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Sala: An Autonomous Water Trash Skimmer Using Path Planning Algorithm

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[1, 2, 3, 4, 5] Pamantasan ng Lungsod ng Maynila

Abstract

This research aims to develop and evaluate the prototype Sala. This autonomous water trash skimmer utilizes a path planning algorithm for the effective collection of plastics, particularly microplastics - referred to as small plastic particles that are less than 5 mm. These can be found in various significant aquatic habitats, encompassing oceans, lakes, and rivers. The primary objective of this study is to lessen the accumulation of plastic trash in aquatic habitats. To address the issue, Sala is equipped with a dual filtration system that separates the microplastics from macro-plastics. Additionally, Sala has a mobile application that has been developed to monitor the robot's activities. The application shows the fullness of the microplastics compartment and the concentration levels of microplastics in the sample water with the help of an ultrasonic sensor. The rapid and dependable flow of data between the robot and the application is notably facilitated by ESP8266, ensuring seamless connection. Using Arduino Mega 2560, in conjunction with a path following algorithm, facilitates the effective gathering of microplastics.

Keywords: marine waste management, microplastic, path planning, ultrasonic sensor, water robot.

1. Introduction

The emergence of water pollution resulting from the accumulation of plastic waste and microplastics has become a significant and urgent environmental concern in recent times. Plastic debris in aquatic environments substantially risks various ecological systems, wildlife populations, and human well-being. Inadequate waste management practices primarily cause plastic pollution in aquatic environments, release pollutants from industrial activities, and breakdown of larger plastic objects [1], [2].

Microplastics, particles smaller than 5 mm, have been observed in various aquatic environments, including rivers, lakes, and oceans. Identifying these particles has generated concerns regarding their potential consequences on the environment and human well-being [3], [4]. In a recent investigation by researchers hailing from the Mindanao State University - Iligan Institute of Technology, an intriguing discovery was made regarding microplastics within the surface water of Laguna de Bay [5]. As the largest lake in the Philippines, its findings of inaugural documented evidence of the presence of microplastics within the surface water of the lake is significant. This prevalence can be attributed primarily to the extensive human activities occurring in the regions adjacent to this lake area, notably encompassing cities within the Metro Manila area. The increasing occurrence of microplastics originating from single-use items, such as plastic bottles and packaging, is a considerable concern [6]. Microplastics in Laguna de Bay's surface water raise questions about the potential impacts on the lake's ecosystem and the communities relying on its resources. Additionally, concerns have been raised about the potential sinking of microplastics to the lake's deeper regions and sediments, which necessitates further investigation [5].

In this study, the researchers aim to address the pressing issue of plastic waste and microplastic pollution by focusing on the San Juan River in Quezon City, which serves as a vital water body in the area, and understanding the occurrence and sources of microplastics in its waters is crucial for developing effective strategies to mitigate plastic pollution. Motivated by the findings from a recent investigation in Laguna de Bay, the primary objective of this research endeavor is to provide a prototype aimed at lessening the build-up of water and plastic residues within aquatic ecosystems and offer valuable elucidations regarding the specific types of microplastics found.

related Literature and Studies

A. Path Planning for Water-Based Robots

Path-planning mechanisms have been used for underwater robot operations. A 2019 study shows results for enhanced robot tracking and navigating after using it in a multi-fin underwater robot through a mathematical model [7]. It can also be used through an improved ant colony system (IACS) to introduce a novel path-planning algorithm for water area-based robots. There is improved efficiency and accuracy for robot path planning when partnered with a pheromone updated mechanism and adaptive weighted factor into its classic ant colony optimization algorithm, as revealed from the test results from simulations and experiments [8]. Such results show implications and potential aid in the environmental monitoring and scientific research of using path-planning to improve the navigation and tracking of water-based robots.

