Water Hyacinth Removal Bot

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***Abstract*—This paper outlines the design and deployment of a water hyacinth removal bot. For operational efficiency in clearing water hyacinth from river surface. The system works through the utilization of a direct current conveyor system, supplemented with load monitoring capabilities. The system provides efficient operation and real-time monitoring through the utilization of an IoT device like the ESP32. The new methodology is focused on promoting sustainable aquatic ecosystem management and operational maintenance of waterways.**

***Index Terms*—Water hyacinth removal, river cleanliness, automation, Internet of Things, and ecological sustainability ESP32, IoT, Water hyacinth, Conveyor mechanism, Aquatic ecosystem.**

I. INTRODUCTION

One of the most critical problems in global tropical and subtropical freshwater water bodies is floating water weed Eichhornia crassipes [1], or Eichhornia crassipes [2]. Water hyacinth has spread and grown very quickly in water bodies in recent days where it is planted. Eutrophication of water bodies is the primary reason for weed growth in most of the world. Natural enemies of water plants will also control the growth and population of water hyacinth. Biological control of weeds [2], i.e., controlling the water plants by providing some necessary nutrients to the water, is the best way of controlling the growth of these water plants. It is effective in controlling these plants for a longer time period [4][5]. So, for maintaining the plant in healthy state, other protection and management practices also as well as apart from biological control must be followed in the short term.
The Water Hyacinth Removal bot programmed to address the issue of Water Hyacinth in fresh water. Clear water hyacinths from the bed of a river. Fitted with a camera to monitor in real-time, the system enables users to the system enables users to and visually observe the destruction process from a distance. The data can be
analyzed to enhance the process of elimination and confirm the body works as intended. After harvesting the plants, the bot may either be left on the beach for processing or put away for future use, depending on how the system is designed.

Implementation of an automated water hyacinth removal system is marred by a number of challenges [4]. The biggest challenges are to deliver efficiency and accuracy in different conditions, including water flow, presence of debris, and water level modifications. These conditions play a significant role in affecting the performance of conveyor belts and sensors. Nevertheless, various research studies have tried to implement innovative approaches to enhance the efficiency and responsiveness of water purification systems. For example, Johnson et al. utilized real-time sensor data and machine learning algorithms to establish a control methodology maximizing operational performance based on changing water conditions, thus delivering efficient aquatic weed removal [5]. Similarly, Patel et al. presented an obstacle avoidance strategy using ultrasonic sensors, which enhanced boat navigation by sensing both water hyacinth and other obstacles, thus making removal time-efficient [6]. Conversely, Gupta et al. developed a self-adjusting conveyor system that modulates the direction and speed of the conveyor as a function of the amount of water hyacinth present, thus ensuring efficiency in different quantities of vegetation [4].
Cost and scalability are the main issues where automatic water hyacinth harvesters are to be used, especially in rural or developing countries. The factor of the incorporation of conveyor units, automatic controllers, and sensors has most significance towards the operation and dependability of the system on mass production level.The cost of quality sensors and automated systems is very high and may

discourage mass use. The paper provides the design and development of a cost- effective Water Hyacinth boat that works under remote control. It is constructed from a conveyor with a harvesting system and motors as power. ESP32 with Wi-Fi or Bluetooth powers the prototype and incorporates obstacle sensors. The boat is designed to provide a cheaper, green, and efficient means of preventing water pollution by aquatic weeds.

II. LITERATURE SURVEY

This literature review shall try to find out the different methods of harvesting water hyacinth and whether automation is capable of providing a sustainable, scalable solution, par- ticularly as part of IoT-based solutions. While environmental sustainability, performance, and efficiency of different removal processes are of utmost priority, current research has estab- lished the integration of mechanical, biological, and chemical processes as the best option. This critique combines exist- ing literature, describes the techniques used (e.g., herbicide spraying, mechanical clean-up, weevil biological control), and quotes major hurdles like contamination of the environment, labor expense, and lack of scalability. It also points out the use of automation using autonomous boats and sensor systems in order to maximize efficiency and sustainability of bulk river clean-up

A. Traditional Water Hyacinth Removal Methods:

Manual and mechanical equipment have been used in the past to harvest water hyacinth, including cutting machines, harvest boats, and manual collection by human effort [2] [4]. While these systems are moderately efficient in small- scale harvesting, they are highly limited in scaling, involve massive human labor, and are of high maintenance cost due to frequent maintenance. Additionally, these traditional systems lack real-time monitoring, which is crucial in dynamic aquatic environments like lakes and rivers [3]. In aquatic weed harvesting, especially in large and infested aquatic environments, these limitations highly limit the efficiency, rate, and sustainability of the harvesting process.

