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Department of Product & Systems Design Engineering

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Intro to Maritime Robotics

Personal Info: studies

1997–2003

Degree in Mathematics from the Faculty of Science of the University of Patras

2003–2009

PhD in the Department of Mechanical & Aeronautical Engineering at the same University in the research area of Robotics.

2009–2019

Lecturer in the Department of Product & Systems Design Engineering, University of the Aegean.

2017–2018

Research engineer in the Robotics Intelligent Transportation Systems (RITS) research group at the **INRIA de Paris Institute for Research and Technology**.

2019–2024

Assistant Professor at the Department of Product & Systems Design Engineering of the University of the Aegean with subject "Motion Planning for Autonomous Moving Units".

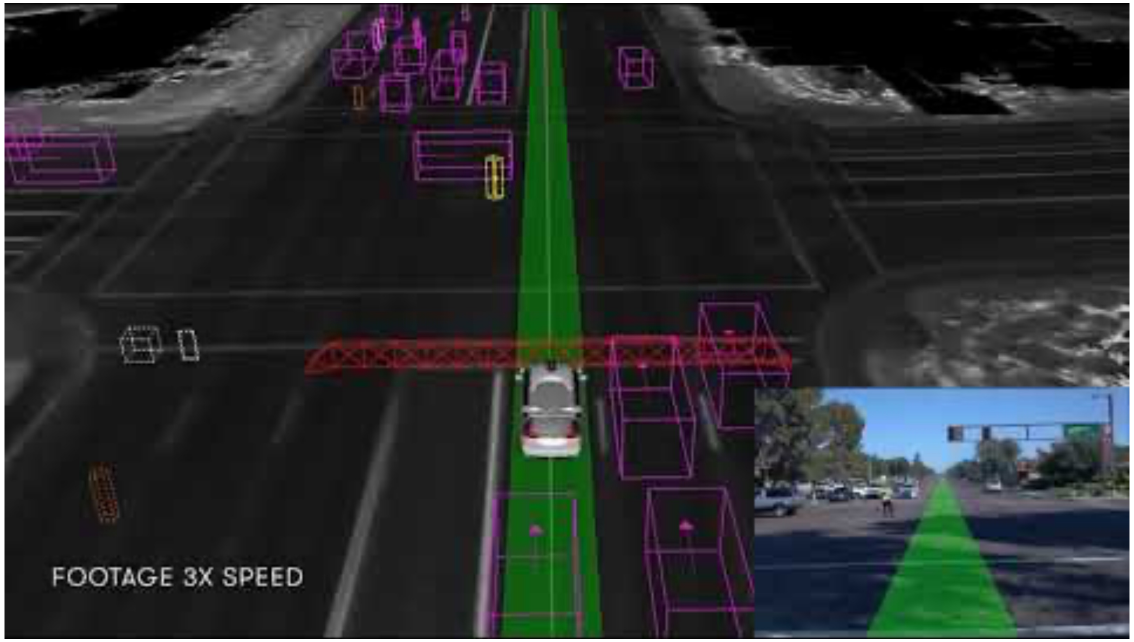
2024 -

Associate Professor at the Department of Product & Systems Design Engineering of the University of the Aegean with subject "Motion Planning for Autonomous Moving Units".

Personal Info: research interests

Robotic Logistics: studies the development of algorithms for the optimal flow of products within a factory or a city using robotic systems.

Personal Info: research interests



Intelligent Transportation Systems: deals with the development of intelligent vehicle fleet management systems (autonomous or semi-autonomous) which have as an objective the most efficient, safest and most economical transport of people or goods.

Personal Info: research interests

- **Motion Planning for Maritime robotics:** involves computing safe, efficient routes from a start to a goal while avoiding obstacles, following maritime rules (like COLREGs), and adapting to dynamic conditions such as currents and limited visibility.
- It combines robotics, control theory, and navigation to enable intelligent, autonomous operation in complex marine environments.

Intro to Maritime Robotics

- **Contents**
  - ❑ What is Maritime Robotics?
  - ❑ Why Maritime Robotics?
  - ❑ Key Platforms
  - ❑ Core Technologies
  - ❑ Challenges in the Field
  - ❑ Trends & Future Directions
  - ❑ Overview of all our gear

What is Maritime Robotics?

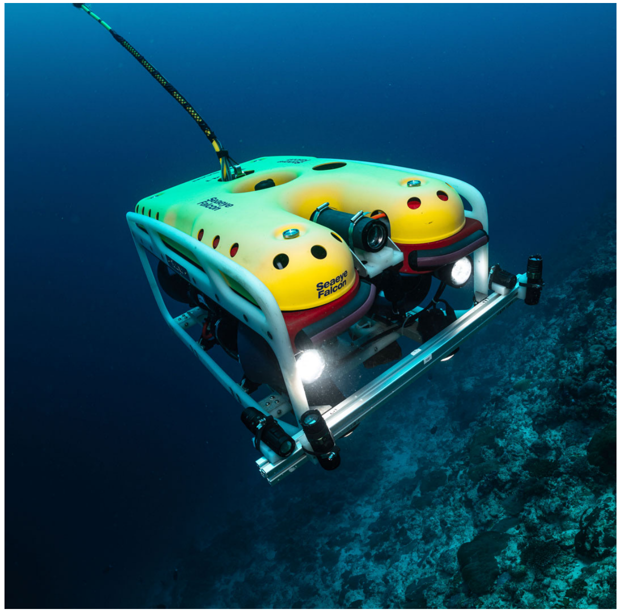
- **Maritime robotics** refers to the design, development, and deployment of robotic systems specifically for marine environments.

- These systems include:
  - **Unmanned Surface Vessels (USVs)**,
  - **Autonomous ships**,
  - **Underwater Unmanned Vehicles** and
  - **Hybrid maritime platforms**.

- Applications such as
  - **navigation,**
  - **surveillance,**
  - **environmental monitoring,**
  - **maritime logistics,**
  - **search and rescue, and**
  - **defence**.