More recent studies aim to develop a path-planning and control method for water surface robots through an upgraded A* algorithm by evaluating through simulations and experimentations. Results demonstrated enhanced accuracy and efficiency in robot path-planning and control for water surface robots [9]. To devise a new path planning and trajectory control approach for amphibious robots equipped with water jet propulsions mainly used on challenging terrains, a mathematical model of the robots' motion and dynamics was created. It will generate a trajectory generator and LQR-based controller, tested on a real robot where findings showed it could navigate challenging terrains [10]. The results from both studies indicate significance in the control engineering applications, marine industry, military, and rescue missions, and even more so, environmental explorations.

B. Ultrasonic Sensor for Floating Water Debris

An autonomous system for detecting and tracking garbage on water surfaces using an ultrasonic sensor module and a camera with a GPS module to track the cleaning bot's location and a wireless connection module to relay data to the operator was tested in a swimming pool to see its effectivity. The results exhibited that the cleaning bot can efficiently clean the water's surface and navigate autonomously, including avoiding obstacles and modifying speed based on the trash density [11].

Likewise, operating a sensor fusion to propose an autonomous system for water quality monitoring and surface cleaning through a system of an autonomous floating robot outfitted with a turbidity sensor, ultrasonic distance sensor, and pump for filtering water surface. The proposed system was tested in water ponds and through a logic program combining sensor data regulating the movements and surface cleaning activities of the robot. Results showed its effectiveness in monitoring water quality and cleaning water surface [12] which proves significant in its potential range of environmental applications such as oil spill detection and water pollution management in lakes, rivers, and seas.

A programmable logic controller (PLC) for a smart system in a Seabin prototype was developed and tested its efficiency in removing floating garbage from bodies of water. The Seabin prototype is a floating trash can place in marinas, harbors, and other bodies of water to collect floating litter, debris, and microplastics from the ocean's surface. The smart system for this project was then intended to increase the efficiency of the Seabin by operating a PLC that allows real-time monitoring and control of the pump motor, water level sensors, and other Seabin components. It was recommended that a human-machine interface (HMI) be used to control and monitor the system, allowing the operator to visualize and control the operation of the Seabin remotely. The system's performance was assessed using a series of trials illustrating the PLC's capacity to control the Seabin's operation, allowing it to gather and segregate floating debris from the water efficiently [13].

2. Methodology

A. Research Design

The proposed study will integrate a prototype research design by developing a working model prototype that collects water debris from freshwater by equipping it with a dual filtration system for segregating larger water wastes from microplastics. A mixed-exploratory methodology will be utilized to investigate the potential viability and efficacy of the proposed Sala system.

The researchers utilized the V-model methodology for research and development purposes. The V-Model technique is highly appropriate for the present research investigation, specifically within the realm of designing and evaluating a technological intervention such as the Sala robot for microplastic retrieval. The V-Model's structured and systematic methodology, prioritization of early validation, concurrent development and testing, traceability, and early identification of defects render it highly suitable for a research investigation centered on the development and testing of a technological solution, such as the Sala robot, and its functionalities which include microplastic collection, monitoring of microplastic concentration level, and the efficacy of its path planning algorithm.

B. Sampling Technique and Instrument

Convenience sampling, as a method of participant selection, offers the advantage of choosing individuals based on their availability and accessibility. The study employed a mixed-methods approach, utilizing both face-to-face and online structured interviews with predefined questions to gather data from Estero Rangers, river and creek clean-up volunteers, and barangay representatives. In accordance with ethical study protocols, researchers took measures to secure informed consent from all participants before conducting interviews and collecting data. On average, the interviews had a duration ranging from 20 to 30 minutes.

The conducted survey was able to gather 21 respondents, comprising of three different groups, first is the IT professionals, second are the Engineering professionals that specialize in robotics, and lastly creek and river clean-up volunteers. There are 8 (38.1%) IT professionals, 8 (38.1%) Engineering professionals, and 5 (23.8%) creek and river clean-up volunteers who were able to see the demo video of the application and the robot. The questions used for the survey questionnaire were based on the four selected criteria of ISO Standard 25010: Functional Suitability, Performance Efficiency, Usability.