TABLE 1. COMPREHENSIVE COMPARATIVE ANALYSIS OF RECENT WORK

Papers	**Insights**	**Methods Used**	**Problem Statement**	**Conclusions**
1.Invasion and control of water hyacinth (*Eichhornia crassipes*) in China	Herbicides are effective in controlling water hyacinth, but environmental concerns remain	Herbicide application (glyphosate, 2,4-D, paraquat).	The challenge of controlling water hyacinth without harming the environment	Herbicides are effective but need to be used carefully to avoid pollution.
2 Water Hyacinth—Removal and Control of an Invasive Species	Multiple methods for control can be used together for more effective management.	Mechanical removal, biological control (weevils), chemical control.	Invasive nature of water hyacinth leads to ecosystem disruption	A combination of mechanical, biological, and chemical control is optimal
3. The Effectiveness of Mechanical Control of Water Hyacinth	Mechanical methods can be effective, but they are labor-intensive and costly	Shredding, harvesting machines, and physical removal techniques	Shredding, harvesting machines, and physical removal techniques	Mechanical methods can reduce water hyacinth, but they need optimization for cost-effectiveness.
4. Design and Fabrication of an Automatic Water Hyacinth Removal System	Automation could significantly reduce labor and increase efficiency in large-scale water hyacinth removal	Automated boat design with conveyor system for water hyacinth removal..	The challenge of scaling water hyacinth removal with limited human resources.	Automation offers a more efficient and scalable solution for water hyacinth removal.

5. Characterization and Removal of Water Hyacinth	Water hyacinth removal needs to be efficient and cost-effective for larger areas.	Mechanical removal, land-based vehicles, watercrafts	The large-scale removal of water hyacinth is resource-heavy and costly.	Mechanical methods are effective but costly, highlighting the need for more efficient systems.
6. A Comprehensive Study on an Integrated Approach for Water Hyacinth Management to Conserve Natural Water Resources in India	Integrated approaches offer better long-term solutions for water hyacinth management systems.	Integrated approach using mechanical, biological, and chemical control. regulation.	Water hyacinth threatens water resources, particularly in developing regions. reduction of wastage.	An integrated management approach combining various control methods is more sustainable. provide actionable insights for urban planning.
7. Experimental Water Hyacinth Invasion and Destructive Management	Water hyacinth invasion can significantly affect local biodiversity and water quality.	Laboratory and field studies, chemical and mechanical control trials.	Water hyacinth can cause major ecological damage by altering biodiversity and water quality.	Effective management requires both control of existing hyacinth and prevention of future invasions.
8 Biological Control of Water Hyacinth: A Review	Biological control agents like weevils can provide long-term control but need monitoring.	Use of biological agents (e.g., weevils, fungi).	Traditional control methods are not sustainable in the long run	Biological control is promising, but it requires careful management and monitoring for success..
9. Water Hyacinth Control in Lake Victoria: A Review	Long-term control of water hyacinth in large water bodies requires multi-pronged strategies	Chemical control, mechanical harvesting, biological control.	Water hyacinth threatens ecosystems in Lake Victoria, with few effective solutions in place.	Multi-method strategies, including biological control and mechanical harvesting, are necessary for long-term success.
10. Water Hyacinth Management in Hartbeespoort Dam	Effective management is crucial to preserve water quality and prevent ecosystem damage.	Mechanical harvesting, biological control, chemical treatments.	Hartbeespoort Dam suffers from water hyacinth infestation, affecting water quality.	Integrated control methods involving mechanical and biological techniques show promise for managing water hyacinth.