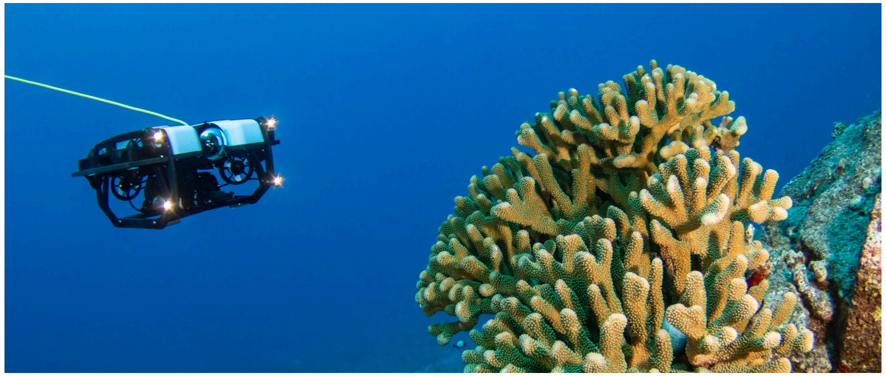
- Maritime robotics integrates technologies from **robotics, marine engineering, artificial intelligence, sensing, and communication systems**, often within the constraints of international maritime regulations such as **COLREGs**.

What is Maritime Robotics?



- **Distinct from Marine Robotics.**
- **Marine Robotics** is the field of engineering and science focused on the **design, development, and application of robotic systems** that operate in marine environments — oceans, seas, lakes, and rivers.
- *These robots are used to explore, monitor, and interact with underwater and surface environments where human access is limited, dangerous, or inefficient*.
- ***Types of Marine Robots:***
  - *Unmanned Surface Vessels*
  - *Autonomous Underwater Vehicles*
  - *Remotely Operated Vehicles*
- **Environments**:
  - Deep sea
  - Coastal underwater zones
  - Subsea infrastructure areas

What is Maritime Robotics?



Feature	**Marine Robotics**	**Maritime Robotics**
Primary Domain	Underwater	Surface + Underwater (sometimes aerial too)
Focus	Subsea exploration and operations	Broader maritime operations and logistics
Typical Vehicles	AUVs, ROVs, gliders	USVs, AUVs, autonomous ships, UAVs
Applications	Oceanography, subsea inspection	Surveillance, shipping, SAR, defense
Navigation & Communication	Acoustic-based, no GPS underwater	GPS + radio/satellite + inter-vehicle links
Regulatory Context	Less regulated, mainly research/industry	Must often comply with maritime laws (e.g., COLREGs)

What is Maritime Robotics?

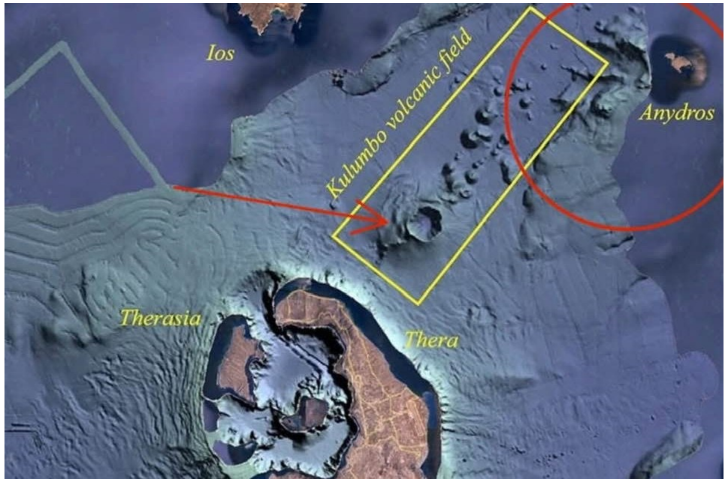
- Maritime robotics is becoming increasingly vital due to its expanding role in **automation**, **defense**, and **environmental monitoring:**
  - **Automation:** The global maritime industry is rapidly adopting autonomous technologies to enhance efficiency, reduce operational costs, and improve safety.
  - **Defense**: In naval and security operations, maritime robots provide critical capabilities such as underwater surveillance, mine countermeasures, and coastal monitoring—reducing risks to personnel while enhancing situational awareness and operational reach in contested or hazardous areas.
  - **Environmental Monitoring**: Maritime robots are essential tools for sustainable ocean management.

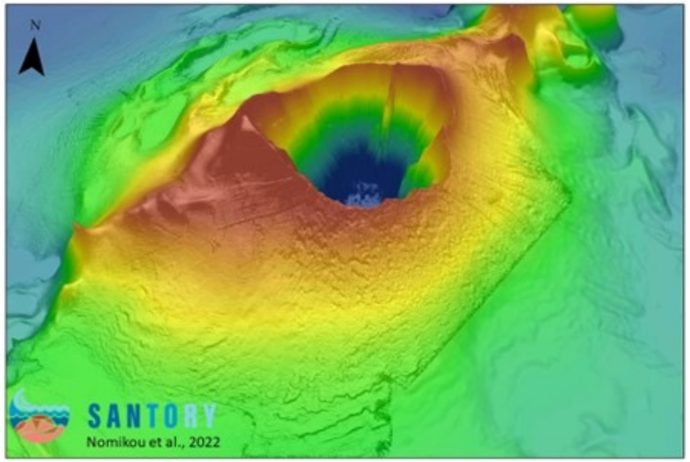
Why Maritime Robotics?

- **Safer, Smarter Operations**
    - Maritime robotics improves safety by replacing humans in hazardous tasks like deep-sea exploration, hull inspection, and mine detection.
    - Unmanned systems carry out these missions accurately and safely, while onboard sensors and intelligent controls enable them to adapt and make smart decisions in challenging environments.
    - This fusion of safety and intelligence is reshaping high-risk maritime operations.

Why Maritime Robotics?

- **Use case in Greece: Monitoring the Kolumbo Submarine Volcano**
  - The **Kolumbo Volcano**, located approximately 7 km northeast of Santorini in the Aegean Sea, is one of the most active submarine volcanoes in the Mediterranean.
  - Sitting at a depth of ~500 meters, Kolumbo poses potential risks due to its volcanic activity, underwater gas emissions, and proximity to populated islands.
- **Challenges**
  - Harsh underwater conditions
  - The need for costly manned missions
  - Difficulties in collecting long-term, high-resolution data on seismic activity, gas emissions, and hydrothermal processes





Why Maritime Robotics?

- **Efficiency Through Automation**
  - **Maritime robotics enhances efficiency by automating ocean tasks** that are traditionally labor-intensive, risky, and expensive.
  - **USVs and UUVs** can conduct monitoring, surveying, and transport with minimal human input, reducing costs and exposure to hazards.
  - These systems offer **precision, real-time response, and scalability**, making them ideal for demanding domains like offshore energy, environmental monitoring, and maritime security.

Why Maritime Robotics?

- **Example: Autonomous Hydrographic Survey Using USVs**
  - **Autonomous USVs equipped with multibeam echo sounders** offer a more efficient alternative to traditional crewed hydrographic surveys.
  - They follow **preplanned, adaptive routes**, collect high-resolution data, and transmit it in real time—**reducing costs by over 60%**, eliminating the need for onboard crew, and enabling **24/7 operation** in areas unsafe for larger vessels.
  - This results in **faster, safer, and more precise** survey missions through automation.