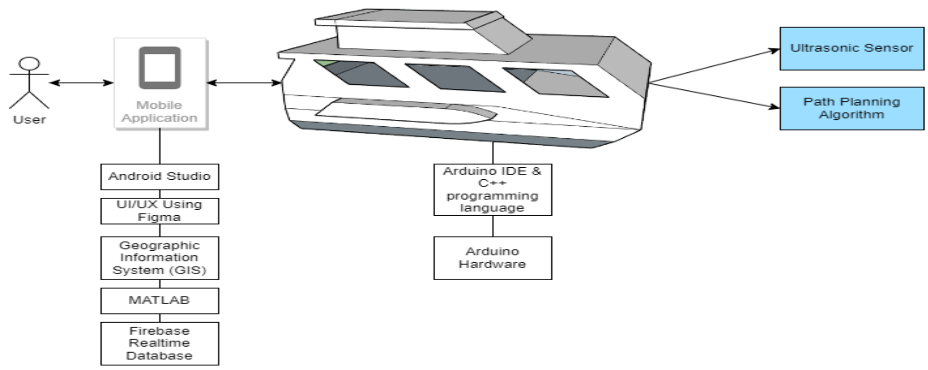
Further, robot testing was conducted in accordance with its robot, and the application's functionality is working and performing as intended. Tests are also conducted for the accuracy of getting the mass of the microplastic collected, in which the computation can be seen in equation 5, and the length of the path taken by the robot based on the predetermined patterns in the application; this is tested through a static distance measurement test. The researchers also gathered feedback from participants regarding the robot's ease of use and effectiveness in cleaning up debris through a demo video. The demo video is provided to participants through an online Google Forms survey.

Table i. The Four-Point Likert Scale of Agreement (Suga, 2023)

Description	Likert-Scale	Likert Scale Interval
Strongly Disagree	1	1.00 – 0.99
Disagree	2	1.99 – 1.00
Agree	3	2.99 – 2.00
Strongly Agree	4	4.00 – 3.00

C. System Design

1) System Architecture



2) Fig. 1. The system architecture of Sala encompasses several key components: the user, the Sala mobile application, the ultrasonic sensors, and the path-planning algorithm.

3) Sala Mobile Application User Interface

Fig. 2. The features of the Sala Mobile application comprise a homepage with robot options, microplastic concentration monitoring, its path planning fragment, the distance between the robot and the shore, the remote control option, and the water pump's switch button.

