Chapter

1 Graines Academy : Overview and Project Context

Contents

1.1 Introduction

Rapid accumulation of marine debris, particularly plastics, poses a significant threat to oceanic ecosystems, coastal economies, and global sustainability. The Ocean Cleaner project aims to address this critical environmental challenge by developing an autonomous surface vehicle capable of navigating coastal and open ocean waters to efficiently collect waste. This project is undertaken in collaboration with Graines d'Entrepreneurs, a Tunisian startup dedicated to fostering entrepreneurial skills and innovative thinking among young people. Using advanced technologies such as autonomous navigation, computer vision, and sustainable power systems, the project seeks to create a scalable solution for the collection of marine waste. This chapter introduces the host company, outlines the problem of ocean pollution, reviews existing solutions, and details the key technologies and objectives of the Ocean Cleaner project.

1.2 Host Company

1.2.1 Company Overview

Graines d'Entrepreneurs is a Tunisian startup founded in 2018 and headquartered in La Marsa, Tunis. The organization is dedicated to fostering an entrepreneurial spirit among young people by providing them with opportunities to develop innovative ideas and projects. As a social enterprise, Graines d'Entrepreneurs places a strong emphasis on experiential learning, creativity, and practical education. Through a variety of interactive programs, including workshops, hands-on training sessions, and project-based challenges, the company inspires and empowers youth to explore entrepreneurship and leadership. By connecting participants with experienced mentors, real-world problems, and a collaborative community, Graines d'Entrepreneurs equips aspiring young leaders with the mindset, problem solving abilities, and skills necessary for success in the rapidly evolving world of entrepreneurship.

Figure 1.1: Graines d'Entrepreneurs LOGO

1.2.2 Domain of Activity

The core activity of Graines d'Entrepreneurs is entrepreneurship education. The startup organizes workshops, training sessions, and incubation programs designed for children, teenagers, and young adults. Their programs typically include hands-on learning experiences, professional mentoring, and opportunities to develop real-world projects. The objective is to cultivate creativity, leadership, and problem solving skills in young people, helping to create a dynamic entrepreneurial ecosystem in Tunisia and beyond.

1.2.3 Company Products and Services

Graines d'Entrepreneurs offers a range of educational programs tailored for young learners:

Weekly Workshops: Interactive sessions that guide students through the process of ideation, project planning, and pitching, using tools like the Business Model Canvas. These workshops simulate the stages of creating a startup or social initiative, fostering skills applicable to projects such as The Ocean Cleaner.

Startup Days and Bootcamps: Intensive programs, such as Junior Startup Day and the Seeds4Tomorrow initiative, where participants develop and pitch innovative projects in a hackathon-style format. These events often focus on real-world challenges, including environmental issues.

Training for Trainers: Programs to train educators and coaches in active pedagogy, positive education, child psychology, and entrepreneurial coaching, ensuring scalable impact across schools and communities.

Customized Educational Content: Collaborations with schools and regional institutions to integrate entrepreneurship into curricula, supported by partnerships with organizations like the Swiss Ed TECH Collider and regional economic promotion bodies. These offerings provide a robust platform for developing innovative projects like The Ocean Cleaner, enabling young entrepreneurs to apply their skills to environmental challenges through structured guidance and mentorship.

1.3 Review of Key Technologies and Components for Autonomous Navigation Boats

1.3.1 Historical Overview of Autonomous Robots

The development of autonomous robots, including those designed for marine environments, has evolved significantly over the past century. The concept of autonomy in robotics traces back to the 1940s, when William Grey Walter created the first autonomous robots, known as "turtles," which used simple sensors and circuits to navigate their environment. These early robots laid the groundwork for autonomous systems by demonstrating basic obstacle avoidance and self-directed movement.

In the 1960s, advancements in computing enabled more complex robots. The Stanford Research Institute's Shakey robot, developed between 1966 and 1972, was a landmark, combining sensors and planning algorithms to navigate indoor spaces. Marine robotics, however, lagged until the 1980s, when remotely operated vehicles (ROVs) equipped with sonar and cameras became common for underwater exploration. Though human-controlled, ROVs laid the foundation for autonomous marine systems.

The 1990s ushered in true autonomy for marine robotics, with MIT's 1993 "Sea Grant" AUV using sonar and basic navigation algorithms for underwater missions. Surface-based autonomous boats also emerged, powered by advances in GPS, inertial navigation, and computing, followed by the U.S. Navy's autonomous surface vessels in the 2000s, which integrated LiDAR and radar for tasks like mine detection.

By the 2010s, autonomous boats gained momentum in research and commercial applications, spurred by events like the 2014 Maritime RobotX Challenge, which drove innovation in obstacle avoidance and mapping. Today, these boats use AI, machine learning, and sensor fusion for robust navigation, supporting tasks from environmental monitoring to cargo transport.

1.3.2 Sensor Technologies

Sensor technologies are critical for enabling autonomous boats to perceive their environment, localize themselves, and navigate safely. The primary sensors used in autonomous navigation boats include LiDAR, GPS, and inertial measurement units (IMUs).

1.3.2.1 Lidar

LiDAR (Light Detection and Ranging) provides high-resolution environmental mapping, essential for safe navigation in cluttered or low-visibility marine settings. It detects obstacles such as other vessels, docks, or floating debris, enabling the boat to plan collision-free paths. In this project, LiDAR serves as a primary tool for obstacle detection and spatial awareness, particularly in narrow waterways or areas with poor visibility like fog or nighttime. **Key Aspects of Lidar Include:**

- **High-precision Obstacle Detection:** Accurately identifies obstacles such as other vessels, docks, and floating debris, allowing for safe navigation and collision avoidance.
- **Environmental Mapping:** Generates detailed 2D spatial maps, enabling the boat to operate in cluttered or narrow waterways.
- **All-weather Operation:** Performs reliably in various lighting and weather conditions, including fog, shadows, and nighttime, where traditional vision systems may fail.

1.3.2.2 IMU (Inertial Measurement Unit)

The Inertial Measurement Unit (IMU) tracks the boat's motion and orientation, ensuring stable navigation in the dynamic marine environment affected by waves, currents, and wind. It provides real-time data on acceleration, angular velocity, and attitude (roll, pitch, yaw), supporting precise maneuvering. In this project, the IMU integrates with other sensors to maintain course accuracy and execute tasks like aligning with waste targets or docking. **Key Aspects of IMU Include:**

- **Stabilization and Control:** Provides real-time data on acceleration and angular velocity to stabilize navigation and maintain accurate heading.
- **Dynamic Compensation:** Compensates for the effects of waves, currents, and wind, ensuring consistent performance in challenging marine environments.

1.3.2.3 GPS (Global Positioning System)

The Global Positioning System (GPS) delivers geolocation data, allowing the boat to determine its absolute position in open waters. It is vital for long-range navigation, enabling the boat to follow predefined waypoints or cover designated cleaning zones systematically. In this project, GPS enhances localization accuracy when combined with other sensor data, ensuring efficient navigation across large marine areas for comprehensive waste collection.

Key Aspects of GPS Include:

- **Global Positioning:** Provides accurate latitude, longitude, and altitude information for route planning and waypoint following across large water bodies.
- **Resilient Localization:** Maintains reliable navigation even when local visual references are unavailable, and supports sensor fusion with IMU for drift correction.
- **Autonomous Mission Execution:** Enables the boat to autonomously follow predefined routes and reach target destinations with minimal human intervention.

1.3.3 Mapping and Localization Methods

Mapping and localization are foundational capabilities in autonomous robotic systems, enabling them to perceive, interpret, and navigate within their operating environments. These processes are essential for safe, reliable, and efficient autonomous movement, particularly in unknown or dynamically changing settings.

Mapping involves constructing a spatial representation of the environment using sensor data. This map may be two-dimensional (2D), depending on the application and available sensors. Mapping enables the robot to understand environmental features, identify obstacles, and define navigable regions.

Localization refers to the robot's ability to determine its position and orientation (pose) relative to the map. Accurate localization ensures that the robot can track its motion over time, follow planned paths, and make context-aware decisions.

One of the most widely used approaches is **Simultaneous Localization and Mapping (SLAM)**. SLAM allows a robot to build a map of an unknown environment while concurrently estimating its own pose within that map. SLAM techniques process data from sensors such as LiDAR, cameras, IMUs, and GPS to iteratively refine both the map and the estimated location.

1.3.4 Path Planning

Path planning is a fundamental aspect of autonomous navigation, enabling robots to compute safe and efficient routes toward their destinations. It ensures the robot can navigate through complex environments while avoiding obstacles, respecting motion constraints, and optimizing overall performance.It aims to find an optimal path that minimizes distance, time, while avoiding static obstacles and respecting environmental boundaries. To function reliably, autonomous path planning must address multiple essential challenges:

Obstacle Avoidance: Continuously detects and avoids both static and dynamic obstacles using data from sensors like LiDAR.

Dynamic Adaptation: Responds in real time to changes in the environment by recalculating safe and feasible paths.

Motion Constraints: Accounts for the robot's physical limitations, including turning radius, acceleration, and speed, to ensure the path is executable.

Path Efficiency: Selects paths that align with operational goals, such as minimizing time, energy consumption, or exposure to risk.

Autonomous navigation relies on integrating sensors, mapping, localization, and path planning to enable boats to operate independently in marine environments. These technologies address challenges like obstacle avoidance and environmental uncertainty. Together, they empower robust autonomous boat systems for diverse real-world maritime applications.

