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Developing a Floating Robot for Mechanical Control of Water Hyacinth

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Abstract — Water hyacinth has become widespread in freshwater bodies in several countries, leading to various issues, particularly its substantial water consumption and the resulting need to control its growth. Among the different methods of controlling water hyacinth, mechanical control stands out as the most effective and environmentally friendly approach. A proposed harvester robot has been developed, capable of efficiently cutting and collecting water hyacinth from the water's surface. The robot boasts several advantages, including its ability to operate in narrow water paths and lakes, use clean energy sources to preserve the water ecology, employ a GPS module for safety and error detection, and generate maps for evaluating work and predicting annual growth. When compared to other technologies dealing with water hyacinth, this innovative water hyacinth harvesting robot presents a significantly lower cost of 0.01 $/kg, making it an optimal solution for addressing water hyacinth problems.

Keywords— *Water hyacinth, aquatic weed control, mechanical aquatic weed removal, water hyacinth harvester, water sustainability.*

I. INTRODUCTION

One of the most significant challenges in water bodies located in tropical and subtropical regions is the presence of large masses of the floating aquatic weed *Eichhornia Crassipes*, known as Water Hyacinth. This weed was first reported in the Egyptian region during the late 1800s. Today, it poses numerous problems in rivers, lakes, irrigation canals, and agricultural drainage networks, particularly in the River Nile region after the construction of the Aswan High Dam [1]. Water hyacinth is notorious for its high water consumption rate. In various climate conditions, it exhibits an evapotranspiration rate 3.2 to 3.7 times greater than the normal evaporation rate of the water surface[2]. This becomes a major concern, especially in water-scarce situations in Egypt. While the total area covered by water hyacinth in Egypt remains unpublished, estimated figures suggest coverage of approximately 487 km^2 in irrigation and drainage network canals and about 151 km^2 in lakes, resulting in a loss of 3.5 Gm^3 of water [3]. The consequences of water hyacinth proliferation are far-reaching, including obstructing water transportation, affecting water supply systems, and hydropower, leading to water floods by blocking water flows, impacting biodiversity, consuming excessive water oxygen, fostering the growth of pests and vectors, and adversely affecting fish populations [4], [5].

Water hyacinth exhibits rapid and extensive growth capabilities. For instance, within just 50 days, a single plantlet with specific dimensions can expand and generate numerous offsets. If left unchecked, this plant can lead to disastrous effects, covering vast areas in water bodies like Lake Nasser with a staggering number of new offsets [6], [7]. Its swift reproduction causes it to form extensive mats that cover the water's surface, blocking sunlight from reaching other aquatic plants and leading to decay and oxygen depletion, ultimately harming pond creatures [8]–[10]. As a result, this invasive species has become a grave concern in many countries worldwide, spreading from the American tropics and now widely distributed in tropical and subtropical regions, occupying water systems such as lakes, ponds, canals, and rivers. Water hyacinth is characterized by its lavender-purple blossoms and glossy, rounded green leaves, and it floats freely due to a buoyant structure near its base [3], [8], [11] as shown in Fig.1. Eichhornia crassipes is found in various regions globally, thriving in tropical and subtropical climates, and even expanding into Mediterranean climate zones [12]–[14] as shown in Fig.2.

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Fig. 1. Morphological description of not matured water hyacinth (photo by Lin Shang 2015)

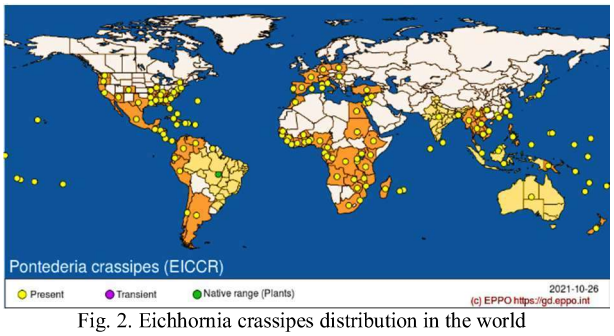


Fig. 2. Eichhornia crassipes distribution in the world

A. Herbicide control

In South Africa, herbicide application stands as the primary approach to control Water Hyacinth. Despite its rapid action and efficacy, achieving comprehensive control requires a sustained commitment, involving regular follow-up applications for two decades or more. Water Hyacinth exhibits high susceptibility to herbicides like 2,4-D, diquat, paraquat, and glyphosate, making them effective in managing this invasive species in smaller water systems like irrigation canals and dams covering approximately one hectare in size [15].