4) System Flowchart

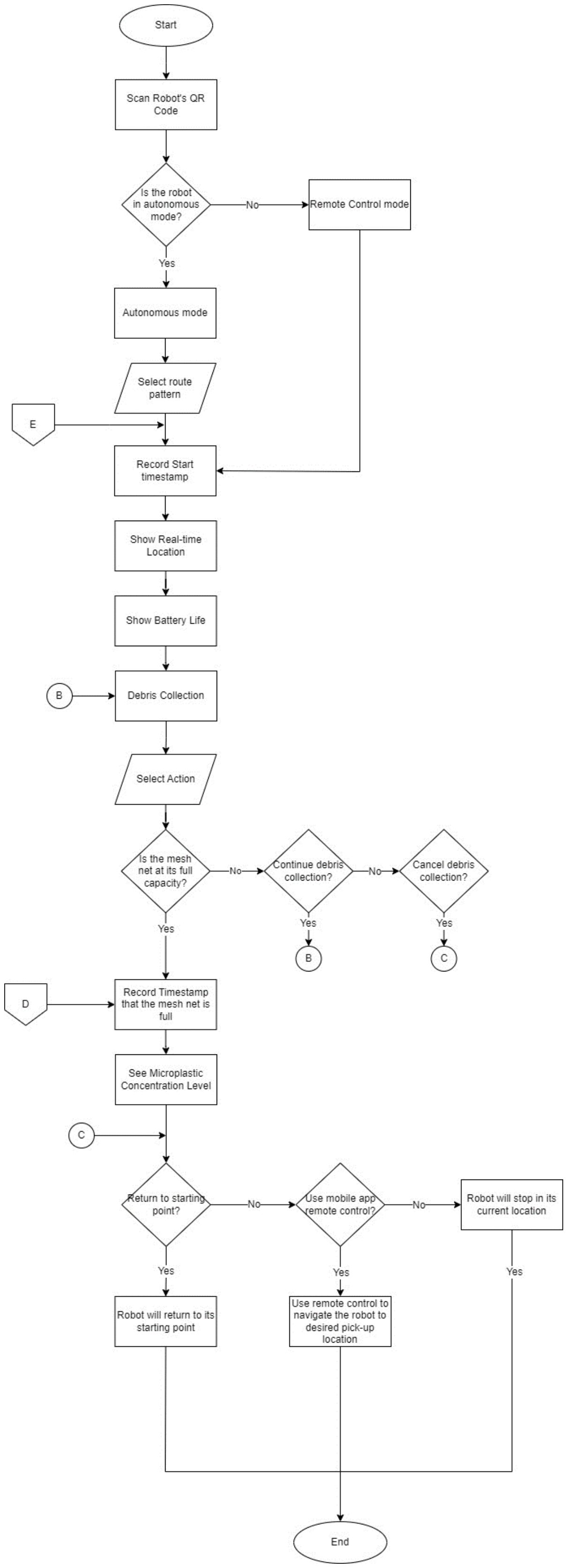


Fig 3. Sala Main System Flowchart.

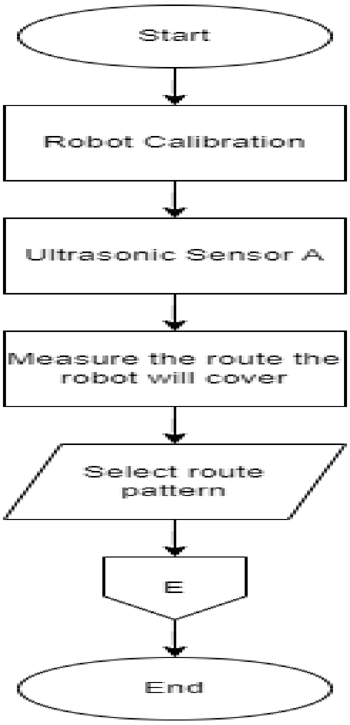


Fig 4. Path Planning System Flowchart.

Initial robot operation entails calibrating and measuring its intended path. Use ultrasonic sensor A, strategically placed at the robot's front. After calibration, the user will choose the robot's best path plan to improve debris collecting.

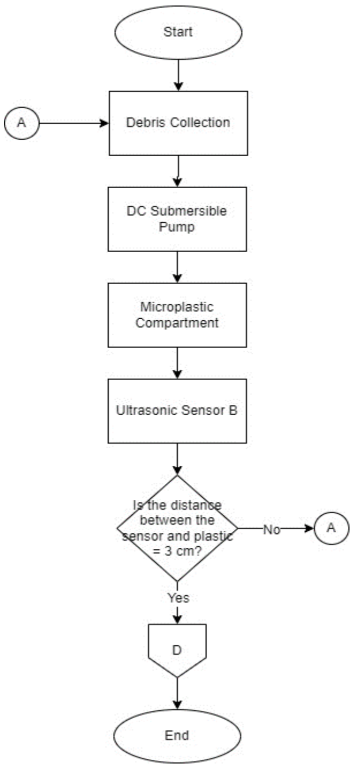


Fig 5. Microplastic Concentration Level Using Ultrasonic Sensor.

The figure below depicts how *Figure 4* works. With the use of ultrasonic sensor HC SR04, this measures the distance between the microplastic collected by the robot. Once the ultrasonic sensor detects that the distance between it and the microplastic collected is equal to 3 centimeters, the robot will prompt the mobile application that the compartment is full.