1.4 Project Context and Aims

1.4.1 Problematic

The escalating crisis of ocean pollution, driven by an estimated 8–14 million metric tons of plastic entering marine environments annually, poses severe threats to marine ecosystems, biodiversity, and human livelihoods. Plastic debris, including plastic garbage and microplastics, accumulates in coastal waters, ocean gyres, and remote marine regions, leading to habitat destruction, entanglement of marine life, and ingestion-related fatalities. Current waste collection methods face significant challenges:

Limited Coverage: Manual cleanups and crewed vessels are restricted to accessible coastal areas, leaving vast open ocean regions unaddressed. High Operational Costs: Large-scale systems like The Ocean Cleanup's Interceptor require substantial infrastructure and maintenance, making them cost-prohibitive for widespread deployment, particularly in developing regions.

Environmental Footprint: Many existing solutions rely on fossil fuel-powered vessels, contributing to greenhouse gas emissions and contradicting sustainability goals.

Autonomous Navigation Challenges: Existing autonomous surface vehicles (ASVs) often lack robust navigation systems to handle dynamic marine conditions (e.g., currents, waves, obstacles) and advanced waste detection capabilities to identify diverse debris types efficiently. These issues underscore the need for an autonomous, cost-effective, and environmentally friendly solution to enhance marine waste collection, particularly in diverse and challenging marine environments.

1.4.2 Study of Existing Solutions

A diverse array of solutions has emerged over the years to tackle the persistent problem of aquatic waste collection. These approaches span from traditional manual cleanup operations and community-led initiatives to cutting-edge robotic systems and autonomous vehicles, reflecting both the urgency of the issue and the rapid evolution of technology in this field. The study of existing solutions is an essential step, as it allows us to identify the strengths and weaknesses of current projects. This will help us in the development of our project. We have chosen to analyze two existing projects:

- Project «The Seabin»
- Project «The WasteShark Boat»

1.4.2.1 The Seabin

The Seabin Project provides a practical, stationary solution for collecting floating debris in marinas and docks. Below is a summary of its technical specifications and an explanation of its waste collection mechanism. At its core, the Seabin uses a submersible pump to pull water and surface debris into a mesh basket. As the water gets filtered, the trash is trapped inside the basket while cleaner water flows back out into the harbor. The device holds up to 20 kg of waste and needs to be emptied by hand every so often. It works best in sheltered, powered locations and needs regular maintenance for optimal performance.

Figure 1.2: The Seabin Project.

Unlike the stationary Seabin, my project introduces an autonomous, mobile boat that can travel across rivers and lakes, even in choppy or changing conditions. Thanks to its ability to navigate and adapt, it can reach trash in places where fixed devices can't operate. This flexibility makes it a more versatile and responsive solution for real-time water cleanup.

Comparison with the Seabin Project

The table below outlines the main differences between the two systems:

Table 1.1: Comparison between the Seabin and Our Autonomous Cleaning Boat

Feature	**Seabin Project**	**Our Autonomous Boat**
Mobility	Stationary	Fully mobile
Debris Collection Method	Water and surface debris pulled into mesh basket by pump	Waste detected, tracked, and collected using onboard net system
Autonomy	Requires manual setup and maintenance	Operates autonomously, tracks and collects waste without human intervention
Location Suitability	Sheltered, powered areas only (like marinas)	Capable of operating in dynamic environments
Maintenance	Must be manually emptied and monitored	Periodic maintenance
Total Design Weight (Kg)	55	7.29734
Control	Manual setup only	Remotely controllable with autonomous features

As shown in Table 1.1, our project provides several functional advantages over the Seabin. While the Seabin is limited to static use in specific areas, our boat introduces **mobility**, **real-time waste tracking**, and **automated collection**. Its lightweight and compact design make it suitable for navigating tight or remote environments. Additionally, the autonomous capabilities reduce human intervention and extend operational range, making our solution more adaptive and scalable for widespread water cleanup operations.

1.4.2.2 The WasteShark Boat

The WasteShark is an environmentally friendly aquatic drone designed to remove floating waste from urban waterways, ports, and marinas. Inspired by the whale shark's filter-feeding technique, it is available in both remote-controlled and fully autonomous versions, providing a flexible solution for surface water cleanup.

It moves across the water's surface, collecting floating debris into an onboard basket with a capacity of up to 200 liters. WasteShark can operate on preset routes or be steered manually and is equipped with obstacle-avoidance sensors for optimized cleaning. Once full, the basket must be manually emptied before reuse. Depending on the model, the cost ranges from $17,000 to $23,600.

Figure 1.3: The WasteShark Boat.

Comparison with the WasteShark Project

In contrast, our autonomous boat presents a more compact, lightweight, and cost-effective alternative designed to clean water bodies in real-time. The comparison is detailed in the table below:

Table 1.2: Comparison between WasteShark and Our Autonomous Cleaning Boat

Feature	**WasteShark**	**Our Autonomous Boat**
Mobility	Mobile	Fully mobile
Debris Collection Method	Floating debris collected in onboard basket	Trash tracked and collected with a net system
Autonomy	Available in manual and autonomous versions	Fully autonomous with manual override
Navigation	Preset paths and manual steering; uses obstacle sensors	Autonomous path planning and waste tracking
Waste Capacity	Up to 200 liters (approx. 200 kg)	10 kg net capacity
Operational Environment	Urban waterways, ports, and marinas	Rivers, lakes, marinas, and natural environments
Weight (Kg)	72	7.29734
Total Boat Dimensions (mm)	Approx. $1570 \times 1090 \times 540$ (typical WasteShark spec)	$630 \times 756 \times 423$
Price Range	\$17,000 – \$23,600	Approx. \$1,500

As shown in Table 1.2, the WasteShark, with a weight of approximately 72 kg, is a relatively large and heavy device. Its deployment and retrieval in marinas or ports typically require lifting equipment and regular maintenance, which can be costly and logistically demanding. In contrast, our autonomous boat weighs only 7.3 kg, making it over ten times lighter. This lightweight structure, combined with a compact form factor and a much lower cost of around \$1,5000, enables quick and easy handling, even in remote or constrained environments. Moreover, its autonomous capabilities and real-time adaptability allow it to access hard-to-reach areas such as narrow riverbanks, small lakes, and natural water bodies, offering a practical and scalable solution for localized water cleanup operations.

1.4.3 Proposed Solutions

To address the limitations of existing solutions, such as the stationary operation of the Seabin and the high cost and weight of the WasteShark, the **Ocean Cleaner Project** proposes a lightweight, cost-effective, and fully autonomous surface robot (ASV). This vehicle is designed for versatile waste collection in rivers, lakes, and marinas. The following solutions integrate advanced technologies and sustainable engineering to enhance mobility, autonomy, and scalability. The proposed solution is based on the following key components and innovations:

- **Mechanical Design:** The prototype vessel features a mechanical design specifically aimed at providing stability and ensuring smooth navigation in various water conditions.
- **Autonomous Navigation:** The boat will utilize advanced navigation technologies, including Lidar, IMU, and computer vision, to plan and follow optimal paths while avoiding obstacles. This will enable efficient coverage of polluted areas with minimal human intervention.
- **Intelligent Waste Detection:** Onboard cameras and sensors, integrated with machine learning algorithms (such as YOLO for object detection), will allow for real-time identification and localization of floating waste.
- **Automated Collection Mechanism:** A specially designed mechanical system will be installed to collect and store various types of debris encountered during the mission, ensuring effective removal and secure storage until proper disposal.
- **Remote Monitoring and Data Collection:** The vessel will transmit live status updates and environmental data to a remote monitoring station, allowing for real-time mission control and the collection of valuable insights on pollution patterns.

Chapter

2 System Design and Software Architecture

Contents

2.1 Introduction

2.2 Hardware Component

2.2.1 Introduction

In any robotics project, hardware serves as the foundation that turns innovative ideas into a functional reality. For our MVP, an autonomous boat designed to collect waste in marine and lake environments, the hardware is the physical core that determines how effectively it can navigate waterways, detect debris, and execute its environmental cleanup mission. Selecting the right hardware isn't about choosing the most advanced or expensive components, it's about finding the optimal combination that aligns with Cleaning Boat's goals, balancing performance, compatibility, cost, and resilience against water and debris.

2.2.2 Processing unit

The processing unit must handle multiple critical tasks: running the Robot Operating System (ROS Noetic) for seamless component integration, executing an AI model for real-time waste detection from camera images, processing sensor data for navigation, and controlling motors for propulsion. To optimize performance and distribute workloads, we propose dual-microcontroller architecture. The primary microcontroller will manage ROS, the AI model, and high-level processing, while a secondary microcontroller will handle GPS data processing and motor control, ensuring efficient task separation and system reliability.

2.2.2.1 Microcomputer Selection

The microcomputer must offer sufficient computational power to run ROS, support AI model inference (e.g., for enhancing camera image quality and waste classification), and process sensor data in real time. We evaluated two popular options: the Raspberry Pi 4 (8GB RAM) and the Raspberry Pi 5 (8GB RAM), both capable of meeting Boat Cleaning's demands in marine environments. The table below compares their key features to determine the best fit.

Table 2.1: Comparison between Raspberry Pi 4 and Pi 5 (both 8GB RAM)

Feature	Pi 4 (8GB RAM)	Pi 5 (8GB RAM)
CPU	Quad-core Cortex-A72 @ 1.8GHz	Quad-core Cortex A76 @ 2.4GHz
RAM	8GB LPDDR4-3200	LPDDR4X-4267
Ubuntu 20.04 Support	Yes, official support and easy setup	No official support, requires custom setup
ROS Noetic Support	Yes, fully compatible	Yes, but may have compatibility issues

The Raspberry Pi 4 (8GB) is the better choice for running Ubuntu 20.04 and ROS Noetic due to its official support and straightforward installation. The Raspberry Pi 5 (8GB), while offering superior performance, lacks official Ubuntu 20.04 support, potentially complicating ROS Noetic setup. Additionally, there are other micro-computers like the NVIDIA Jetson Nano, but we can't choose them due to their higher cost (approximately $99) and potential setup challenges.

