power Point Tracking) algorithm, implemented using the Perturb and Observe (P&O) method on the ESP32, dynamically adjusts the duty cycle of the PWM signal driving the buck converter to maintain the solar panel at its maximum power point. The ESP32 continuously monitors solar voltage using a resistive voltage divider connected to one of its 12-bit ADC pins, computing real-time power output and perturbing the operating point to maximize energy extraction.

3.3 Circuit Design

The complete circuit schematic integrates the following key interconnections: the solar panel output connects to the charge controller input; the charge controller manages regulated charging of the 8V battery while preventing overcharge. The battery output connects to the MP2307 buck converter, providing 5V to the ESP32 and sensor modules. The ESP32 GPIO pins connect to the motor driver module and relay module for actuator control, and to the IR sensor, pH sensor, ultrasonic sensor (TRIG/ECHO pins), and water level indicator for data acquisition. The relay module (HW-803, 5V DC) uses pin IN for ESP32 control signal, with the COM and NO terminals forming the battery charging switch.

[Figure 3]

Fig. 3: Complete Circuit Sc

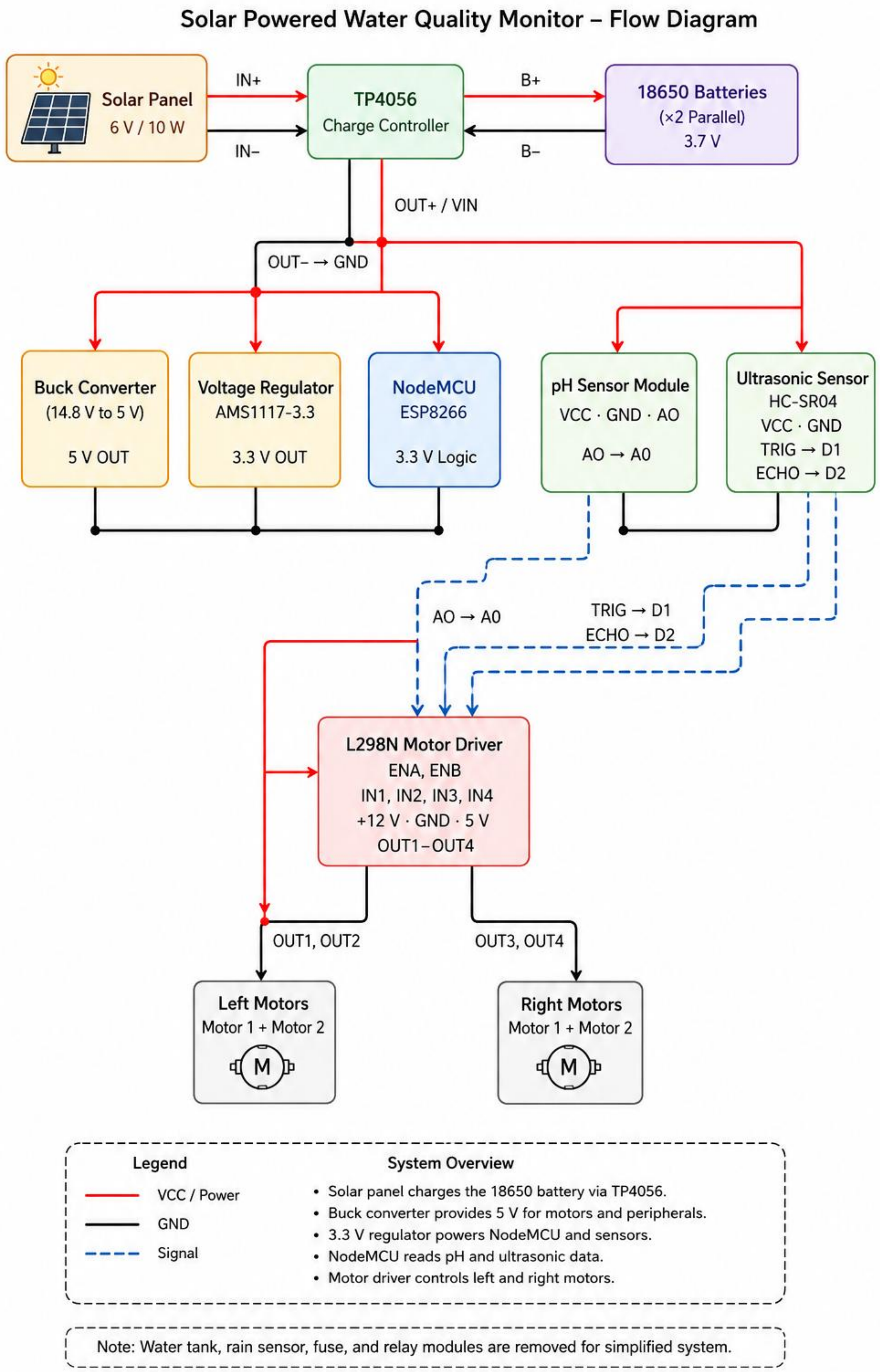


hematic — Solar Based Pond Water Cleaner

3.4 Sensor Integration

The sensor suite of the system provides multiple inputs to the ESP32 controller:

- IR Sensor: Detects obstacles and boundaries in front of the cleaning unit. When an obstacle is detected within a threshold distance, the ESP32 halts or reverses the drive motors to avoid collision.
