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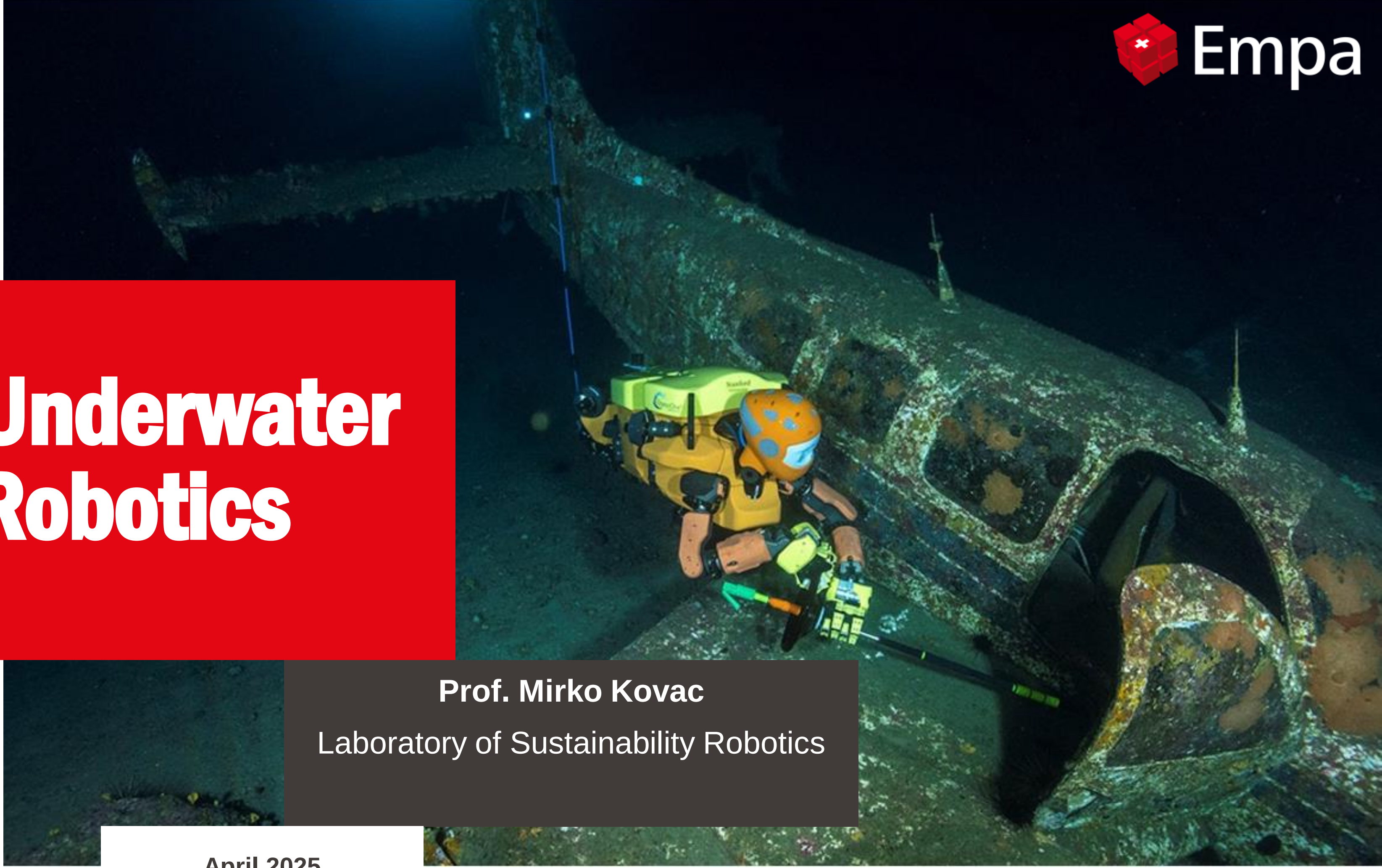

Underwater Robotics

Prof. Mirko Kovac

Laboratory of Sustainability Robotics

April 2025

École polytechnique fédérale de Lausanne

OceanOneK – A Humanoid Robot that can dive in ocean depths

Learning Goals

- ❑ *Why should we use robotics for underwater monitoring?*
- ❑ *How would one construct an underwater robot?*
- ❑ *What are emerging technologies can help underwater robot development?*

McGill University

Aquanaut a– Nuticus Robotics Inc.

Contents

Objectives & Scope

Understand the importance of underwater robotics in monitoring and protecting aquatic ecosystems.

Recognize key environmental challenges (e.g., pollution, habitat loss) and how robotic systems can help address them.

Gain familiarity with fundamental underwater robotic technologies and their applications in sustainability.