B. Integration of Water Hyacinth Removal Methods:

To overcome the shortcomings of traditional removal methods, merging of automation, IoT, and sensor technologies has been discovered to be a good solution for water hyacinth management. Utilization of the likes of ultrasonic sensors, load sensors, GPS modules, and microcontrollers like Arduino or ESP32 enables real-time sensing, navigation, and control of the bot[6]. Merging enables autonomous control, reduces human interaction, and enables scalability to large bodies of water. Cloud-based data logging and remote control through Wi-Fi or Bluetooth modules also enable continuous monitoring, real-time alarms, and adaptive decision- making—enabling the entire system to be intelligent, efficient, and environmentally friendly [3].

Key Takeaways from the Literature Review on Water Hyacinth Removal Bot:

Assessment of water hyacinth harvesting systems through the use of IoT entails highly advanced automation as well as sensor technology and effective aquatic weed control systems on large scales. Installation of IoT systems enables monitoring of the dissemination of the hyacinth as well as the quality of the water in real time, and this enables the vessel to schedule its operations in relation to the conditions in the surrounding environment. Installation of ultrasonic sensors, under object detection, enables accuracy in navigation as well as obstacle avoidance in targeting water hyacinth harvesting. Provision for the sensors' accuracy based on different aquatic environments, including turbid as well as turbulent water, is a fundamental challenge [6]. Incorporation of ultrasonic sensors as well as other detection technologies based on the use of cameras, for instance, would enable detection as well as targeting of water hyacinth by the system, and this implies the functional efficiency of the vessel.

Cost and Scalability are the most vital in the large- scale deployment context [9]. Internet of Things (IoT)-enabled device deployment, i.e., ultrasonic sensors, environment sensors, and communication modules, has offered a cost- efficient and scalable solution for autonomous water hyacinth harvesting. There are issues that need to be solved, i.e., sensor lifespan, water damage resistance, organic deposit (biofouling buildup) accumulation, and long-term maintenance. Self- cleaning material, nanocoating, and water- and rugged-proof enclosures can greatly improve the lifespan of these sensors [10]. Also, efficient communication protocols like LoRa, Zigbee, and NB-IoT can be utilized to enhance the data communication in broad or distant deployments with low power consumption.

Energy efficiency is a major concern, especially in autonomous ships with batteries that need to be maintained in functional state for some time. High energy usage is due to continuous operation of motors, sensors, and real-time data communication. In an attempt to mitigate this factor, energy harvesting technology such as solar cells and hydrokinetic power conversion technology can be integrated into the system in an attempt to supplement the power source, thereby reducing the number of battery exchange cycles [7], [9]. Additional contribution to the sustainable factor can be achieved through the use of adaptive power control algorithms, where applicable, to control the energy consumption based on real-time ambient conditions.

Integrity and data safety are top priority in open water operation. Interference or even environmental hazard may be generated if third-party access is provided to sensors or control units in an unauthorized manner. Cryptographic methods, blockchain secure data, and intrusion detection can be applied to protect against such a threat and ensure trouble-free operation [3]. Another security factor is the use of tamper-proof hardware modules in IoT devices.

III. METHODOLOGY

The Water Hyacinth Removal Boat system was created with the aim of utilizing IoT, automation technologies to harvest and collect water hyacinths from water bodies in an efficient manner. ESP32, Bluetooth-controlled systems, a conveyor mesh system, and a web server interface camera are utilized in the system to control and monitor. The methodology section also provides a brief overview of designing, evaluating, and implementing IoT-based automation and machine learning approaches to efficient water hyacinth harvesting, as shown in Tables II and III.

A. Sensor and Control System:

The ESP32 microcontroller is the central system component, and it controls different sensors and actuators to enable autonomous operation [3], [6]. The boat is controlled through Bluetooth, enabling remote control through a mobile app. The camera module, connected to a web server interface, enables real-time monitoring of the environment surrounding the boat and the level of hyacinth infestation [3]. The conveyor mesh mechanism is used to harvest and destroy floating water hyacinths, enabling effective waste disposal [4], [5].