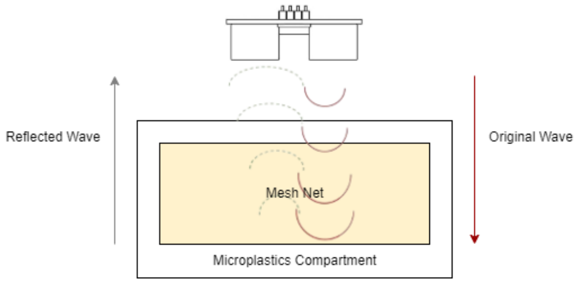


Fig 6. Ultrasonic Sensor for monitoring Microplastic Compartment's Fullness.

5) Circuit Diagram

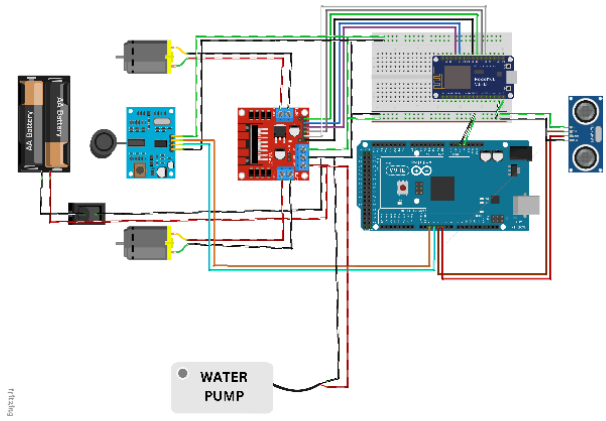


Fig. 7. The circuit diagram used in the Sala.

D. Data Analysis and Procedures

1) Survey Results

Using the formula below, the researchers computed the mean of the survey results to evaluate the system. The survey results were tallied and rated using the four-point Likert scale of agreement, as shown in Table I.

$$\bar{x} = \frac{\Sigma x}{n}$$

Where:

$\bar{x}$ is the sample mean

Σ is the summation notation, summing up a series of values (xi), where xi denotes all x-values

n is the number of items within the sample

2) Evaluation of Sala

The ISO standard quality model 25010, which offers a thorough framework for evaluating the quality characteristics of software systems, will be used to evaluate Sala as it specifies several important criteria that can be used to evaluate the Sala system which are the *Functional Suitability, Performance Efficiency, Usability, Maintainability, and Portability.*

The functionality of the Sala system should be assessed when collecting water waste, filtering microplastics, and correctly identifying them using the microplastic identifier module. The device should show dependably accurate results when measuring the amount of microplastics in water samples.

The Sala system's usability should also be assessed, considering its simplicity and user-friendliness. The system should have a user-friendly interface that makes it simple for researchers and stakeholders to interact, facilitating easy operation, monitoring, and data interpretation.

3) Microplastic Concentration Measurement

The equation below determines the microplastic concentration per unit volume of water. The standard unit of measurement for the concentration of microplastics is particles per liter (particles/L).

$$Amc \times (Nh - Ih) = MAM$$
$$MAM \times Md = TPM$$
$$Q \times t = V$$
$$\boldsymbol{C = \frac{TPM}{V}}$$

Where:

Amc is the area of microplastic compartment
Nh is the new height
Ih is the initial height
MAM is the microplastics accumulated mass
Md is the microplastic density constant at $1g/cm^3$
TPM is the total microplastic mass
Q is the pump rate constant at 5L/min.
t is the elapsed time
V is the volume of sampled water in liters
C is the microplastic concentration level (particles/L)

The amount of microplastics acquired is computed based on the ultrasonic sensor of the Sala robot which measures the height of the microplastics compartment. The area of the microplastics compartment, the initial height, and density of microplastics shown in formula 1 and 2 are constants.

As for the computation of the volume of sampled water shown in formula 3 the pump rate of the Sala robot is constant (5L/m) multiplied to the elapsed time that the robot is collecting microplastics.