B. Biological control

Plants like Water Hyacinth exhibit exponential growth and expansion, partly because their original habitats lack natural enemies like browsers or pathogens. To address this issue, biological control, or biocontrol, involves introducing these natural enemies to curtail the plant's competitive advantage and reduce its vitality to a level comparable to that of the native vegetation. Commonly employed biocontrol agents include insects, mites, or pathogens like fungi or bacteria, which specifically target various plant organs, including leaves, stems, roots, flowers, fruits, or seeds [16].

The project's objectives include developing an intelligent cleaning robot with a hybrid driving system capable of performing underwater rhizome cutting, gathering aquatic plants, compression, and facilitating land-water circulation. Additionally, the robot will be equipped with intelligent navigation capabilities to maneuver in confined spaces, and river data will be linked to specific locations through geographical information system (GIS) modeling. Lastly, the intelligent cleaning robot group will be controlled for large-scale, multi-point data collection, and water quality evaluation, with the operation centralized on a cloud network.

C. Mechanical control

Utilizing mechanical control methods is an eco-friendly means of removing water hyacinth, offering the added benefit of using the harvested plants as biomass for various applications [7], [17]. Mechanical techniques involve both manual labor and machinery to harvest aquatic weeds.

Mechanical control (manually):

This approach is controlling water hyacinth through manual extraction, which consists of removing the weeds from small lakes or canals by draining the water and using nets, hands, or rakes for retrieval. Another option is to pull the weeds manually from the water surface. However, this method is only practical for small water bodies and proves ineffective for larger ones. It demands considerable labor and carries risks associated with exposure to harmful microorganisms like bilharzia and potential encounters with crocodiles. Moreover, handling the harvested weeds poses transportation challenges [4]. Researchers have also developed a tool to aid in the manual control of water hyacinths, as described in [18].

Mechanical control (using machines):

This method for controlling water hyacinth is regarded as costly, as it necessitates the use of large machines like mowers, crusher boats, destruction boat dredgers, and weed harvesters, along with bulldozers, conveyors, and trucks for transportation. However, this technique may not be adequate for managing extensive infestations [4], [19]. In some scenarios, these machines can effectively clear pathways for boats to apply herbicides.

Recently, researchers have been exploring the concept of robotic harvesters as a mechanical solution to control the growth of aquatic weeds [20], [21]. Previous investigations have led to the development of constructions for wheeled harvesters, tracked harvesters, brush cutter heads, and sand-fixing equipment. Additionally, controlling systems based on cloud network technology with the global positioning system (GPS) and the BeiDou navigation satellite system (BDS) have been implemented, enabling robots to collaborate and perform functions like data collection in desert and forest areas [22]–[24]. The integrated design of an autonomous robot showcased in this study demonstrates its capability to control water hyacinths and collect GIS data for scanned river basins. The proposed design incorporates innovative and unique mechanisms [25]–[27]. The primary goals of water hyacinth harvesters are to enhance aquatic habitats' functionality and health, while also providing economic and societal benefits.

This paper introduces a mechanical robot known as the aquatic weed robot-harvester, or water mower, mowing boat, and weed-cutting boat. Its purpose is to manage inland watercourses by cutting and harvesting underwater weeds, reeds, and other aquatic plant life. The robot operates on solar

energy during the daytime, eliminating the need for external power sources. With its small size and submersible depth, the robot can navigate narrow watercourses and perform water sample analysis, facilitating informed decisions regarding water quality management, particularly in lakes affected by sewage leakage.