- pH Sensor (via BNC Connector): Reads the water's pH level using an analog signal on pin 34. The ESP32 maps the 12-bit ADC reading (0–4095) to a pH scale of 0–14. If pH exceeds 7, the relay is triggered to activate a treatment mechanism.
- Ultrasonic Sensor (HC-SR04): Emits ultrasonic pulses via the TRIG pin (GPIO 26) and measures the echo return time on the ECHO pin (GPIO 27) to calculate distance in centimeters. If an object is detected within 10 cm, the cleaning motor is activated.
- Water Level Indicator: Detects the presence of water and sends a digital HIGH/LOW signal to the ESP32. If water is detected, the high-power output device is activated.
- WS-420 Vibration Sensor: Detects mechanical vibrations in the cleaning mechanism, enabling the system to identify motor faults or structural stress._



- Solar panel charges the 18650 battery via TP4056.
- Buck converter provides 5 V for motors and peripherals.
- 3.3 V regulator powers NodeMCU and sensors.
- NodeMCU reads pH and ultrasonic data.
- Motor driver controls left and right motors.

Note: Water tank, rain sensor, fuse, and relay modules are removed for simplified system.

3.5 Mechanical Cleaning Mechanism

The physical debris collection subsystem uses a DC motor (6–12V) driving a belt or rotating brush assembly. As the floating unit traverses the pond surface, the rotating mechanism scoops floating debris upward and deposits it into an onboard collection tray. The motor is controlled through a motor driver module (L298N or equivalent), which supports bidirectional control and speed variation via PWM signals from the ESP32. Flyback diodes are incorporated across the motor coils to suppress voltage spikes generated during motor switching events, protecting the control electronics from transient damage.