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Motivation & Relevance to Sustainability

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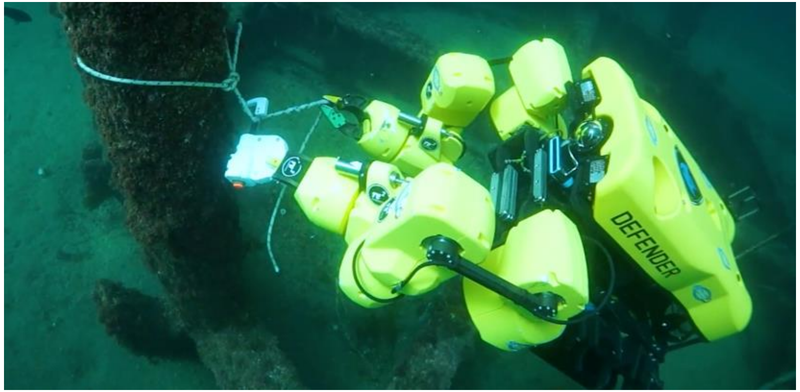
Why Underwater Robotics for Sustainability?

- *Environmental Monitoring*
  - Underwater robots can gather data in challenging or remote marine environments
- *Marine Ecosystem Preservation*
  - Robots assist in coral reef health assessments, seabed mapping, and tracking biodiversity
- *Resource Management*
  - Robots can help identify and monitor pollution sources, overfishing areas, and the effects of climate change on marine life

McGill University



SARCOS Robotics, Inc.

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Motivation & Relevance to Sustainability

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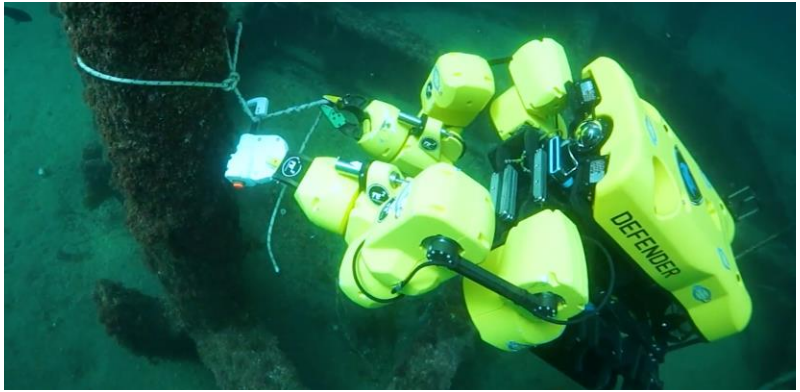
Link to Environmental Engineering

- *Tools for sustainable solutions*
  - Water quality assessment, underwater infrastructure inspection (e.g., pipelines, wind farms), and damage mitigation in sensitive habitats

- *Enhancement of data accuracy and frequency*
  - Robots enable continuous and reliable monitoring, improving decision-making for environmental policies

McGill University



SARCOS Robotics, Inc.

Environmental & Sustainability Challenges

State of the Marine Environment

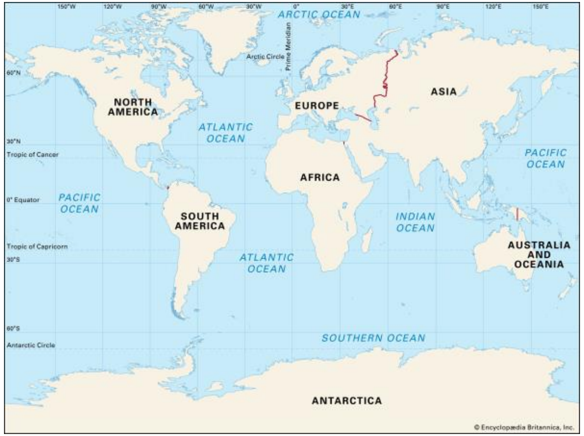
Key Facts

- Over 70% of Earth's surface is ocean, playing a crucial role in climate regulation, **carbon** cycling, and **biodiversity**
- Oceans produce over half of the world's **oxygen** and absorb significant portions of human-generated CO_2

Ecosystem Services Provided by Oceans

- Fisheries and aquaculture for global food security
- Natural coastal protection (mangroves, coral reefs)
- Pharmaceuticals, minerals, and renewable energy sources

Ocean map



Britannica

Major Environmental Stressors on the Oceans

Pollution & Plastic Debris

- ❑ Millions of tons of plastic waste enter the oceans each year
- ❑ Chemical pollutants, heavy metals, and agricultural runoff causing eutrophication and dead zones