II. ROBOT DESIGN APPROACH

A catamaran hull is a watercraft design characterized by having two parallel hulls or pontoons, unlike the single hull seen in conventional boats. These two hulls are usually connected by a platform or bridge, offering several benefits compared to monohull boats, including enhanced stability, speed, and maneuverability as shown in Fig.3.

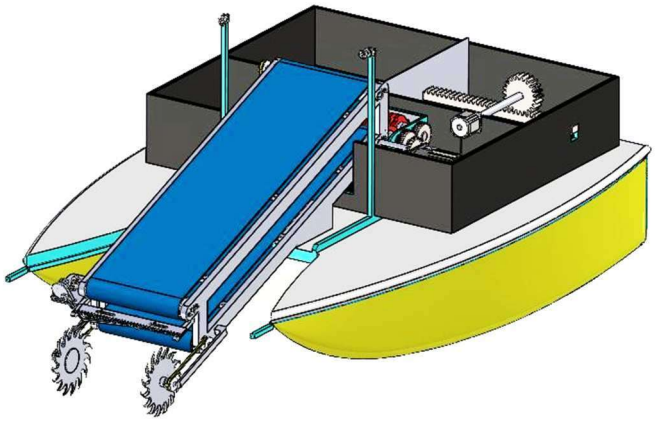


Fig. 3. Full design of water hyacinth robot

A. Maneuvering of water hyacinth harvester robot

Following the aforementioned characteristics, the hull was developed. The buoyancy equation, which relates an object's essential dimensions to its light displacement, must be thoroughly considered during the preliminary design phase.

$$L_H . B . T . C_P . \rho = LTD + DWT \quad (1)$$

Displacement
The weight of water displaced by the boat is presented in Eq.2.

$$LTD \text{ or } D = 0.6\, L_H^{1.33} . B^{1.33} . T^{0.67} \quad (2)$$

Prismatic Coefficient
a measure of how much the boat's shape deviates from that of a rectangular prism (calculated from Eq.3).

$$C_P = \frac{V}{A*L} \quad (3)$$

Displacement to Length Ratio $\frac{D}{L}$
the ratio of the weight of the boat to the weight of water displaced by the boat (Eq.4).

$$\frac{D}{L} = \frac{\frac{D}{2.240}}{(0.01*LWL)^3} \quad (4)$$

Sail Area to Displacement Ratio $\frac{SA}{D}$
a measure of the boat's sailing performance relative to its weight (Eq.5).

$$\frac{SA}{D} = \frac{SA}{(D)^{\frac{2}{3}}} \quad (5)$$

Capsize Screening Formula:
a measure of a boat's susceptibility to capsizing calculated from Eq.6.

$$Cap = \frac{B}{(D/64.2)^{\frac{1}{3}}} \quad (6)$$

The angle of Vanishing Stability *AVS*
the angle at which the boat's stability is lost and it capsizes (Eq.7).

$$AVS = 110 + \frac{400}{SSV-10} \quad (7)$$

$$SSV = \frac{B^2}{BR*DCB*\sqrt[3]{D}} \quad (8)$$

Ballast to Displacement Ratio
the ratio of the weight of the ballast to the weight of water displaced by the boat (Eq.9).

$$BR = \frac{Ballast}{D} * 100 \quad (9)$$

Hull Speed:
the maximum speed the boat can travel based on its waterline length (Eq.10).

$$\text{Hull Speed} = \frac{1.34}{(LWL)^{0.5}} \quad (10)$$

B. Force analysis of the water hyacinth harvester robot is shown in Fig.4.

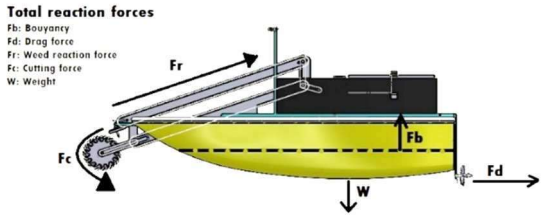


Fig. 4. Force analysis on water hyacinth robot

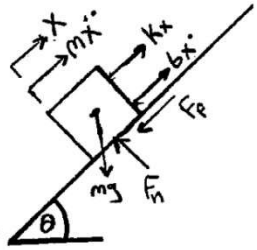
Buoyancy force in the upward direction given in Eq.11.

$$F_b = \rho V g \quad (11)$$

The weight of robot force in the downward direction is calculated from Eq.12.

$$W = m.g \quad (12)$$

The weed reaction force on the robot affects in belt direction.