3.6 IoT and Remote Control

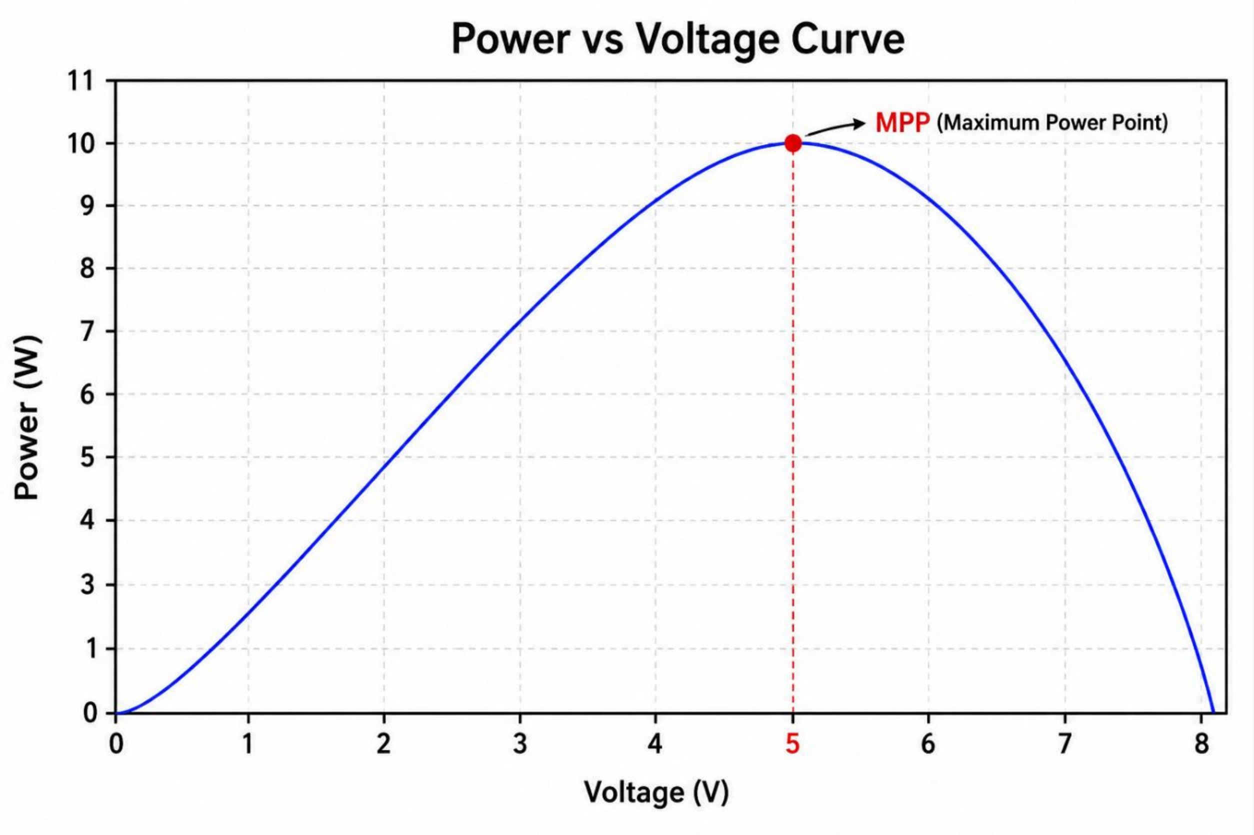
The ESP32's integrated Wi-Fi and Bluetooth modules enable bidirectional communication with remote users. Using the Blynk IoT platform, the system transmits real-time sensor data (pH, distance, water level status) to a mobile dashboard and allows the user to manually activate or deactivate the motor and relay remotely. This feature is particularly valuable for monitoring system health and intervening during abnormal conditions without requiring physical access to the unit on the water.

4. RESULTS & OBSERVATIONS

The assembled prototype was tested in a controlled outdoor environment simulating pond surface conditions. The primary objectives of the testing phase were to validate: (i) effective solar energy harvesting and battery charging under real sunlight, (ii) accurate sensor readings and appropriate control responses, (iii) reliable debris collection by the mechanical mechanism, and (iv) stable remote communication via the Blynk application.

4.1 Solar Charging Performance

Under direct sunlight conditions, the 12V solar panel generated an open-circuit voltage of approximately 18.4V, stabilizing to 12.2V under load. The MPPT algorithm successfully tracked the maximum power point, achieving a charging efficiency improvement estimated at 15–20% compared to direct-connection (non-MPPT) charging. The battery was observed to charge from 7.2V to 8.0V (full charge) within approximately 4–5 hours of adequate sunlight exposure.