Why Maritime Robotics?

- **Essential for Environmental Monitoring**
  - **Maritime robotics enables continuous, non-invasive monitoring of marine ecosystems** using USVs and UUVs equipped with advanced sensors.
  - These systems can **measure water quality, detect pollution, and track biodiversity**, even in remote or hazardous areas.
  - By collecting **real-time, high-resolution data** over large areas and timeframes, they provide vital insights for ocean health, support early warning systems, and **inform sustainable marine policy**.

Why Maritime Robotics?

- **Example – Monitoring Algal Blooms with Autonomous Surface Vehicles**
    - **Unmanned Surface Vehicles (USVs)** offer a powerful solution for detecting and tracking **harmful algal blooms (HABs)**.
    - Equipped with optical and chemical sensors, they **autonomously monitor key water parameters** and adapt their paths to map blooms in real time.
    - This approach **improves early detection, enhances coverage, and reduces costs**, making it a critical tool for protecting marine ecosystems amid growing climate and pollution challenges.

Why Maritime Robotics?

- **Enabler of Blue Economy Growth**
  - Maritime robotics drives the growth of the Blue Economy by enabling sustainable, efficient operations across marine industries such as exploration, aquaculture, and offshore energy.
  - Autonomous systems provide safe, cost-effective solutions for real-time data collection and intervention in remote or hazardous environments.
  - By advancing automation and data-driven decision-making, they support innovation, sustainability, and better management of ocean resources.

Why Maritime Robotics?

Example: Supporting Sustainable Aquaculture with Maritime Robotics

- In sustainable aquaculture, autonomous robots are revolutionizing operations through continuous monitoring of fish health, water quality, and infrastructure.
- Equipped with sensors and AI, these systems detect issues like net damage or abnormal fish behaviour in real time, reducing the need for divers, cutting costs, and minimizing environmental impact.
- They support informed decision-making and promote productivity, sustainability, and resilience in marine food production—key goals of the Blue Economy.

High – Level Map of Autonomous Systems

Components of Maritime Robotics

- Platforms
  - Platforms like USVs and UUVs serve as the physical foundation for operations.
  - They are equipped with various technologies to perform diverse tasks across different environments.
- Sensors
  - Sensors are essential for collecting data about the environment, including visual, acoustic and environmental data.
  - They enable platforms to perceive their surroundings and make informed decisions during missions.
- Autonomy
  - Autonomy encompasses the algorithms and software that allow platforms to process data and navigate without direct human control.
  - It includes levels of autonomy, from remote control to fully autonomous operations, adapting to mission requirements.

Key Platforms

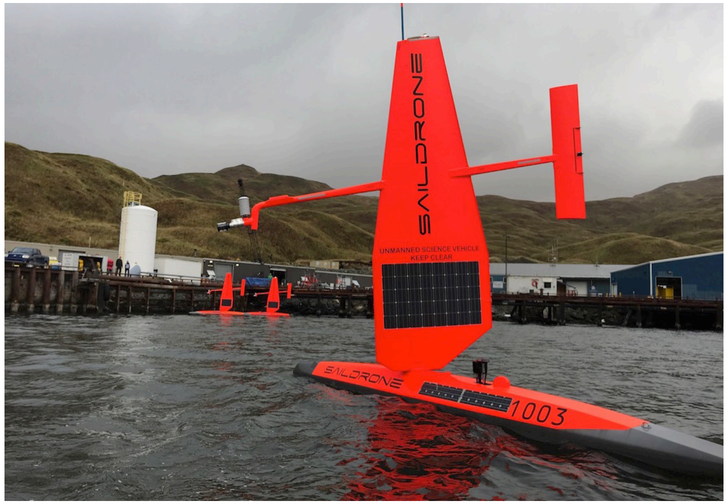
- **Autonomous Ships** are vessels that operate with reduced or no human intervention by using advanced technologies such as artificial intelligence (AI), sensors, control systems, and connectivity.
- They can perform navigation, collision avoidance, and decision-making tasks typically carried out by crew members.

Key Platforms: Level of Autonomy

Level 0: Basic operation / Human controls the vessel	•A human sets targets or manually controls the vessel, while the system adjusts operations to minimize deviations. This forms a **closed-loop feedback system**
Level 1: Assisted operations / Hands-on, eyes-on, mind-on	•The human operator makes decisions based on received data, adjusting setpoints as needed. Automation supports by updating information and handling simple, decision-based tasks.
Level 2: Partial automation / Hands-off (sometimes), eyes-on, mind-on	•The system monitors conditions, acts to meet setpoints, and informs the human of its actions. •Human confirmation may still be required before execution.
Level 3: Conditional automation / Hands-off, eyes-off (sometimes), mind-on	•The system monitors and maintains setpoints, acting without human input for limited periods based on context.
Level 4: High automation / Hands-off, eyes-off, mind-off (sometimes)	•Tasks run mostly without human input. •The system only alerts the operator when it cannot meet setpoints on its own.
Level 5: Autonomous / Hands-off, eyes-off, mind-off = human-of	•The system sets and achieves goals independently, using onboard intelligence to perceive, interpret, and respond to situations for safe, compliant operation.

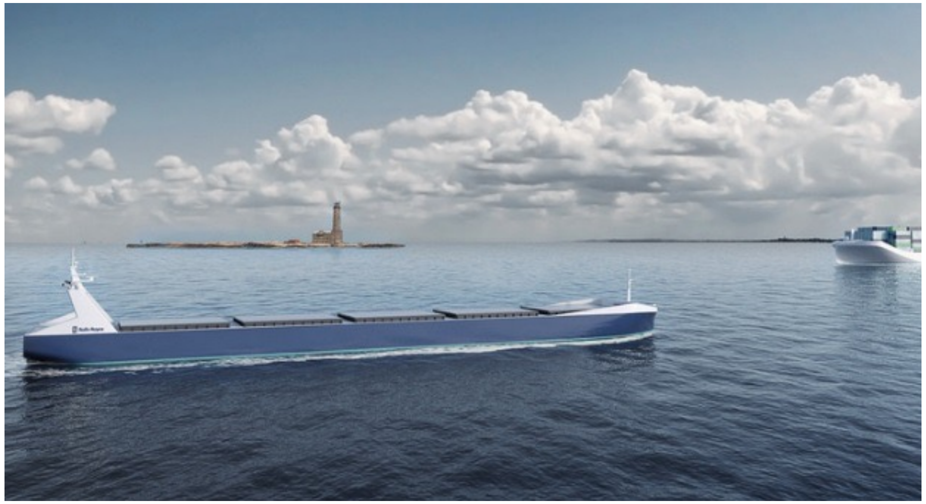
Key Platforms

- **<u>Unmanned Surface Vessels (USVs)</u>** are boats or ships that operate **on the surface of the water without a human crew on board**.
    - They are controlled either **remotely** by human operators or **autonomously** through onboard systems such as sensors, artificial intelligence, and navigation software.