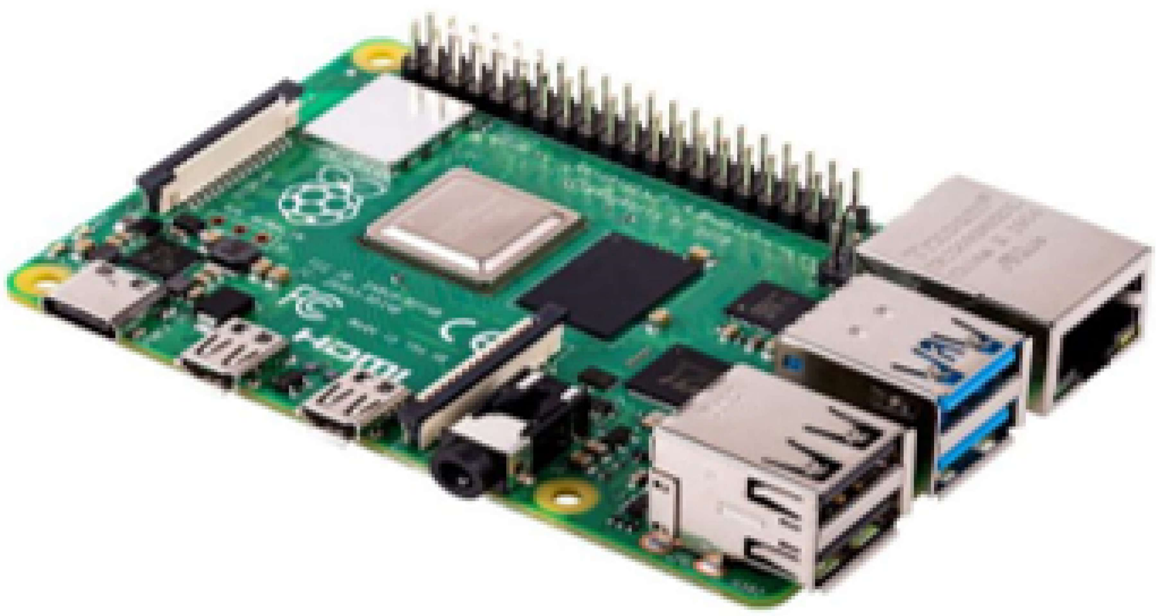

Figure 2.1: The Raspberry Pi4 8GB.

2.2.2.2 Microcontroller Selection

The microcontroller is tasked solely with reading GPS data and controlling motors, operating as a slave to the Raspberry Pi 4. This division of responsibilities allows Raspberry Pi 4 to manage complex computations while the secondary microcontroller handles these specific real-time tasks. By offloading GPS data processing and motor control, the system achieves efficient performance. The Arduino Uno has been selected for this role due to its simplicity and suitability

Table 2.2: Arduino Uno Characteristics

Feature	**Arduino Uno**
CPU	ATmega328P, 16 MHz
Memory	32 KB Flash, 2 KB SRAM, 1 KB EEPROM
I/O Pins	14 digital (6 PWM), 6 analog inputs
Communication	UART, SPI, I2C
GPS Shield Compatibility	Compatible with dedicated shields like the Adafruit Ultimate GPS Shield for seamless GPS integration

The Arduino Uno efficiently handles Boatcleaninge's GPS data reading (via UART with a Ublox NEO-6M) and motor control (using PWM outputs), acting as a reliable slave to the Raspberry Pi 4. The Uno's simplicity and affordability make it ideal for real-time tasks in marine environments.

Figure 2.2: The Arduino Uno.

2.2.3 Sensor

Sensors are the perceptive tools that allow The MVP to understand its environment and maintain situational awareness. They collect critical data for navigation, obstacle avoidance, and waste detection in challenging aquatic settings.

2.2.3.1 Lidar Selection

To ensure The Robot can effectively navigate and detect obstacles in marine environments, we evaluated three sensor types: RPLIDAR (a LiDAR-based sensor), ultrasonic sensors, and Time-of-Flight (ToF) sensors. The table below compares their key characteristics to determine their suitability for the boat's autonomous waste collection mission.

Table 2.3: Comparison of Distance Sensors for Autonomous Cleaning Boat

Feature	**TOF Sensor**	**Ultrasonic Sensor**	**RPLidar 360°**
Working Principle	Emits infrared light pulses and measures return time for distance or depth mapping.	Emits high-frequency sound waves and measures echo return time for distance.	Emits laser pulses and measures time-of-flight to create a 360° point cloud for mapping.
Range	0.1 m – 12 m	0.02 – 4 m	0.15 – 12 m
Field of View	2°	30–40°	360°
Communication Protocol	UART / I2C	GPIO Timing	UART

Each sensor offers unique benefits for boat cleaning. TOF sensors are accurate for short-range waste detection but limited by a narrow 2° field of view, requiring multiple units. Ultrasonic sensors are useful for nearby obstacles but suffer from limited coverage and sensitivity to water interference. RPLIDAR, with its 360° field of view, provides wide coverage and reliable mapping, making it the most suitable for open-water navigation and obstacle avoidance.

The RPLIDAR remains the top choice for the MVP due to its 360° field of view and high accuracy, enabling comprehensive environmental mapping and navigation in complex marine settings.

2.2.3.2 Camera Selection

A camera serves as Boat Cleaning 's key sensor for visual waste detection, capturing images to identify and classify debris in marine environments. Integrated with an AI model, enabling the boat to accurately target waste during its cleanup mission. I have selected a Raspberry Pi Camera, as it integrates seamlessly with Raspberry Pi 4.

Figure 2.3: The RPLidar A1.

The Raspberry Pi Camera with a 5MP resolution and 60° field of view is chosen for its ability to deliver clear images optimized for the AI models with resolution 640x640, ensuring precise waste detection. Its focused field of view supports the boat's mission by enabling accurate identification and targeting of debris in marine environments.

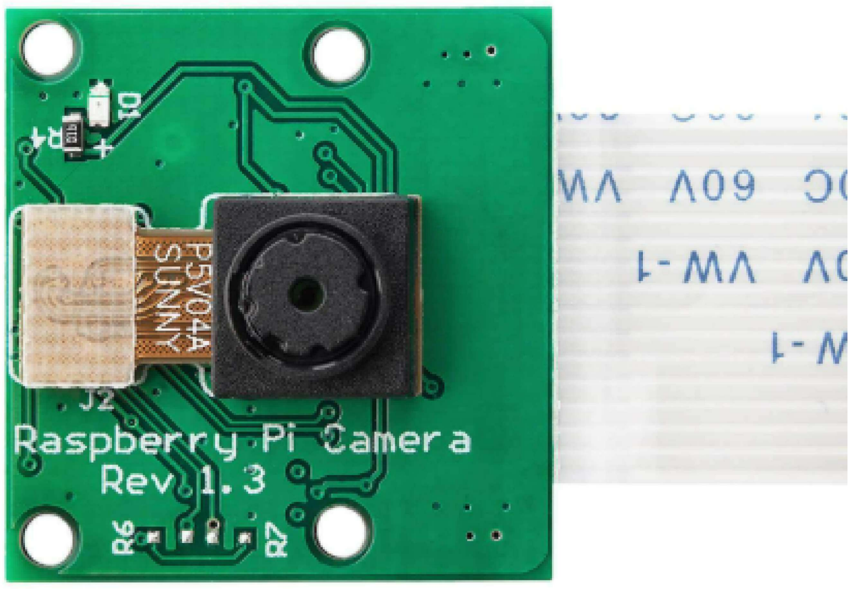

Figure 2.4: The Raspberry Cam V1(5MP).

2.2.3.3 The Imu

The Imu is vital for autonomous navigation, measuring angular velocity to track rotational movements and ensure stability. It compensates for wave-induced motions, enabling precise heading control in challenging marine environments.Two types of IMUs were considered: the

6-axis IMU, which includes an accelerometer and gyroscope, and the 9-axis IMU, which adds a magnetometer for absolute orientation.

While the 6-axis IMU suits basic motion tracking, the 9-axis IMU provides better navigation accuracy by using Earth's magnetic field for heading estimation. For this reason, the 9-axis IMU was chosen to ensure reliable orientation in challenging marine environments.

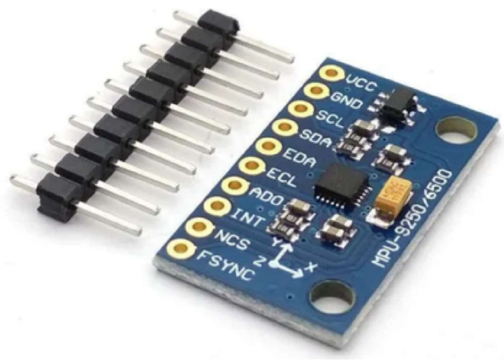

Figure 2.5: The Imu 9-axis.

2.2.3.4 GPS

GPS is essential for the Ocean Cleaner autonomous navigation, enabling the system to follow predefined map points programmed for waste collection routes. It ensures precise self-localization, allowing robots to determine their position in marine environments accurately.

The SIM808 module was selected for its dual functionality, combining GPS positioning with GSM/GPRS communication. This integration allows the Ocean Cleaner to determine its location accurately. ts high GPS sensitivity ensures reliable performance even in weak signal condition.

