Design and optimization of a modular aquatic robot for collecting floating microplastics

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Abstract

Microplastic pollution has become one of the most significant environmental problems affecting aquatic ecosystems worldwide. These plastic particles, which are smaller than 5 mm, are difficult to remove due to their buoyancy and variety of shapes, which limits the efficiency of traditional collection methods. In this study, a modular aquatic robot was designed and built to evaluate how the angle of the filtration system influences the capture efficiency of simulated floating particles. The experiment was conducted in a controlled aquatic environment using a school swimming pool, where 35 simulated microplastic particles were placed in each trial. Two configurations of the filtration system were compared: one horizontal (0°) and one inclined (45°). The robot operated for four minutes per trial, and each experimental condition was repeated six times to ensure the reliability of the results. The results showed that the 45°-inclined system achieved capture efficiencies between 41% and 47%, while the horizontal configuration achieved only between 10% and 14%. Furthermore, the inclined system exhibited less variability between experimental runs, indicating greater stability in the collection process. These findings suggest that geometrically optimizing the filtration system can significantly improve the performance of aquatic robots designed to collect floating pollutants, demonstrating the potential of environmental robotics as a tool for monitoring and cleaning aquatic ecosystems. We chose this project to highlight the importance of technology and engineering in developing innovative solutions for real-world problems. It also aims to show that, even with limited resources, we can create meaningful alternatives to address global challenges like microplastic pollution.

Background & Motivation

Microplastics are widely distributed in aquatic environments and pose risks to marine life and potentially human health. Their small size and floating behavior make them difficult to remove using conventional methods, which are often inefficient and inconsistent.

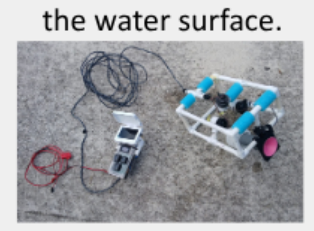
This project was inspired by the need to develop practical and innovative solutions using accessible technology. Initially, the idea was to create biocement using algae, but due to time limitations, the focus shifted toward aquatic robotics. Previous experience with robotics led to the development of this project as a way to apply engineering to a real environmental problem.

Beyond solving a technical challenge, this project represents the importance of using innovation and available resources to create solutions for global issues. It also reflects the reality of coastal communities like Puerto Rico, where environmental challenges directly impact daily life.

Methodology

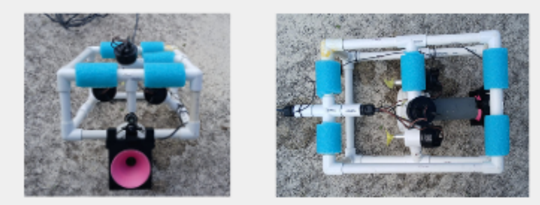
System Setup

A school swimming pool was used as a controlled aquatic environment. In each trial, 35 simulated microplastic particles (3 mm and 5 mm) were manually placed on the water surface.



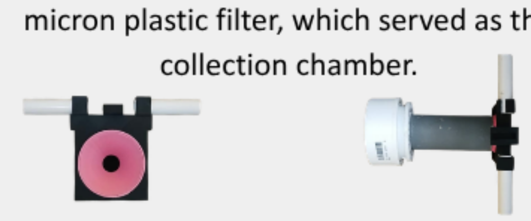
Robot Structure Design

A rectangular floating structure was developed to provide stability and buoyancy, allowing the robot to move effectively through the water.



Collection System Development

A passive front-entry collection system was designed using 3D printing. It consisted of a funnel that directs particles into a PVC pipe connected to a pipe cap fitted with a 300-micron plastic filter, which served as the collection chamber.

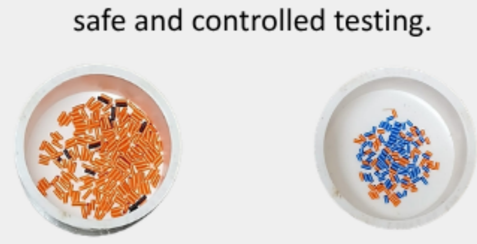


Conducting the Experiment

The robot operated for 4 minutes in each trial, allowing the passive collection system to capture floating particles as the robot moved.

Microplastic Simulation

Simulated microplastics were created using 3D printing filament, with particle sizes of approximately 0.5 cm and 0.3 cm to ensure safe and controlled testing.

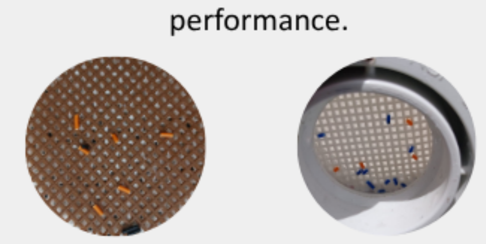


Visualization System

An underwater fishing camera was used to observe and monitor particle movement and collection during the experiments.

