Course: Instrumentation and Control Systems (ME304)

Underwater Microplastic Sampling using a Biomimicking Robotic Stingray.

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Introduction-

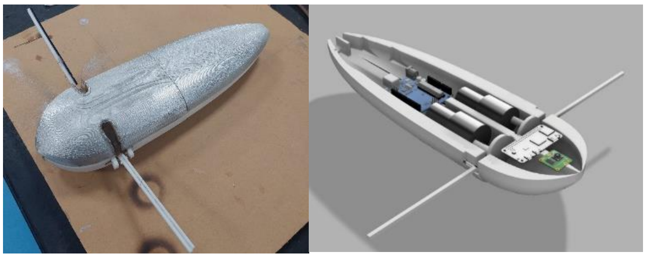
The alarming proliferation of microplastics in aquatic ecosystems has emerged as a pressing environmental concern, posing significant threats to marine life and human health. In response to this challenge, we went for an innovative approach integrating biomimicry and robotics for their potential in environmental monitoring and remediation.

In the first part of our project, we focused on the design and fabrication of the robotic stingray, drawing inspiration from the graceful and efficient locomotion of natural stingrays. The second part of our project involved equipping the robotic stingray with microplastic sampling capabilities.

Design of the Robot-

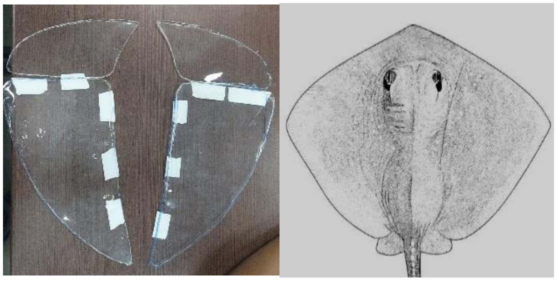
Stingrays exhibit a unique undulating motion, utilising their pectoral fins to propel themselves through water with remarkable agility and minimal energy expenditure. We sought to replicate its efficacy in our robotic design by studying the kinematics and hydrodynamics underlying this motion.

Body: For the central section, which houses all the electronics and actuators, we opted for a streamlined boat-shaped structure.



This part was 3D printed using PLA, with 30% infill to ensure that the bot is strong enough to resist its own buoyant force.

Fins: Stingrays have broad fins that run the full length of their bodies, giving them a flat, roundish shape. The fins are made with flexible material called PDMS (Polydimethylsiloxane), which is known for its elasticity and durability underwater. Plastic sheets are attached to the PDMS material to provide structural support and enhance the fin's shape and performance.



Actuation of the Robot-

Propulsion System: Unlike traditional propellers or thrusters, our robotic stingray features a unique propulsion system inspired by the undulating motion of stingray fins. Two flexible arms on each side of the robot execute a reciprocating motion, creating a sine wave pattern for movement. This biomimetic design enhances manoeuvrability and efficiency in aquatic environments, showcasing the transformative potential of biomimicry in propulsion technology.

Reciprocating Motion Mechanism: Each arm of the robotic stingray is connected to a DC motor through a cam follower mechanism. When the DC motor rotates, the cam follower converts this rotational motion into linear motion, resulting in the reciprocating movement of the arms. This ingenious mechanism allows for precise control over the motion of the arms, enabling them to mimic the undulating propulsion of natural stingray fins.

Control System: The movement of the robotic stingray is controlled by a sophisticated control system, which adjusts the speed and direction of the DC motors powering the arms. The robot can navigate through different water conditions and environments by modulating the frequency of the reciprocating motion.

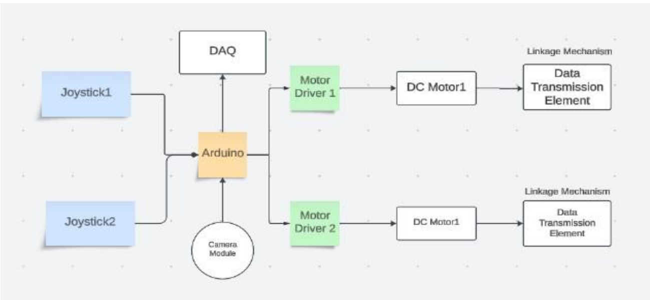
Sensing and Navigation: The robotic stingray is equipped with a camera at the front section so we can detect obstacles and navigate to specific sampling locations.