2.2.4 Actuators

Actuators are the components that enable the MVP to move and execute its mission in marine environments. They translate control signals from the processing unit into physical actions, ensuring precise navigation and operational efficiency.

To ensure optimal performance of the project, the type of motor selected should possess specific characteristics. We recommend using underwater DC motors that can be seamlessly integrated into the mechanical conception without risking water ingress. These motors

Figure 2.6: The SIM808 Module.

should support differential steering, enabling precise navigation and obstacle avoidance in marine environments. Choosing such motors ensures reliable and controlled propulsion, which is essential for the autonomous waste collection mission. The table below compares the APISQUEEN U2 MINI 1.3Kg 16V 130W and APISQUEEN U01 12V-16V 2Kg 390W thrusters, evaluating their suitability for Ocean Cleaner's propulsion needs:

Table 2.4: Comparison of APISQUEEN U2 MINI and U01 Thrusters

Feature	**APISQUEEN U2 MINI**	**APISQUEEN U01**
Thrust	1.3 kg	2 kg
Voltage	12–16 V (3–4S LiPo)	12–16 V (2–4S LiPo)
Max Power	130 W	390 W
Max Current	8 A	17 A
Weight	210 g	178 g
Arduino Uno Compatibility	Yes, via PWM through motor driver	Yes, via PWM through motor driver

The APISQUEEN U2 MINI 1.3Kg 16V 130W thrusters were selected for Ocean Cleaner because their lower power consumption (130 W) compared to the U01's 390 W significantly reduces battery demands, addressing critical power supply constraints for the system.

2.2.5 Power System

The power system is vital for the Ocean Cleaner project, ensuring operational efficiency and endurance in marine environments. Initially, a single battery was selected to power all

Figure 2.7: The APISQUEEN U2 MINI .

components. However, the motors' high power demands (130 W each, up to 8 A) risked overheating, compromising system reliability.

To address this, a distributed power system was adopted, using dedicated LiPo batteries for each motor and a power bank for the Raspberry Pi and SIM808 module. This approach distributes the power load, minimizes overheating, and ensures stable operation, enhancing the Ocean Cleaner's effectiveness in marine cleanup missions.

2.2.5.1 LiPo Battery Selection

For the Ocean Cleaner project's propulsion system, we chose the Zeee 4S 14.8V 5200mAh 100C LiPo Battery with EC5 Connector. This battery was selected to meet the high-performance demands of the underwater thrusters while ensuring reliability and efficiency in a marine environment.

• Voltage (14.8V): The 4S configuration delivers 14.8V, which is ideal for powering the motors efficiently, providing the necessary thrust for navigation.

• Capacity (5200mAh): With a 5200mAh capacity, this battery strikes a balance be-tween weight and runtime, allowing Ocean Cleaner to operate for extended peri-ods without adding excessive bulk.

• Discharge Rate (100C): The 100C rating enables the battery to supply up to 520A of current (5200mAh × 100C / 1000), far exceeding the 16A needed for two thrusters (8A each). This ensures consistent performance during high-demand situations like wave navigation or rapid maneuvers.

The Zeee 4S LiPo battery's robust design and high discharge capability make it an excellent match for Ocean Cleaner's propulsion needs.

Figure 2.8: The Zeee 4S Lipo.

2.2.5.2 Power Bank Selection

For the control electronics of the Ocean Cleaner project, a TECTIN 20000mAh 66W Power Bank is selected, featuring wired connectivity, 66W power output, 20000mAh battery capacity, USB Type-C input, two USB outputs, and fast charge capability. This power bank is chosen to provide a stable and versatile power source for the Raspberry Pi and SIM808 module. Its key specifications are outlined below:

- **Capacity (20000mAh):** The 20000mAh capacity ensures long-lasting power for the Raspberry Pi and SIM808 module, supporting extended. missions without frequent recharging.
- **Power Output (66W):** The 66W output comfortably meets the power demands of the Raspberry Pi (15–20W), Arduino (1–2W), and SIM808 module (2–10W), with sufficient reserve capacity.
- **Two Ports:** The two USB outputs enable simultaneous powering of the Raspberry Pi and SIM808 module, simplifying the power setup.
- **Fast Charge:** The fast charge capability minimizes downtime by rapidly recharging the power bank between missions

Figure 2.9: The Power Bank.

2.2.6 Conclusion

The careful selection of hardware components ensures the boat meets its performance, reliability, and operational requirements. By evaluating and choosing appropriate materials, sensors, actuators, and control systems, the design achieves an optimal balance between efficiency, cost, and functionality. This robust hardware foundation supports successful integration with the mechanical and software systems, paving the way for effective prototyping and testing.

2.3 Software Components

This section outlines the software components utilized in the design, simulation, and operation of the waste collection robot. The software stack includes tools for mechanical design validation, robot control, navigation, and waste detection, ensuring a cohesive system capable of autonomous operation in a marine environment.

2.3.1 SolidWorks CAD Software

SolidWorks is a comprehensive computer-aided design (CAD) and computer-aided engineering (CAE) software used for modeling, simulation, and assembly of mechanical systems. Although primarily mechanical, its role in the software workflow of this project was essential.

Figure 2.10: Solidworks Logo.

2.3.1.1 Overview of SolidWorks

In this project, SolidWorks was utilized to create detailed 3D models of the robot's chassis and other mechanical components. Its simulation capabilities, including finite element analysis (FEA) and motion studies, were critical for validating the structural integrity and functionality of the designed components under marine conditions.

2.3.1.2 Applications in the Project

- **3D Modeling and Assembly:** SolidWorks was used to design the individual pieces of the MVP, including the robot's chassis, waste collection mechanism, and mounting interfaces for hardware components. The software's assembly environment enabled precise integration of these components

- **Structural Analysis:** Using SolidWorks Simulation, finite element analysis (FEA) was conducted to evaluate the structural integrity of the robot's shape and components. The analysis accounted for various loads, such as water pressure at different depths and mechanical stresses encountered during navigation.

- **Material Selection Support:** SolidWorks facilitated material selection by allowing simulations with different material properties. This helped optimize the design for corrosion resistance, weight reduction and buoyancy line level.

SolidWorks played a pivotal role in bridging the mechanical design and software integration phases, providing a robust platform for validating the physical design before hardware and software implementation. Furthermore, SolidWorks provides tools that support the next development steps by enabling the creation of accurate 3D models, which can be exported to use in simulation environments.

2.3.2 Robot Operating System (ROS)

2.3.2.1 Overview of ROS

ROS (Robot Operating System) is an open-source framework designed to simplify the development of complex and modular robotic systems. It offers essential tools, libraries, and communication mechanisms that enable developers to build robot software in a structured and scalable manner.

Figure 2.11: ROS Logo.

The development environment was set up on Ubuntu 20.04 (Focal Fossa), which is the only officially supported version for ROS1 Noetic. This ensures compatibility with key simulation tools such as Gazebo 11 and RViz, which are essential for modeling physical interactions, testing sensor data, and visualizing system behavior.

2.3.2.2 ROS1 Simulation Tools

Gazebo 11 is a powerful open-source 3D robotics simulator that provides a realistic environment for testing robot models with accurate physics, sensor simulation, and dynamic interactions. It is the final long-term support (LTS) release of the Gazebo classic series and is fully compatible with ROS1 Noetic. Gazebo 11 allows developers to simulate complex scenarios, making it ideal for evaluating robot behavior before physical implementation.

Figure 2.12: Gazebo 11 Logo.

RVIz (ROS Visualization) is a 3D visualization tool for ROS that allows developers to view sensor data, robot models, and coordinate frames in real time. It is especially useful for debugging and understanding how a robot perceives its environment and executes navigation tasks. In this project, RViz was used to visualize the boat's position, orientation, sensor outputs, and planned paths during simulation.

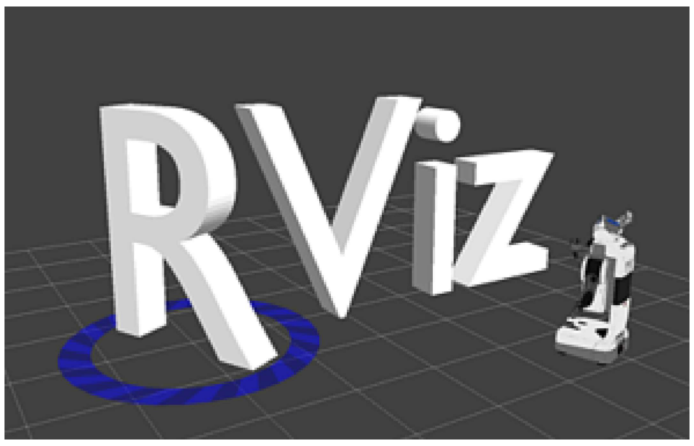

Figure 2.13: RVIz Logo.

2.3.2.3 ROS1 Node Organization and Communication

The fundamental building blocks of any robotic system are called nodes. A node is an independent executable that performs a specific task, such as reading sensor data or controlling actuators. These nodes are designed to work collaboratively by communicating with one another through topics, services, or actions

Language Compatibility for ROS Nodes

ROS1 Noetic provides robust support for developing node files in both Python3 and C++. This flexibility allows developers to choose the programming language that best fits each specific task or their own expertise. Python3 is often preferred for rapid prototyping, scripting, and ease of integration with existing Python libraries, while C++ is ideal for performance-critical applications and low-level hardware interaction.