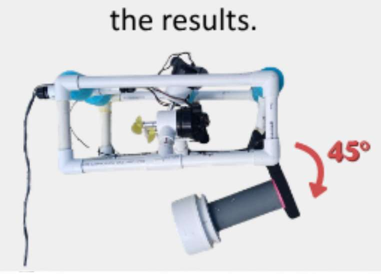
Particle Count

After each run, the collection chamber was emptied, and the number of captured particles was recorded to evaluate performance.



Replicates

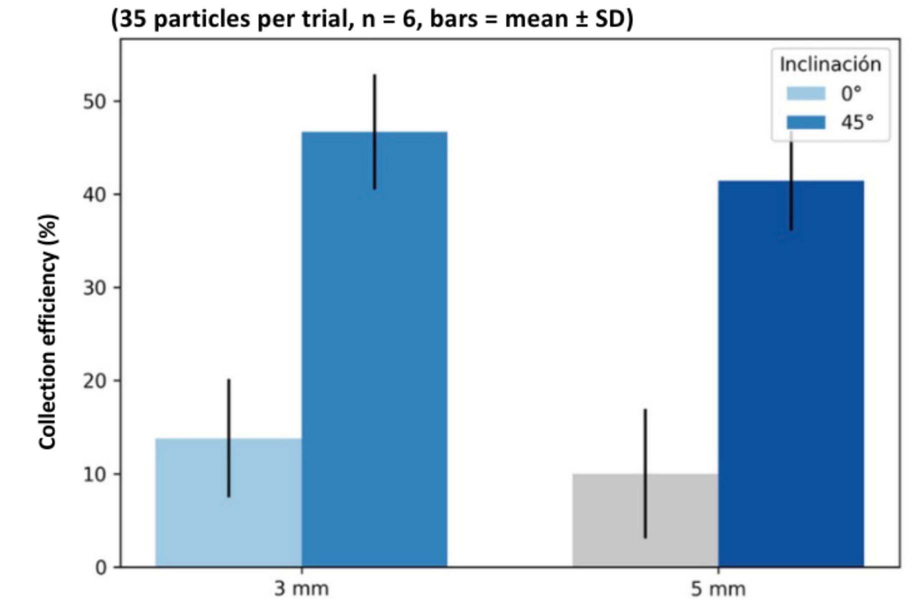
Each experimental condition was repeated 6 times (n = 6) with each inclination (45° and 0°) to ensure consistency and reliability of the results.



Results & Discussion

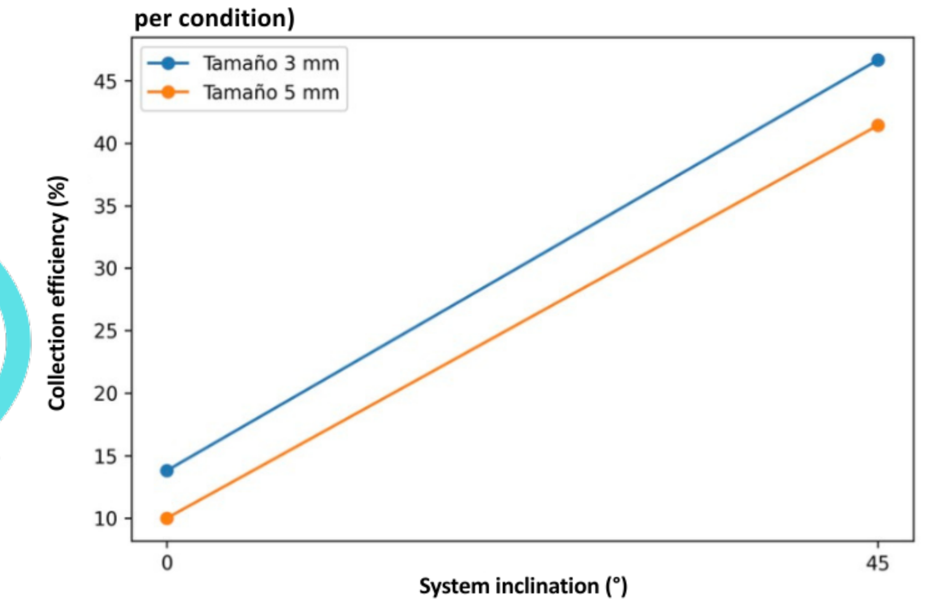
The results showed that the inclination of the capture system has a significant effect on the collection efficiency of the aquatic robot. The 45° inclined configuration achieved capture efficiencies between 41% and 47%, while the horizontal (0°) configuration produced considerably lower efficiencies, ranging from 10% to 14%. This pattern was consistently observed for both 3 mm and 5 mm particles, indicating that the effect of the system's geometry is independent of particle size. Additionally, the data showed less dispersion under the 45° condition, suggesting a more stable and reproducible performance. In contrast, the horizontal configuration exhibited greater variability between trials, indicating less control over the flow of particles toward the capture module. Overall, these results suggest that optimizing the geometry of the filtration system improves the direction of water flow, facilitating the transport of suspended particles into the collection chamber and increasing overall efficiency.