TABLE 2. METHODOLOGY OVERVIEW (Sensor System)

Sr No.	Category	Techniques/Methods	Key Features	Limitations
1.	Sensor Integration	Camera Module	Real-time monitoring of bot	Affected by water turbulence and lighting conditions
2.	Communication System	Bluetooth Interface	Remote-controlled operation and data transmission	Limited range of Bluetooth connectivity
3.	Embedded Systems	ESP32, DC Motors	Efficient motor actuation and sensor control	Limited onboard processing power
4.	Hyacinth Collection	Conveyor Mesh System	Continuous collection and removal of hyacinths	May require manual intervention for heavy loads

TABLE 3. METHODOLOGY OVERVIEW (Analysis)

Sr No.	Category	Techniques/Methods	Key Features	Limitations
1.	Remote Monitoring	Camera and Web Server Interface	Real-time video feed for surveillance	Requires stable network connection
2.	Motor Control	Relay-Based Switching Mechanism	Enables smooth motor operation and conveyor control	Requires precise timing adjustments
3.	Energy Management	Low-Power Motor Control	Reduces battery consumption for longer operation	Limited efficiency in high-load conditions
4.	Manual Navigation	Bluetooth-Based Remote Control	Allows user to steer and operate the bot from a distance	Limited by Bluetooth range and potential signal drop

B. Data Analysis and Control:

The vessel receives real-time environmental and position data from onboard sensors and sends through Bluetooth to a corresponding computation or mobile platform. The web server interface provides real-time video streams from the camera for remote monitoring and manual override where required. Sensor data is locally computed by the ESP32 to provide real-time navigation and operating options. The addition of low-power motors and low-energy energy management systems increases operating efficiency and battery life further. The proposed method provides an efficient, automated, and remotely controlled water hyacinth harvesting system.

IV. PROPOSED METHODOLOGY

The technique to be applied in IoT-Based Water Hyacinth Removal Boat is to integrate automation and remote monitoring to efficiently harvest water hyacinths from water bodies. The system uses an ESP32 microcontroller, Bluetooth control, conveyor mesh harvesting, and web server interface camera for remote monitoring.

A. ***Architecture Flow of Proposed Methodology:*** The design of the above suggested automatic flow control system is a step-by-step systematic process:

Step 1: Data from the camera module is gathered and processed to detect obstacles and identify water hyacinths to give accurate input for further processing.

Step 2: The collected data is processed by employing noise removal and detection accuracy improvement techniques and enhancing navigation efficiency and hyacinth identification.

Step 3: The boat’s movement is governed through real-time sensor feedback, with DC motors used for propulsion and servo motors used for accurate steering to move through the water body efficiently.

Step 4: Once water hyacinths are identified, the conveyor mesh system is activated to pick up and transport the hyacinths to the onboard storage compartment to dispose of them.

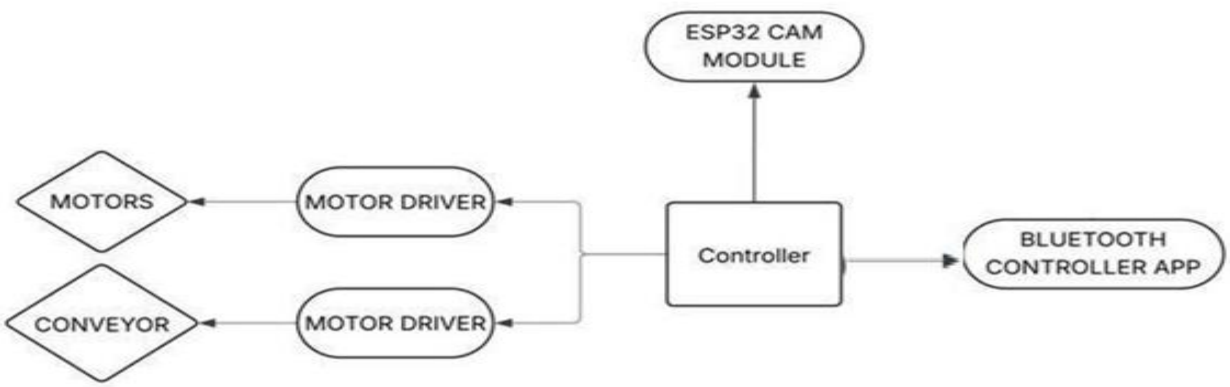
Step 5: Real-time data, such as the vessel’s running status, is transmitted to a web-based dashboard for remote monitoring and manual control if necessary.