Role of the ROS Master

The ROS Master acts as the central coordination service in any ROS1 Noetic system. Its main role is to manage the registration of nodes, topics, and services. When a node wants to publish or subscribe to a topic, it first communicates with the ROS Master to register its intent. The master then facilitates the connection between publisher and subscriber nodes by sharing their network addresses, enabling them to establish a direct peer-to-peer communication link. Although the master is essential for establishing these connections, it does not handle or forward any actual message data once the nodes are connected

Figure 2.14 illustrates this architecture in detail, showing how nodes interact with the ROS Master to initiate communication.

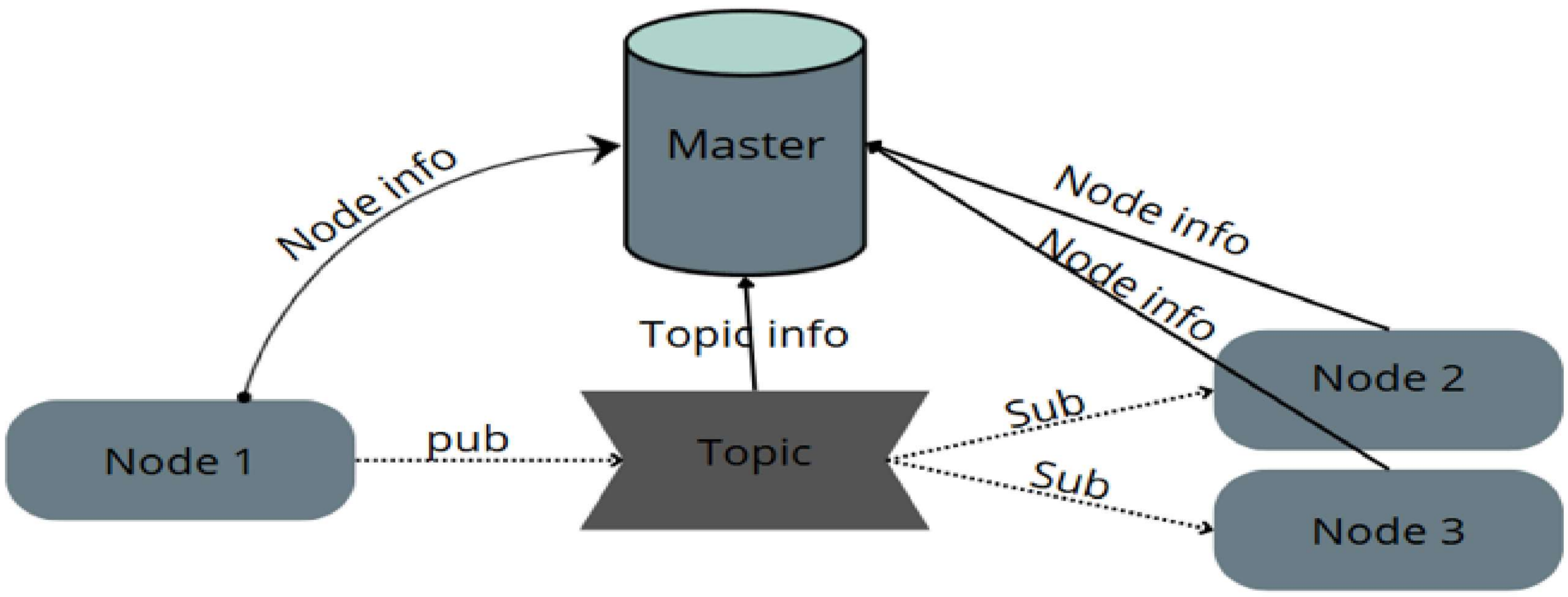

Figure 2.14: ROS Master Architecture.

Communication Between Nodes Communication in ROS1 Noetic is primarily handled using a publish/subscribe model via topics. A node that generates data publishes messages to a named topic, while other nodes that require this data subscribe to the same topic. Figure 2.15 illustrates this process, showing how nodes exchange messages through a shared topic channel.

Figure 2.15: Communication Between Nodes.

Importance of Handling Multiple Publishers on One Topic When multiple nodes publish to the same topic, such as a velocity command topic, the subscriber will always receive only the latest message sent. ROS does not provide built-in arbitration or prioritization between publishers.

2.3.2.4 ROS Packages

The waste collection robot's software architecture leverages several standard ROS1 Noetic packages to enable autonomous navigation, localization, and mapping in a marine environment. The following packages were selected for their robust functionality and compatibility with the project's requirements. Figure 2.16 illustrates the overall organization of the ROS packages employed in this system.

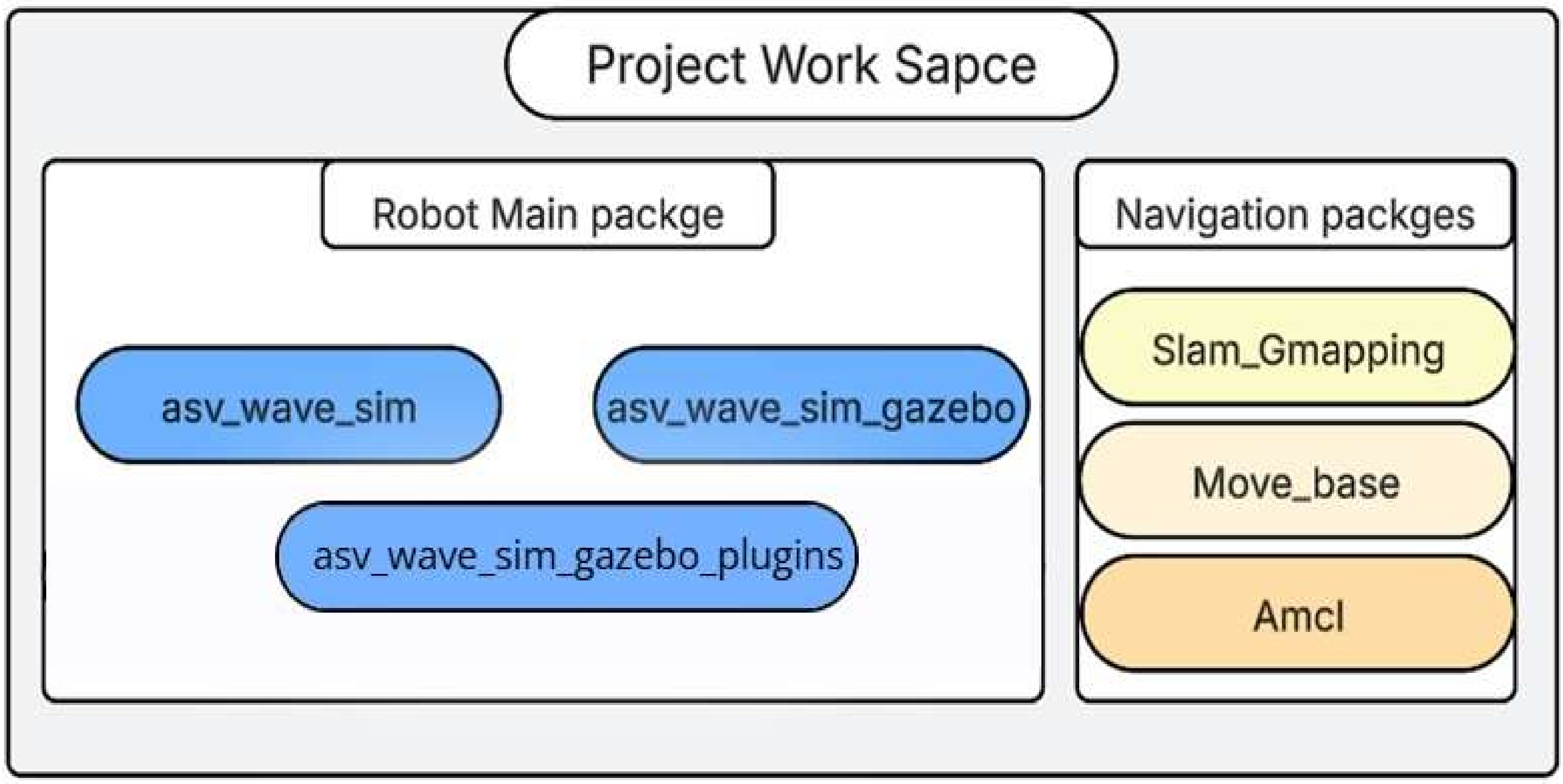

Figure 2.16: Ros Package Hierarchy Overview.

`asv_wave_sim`**:** This package simulates an Autonomous Surface Vehicle (ASV) in a wave-affected water environment within Gazebo. It models water physics, including waves, currents, and buoyancy, using plugins like libHydrodynamicsPlugin.so. In this project, `asv_wave_sim` tested the robot's behavior under maritime conditions, such as hydrodynamic forces and interactions with floating debris. The `asv_wave_sim_gazebo` package is central, enabling the implementation and testing of various functionalities in a simulated environment using ROS tools such as RVIZ and Gazebo. Additionally, the `asv_wave_sim_gazebo_plugins` package incorporates pre-existing code to simulate water physics and ocean behavior. These packages streamline development and minimize risks of material damage or unforeseen errors during early testing phases.

`move_base`**:** This package provides a high-level interface for autonomous navigation, combining global and local planners for path planning and obstacle avoidance. It used for local obstacle avoidance, integrating with costmaps configured via YAML files to handle static and dynamic obstacles. Recovery behaviors, like rotating in place, ensured robust navigation in cluttered waters.

amcl: The Adaptive Monte Carlo Localization (AMCL) package enabled probabilistic localization, estimating the robot's pose within a known map using sensor data (e.g., sonar, LiDAR) and odometry. AMCL employed particle filtering to localize the boat accurately, integrating GPS and IMU data, and was configured to align with the robot's base link and map frame.