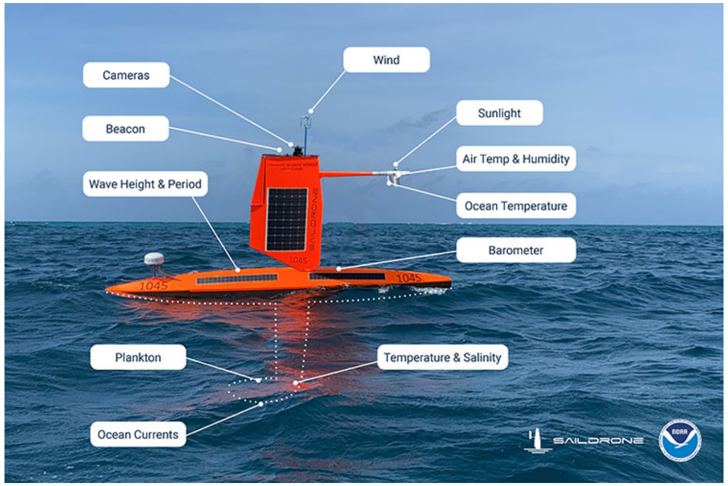
Key Platforms

- **Relation to Autonomous ships: USVs** are often **smaller and more mission-specific** than large **Autonomous ships**, but they both fall under the broader category of **uncrewed maritime systems**, and both use automation and AI to improve performance and safety.



Key Platforms

- **BlueROV2**: A versatile, low-cost, open-source ROV designed for underwater inspection, research, and education, offering modular expandability and precise control in depths up to 100 meters.
- **Saildrone**: A long-endurance, wind- and solar-powered unmanned surface vehicle (USV) designed for autonomous ocean data collection across vast distances with minimal environmental impact.



Key Platforms

- **Sea Hunter**: An autonomous, military-grade trimaran developed by DARPA and the U.S. Navy for long-duration anti-submarine warfare and surveillance missions, demonstrating advanced autonomy and endurance without onboard crew.

Challenges in the Field

Harsh Environments: Saltwater and Storms

- Unmanned maritime systems must be built to endure harsh marine conditions, such as corrosive saltwater, storms and high waves.

Challenges in the Field

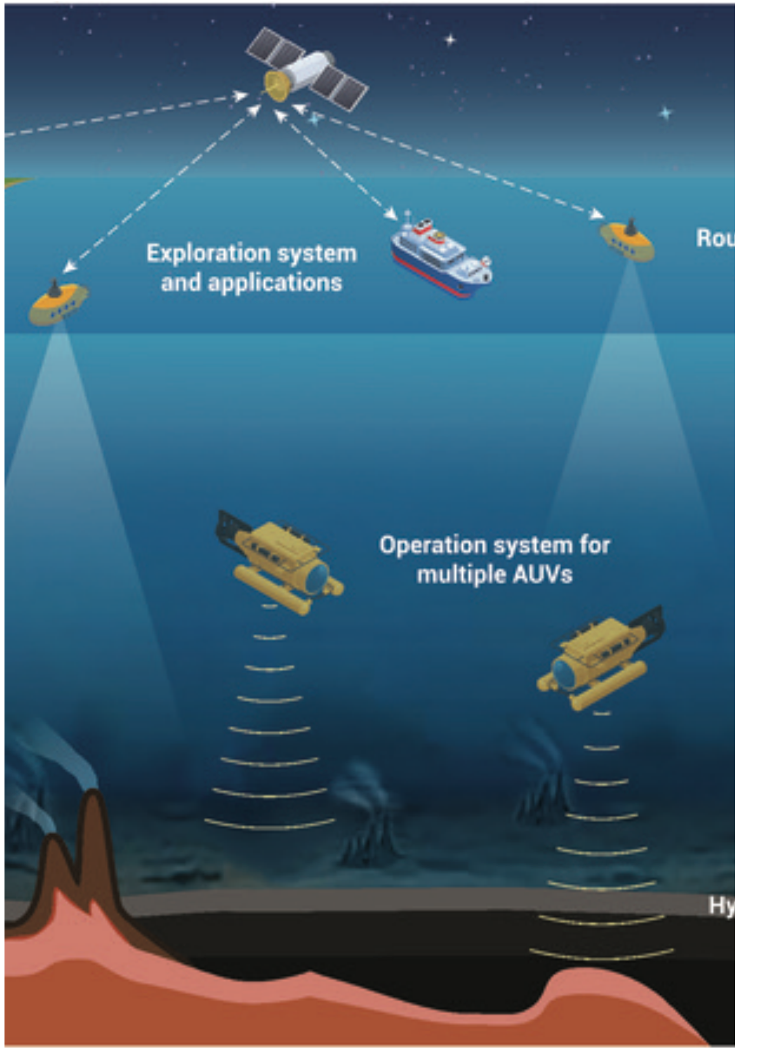
Sensor Fusion Complexity

- **Sensor fusion combines data from multiple sources**—like GPS, INS, radar, LiDAR, cameras, and sonar—to build a unified and accurate view of the environment.
- It is complex due to varying sensor characteristics and potential data conflicts.
- **Advanced algorithms** (e.g., Kalman filters, AI models) are used to process this information in real time, especially in dynamic or noisy conditions.
- Despite these challenges, **sensor fusion is critical** for reliable perception, navigation, and autonomy in maritime systems.

Challenges in the Field

Communication Loss

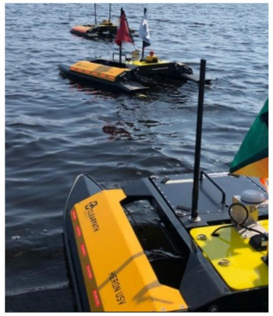
- Communication loss poses a major challenge for unmanned maritime operations, requiring fail-safes and onboard autonomy to maintain safety.
- Hybrid communication and robust planning improve resilience, ensuring reliable and successful missions in remote or harsh environments.