Apply Newton's 2nd law on the belt conveyor in Eq.13.

$$m\ddot{x} = \sum f_x \quad (13)$$

$$m\ddot{x} = f_k + f_B + f_f + mg\sin\theta \quad (14)$$

Where:

$f_k = kx$

$f_B = b\,\dot{x}$

$$f_f = \frac{-4A}{bt} = -\lambda \quad (15)$$

$$V_b = \omega_{(t)} \frac{D_m}{2} \quad (16)$$

$$\dot{x} = \dot{\theta}_{(t)} \frac{D_m}{2} \quad (17)$$

$$F_r = f_{tight} + f_{slack} \quad (18)$$

$$f_{tight} = 1.123 f_{slack} + 120 \quad (19)$$

$$\frac{f_{tight}}{f_{slack}} = e^{\mu\theta} \quad (20)$$

The power consumption for belt operation in Eq. 21.

$$p = (f_{tight} + f_{slack})\, v \quad (21)$$

Maximum capacity of conveyor (M) in Eq.22.

$$M = \rho Q = \rho k\, (0.9B - 0.05)^2 \times v \quad (22)$$

Productivity of water hyacinth harvester after shredding and compressing in ballets calculated from Eq.23.

$$Pro = V_{pal} \cdot \rho_{pal} \cdot t \quad (23)$$

III. Operation and Methodology

An autonomous water hyacinth harvester's maneuvering system typically consists of a mix of sensors, control systems, and propulsion components. The sensors serve the purpose of guiding the harvester through water and detecting the presence of water hyacinth. Propulsion mechanisms receive instructions from the control systems, based on sensor data, and enable the harvester to move in the desired direction. Depending on the harvester's design, various propulsion systems may be integrated into an automatic water hyacinth harvester. However, controlling such a harvester can be challenging due to the unpredictable nature of water bodies and potential obstacles. The harvester must navigate through tight channels, past obstructions, and in shallow water without getting stuck or causing harm to the environment. These complexities need to be taken into account during the harvester's design to ensure effective and secure operation. Aspects like the harvester's size, shape, propulsion system speed, and steering algorithms play crucial roles in determining its maneuverability. For instance, a smaller harvester may exhibit better agility and maneuverability in confined spaces, but it might have limitations in its ability to collect a large quantity of water hyacinth. Additionally, the propulsion system's speed can also influence the harvester's maneuverability. To facilitate smoother movement of the motor and conveyor system, multiple rollers are utilized between the motor and the cutters, as well as the side cutters. These rollers serve as connectors, allowing various components to move together seamlessly. By connecting the rollers, continuous motion is achieved, effectively transferring the motor's rotational action to the cutters and side cutters. This connection mechanism is vital for the successful chopping and processing of water hyacinth. The complete flow chart of the water hyacinth harvesting robot is shown in Fig.5.