Step 6: Power usage is continuously monitored and optimized using energy-efficient algorithms to maintain long-term operating life and potential integration of solar power for sustainability.

Step 7: Upon completion of the cleaning cycle or when the battery is critically low, the system automatically shuts down or reboots to repeat the cycle of operation, allowing for continuous removal of water hyacinth.

The water hyacinth removal boat based on IoT automatically identifies, harvests, and tracks aquatic weed removal. A conveyor system harvests hyacinths, while cameras identify them. There is real-time data transmission for remote monitoring and optimized power consumption for efficiency. The system has continuous operation with auto-shutdown or restart depending on battery levels.

V. BLOCK DIAGRAM AND SPECIFICATIONS



Specifications:

1) Microcontrollers and Modules:
ESP32-WROOM-32 (Main Controller) Dual-core 32-bit CPU, up to 240 MHz 520 KB SRAM
Integrated Wi-Fi (802.11 b/g/n) and Bluetooth 4.2
Operating voltage: 3.3 V
Used for controlling boat motors, sensors, conveyor motor, and communication

2) Camera Senor and Module:
ESP32-CAM Module (Camera) OV2640 2MP camera sensor 4MB PSRAM
Wi-Fi enabled (802.11 b/g/n) Operating voltage: 3.3 V
Provides live video monitoring of the river surface.

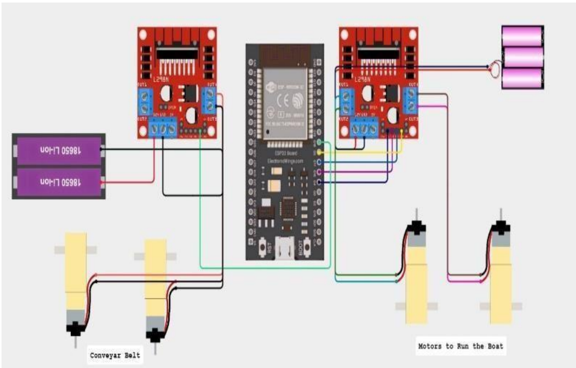
3) Power Supply:
Batteries: 18950 Li-ion Battery
Type: Lithium-ion (Li-ion) or Lithium Polymer (Li-Po) Voltage: 3.7 V nominal
Capacity: 2200 mAh or higher (higher capacity recommended for longer runtime)
Quantity: 3 batteries for the main ESP32, camera, and other electronics; 2 batteries dedicated for conveyor motor
Battery protection circuitry included (overcharge, over discharge, and short circuit protection)

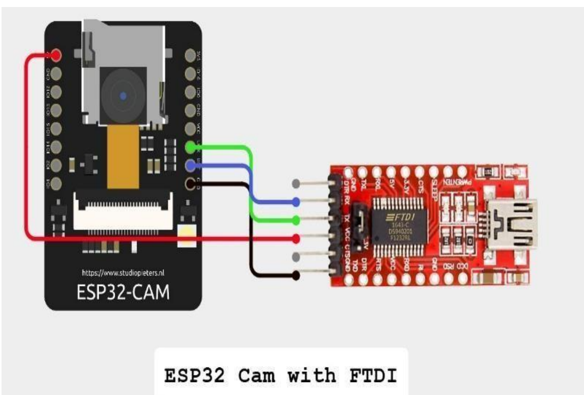
4) Motors and Drivers:
a) Boat Drive Motor
Type: DC motor
Voltage: Compatible with battery voltage (typically 6V or 12V depending on motor selection)
Torque: Suitable to propel the boat with its payload
b) Conveyor Motor
Type: DC motor
Voltage: Matches battery voltage (3.7V to 6V typical)
Quantity: 1
Purpose: Drive conveyor belt for water hyacinth removal
c) Motor Driver
Model: L298N or TB6612FNG (Dual H-Bridge Driver)
Current rating: ≥ 2A per channel
Quantity: 1 (to drive boat propulsion and conveyor motor) Purpose: Control direction and speed of DC motors