Figure 1 Picture of the final robot and controller

Electronics-

Our robotic stingray propulsion system incorporates two DC motors capable of rotating at 100 rpm, controlled by an Arduino microcontroller and motor driver shield.

Control is facilitated through a two-axis joystick, enabling precise manipulation of speed and direction for efficient navigation through water and microplastic sampling. The joystick on one axis controls both motor's rpm symmetrically, while on the other axis, it subtracts rpm from one motor and adds the same to the other, thus making the fins move at different speeds, allowing it to turn underwater.



Microplastic Sampling-

We have employed an ingenious method utilizing a Polydimethylsiloxane (PDMS) layer. PDMS, known for its remarkable adhesive properties (when uncured), is a versatile substrate onto which microplastics readily adhere underwater.

The utilization of PDMS sheets offers several advantages in our sampling approach. Firstly, the inherent adhesive nature of PDMS allows it to attract and retain microplastic particles upon contact, facilitating the efficient collection of samples from the aquatic environment. This adhesion mechanism ensures that even the smallest microplastic particles, which might otherwise evade detection, are captured and secured for subsequent analysis.

Furthermore, PDMS exhibits excellent biocompatibility and inertness, minimizing the risk of contamination or interference with the collected samples. This ensures the integrity of the microplastic samples, enabling accurate analysis and interpretation of the data obtained.

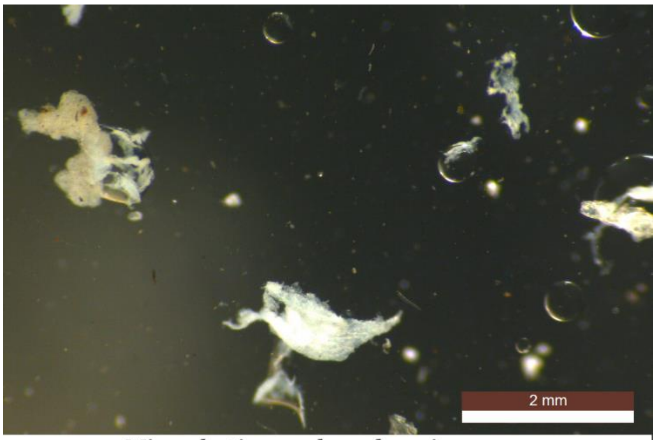
As our robotic stingray navigates through underwater environments, the PDMS sheets serve as reliable collectors, silently accumulating microplastic particles suspended in the water column. Once the sampling process is complete, the PDMS sheets are carefully retrieved, preserving the captured microplastics for further examination.