`slam_gmapping`**:** This package facilitated Simultaneous Localization and Mapping (SLAM), building 2D occupancy grid maps of unknown marine environments while tracking the robot's position. Using laser scan data and odometry, it employed a particle filter algorithm, configured via YAML files for map resolution and update rates, to support navigation and localization tasks. These packages provided a robust framework for simulating and controlling the waste collection robot, ensuring adaptability to marine conditions and supporting seamless transitions from simulation to real-world deployment.

2.3.2.5 File Model Types Used in ROS

The development and simulation of the ASV within the ROS ecosystem required the use of several specialized file formats, each serving a distinct role in robot modeling, visualization, and simulation. The following file types were utilized in this project:

- **URDF (Unified Robot Description Format):** This file serves as the primary description of the ASV's physical configuration, including its links, joints, sensors, and coordinate frames. This XML-based format allows for the modular construction of the robot model and references external mesh files for both visualization and collision detection.

- **SDF (Simulation Description Format):** These files are utilized primarily within the Gazebo simulator to provide a more detailed and flexible representation of both the robot and the simulation environment. SDF supports advanced features such as sensor plugins, environmental properties, and extended physics configurations.

2.3.3 Navigation Stack

This section explores the key concepts, algorithms, and tools used in autonomous robot navigation, focusing on perception, localization, mapping, and path planning. It covers autonomous navigation frameworks, Simultaneous Localization and Mapping (SLAM), localization techniques, and trajectory planning algorithms, with an emphasis on their implementation in the Robot Operating System (ROS).

2.3.3.1 Autonomous Navigation

Autonomous navigation enables robots to move through environments without human intervention, relying on sensor data, path planning, and obstacle avoidance. Key components include global and local planners, sensor integration (e.g., LIDAR, cameras), and ROS-based frameworks like `move_base`.

- Overview of global and local path planning.
- Sensor requirements and data processing.

This diagram illustrates the core components of an autonomous navigation system for a mobile robot or ASV. The process begins with localization, where sensors such as GPS and IMU determine the robot's position. Mapping modules then build an environmental map using data from sensors like LiDAR and cameras. Path planning algorithms compute optimal trajectories to reach the goal while avoiding obstacles. Finally, the control module adjusts the robot's actuators to follow the planned path. The entire system relies on continuous sensor data to update localization and mapping, enabling robust and adaptive autonomous movement.

The figure 2.17 illustrates this process.

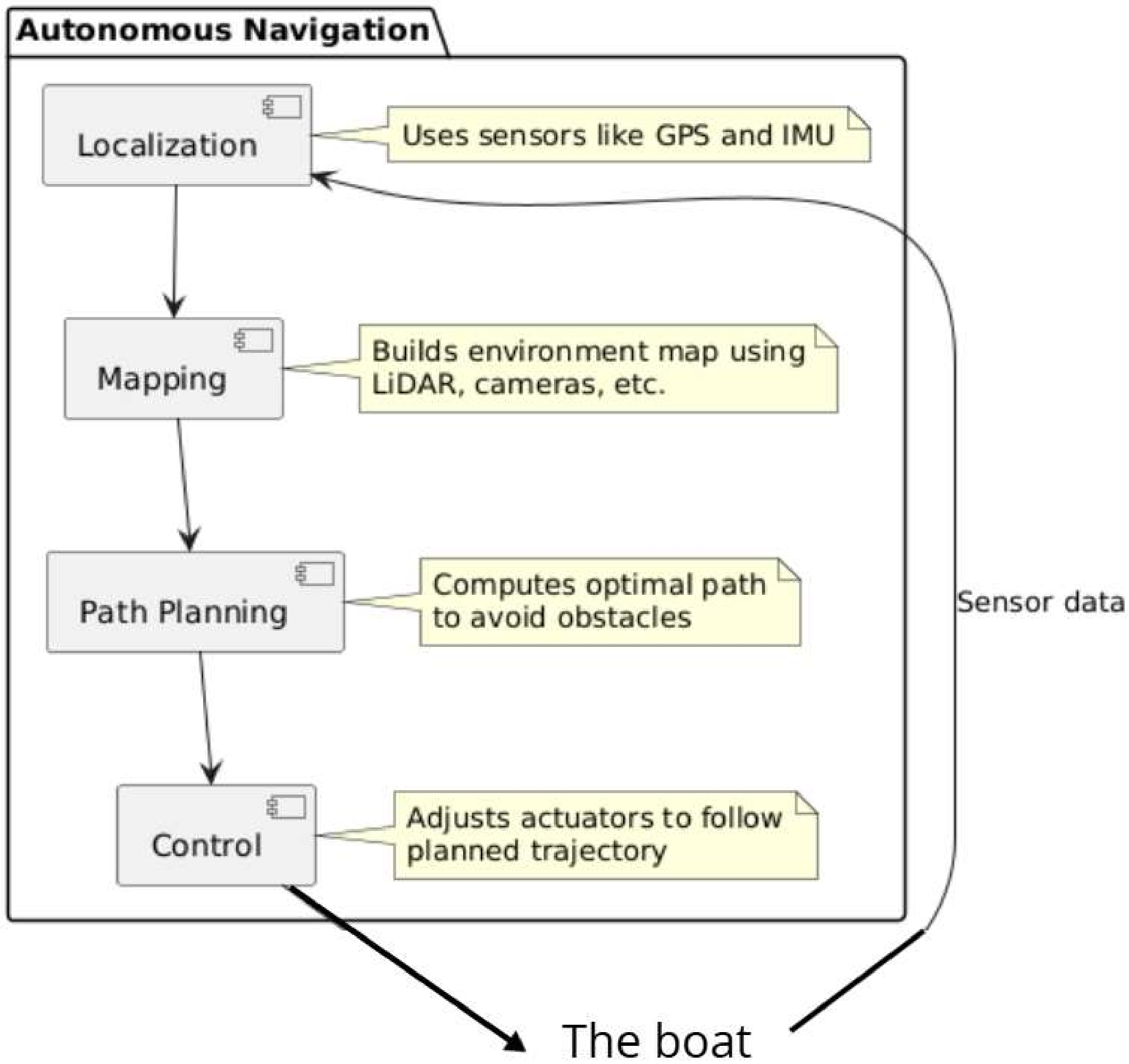

Figure 2.17: Autonomous Navigation Flow Diagram

2.3.3.2 SLAM and Localization

Simultaneous Localization and Mapping (SLAM) enables a robot to construct a map of an unknown environment while determining its own pose. Localization focuses on accurately estimating the robot's position within a known map, which is essential for reliable autonomous navigation.

In this project, SLAM and localization were implemented using the `slam_gmapping` and AMCL ROS packages, respectively. These packages provided the essential capabilities for environment mapping and real-time, probabilistic pose estimation, allowing the robot to operate effectively in dynamic marine conditions. The integration of these tools ensured robust navigation, adaptability, and a seamless transition from simulation to real-world deployment.

Gmapping Integration in ROS: Gmapping is a widely used ROS package for 2D LiDAR-based Simultaneous Localization and Mapping (SLAM). The integration process in a ROS-based robotic system involves several coordinated steps, illustrated and numbered as in Figure 2.18:

- 1) Sensor Node: The process starts with the sensor node, which collects raw data from sensors such as LiDAR.
- 2) Teleoperation Node: The `teleop_node` enables remote control or manual driving of the robot, publishing velocity commands.
- 3) Robot Control and Odometry: The `robot_control` node receives velocity commands and manages the robot's movement. It also publishes odometry data as the robot moves, which is essential for mapping.
- 4) Gmapping Node: The core gmapping node subscribes to both the laser scan and the odometry (via tf transforms) to perform SLAM. It processes the incoming data to generate a real-time 2D occupancy grid map.
- 5) Map Server: Once mapping is complete, the `map_server` node is used to save the generated map files (map.pgm and map.yaml), making them available for future localization and navigation tasks.

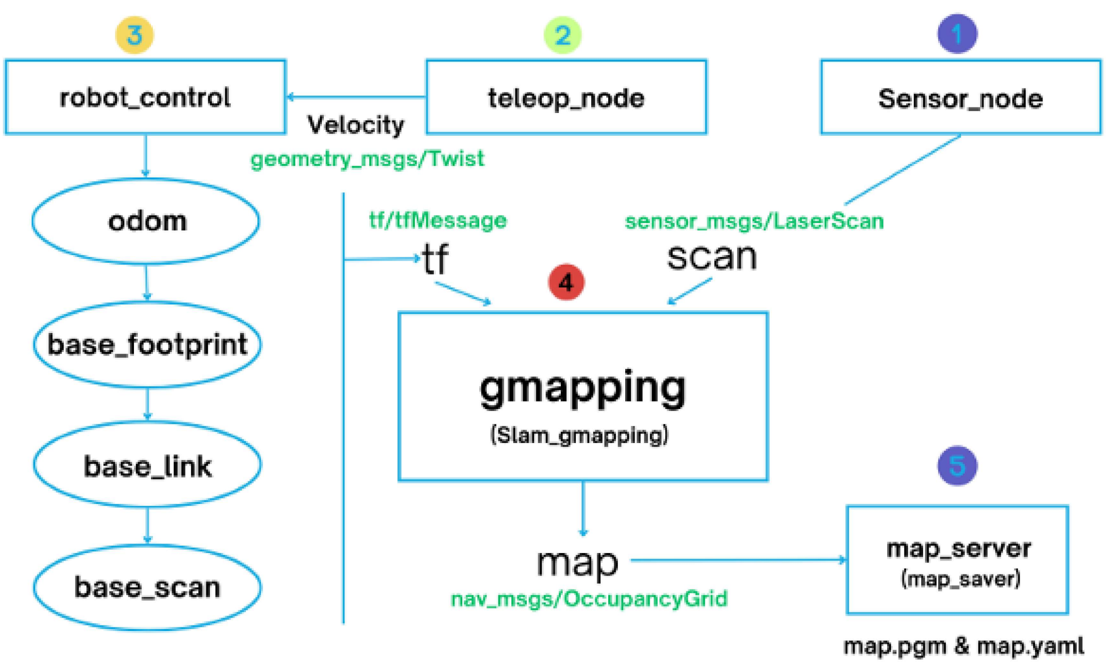

Figure 2.18: Gmapping ROS Integration Diagram

2.4 Mechanical Design

2.4.1 Design Overview

The mechanical concept at the core of this project is focused on designing an autonomous boat with exceptional stability, efficient movement, and reliable waste collection capability. Each design decision aims to fulfill the essential requirements: maintaining steady buoyancy, enabling smooth navigation, and securely supporting the waste collection net and associated systems.