5) Communication Protocols
Wi-Fi (2.4 GHz, 802.11 b/g/n)
Used by ESP32 modules for wireless

communication and video streaming
ESP-NOW (optional)
Low-latency, peer-to-peer communication protocol between ESP32 modules

VI. CIRCUIT DIAGRAM





VII. EXPECTED RESULT AND DISCUSSION

The Water Hyacinth Removal Bot outcomes are based on preliminary design requirements and theoretical research. The bot is constructed to remove water hyacinths and algae from river surfaces using a conveyor system driven by IoT- based devices such as ESP32, and camera systems. The system is anticipated to provide the following outcomes: The expected key results include:

1. *Efficient Water Hyacinth Removal:*
The Water Hyacinth Removal Bot will be able to remove water hyacinths and algae from the surface of rivers or lakes. The conveyor system driven by DC Motors and will pick up floating plants and carry them away, thereby decreasing the occurrence of water hyacinths [1], [2]. The outcome anticipated will be the efficiency of the bot to clean vast areas of water hyacinths within a short time and with ease, offering a continuous solution to the waterway cleansing process.

2. *Real-Time Monitoring and Control:*
ESP32 controller and IoT capabilities will be utilized to provide real-time monitoring and control of the bot operation. The users will have the ability to monitor the bot's progress remotely through an online platform, with the cleaning process status, operation status, and number of water hyacinths collected. This will enhance the users' experience and provide valuable information concerning the operation of the bot.

3. *Sustained Waterway Cleanliness:*
The bot will ensure regular elimination of water hyacinths, thereby avoid clogging of water channels and contributing to the maintenance of the navigability of lakes and rivers. This round-the-clock cleansing process will greatly minimize the effects of water hyacinth overgrowth, enhancing the aesthetic, functional, and environmental quality of freshwater systems [1], [2].

4. *Enhanced Ecosystem Health:*
With the ongoing elimination of water hyacinths, a non-native plant species that lowers dissolved oxygen and stifles native aquatic vegetation, the bot is at the forefront in restoring ecological balance in bodies of water. Water hyacinths create dense mats that block light penetration, lower oxygen levels, and destroy native ecosystems [1]. With their elimination, the bot enables the penetration of light into the water column, thereby enhancing photosynthesis in submerged plants and enhancing the recovery of native plant species.

With native aquatic vegetation communities intact, the water is aerated naturally, sustaining more robust populations of fish, insects, and other aquatic life [2]. This enrichment of biodiversity leads to a more healthy and sustainable aquatic community. In the long term, the bot's function not only serves to avert invasion by unwanted species but also restores intact aquatic ecosystems and consequently offers long-term ecological integrity and freshwater body resilience.

5. *Labor and Operating Cost Reduction:*
Self-sustained operation of the Water Hyacinth Removal Bot will reduce human interference. Traditional removal of water hyacinth is costly and labor-intensive [2], [5]. Through automation, the process should reduce operational and labor costs by a significant amount, thus making it a cost-effective way of managing water hyacinth proliferation on a large scale.

6. *Power Efficiency and Eco-Friendliness:*
The Water Hyacinth Removal Bot will be made to consume minimal power, operate on solar power, or rechargeable batteries. This will allow it to operate continuously without over- relying on external power sources, which will be part of the eco-friendliness of the solution. The bot will provide an environmentally friendly means of cleaning freshwater systems without the application of poisonous chemicals or pollutants.

7. *Scalability and Versatility:*
The bot is also scalable and can be used in any waterway environment. From small lakes, ponds, and as far as large rivers, the bot would find application in a large variety of environments. Its nature will allow it to be modified and adjusted with ease depending on the scale of the task at hand.