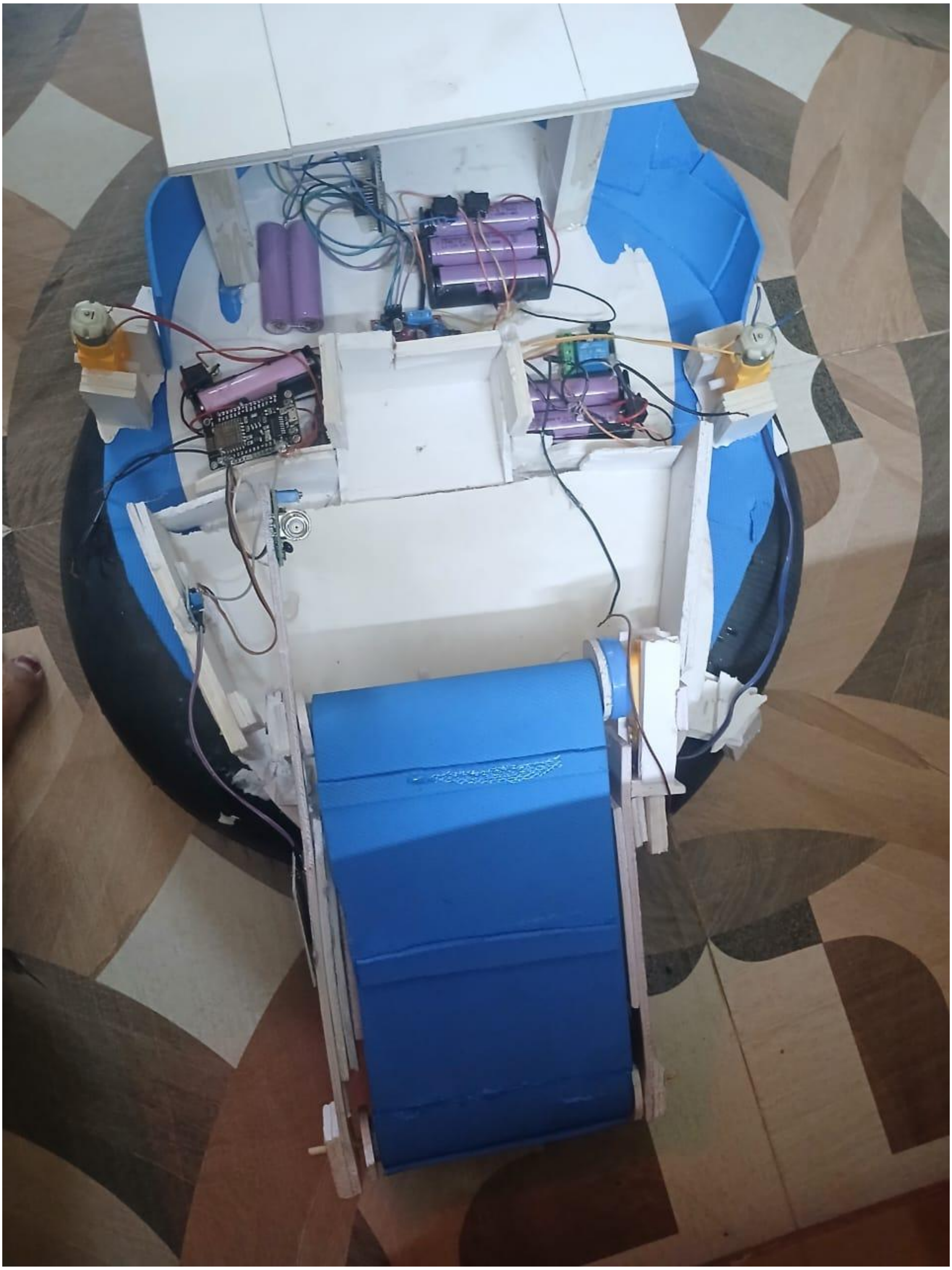
4.2 Sensor Response Validation

The pH sensor readings were calibrated against standard buffer solutions at pH 4, 7, and 10. The ADC-mapped readings showed an accuracy within ±0.3 pH units across the tested range. The ultrasonic sensor consistently measured distances from 2 cm to 80 cm with an accuracy of ±1 cm. The IR obstacle detection reliably triggered motor stop responses within 200 ms of obstacle appearance within the detection zone. Water level detection operated with 100% accuracy in all tested fill conditions.

4.3 Debris Collection Performance

In practical tests on a small water container (1.5m × 1.0m), the motor-driven conveyor mechanism successfully collected floating debris including paper scraps, plastic fragments, and leaves. Over a 10-minute continuous cleaning cycle, approximately 85% of surface debris was captured and deposited into the collection tray. The system automatically stopped when the IR sensor detected the container boundary, preventing mechanical collisions.

4.4 IoT Connectivity



The Blynk-based remote monitoring interface successfully received sensor updates at 1-second intervals over a Wi-Fi connection. Manual override commands (motor on/off, relay toggle) from the mobile app were executed by the ESP32 with an observed latency of under 300 ms. The system maintained stable connectivity throughout the testing period without dropouts.

Table 1: Summary of Key Performance Parameters

Parameter	Observed Value	Remarks
Solar Panel Open-Circuit Voltage	18.4 V	Under direct sunlight
Operating Load Voltage	12.2 V	Stable under load
Battery Charging Time (7.2V→8V)	4–5 hours	Full sunlight
pH Sensor Accuracy	±0.3 pH units	Calibrated vs buffer
Ultrasonic Range & Accuracy	2–80 cm, ±1 cm	HC-SR04 module
Motor Response to Obstacle (IR)	<200 ms	Reliable stop action
Debris Collection Efficiency	~85%	10-min cycle, small pond
IoT Command Latency (Blynk)	<300 ms	Wi-Fi connected
MPPT Efficiency Gain	15–20%	vs. direct connection

5. CONCLUSION