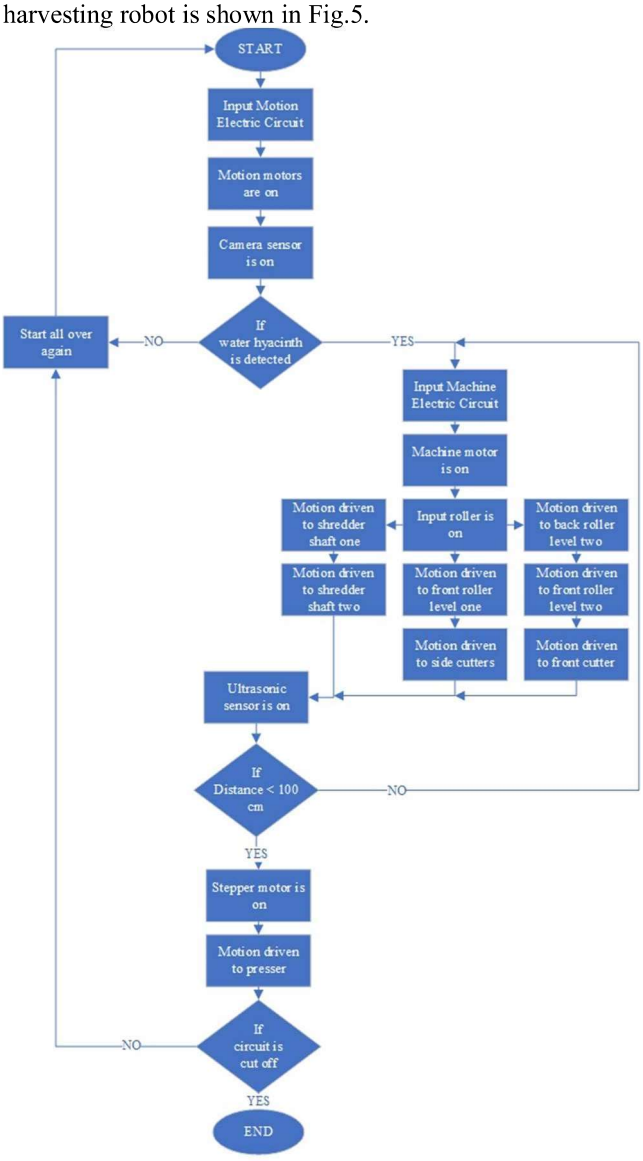


Fig. 5. Flow chart of water hyacinth harvesting robot.

A. *Simulation of water hyacinth harvester robot*

This study uses MATLAB Simulink Multibody to simulate and analyze a water hyacinth boat machine. Before the machine is physically implemented in the actual world, the goal is to assess the benefits of simulation. The simulation helps in the design and optimization process by giving a thorough understanding of the machine's performance, behavior, and effectiveness. The general block diagram and Multibody simulation for the robot motor and mechanism are shown in Fig.6, and 7. Comprehensive analysis is possible due to the automated and random nature of the simulation procedure. The ability to choose which revolute joints you want to alter and choose the ideal starting circumstances.