VIII. CALCULATIONS

1. *Total Weight and Buoyancy Check:* Formula: $F_b = \rho \times V \times g$ Where: F_b: Buoyant force (N) ρ: Density of water (1000 kg/m³) V: Volume submerged (m³)
g: Gravitational acceleration (9.81 m/s²) Given: Total mass = 2 kg
$F_g = m \times g = 2 \times 9.81 = 19.62$ N
$V = F_b / (\rho \times g) = 19.62 / (1000 \times 9.81)$
≈ 0.002 m³ = 2 liters

2. Motor Torque Calculations:
a) Propulsion Motor:
Formula: $F = 0.5 \times C_d \times \rho \times A \times v^2$ Definitions:
C_d: Drag coefficient (~1.0 for flat body) A: Cross-sectional area (assume 0.05 m²) v: Desired velocity (0.3 m/s)
Calculation:
$F = 0.5 \times 1 \times 1000 \times 0.05 \times 0.3^2 = 2.25$ N
Torque at propeller: $\tau = F \times r = 2.25 \times 0.03 = 0.0675$ N·m

b) Conveyor Motor:
Lifting needs torque. Formula: $\tau = (m \times g) \times r$ Given: m
= 0.5 kg, r = 0.02 m
Calculation: $F = 0.5 \times 9.81 = 4.905$ N $\tau = 4.905 \times 0.02$ =
0.0981 N·m

3. Actual Runtime Estimation for Bot:
a)Propulsion System Runtime Estimation:
Battery (Propulsion System):
Voltage: 11.1 V (3-cell Li-Ion) Capacity: 2200 mAh = 2.2 Ah

Component Current Consumption:
1. 2 × DC Motors (Drive) =1.5 × 2 = 3.0 A
2. ESP32 Microcontroller=0.12 A
3. Camera Module=0.25A

4. L298N + Heat Losses=0.2A Total = 3.57 A
Calculation:
$I_{total} = 3.0+0.12+0.25+0.2=3.57$A
$Runtime_{ideal} = 2.2/3.57 = 36.96$ minutes
$Runtime_{actual} = 36.96 \times 0.80 = 30$ minutes

b) Conveyor System Runtime Estimation:
Battery (Conveyor System) Voltage: 7.4 V (2-cell Li-Ion) Capacity: 2200 mAh = 2.2 Ah

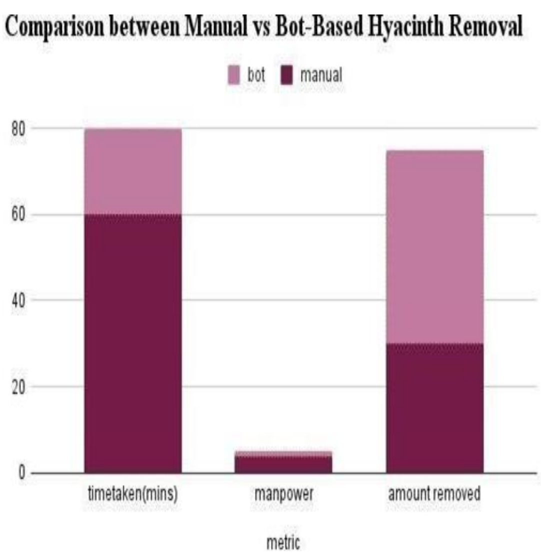
Component Current Consumption:
1. 2 × DC Motors (conveyor)= 1.2 A × 2 = 2.4 A
2. L298N driver losses=0.1A Total = 2.5A
Calculation:
$I_{total} = 2.4+0.1=2.5$A
$Runtime_{ideal} = 2.2/2.5 = 52.8$ minutes
$Runtime_{actual} = 52.8 \times 0.80 = 40$ minutes

4. Load Distribution & Stability: Formula: $M = F \times d$ Example:
F = 19.62 N, d = 0.05 m → M = 0.981 N·m

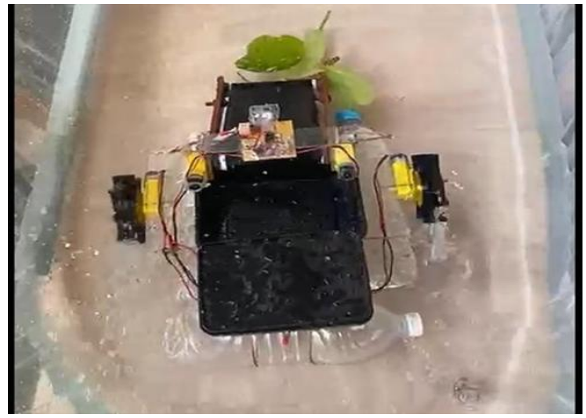
	Calculation Type	Result
1	Total Weight and Buoyancy Check	Fg = 19.62 N, V = 2 L
2a	Propulsion Motor Force	F = 2.25 N
2a	Propeller Torque	τ = 0.0675 N·m
2b	Conveyor Motor Torque	τ = 0.0981 N·m
3a	Propulsion System Runtime	Ideal = 36.96 min, Actual = 30 min
3b	Conveyor System Runtime	Ideal = 52.8 min, Actual = 40 min
4	Load Distribution & Stability	M = 0.981 N·m