3. Results and Discussion

A. Interview Data Results

According to the accounts provided by the participants during the interviews, the aspect that was identified as the most arduous while engaging in their work was the ability to segregate the different types of debris and monitoring the concentration levels of each type of debris manually. One participant said it was difficult to calculate and distinguish between different fractions of debris, such as ¼ and ⅛. They frequently estimated the overall number of debris gathered as a result, and they would note any findings in the remarks area. The Estero Rangers who were interviewed indicated that the clean-ups they do mostly entail human labor and that they have not seen any equipment being employed to aid in their clean-up operations. This implies that a significant portion of the cleanup procedure depends on the participants' physical efforts. The participants frequently come across different kinds of waste during their clean-ups. Plastics, microplastics, wood, and Styrofoam are the most often discovered waste. Particularly, the majority of the microplastics they gather are tiny fragments of plastic bottles, bottle caps, and sachets.

All the participants agreed that the amount of debris in a specific region mostly determines the priority levels for clean-ups. The Department of Environment and Natural Resources' (DENR) Estero Rangers have a set timetable for cleanups during the weekdays from 8 am to 5 pm. On the other hand, residents of a different barangay organize their cleanups on weekends and during holidays. This discrepancy in scheduling shows that the order of clean-ups may vary depending on participant availability and the requirements of each region. The Estero Rangers' set weekday timetable enables consistent clean-ups, but the other group's weekend and holiday program considers participants' availability.

B. Robot Testing Preliminaries

The robot testing is done four times, each with varying durations. The visual representations presented for each test illustrate the quantity of microplastics collected. The findings from each trial demonstrate a persistent upward trend in the amount of microplastics accumulated by the robotic device as time progresses. By examining the data gathered from each test, researchers can enhance and optimize the robot's capabilities to achieve optimal efficiency.

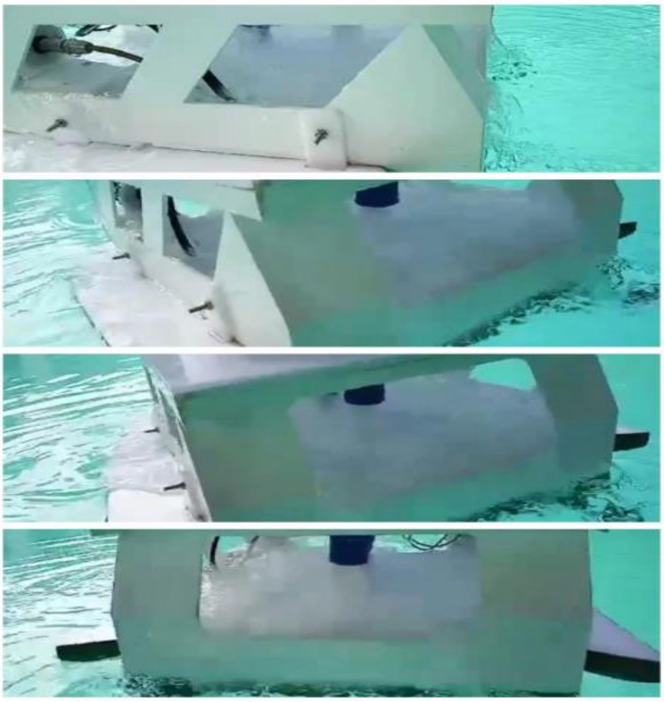


Fig. 8. The researchers calibrated the Sala before the official testing as a preliminary step to ensure the pump was strong enough to deliver the water to the microplastic compartment.