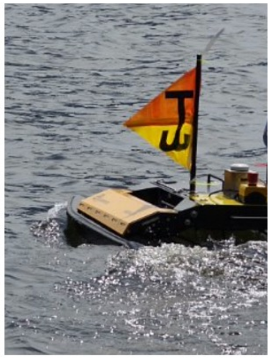


Challenges in the Field

- **Energy Constraints**
  - Energy limitations constrain the endurance and performance of unmanned maritime systems, which rely on efficient power management for propulsion, sensing, and computing.
  - Strategies like adaptive planning, low-power electronics, and energy harvesting help extend missions, but balancing energy use with mission objectives remains a key challenge.

Trends & Future Directions





- **Swarm robotics** enables fleets of unmanned maritime vehicles to collaboratively perform complex tasks like monitoring and search and rescue.
- Using **distributed control and AI**, these systems adapt to changes and remain resilient to failures.
- Advances in **edge computing** and communication support real-time coordination across wide ocean areas.

Research Directions and Applications

Research Challenges

- Robust navigation in GNSS-denied environments.
- Underwater communication (acoustic vs optical vs hybrid).
- Human – robot interaction in port/urban marine settings.

Application Domains

- Environmental Monitoring (pollution, mapping, biodiversity surveys)
- Maritime Security (border surveillance, illegal fishing detection)
- Offshore Energy (infrastructure inspection, maintenance)
- Autonomous Shipping (port logistics, collision avoidance)

Looking Ahead

- From TRL 3-4 prototypes to TRL 7+ operational platforms.
- Fusion of generative AI, neuro-symbolic reasoning @ marine autonomy.

Core Technologies: Navigation (Motion Planning & Collision Avoidance)

Motion planning in maritime robotics involves generating **safe, efficient paths** for autonomous navigation in complex, changing environments.

Planners must **comply with navigation rules (e.g., COLREGs)** while handling dynamic challenges like **currents, waves, and moving obstacles**, making maritime path planning significantly more complex than on land.

Core Technologies: Navigation (Motion Planning & Collision Avoidance)

Traditional trajectory planning methods, often adapted from ground-based robotic platforms, fail to consider the unique kinematics and manoeuvrability constraints of USVs.

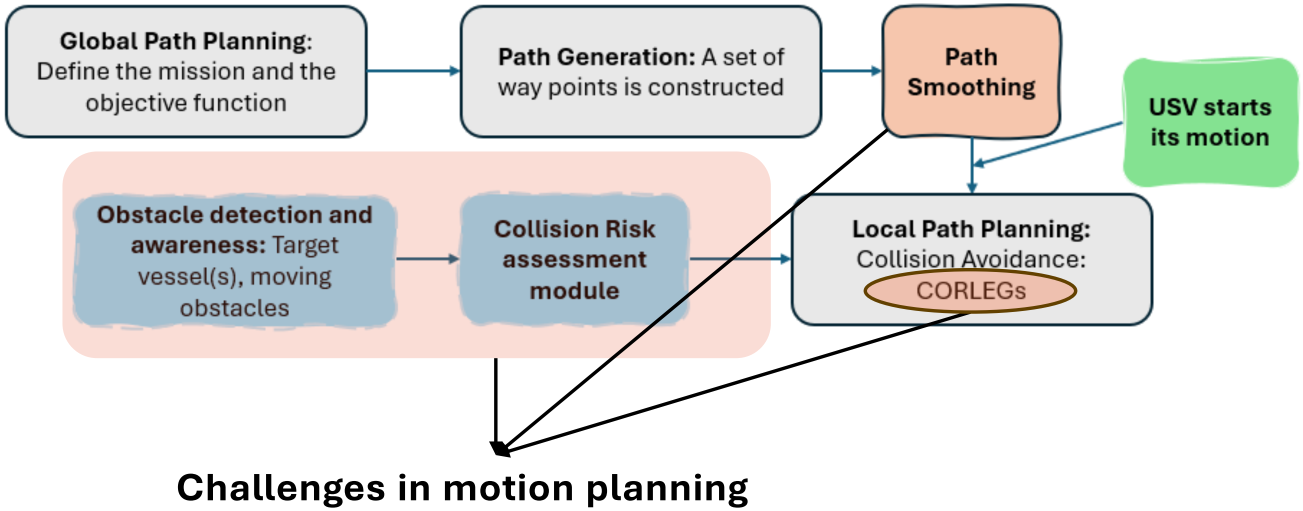
Moreover, ensuring safe navigation while following COLREGs remains a challenge.

The most promising approaches propose a **two-stage approach** for the Trajectory Planning Problem (TPP) of an USV which is moving in dynamic maritime environments.

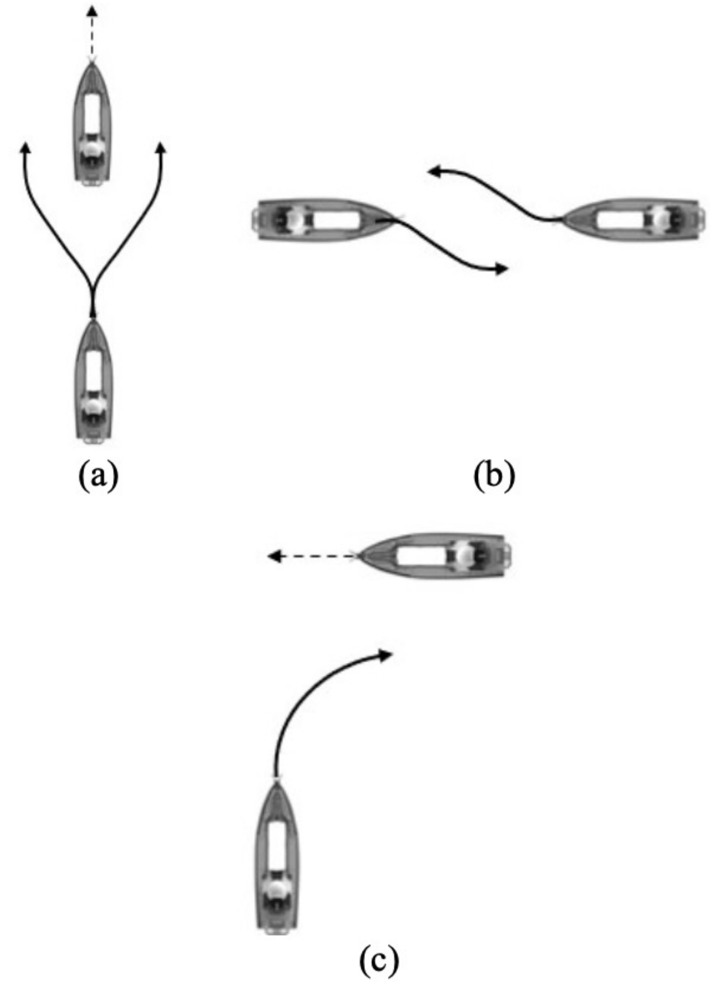
- **In the first stage**, a traditional approach is used to to create a safe path in a given map of the maritime environment based on free and occupied spaces.
- **In the second stage**, the USV starts moving from the predefined starting state to the ending state by following the given path.
  - If the USV detects by its onboard sensors a moving obstacle, then in most cases a machine learning based approach produces a COLREGs-compliant trajectory for the USV.