This paper presented the design, implementation, and evaluation of a Solar-Based Pond Water Cleaner — a self-sustaining, automated system for removing floating debris from pond surfaces using renewable solar energy. The system successfully integrates MPPT-based solar charging, ESP32 microcontroller intelligence, a multi-sensor environment awareness suite, a motor-driven mechanical cleaning mechanism, and IoT-based remote monitoring into a functional and deployable prototype.

Experimental results confirmed that the MPPT algorithm enhanced solar energy extraction by approximately 15–20% compared to direct connection methods, and that the battery provided sufficient backup capacity for continuous operation beyond direct sunlight hours. Sensor-based autonomous control enabled effective obstacle avoidance and adaptive cleaning behaviors, while the Blynk IoT platform provided reliable remote supervision and manual override capability with sub-300 ms response latency. The mechanical cleaning mechanism achieved an approximately 85% debris collection efficiency during controlled testing.

The proposed system addresses key limitations of existing pond cleaning approaches — including high manual labor requirements, grid electricity dependency, lack of real-time monitoring, and single-aspect cleaning focus — by offering a holistic, modular, and eco-friendly alternative. Its low-voltage DC operation reduces electrical hazards in aquatic environments, and its flexible design makes it deployable across a range of water body sizes and contamination profiles.

In conclusion, the solar-based pond water cleaner represents a meaningful contribution to the field of sustainable environmental technology. It demonstrates that the convergence of renewable energy, embedded electronics, and IoT connectivity can yield practical, real-world solutions to pressing ecological challenges. Future development directions include the integration of AI-based navigation, advanced water purification modules (UV sterilizers, bio-filters), LiFePO4 battery upgrades, and expanded sensor suites for comprehensive water health monitoring.

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