2.4.2 Catamaran Configuration and Benefits

The adoption of a catamaran configuration provides superior stability compared to monohull designs, owing to its broader beam and dual hulls, which distribute buoyancy across a larger area. This reduces rolling and pitching, particularly when the waste collection net at the stern accumulates debris, causing uneven weight distribution. According to Carlton (2018), the catamaran's wide stance enhances initial stability, minimizing rolling under shifting loads or wave action [1]. Molland et al. (2011) further highlight that twin-hull vessels maintain consistent trim, making them ideal for stable platforms in waste collection tasks [2]. Experimental studies confirm that catamarans can safely handle heavier or uneven loads, critical for autonomous operation [3]. Key advantages include:

- **Enhanced Stability:** Twin hulls evenly distribute weight, ensuring the boat remains upright in rough or unevenly loaded conditions.
- **Efficient Navigation:** Reduced hydrodynamic resistance and minimized rolling support predictable and energy-efficient movement.
- **Increased Load Capacity:** The wide stance allows the boat to carry substantial loads, such as a full collection net, without compromising stability.

2.4.3 Boat Model and Component Layout

Figure 2.19 illustrates a 3D model of the autonomous waste-collecting boat, showcasing its catamaran configuration and key structural features. The model highlights the twin-hull design, a central platform housing electronics and propulsion systems, and a dedicated stern area for the waste collection net. This layout optimizes space utilization, ensuring that navigation and propulsion mechanisms remain unhindered while the net efficiently captures debris. The central platform provides a stable mounting surface for critical components, facilitating integration with the hardware and software systems.

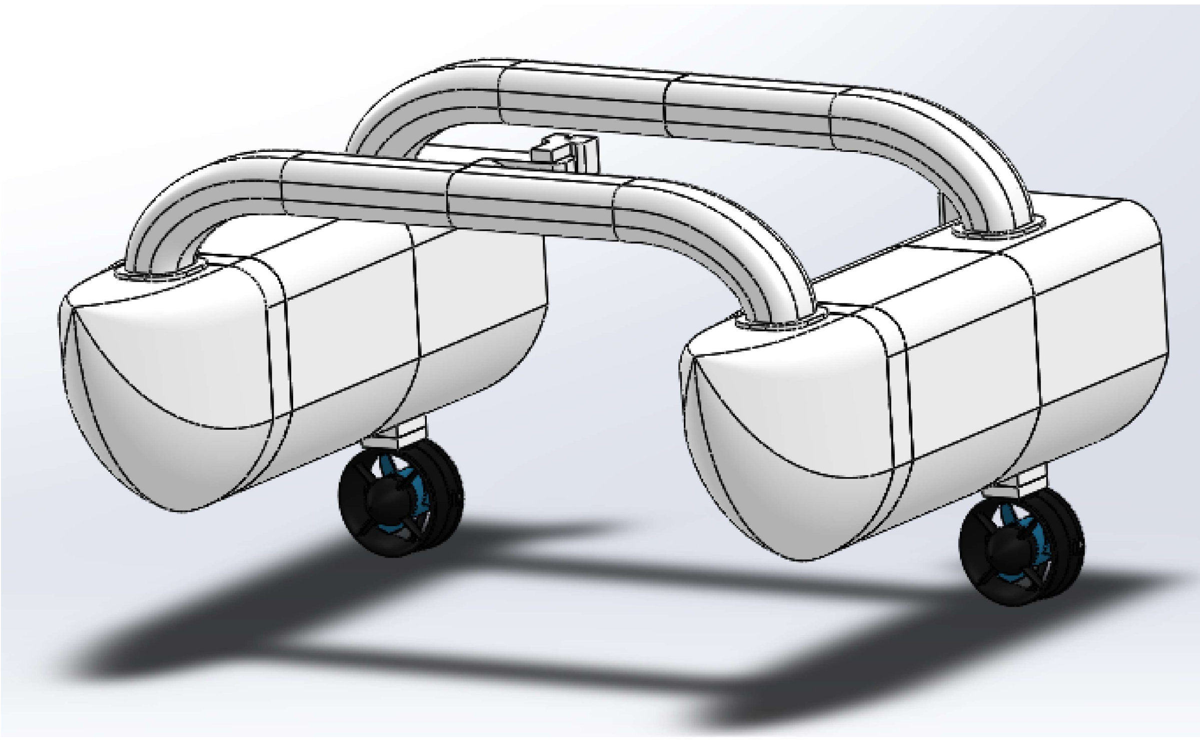

Figure 2.19: 3D model of the autonomous catamaran waste-collecting boat

2.4.4 Structural Design and Validation

The structural design of the boat ensures robustness, hydrodynamic efficiency, and compliance with marine standards, validated through simulations and engineering analyses. The following subsections detail the hull material selection, geometric design, hydrodynamic performance, and structural integrity of critical components.

2.4.4.1 Hull Material and Thickness

The boat's hull is constructed from acrylonitrile butadiene styrene (ABS) plastic with a uniform wall thickness of 4 mm. ABS is selected for its durability, impact resistance, and suitability for marine environments, as widely recognized in small-scale watercraft construction [4]. Established references indicate that ABS hulls with thicknesses between 3 mm and 6 mm provide sufficient mechanical strength for typical operational loads [5][6]. Given this alignment with industry standards, detailed structural analysis of the hull thickness was deemed unnecessary, confirming the material's adequacy for the boat's requirements.

2.4.4.2 Bow and Hull Geometry

The bow features an elliptical cross-section to minimize hydrodynamic drag, allowing water to flow smoothly around the vessel and enhancing propulsion efficiency [7]. This geometry, compliant with hydrostatic principles and marine standards such as ISO 12217-1 [8], ensures stable buoyancy and balance under varying loads. Smooth surfaces and rounded transitions throughout the hull reduce frictional losses, while careful weight distribution maintains adequate freeboard and transverse stability, critical for autonomous waste collection tasks [2].

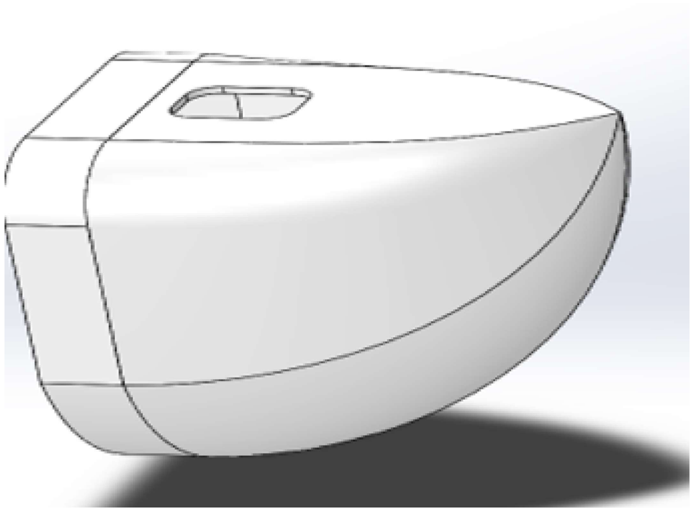

Figure 2.20: Elliptical bow cross-section

2.4.4.3 Hydrodynamic Flow Analysis

To validate the boat's hydrodynamic performance, an external flow simulation was conducted using SolidWorks Flow Simulation. The boat's buoyancy line (waterline) was determined by applying Archimedes' principle, ensuring the hull displaces a volume of water equal to the vessel's total mass. The total mass comprises the boat's material weight (2,161 g) and the operational load (5,136.34 g), yielding a combined loaded weight. The hull's total volume, measured from the SolidWorks 3D model, is 5,215,112.46 mm³ (5.215 liters), resulting in an equilibrium draft of approximately 41 mm, validated by the simulation's free surface results.

The simulation utilized an "External" analysis type, excluding internal spaces, with a transient analysis over 10 seconds under standard Earth gravity. The "Free Surface" option modeled the water-air interface, and an inlet water velocity of 4 knots (2.06 m/s) was set to evaluate fluid behaviour at high operational speeds. The calculation domain defined the virtual space surrounding the boat for accurate analysis.

Pressure Distribution: Figure 2.21 illustrates the pressure distribution on the catamaran hulls at 4 knots, with red areas indicating high-pressure zones and blue-to-green areas representing lower pressure. The balanced pressure distribution confirms the dual-hull design's stability under dynamic conditions, though peak pressure zones suggest potential stress points requiring reinforcement.