Core Technologies: Navigation (Motion Planning & Collision Avoidance)

A schematic overview of the proposed approaches.



A schematic representation of CORLEGS rules: (a) Overtaking, (b) Head-on, (c) Crossing from starboard.



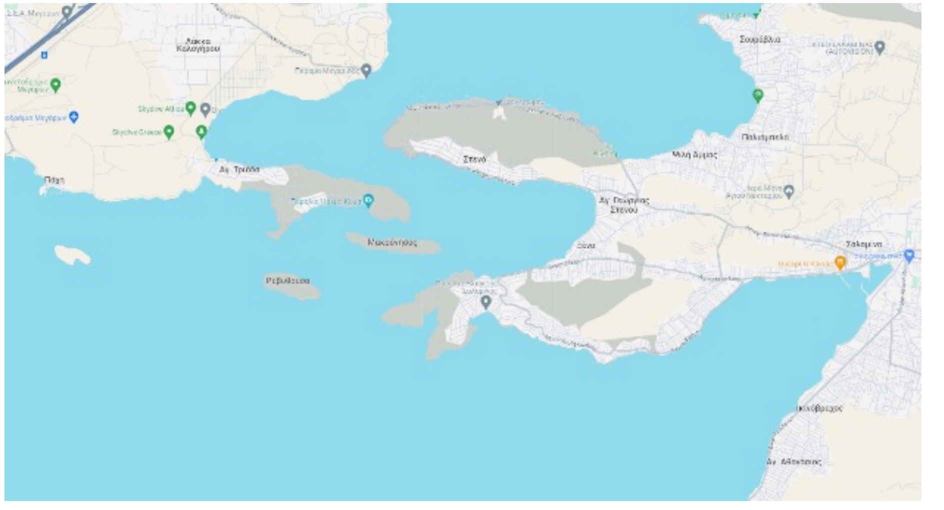
Creating the Global Path

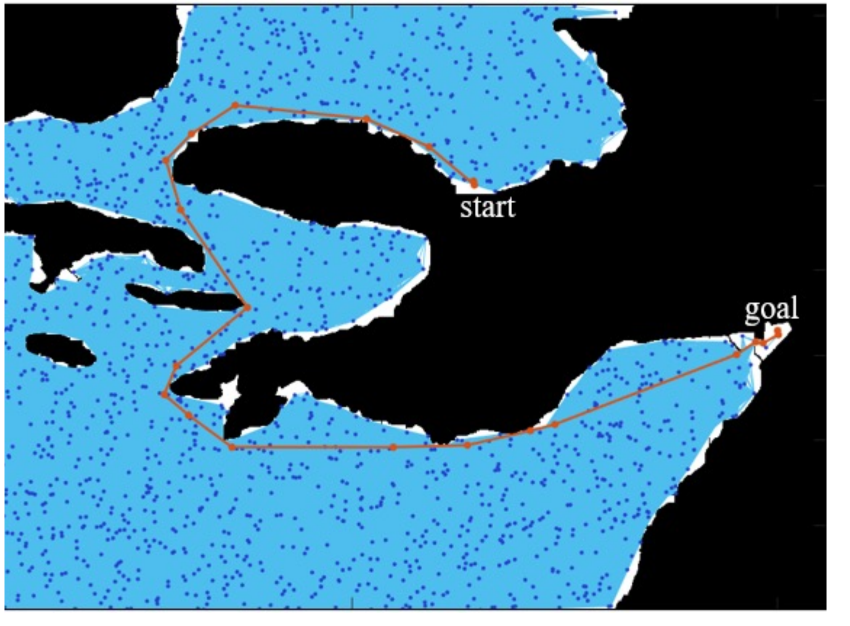
A path which connects an initial point to a destination point considering:

- the weather,
- the land,
- the shallow waters,
- the energy consumption and
- other static obstacles.

The proposed path is defined by using Probabilistic Roadmaps (PRM).

*The given path is composed with a set of waypoints and line segments; **the problem is to define** a "similar" path in shape and distance with fewer waypoints.*

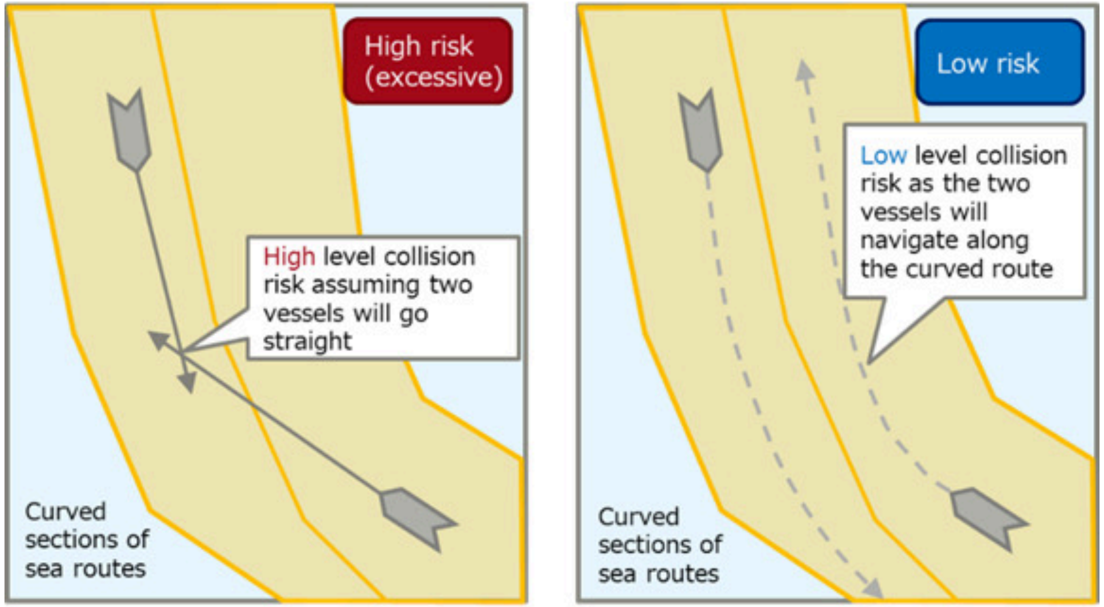




Collision Risk Assessment

- **Collision risk assessment** is a core function in USV navigation, involving the **detection and evaluation of potential collisions** with vessels or obstacles.
- It is essential for enabling **safe autonomous operation** and ensuring **compliance with maritime regulations like COLREGs**.
- **Collision risk assessment** is the process by which a USV determines:
  - Whether there is a potential for collision with a detected target (another vessel or obstacle).
  - How imminent or dangerous the situation is.
  - What rule or maneuver (if any) should be applied to avoid the collision.