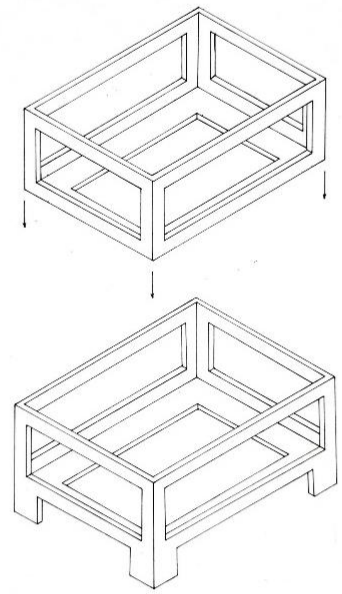


Fig. 9. Microplastic's compartment blueprint was designed appropriately to prevent any leakage or loss of microplastics during the clean-up process. This preliminary step guarantees accurate and reliable data collection, reinforcing the validity of the subsequent test results.

C. Sala Ultrasonic Distance Sensor for Microplastics Concentration Level

Table ii. Static Distance Measurement Test – Ultrasonic Sensor (Microplastics Compartment)

Detected Distance (mm)	Actual Distance (mm)	Absolute Error (mm)
2.51	2.5	0.01
2.72	2.64	0.08

3.32	3.35	-0.03
4.75	4.8	-0.03
5.21	5.5	0.34

The analysis of the measurements shows that the absolute error consistently stays below 0.3mm. This means that the sensor consistently either overestimates or underestimates distances by a margin of less than 0.3mm. The accuracy of the sensor decreases noticeably when measuring distances greater than 5mm. For the measurement of 5.21mm, the sensor recorded an absolute error of 0.29mm, suggesting that it overestimated the value.

D. Sala Path Planning Distance Taken per Trajectory per Path Pattern

Table iii. Static Distance Measurement Test – Pattern A

Directions	Detected Distance (mm)	Actual Distance (mm)	Absolute Error (mm)
North	32.3	30	2.3
East	21.5	20	1.5
East	25.7	25	0.7

Table iv. Static Distance Measurement Test – Pattern B

Directions	Detected Distance (mm)	Actual Distance (mm)	Absolute Error (mm)
North	12.2	11	1.2
East	22.34	21.5	0.84
West	10.8	10	0.8
West	23.52	22	1.52
East	11.65	10	1.65

The static distance measurement test is an important metric for evaluating the accuracy of the path following algorithm in determining the distance between the robot and its intended path. The assessment results show that the path following algorithm performs well in accurately determining the proximity between the robot and its desired trajectory. The absolute error consistently stays below 2.3mm in all measurements, indicating that the algorithm consistently overestimates the distance by a margin of 2.3mm or less. The observation highlights the algorithm's dependable nature in ensuring accuracy while calculating and adjusting the robot's position in relation to its intended path.

E. Sala Evaluation

The researchers' assessment criteria for the study's first objective, "Sala: An Autonomous Water Trash Skimmer using Path Planning Algorithm," and its robot and application are presented in this part. The questions asked were selected based on the criteria of ISO Standard 250.10, namely, functional suitability, usability.

1) Functional Stability

a. Functional Completeness.

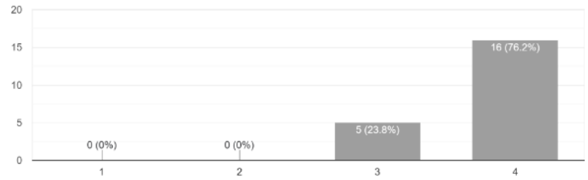


Fig. 10. Among the 21 respondents, there are 5 (23.8%) agreeing users, and 16 (76.2%) strongly agreeing that the application responsible for monitoring the robot's operations has been fully developed and properly working.

b. Functional Correctness

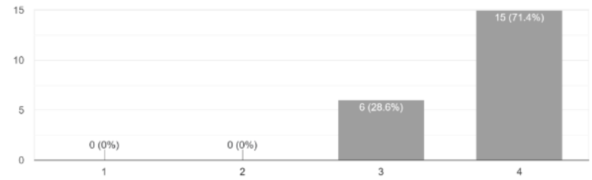


Fig. 11. Among the 21 respondents, there are 6 (28.6%) agreeing users, and 15 (71.4%) strongly agreeing that the robot's mobile application accurately sends notifications and data on the robot's activities.