Summary Table: Calculations:

IX. GRAPH



X. RESULT IMAGES



XI. FUTURE SCOPE

The Water Hyacinth Removal Bot can be designed further and upgraded for application in more complex and varied assignments. The areas of future improvement and the scope of the project to be expanded are as follows:

1. *Integration of Advanced Machine Learning and AI:* Subsequent versions of the bot would incorporate Artificial Intelligence (AI) and Machine Learning (ML) algorithms to enable it to make decisions more effectively [5]. Using AI, the bot would be able to identify the most affected areas in real-time, schedule some zones for cleaning, and adapt to variable environmental conditions.

2. *Improved Navigation System:*
Where the bot relies on ultrasonic sensors for navigation around obstacles, subsequent versions can employ sophisticated vision-based navigation with the assistance of AI-enabled cameras. This would enable the bot to detect and navigate around obstacles more effectively, such as underwater or floating objects and water levels, to enhance its performance in difficult environments. Further, the application of GPS technology would enable more precise location tracking and route planning automatically in larger areas.

3. *Enhanced Energy Efficiency:*
The bot can be energized with more efficient power sources, such as solar panels or wireless charging technology [7], [10], to increase its lifespan. Future design can include energy storage technologies, such as supercapacitors or improved battery

technologies, to enable the bot to run for extended, uninterrupted periods even in regions where sunlight is limited.

4. Multi-Bot Systems:
In the future, autonomous water hyacinth removal robots can be deployed in fleets to carry out large-scale treatments in rivers, lakes, or reservoirs. The robots interact with each other in IoT networks to support cooperative action and enhanced control of large water surfaces [4], [5]. The multi-robot system would enhance overall efficiency in cleaning and offer more response to water hyacinth infestation.

5. Real-Time Environmental Monitoring:
Besides water hyacinth harvesting, the robots of the future can be equipped with sensors to monitor other environmental parameters [3],[6], such as water temperature, pH, dissolved oxygen, and water quality. All these reports can be transmitted in real time to observation centers, providing information about the health of the aquatic ecosystem.

6. *Integration with Cloud-Based Management Systems*: The bot can be interfaced with cloud-based management software that provides remote monitoring, data analysis, and performance tracking. The integration in the cloud would also allow data analytics to track the efficiency of cleaning operations [3]

7. *Additional Functionality for Other Non-Native Species:* The bot is reusable for the harvesting of other invasive aquatic plants other than water hyacinths, such as water lettuce, aquatic moss. The conveyor belt and the cleaning system can be adjusted based on the type of plant, and the bot can be designed to be flexible and effective in more types of environmental management activities.

8. Coordination with Local Authorities for Mass Deployment:
The robot can be mass-produced for municipal or government use to fight waterway contamination on a regional or national scale. Collaboration with regional environmental agencies can facilitate mass deployment of these robots to decontaminate city lakes, rivers, and water reservoirs and thus fight the growing threat of invasive water plant life waterway clogging.

9. Automated Maintenance System Design:
Later versions of the bot can include an automatic maintenance system that can detect and fix minor faults as it works, like debris accumulation, sensor failure, or motor wear. The system will reduce the amount of manual repairs, making the operation of the bot more efficient and enabling continuous, unmanned operation for extended periods of time.

10. Cost Reduction and Accessibility:
As the technology for the water hyacinth removal bot advances, manufacturing costs ought to decrease, bringing the system within reach of small farmers, private property owners, and municipalities. At lower price points, this technology might become a commonplace solution to waterway wellness for many economic players.

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