Local Planning



Collision risk prediction with conventional technology

Collision risk prediction with new technology

Rule Determination (COLREGs Integration)

Once a risk is detected, the system identifies:

- Encounter type (head-on, crossing, overtaking).
- The appropriate COLREG rule to apply.
- Which vessel has the right of way.

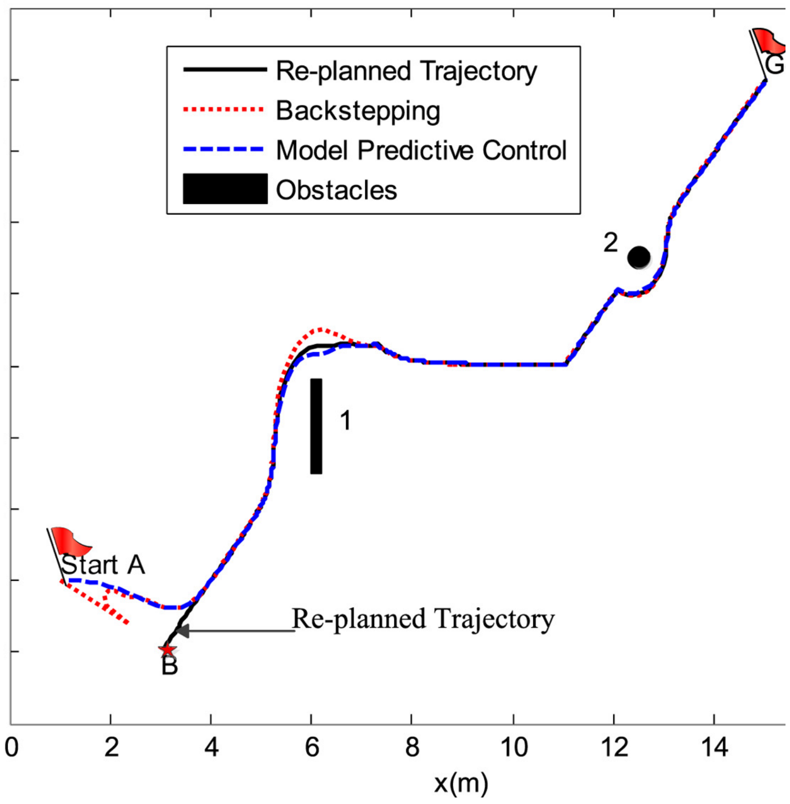
Local Planner

- An efficient algorithm which can provide the proper collision avoidance maneuver.

Core Technologies

Control Systems: PID, Model Predictive Control, Behavior Trees

- Control systems translate navigation goals into real-time actions for unmanned maritime vehicles.
- **PID controllers** manage basic motion like speed and heading, while **Model Predictive Control (MPC)** handles complex trajectory tracking under constraints.
- For high-level decisions, **Behavior Trees** structure adaptive, modular behaviors.
- Together, these methods enable precise and autonomous operation in dynamic marine environments.



Model Predictive Control

- **Model Predictive Control** (MPC) is a key strategy for autonomous USVs, optimizing control actions by predicting future behavior and handling constraints.
- It enables precise path following, collision avoidance, and energy efficiency, while adapting to disturbances like wind and waves—making it ideal for real-time navigation and formation control in dynamic maritime environments.

Core Technologies

- **AI & Autonomy: Object Detection, COLREGs Compliance, Decision-Making**
  - Artificial Intelligence (AI) empowers autonomous maritime systems to perceive, interpret, and act in complex environments.
  - Using deep learning, AI enables real-time object detection and ensures COLREGs compliance by assessing collision risks and guiding maneuvers.
  - By integrating perception and navigation goals, AI supports context-aware decision-making, enhancing safety, autonomy, and situational awareness in dynamic maritime settings.

Core Technologies

Sensing: Radar, LiDAR, Cameras, Sonar

Advanced sensing technologies are critical for situational awareness, obstacle detection, and environmental perception in unmanned maritime systems.

Radar is widely used for long-range detection of surface targets and navigational hazards, functioning reliably in various weather conditions.

LiDAR provides high-resolution 3D mapping and precise distance measurements, making it valuable for close-range navigation and object recognition.

Cameras (visible and infrared) offer visual context, enabling object classification, visual tracking, and optical navigation, especially when combined with AI-based vision systems.

Sonar, essential for underwater perception, is used for depth measurement, seabed mapping, and obstacle avoidance below the surface. Together, these sensors enable multi-modal perception, enhancing the safety, autonomy, and mission capability of unmanned surface and underwater vehicles.

Core Technologies

Communication: Radio, 4G/5G, Satellite, Acoustic Modems

Reliable communication is vital for controlling and monitoring unmanned maritime systems.

- Radio (VHF/UHF) supports short-range tasks, while 4G/5G enables real-time data transfer nearshore.
- Satellite links ensure long-range connectivity, and acoustic modems enable underwater communication.
- A hybrid architecture combining these technologies provides resilient, mission-ready connectivity across surface and subsurface operations.

Overview of all our Gear

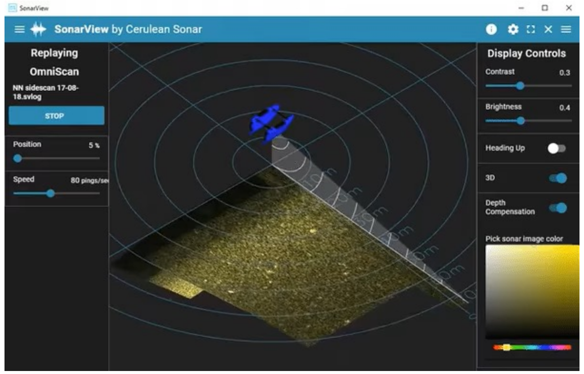
A deep dive into the technology powering our field operations