Microplastic sample on PDMS sheet after successful sampling

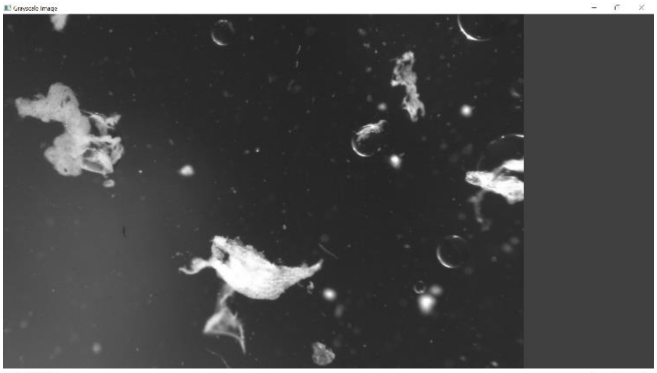
Microplastic Detection-

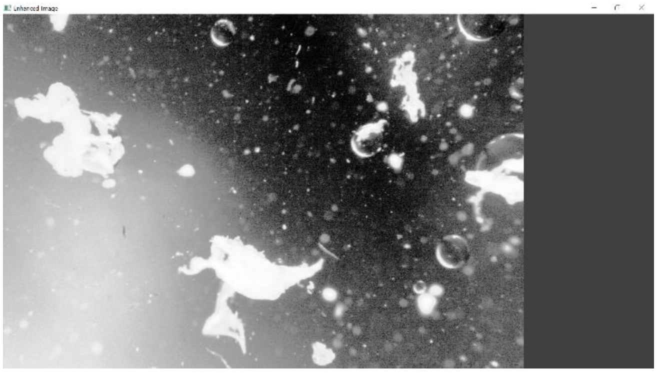
Using a stereomicroscope, we conducted a comprehensive examination of the collected samples. Equipped with binocular eyepieces and adjustable magnification levels, the stereomicroscope offered a detailed and three-dimensional perspective of the microplastic particles. As we scanned the samples, a diverse array of microplastic shapes, sizes, and colours emerged, ranging from translucent fragments to coloured fibres. We documented our findings, recording crucial parameters such as the size, shape, and composition of the microplastic particles. Additionally, we conducted density mapping to ascertain the concentration of microplastics within the samples.

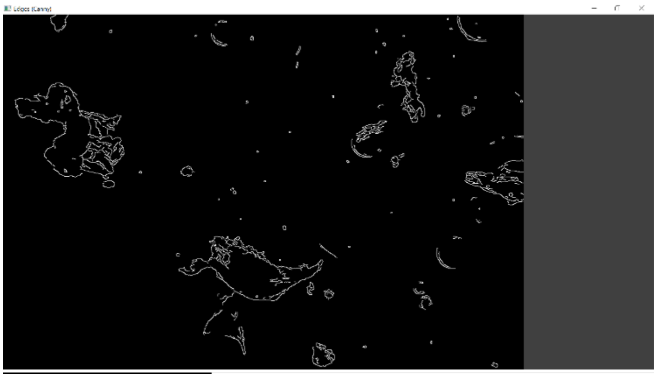
Image Processing: Utilizing the microscope-captured images, we engaged in basic image processing techniques. Initially, we transformed the images into grayscale to simplify their representation. Subsequently, employing the Canny edge detection algorithm, we generated binary images, accentuating the contrast between edges and background. We conducted density mapping analyses to see the spatial distribution and concentration of microplastic particles within the samples. This iterative approach facilitated the extraction of valuable quantitative data, enabling us to gain deeper insights into the microplastic distribution patterns and inform targeted remediation strategies effectively.



Microplastic sample under microscope







Future Prospects-

In future research, we aim to enhance our microplastic detection and sampling capabilities by integrating advanced analytical techniques. These include:

Fluorescence Microscopy: We will leverage fluorescence properties to improve sensitivity in detecting microplastics.

FTIR (Fourier Transform Infrared) Spectroscopy: This technique will provide detailed molecular information for precisely identifying plastic polymers.

Polarizer-Based Spectroscopy: By analyzing optical properties, we can characterize microplastics in terms of size, shape, and composition.

These advancements will strengthen our stingray-inspired robotic sampling platform, offering a comprehensive toolkit for efficient microplastic analysis in aquatic environments.

Also, we are planning to use SMA springs as the actuators for our sting ray bot in future to make it noiseless.

Conclusion-

In conclusion, our project to develop a robotic stingray for underwater microplastic sampling represents a convergence of innovative engineering, biomimicry, and environmental stewardship. By integrating a cam follower mechanism to imbue the stingray's arms with a sinusoidal movement, we effectively replicated the graceful propulsion of real stingrays, enhancing the robot's manoeuvrability and efficiency underwater. The utilization of Polydimethylsiloxane (PDMS) and plastic sheets for the fins not only contributed to the biomimetic design but also facilitated the collection of microplastic samples with precision and reliability.

Looking ahead, our robotic stingray prototype holds great promise as a tool for scientific research, enabling the collection of valuable data on microplastic pollution in underwater environments. By shedding light on this pressing environmental issue, we hope to inspire meaningful action and drive positive change towards a cleaner and healthier future for our oceans.