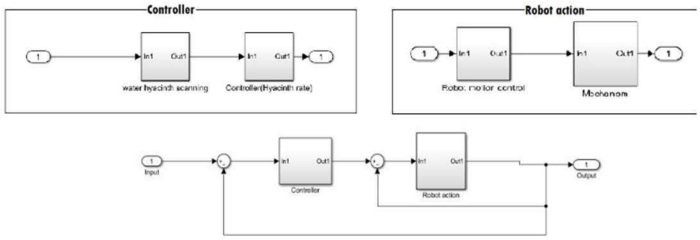


Fig. 6. General block diagram for harvesting robot control

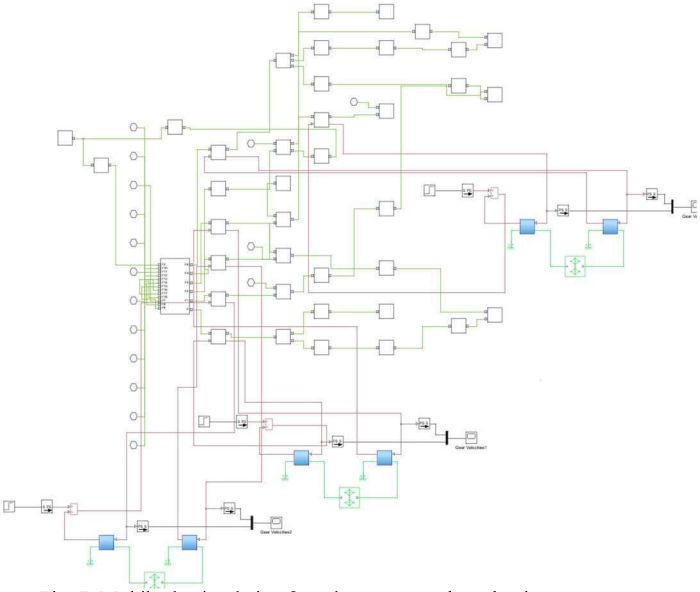


Fig. 7. Multibody simulation for robot motor and mechanism

B. *Control system*

At the core of the system, there is a microcontroller that functions on a 9-volt DC power source, as shown in Fig. 8 which supplies 3.3 volts to the GPS module and the Xbee (sender) module, while the transducer receives 5 volts. The microcontroller receives electrical signals containing obstacle data from the transducer and position coordinates from the GPS module. The Xbee module serves the purpose of creating a radio link between the microcontroller and the PC. For data collection and monitoring, LabView will be employed on the computer to process the received data.

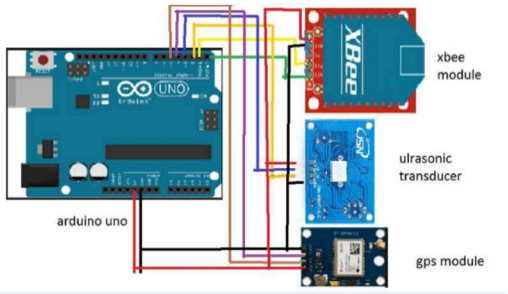


Fig. 8. Wiring diagram for harvesting robot maneuvering control

C. *The proposed water hyacinth harvester robot's cost analysis:*

The feasibility assessment for the proposed water hyacinth harvesting robot includes evaluating the boat, harvesting mechanism, power supply unit, and control unit. Estimated operational and maintenance costs are approximately 20% and 30%, respectively. The feasibility equations provided below [28], [29] are utilized to calculate the productivity cost of the suggested harvesting robot.

Fixed cost of the system (co)

The proposed system's fixed cost (Co) includes the expenses associated with the boat, harvesting mechanism, power supply unit, and control unit, amounting to $10,000.

Annual Operating Cost (Ac)

The annual running costs (Ac) encompass operation costs, set at 20% of the fixed cost, and maintenance costs, estimated to be 30% of the initial investment. The fuel, however, is provided free of charge. Labor and other miscellaneous expenses were not taken into account.

Capital recovery factor (CRF)

The annualized value, equivalent to the initial investment, was calculated using Eq.23: where (d) denotes the discount rate set at 12% in the current analysis. The discount rate allows future cash flows to be adjusted to their present value. The estimated life of the system components (L) is 20 years.

$$CRF=\frac{d(1+d)^{L}}{(1+d)^{L}-1} \quad (23)$$

where (d) denotes the discount rate set at 12% in the current analysis. The discount rate allows future cash flows to be adjusted to their present value. The estimated life of the system components (L) is 20 years.

Annual life cycle cost (ALCC)

The present value of all expenses incurred over the proposed hyacinth harvester robot's lifespan was obtained by adding the present value of the annual expenditure to the initial investment, utilizing Eq. 24 to calculate ALCC.

$$ALCC=(Co\times CRF)+Ac \quad (24)$$

Annual productivity (Ap)

To determine the annual hyacinth productivity (Ap), the daily productivity (the number of operation days per year) was multiplied by the number of operation days per year.

Hyacinth productivity costs (c)

Eq.25 was used to calculate the cost of hyacinth productivity.

$$C = ALCC/A_p \quad (25)$$

IV. Results

Force and productivity analysis:

The outcomes of the study demonstrate the effectiveness of the proposed robot in handling water hyacinth and performing successful harvesting. The robot's key specifications are as follows: dimensions of 120 * 100 * 200 cm, a speed of 0.5 m/s, an hourly coverage area of 10,000 m^2, an average density of 96 kg/m^3 for water hyacinth, and pallet dimensions of 50 * 70 * 30 cm. Figure 9 shows a comprehensive view of the water hyacinth boat machine's overall load, along with the distribution of forces, loads, and torques acting on the motor, is presented. This illustration sheds light on the forces' size and direction affecting different components.