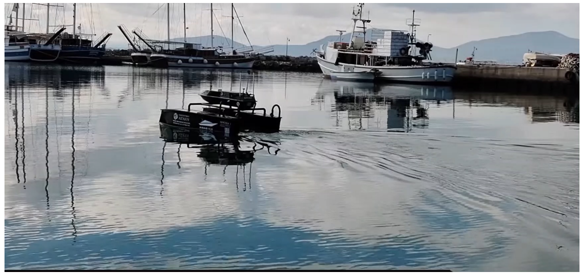
- **What you'll discover**
  - **The autonomous platforms driving our sea trials.**
  - **Onboard systems enabling autonomy and control.**
  - Sensors and payloads for environmental perception.
    - **Side Scan Sonar**
    - Velodyne VLP-16 (Puck) LiDAR (ideal for small platforms)
    - Furuno DRS4DL RADAR
    - Furuno DFF3D SONAR
  - Communication and telemetry setups for fieldwork
  - The software stack powering planning and data flow
  - How all components integrate for real-time missions

Overview of all our Gear
why it matters

- Understanding our gear is essential for:
  - Safely operating autonomous systems
  - Designing and running effective missions
  - Leveraging data for scientific and industrial insights

Overview of all our Gear



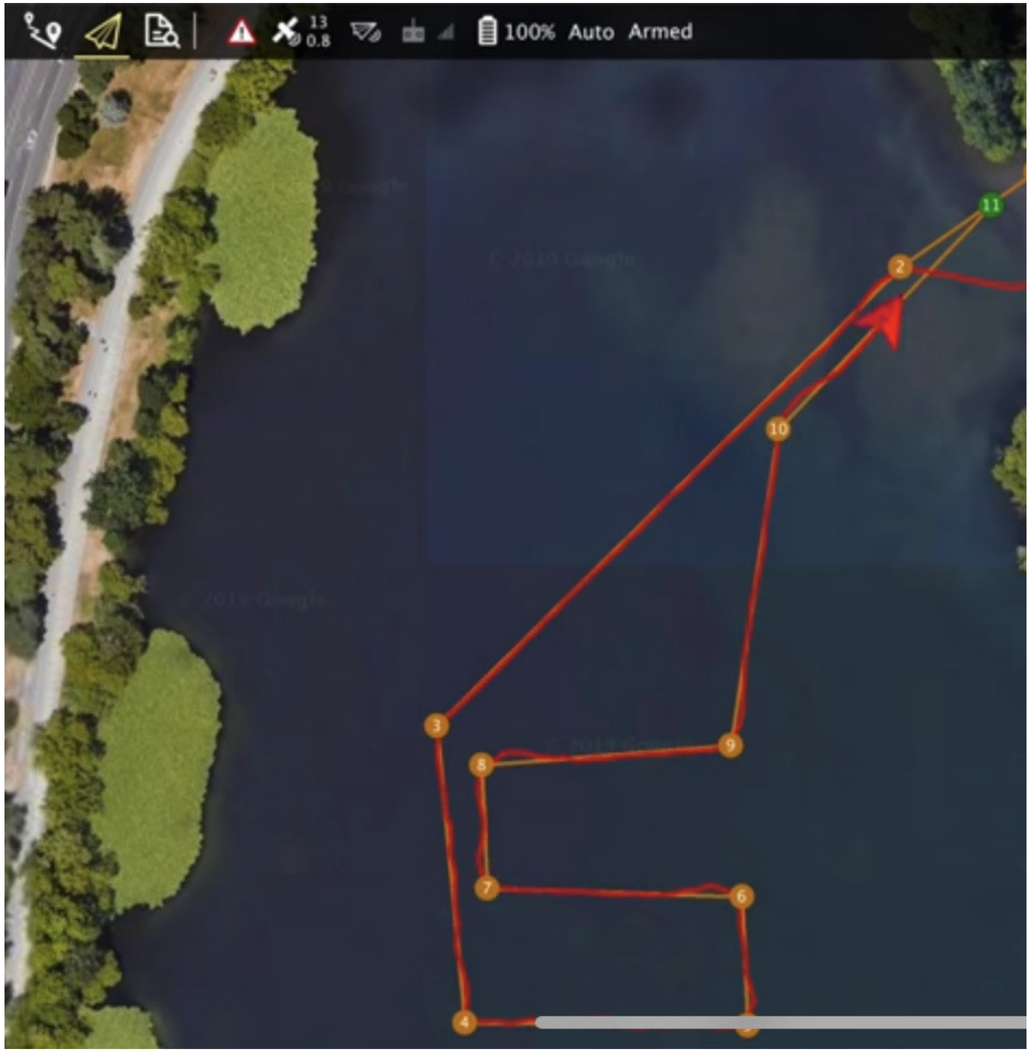


Visual Navigation for USVs

- Visual navigation leverages onboard cameras and computer vision algorithms to enable Unmanned Surface Vehicles (USVs) to perceive and interpret their surroundings for autonomous operation.
- By processing visual data, the system can detect obstacles, recognize navigational markers (e.g., buoys, channel signs), estimate relative positions, and even localize the USV in GPS-denied environments.

ArduPilot for USVs

- ArduPilot is a versatile, open-source autopilot platform that supports a wide range of autonomous vehicles, including Unmanned Surface Vehicles (USVs).
- It provides robust navigation, control, and mission-planning capabilities tailored to marine environments.
- With support for GPS waypoint following, obstacle avoidance, geofencing, and manual override, ArduPilot enables reliable autonomous operation in both inland and coastal waters.
- The system integrates seamlessly with a variety of sensors such as GPS, IMUs, depth sensors, and cameras, while offering real-time telemetry through MAVLink-compatible ground control software like Mission Planner or QGroundControl.
- ArduPilot's flexibility, active community, and support for custom extensions make it an ideal choice for research, surveying, and multi-vehicle fleet operations involving USVs.



Overview of Underwater ROVs and the BlueRoV2 platform

Introduction to Underwater Remotely Operated Vehicles (ROVs)

Fundamental concepts, capabilities, and role in marine operations.

Principles of Operation

Key components, navigation techniques, power and communication systems.

Operational Challenges

Comparison with aerial and terrestrial robotic systems:

- Environmental resistance (pressure, salinity, visibility)
- Communication limitations
- Navigation without GPS

Underwater Manipulation Basics

Principles of robotic manipulation in the underwater domain:

- Gripper mechanics
- Hydrodynamic constraints
- Feedback and control limitations

Overview of Underwater ROVs and the BlueRoV2 platform

The BlueROV2 Platform

Live or recorded demonstration

Key features and modularity

Assembly and Pre-Deployment Setup

Frame configuration

Tether management

Sensor and payload integration

Control System & Tools

User interface and control modes

Integrated sonar

Gripper system operation

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Home - Smart Move