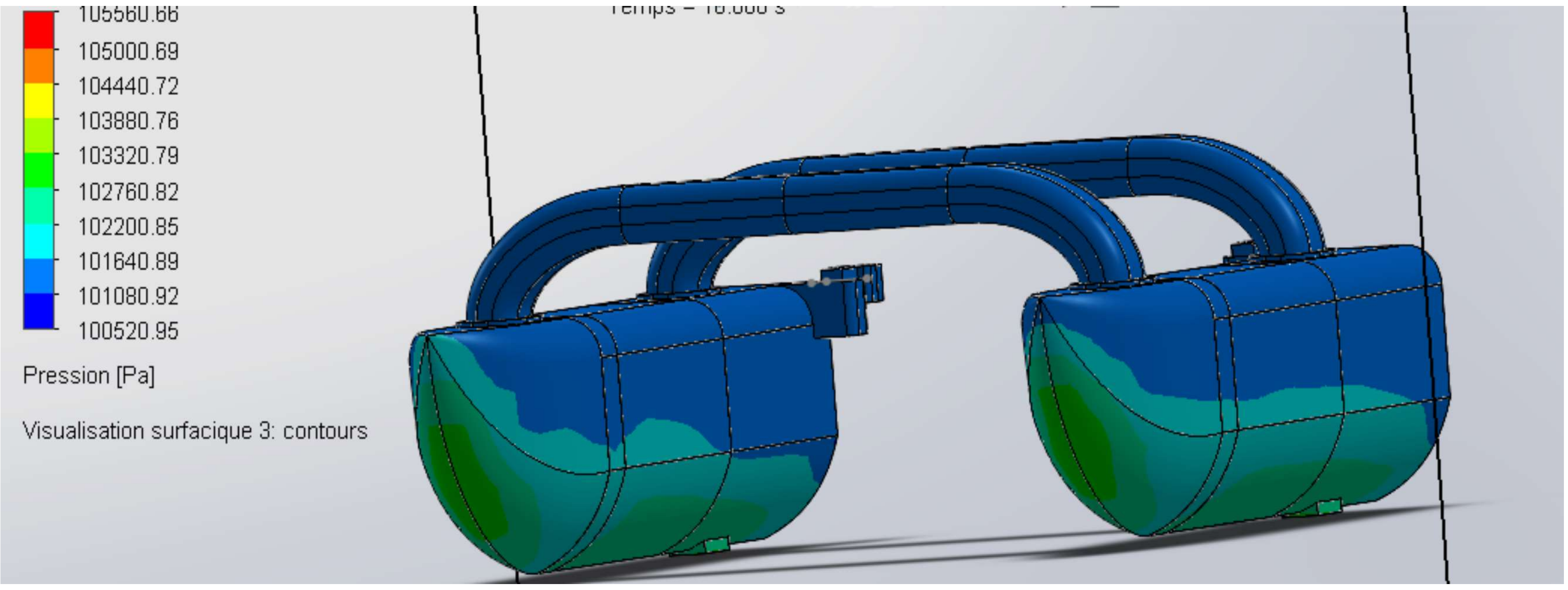

Figure 2.21: Pressure Distribution on Hulls.

Velocity distribution: As shown in Figure 2.22, the velocity distribution reveals fluid dynamics with velocities reaching up to 5.334 m/s near the bow and along the hull. These high-velocity regions indicate areas of reduced pressure that influence drag. The results affirm the hull's hydrodynamic efficiency, promoting smooth water flow and low resistance. However, the high-velocity zones near the bow suggest opportunities for further optimization to reduce drag and enhance movement efficiency.

Net Support Finite Element Analysis: To ensure that the net support structure can withstand a 10 kg load, a static finite element analysis (FEA) was performed using SolidWorks

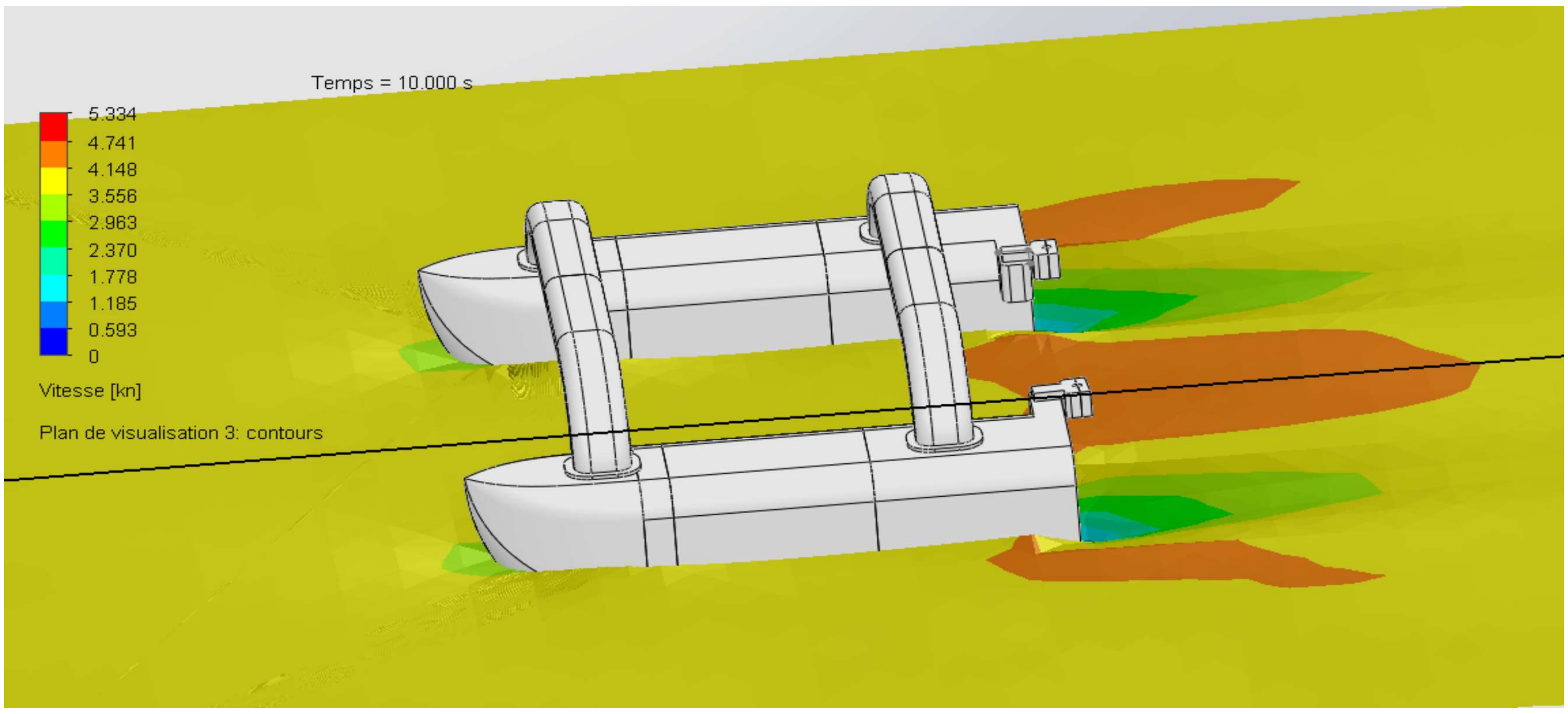

Figure 2.22: Cut Plot – Velocity Distribution.

Simulation. The support, made of ABS plastic and fixed to the boat's stern, was subjected to a pressure load of 98.6 N/m² directed rearward, as indicated by the red arrow in Figure 2.23. The attachment point was constrained (fixed), denoted by a green arrow. The von Mises stress distribution ranged from 1.67×10^{-8} N/m² (minimum, blue) to 7.51×10^3 N/m² (maximum, red), with most areas showing around 3.753×10^3 N/m² (green). These stresses are significantly below the yield strength of ABS, confirming the support's ability to handle the load without material failure or excessive deformation.

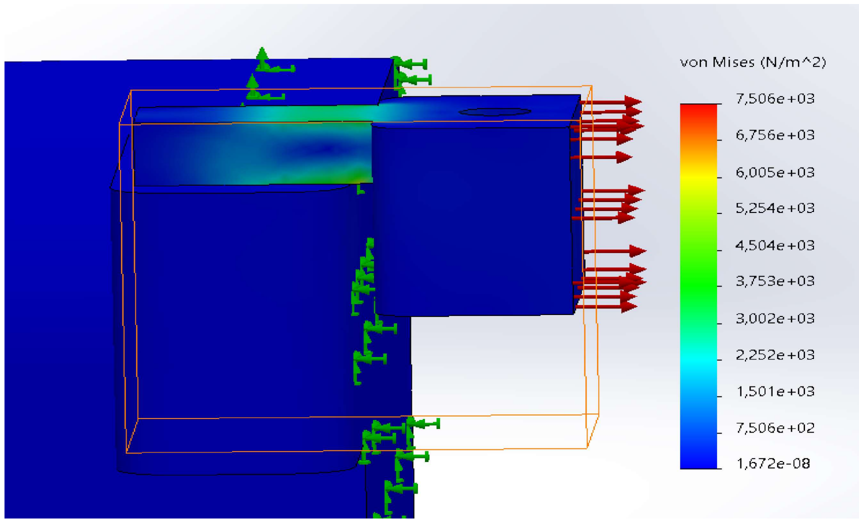

Figure 2.23: Static simulation results for net support structure.

2.4.5 Conclusion

The mechanical design establishes a robust foundation for the autonomous boat's performance and reliability. Through strategic material selection, structural validation, and iterative CAD modeling, the design meets the project's objectives of strength, stability, and operational efficiency. The catamaran configuration, optimized hull geometry, and reinforced net support ensure the boat can effectively collect waste in dynamic marine environments. These validated mechanical components pave the way for successful prototyping, testing, and deployment, as outlined in subsequent sections.