Graph 1. Collection efficiency (%) by particle size and inclination (35 particles per trial, n = 6, bars = mean ± SD)



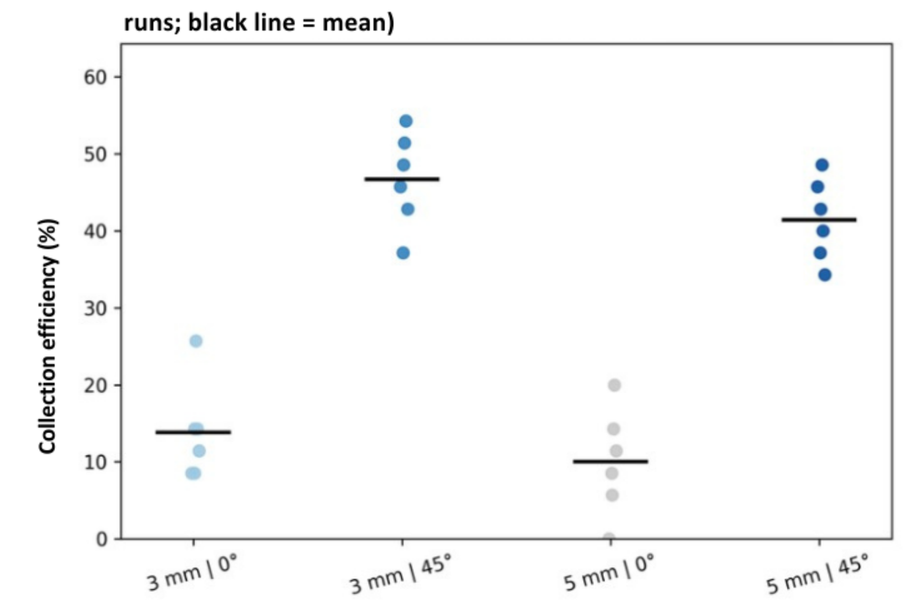
Comparison of the average collection efficiency of 3 mm and 5 mm microplastics under two capture system tilt configurations. The results show a significant increase in efficiency when the collection funnel is positioned at 45°, suggesting that the geometry of the system directly influences the ability to capture suspended particles.

Graph 2. Effect of inclination on average efficiency (line = mean, n = 6 per condition)



Analysis of the impact of the capture system's angle of inclination (0° vs. 45°) on the number of microplastics collected. The 45° inclination helped direct the flow of water and particles toward the capture module, increasing the number of particles collected compared to the horizontal configuration.

Graph 3. Distribution of runs (R1–R6) by condition (Dots = individual runs; black line = mean)



Distribution of the particles collected in each of the six experimental runs for each condition evaluated. This graph illustrates the consistency and variability of the capture system, showing that the runs with a 45° incline consistently yield higher collection values.

Conclusion

The results of the study demonstrated that the inclination of the capture system significantly influences the efficiency of microplastic collection in the aquatic robot. The 45° inclined configuration achieved higher capture rates and showed less variability between trials, indicating a more efficient and stable performance compared to the horizontal (0°) configuration. These findings suggest that the geometry of the filtration system improves the direction of water flow and particles toward the capture module, increasing overall efficiency. The developed prototype demonstrates that optimizing the mechanical design of aquatic robots can enhance the collection of suspended particles, providing a strong foundation for future robotic technologies aimed at mitigating microplastic pollution.

This project also has a direct impact on our communities by showing that it is possible to create positive environmental change through innovation and engineering. On a personal level, it has opened many opportunities in our professional development, allowing us to collaborate with different individuals and programs to further improve and expand this research.

Next Steps

Future work will focus on expanding the impact of this project and improving the robot's.

Technical Improvements

- Test additional filtration angles and designs to further optimize efficiency
- Integrate sensors to detect and quantify microplastics in real time
- Evaluate performance in real environmental conditions (saltwater, currents, waves)

Research Expansion

- Collaborate with mentors in marine science and engineering
- Study environmental factors such as oxidation and long-term durability
- Improve safety features to protect marine life

Environmental Context (Puerto Rico)

Living on a Caribbean island, natural disasters like hurricanes have significantly contributed to microplastic pollution. Events such as Hurricane María caused:

- Massive release of plastic debris from destroyed homes and infrastructure
- Flooding that transported waste into rivers and oceans
- Wave energy that broke plastics into microplastics
- Accumulation of pollutants in mangroves, reefs, and beaches

Even years later, these microplastics remain in the environment, affecting ecosystems and entering the food chain. This project aims to be part of a long-term solution by developing technology that can help mitigate pollution and protect coastal communities.

Acknowledgements

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