c. Functional Appropriateness

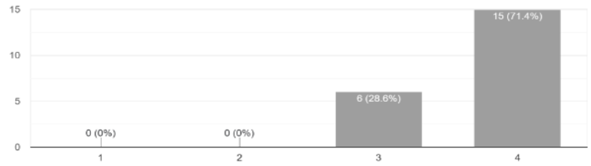


Fig. 12. Among the 21 respondents, there are 6 (28.6%) agreeing users, and 15 (71.4%) strongly agreeing that the robot's design and capabilities align well with the specific requirements for collecting microplastics and debris.

2. Performance Efficiency

a. Time Behavior

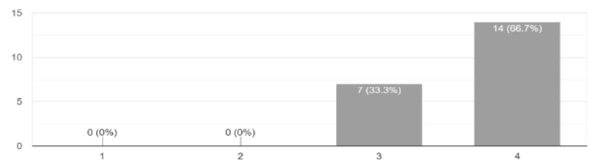


Fig. 13. Among the 21 respondents, there are 7 (33.3%) agreeing users, and 14 (66.7%) strongly agreeing that the robot sends information about the percentage fullness of the microplastic compartment and the microplastic concentration level to the application.

3. Usability

a. User Interface Aesthetics.

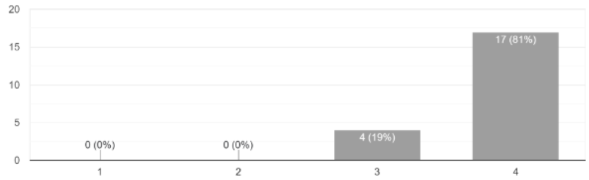


Fig. 14. Among the 21 respondents, there are 4 (19%) agreeing users, and 17 (81%) strongly agreeing that the user interface of the robot is visually appealing and enhances the overall user experience.

b. Operability.

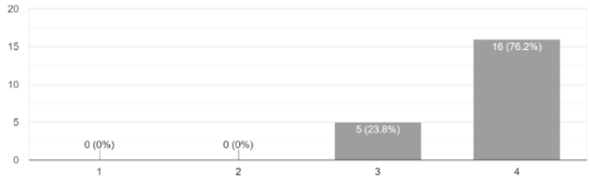


Fig. 15. Among the 21 respondents, there are 5 (23.8%) agreeing users, and 16 (76.2%) strongly agreeing that the users find the robot and the application easy to operate during microplastic collection.

F. Online Survey Results

The rating system shown in Table I was used to rate the mean results of the survey presented in Table V. It shows that the four of the criteria were classified with “strongly agree,” which are Functional Suitability which garnered a 3.73 mean score, Performance Efficiency, with a 3.67 mean score, and Usability garnered a 3.79 mean score.

Table v. The Overall Results From Online Survey

Criteria	Mean	Interpretation
Functional Suitability	3.73	Strongly Agree
Performance Efficiency	3.67	Strongly Agree
Usability	3.79	Strongly Agree

4. Conclusion

The researchers successfully designed and created the Sala robot with a functional dual filtration mechanism separating microplastics from macro water debris. The study focused on ensuring the robot's initial phases' reliability, evaluating the water pump's durability, and the efficiency of the collection system. The preliminary stages helped the researchers yield reliable results on the accuracy tests conducted on the accuracy of microplastic concentration level and the path following algorithm. The integration of the path planning algorithm enhances user control, enabling them to choose the robot's route for optimal waste collection strategically. The area of the microplastic compartment is 165cm enabling the robot to collect 660g of Total Microplastic Mass (TPM) if the compartment is full. The concentration level varies depending on the volume of sampled water in liters. The application accurately shows the robot's activities and is able to prompt the user once the robot is ready for collection. This robot will significantly aid in water waste management and decrease water debris, especially the arduous manual collection of microplastic.

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