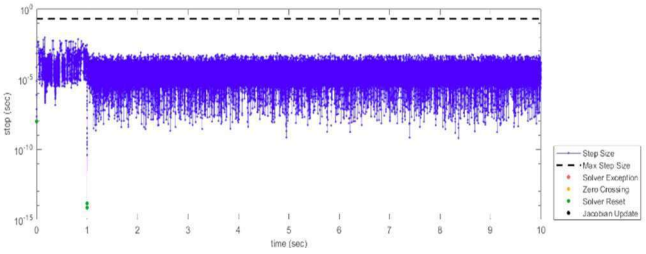


Fig. 9. Forces distribution for harvesting robot

During the initial startup, the motor faces a substantial load, potentially higher than the constant loads during regular operation. As the machine runs, the motor and other vital components bear continuous loads. The diagram also reveals the load and force distribution across various joints and sections, which helps identify areas where reinforcement may be required to maintain the structure's integrity and pinpoint potential stress concentration points.

The results of the robot's operation and the total productivity of the harvested water hyacinth are shown in Table 1. Considering the proposed robot's operational schedule of 300 days per year and factoring in all relevant aspects, it can be concluded that the robot is capable of harvesting approximately 5,115 kg of wet hyacinth daily or about 409 kg of dewatered compressed hyacinth daily. The estimated production cost for dewatered hyacinth is approximately 0.0106 $/kg, making it a viable resource for supplying pharmaceutical, fertilizer, cosmetics, biomass, and other manufacturing plants.

Table 1. The water hyacinth harvested result.

Time (hr)	Area coverage (m2)	Robot speed (m/s)	Harvested weight (Kg)
4	1100	0.5	3650
6	1700	0.5	5115
8	2100	0.5	6750
10	2600	0.5	8000

The following are the benefits of the proposed water hyacinth harvesting technique:

In the following ways, the proposed harvesting technique outperforms other types of harvesting:

Simplicity

The suggested water hyacinth harvesting strategy involves a basic robot powered by a single motor, utilizing a set of uncomplicated parts that can be easily disassembled, installed, and maintained.

Multifunctional

Furthermore, besides its main function of harvesting water hyacinth, the robot can be employed for water purification, removing various crops and suspended impurities from waterways, and monitoring different sections of water bodies.

Environmentally friendly

The suggested system operates without the use of fossil fuels, produces no emissions, and does not include any hazardous or environmentally harmful components, thereby presenting an eco-friendly solution for water hyacinth harvesting.

Efficacy of disinfection

In contrast to conventional methods, the proposed robot performs flower separation and collection during the harvesting process, effectively minimizing the chances of water hyacinth regrowth.

V. Conclusion

The proposed robot is highly adaptable, functioning effectively in diverse aquatic environments like rivers, canals, seas, or bays, regardless of their width. This versatility enables the robot to operate in confined spaces, stagnant waters, and even remote and challenging locations. Operating at a speed of 0.5 m/s with a belt velocity of 2 m/s, the suggested water hyacinth harvester robot demonstrates impressive potential. It distinguishes itself from alternative water hyacinth control methods through its cost-effectiveness, boasting a low productivity cost of $0.01 per kilogram of harvested water hyacinth, surpassing the rates of other technologies. Furthermore, the robot excels in efficiency, reliability, performance stability, ease of deployment, and environmental sustainability.

Symbols and Abbreviations:

L_H:	hull length
B:	beam
DCB or T:	draft
C_P:	Prismatic Coefficient
LTD or D:	light displacement or displacement
DWT:	deadweight
LWL "	length of the boat at the waterline
AVS:	Angle of vanishing stability
SSV:	Screening stability value
BR:	Ballast ratio
DV:	displaced volume
V:	The immersed volume of the hull
A:	The maximum cross-section area
L:	The waterline length

Cap:	Capsize Screening Factor
θ:	angle of wrap
μ:	coefficient of friction

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