Climate Change Impacts

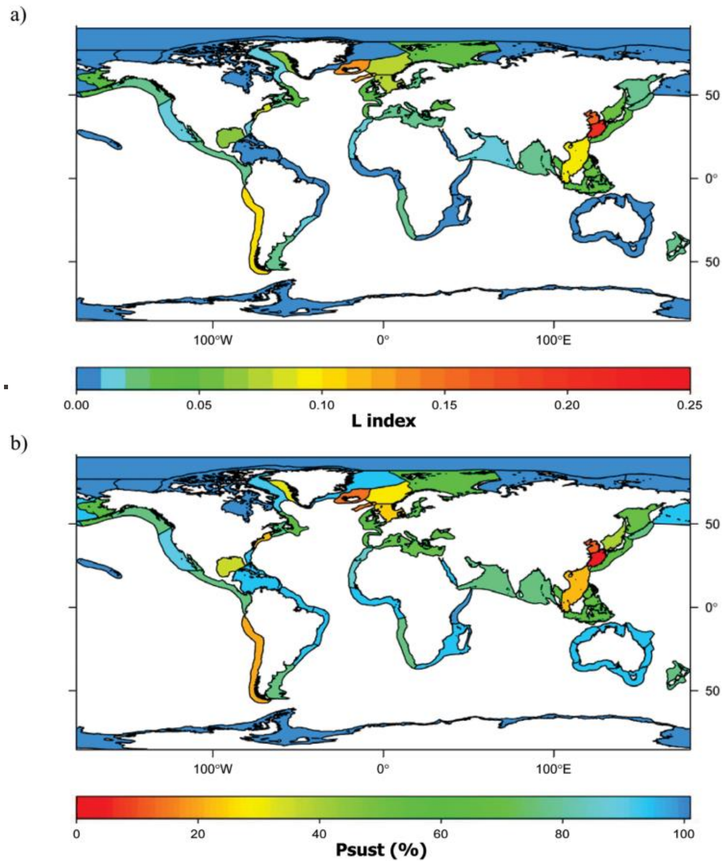
- ❑ Ocean acidification threatening shellfish and coral reefs.
- ❑ Rising sea temperatures leading to coral bleaching and shifts in species distribution

Overfishing & Habitat Loss

- ❑ Unsustainable fishing practices reducing fish stocks
- ❑ Destruction of seabed habitats by trawling and coastal development

* L index: loss in secondary production (Reduction in the rate at which energy is transferred from primary producers)

* Psust: sustainable production level (Maximum level of secondary production)



Coll, M., Libralato, S., Tudela, S., Palomera, I., & Pranovi, F. (2008). Ecosystem overfishing in the ocean. *PLoS one*, *3*(12), e3881.

The Challenge of Monitoring & Managing the Marine Environment

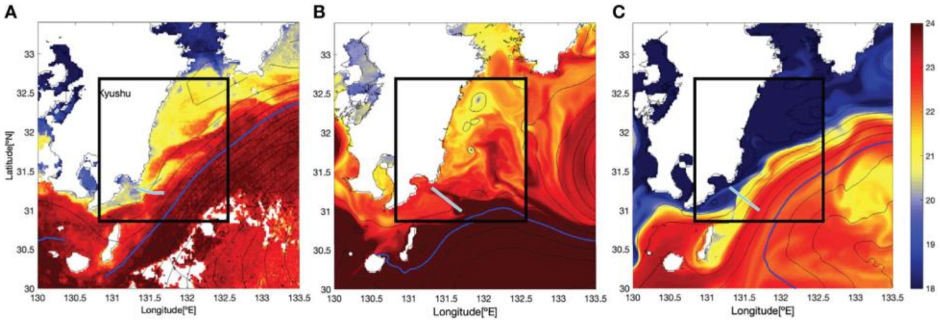
Traditional Monitoring Approaches

- ❑Diver surveys, ship-based sampling, satellite imaging.
- ❑Limitations: Expensive, weather-dependent, risky for divers, limited data collection

Gaps in Knowledge & Data

- ❑Insufficient baseline data on deep-sea environments and many marine species
- ❑Rapid changes outpacing current monitoring capabilities

Satellite Imaging



Sea Surface Temperature °C for (A) satellite observation by Himawari-8 on Nov25th, 2018, and for the ROMS simulation on (B) November 11th and (C) December 20th.

Durán Gómez, G. S., & Nagai, T. (2022). Elevated Nutrient Supply Caused by the Approaching Kuroshio to the Southern Coast of Japan. *Frontiers in Marine Science*, *9*, 842155.

Role of Underwater Robotics in Sustainability

Technology Introduction

- ❑AUVs (Autonomous Underwater Vehicles): Can operate **without** human intervention, ideal for large-scale surveys
- ❑ROVs (Remotely Operated Vehicles): Tethered to a surface ship, providing real-time control and high-definition imaging

Capabilities for Environmental Work

- ❑**Continuous** and repeatable data collection under challenging conditions
- ❑ **Fine-scale** habitat mapping, from coral reefs to hydrothermal vents
- ❑ Detecting and quantifying pollutants, microplastics, and invasive species

AUVs

Bluefin robotics

ROVs

Boxfish robotics

From Data Collection to Impactful Decisions

Data-to-Decision Pipeline

- Robots collect high-quality, real-time data
- Data processed with AI/machine learning to identify patterns, species, or anomalies
- Information used by policymakers, conservationists, and engineers to guide sustainable management efforts

Case Examples

- Coral Reef Health Monitoring: Robots mapping bleaching events can help target restoration efforts
- Marine Protected Areas (MPAs): Continuous robotic surveillance ensures compliance with fishing regulations

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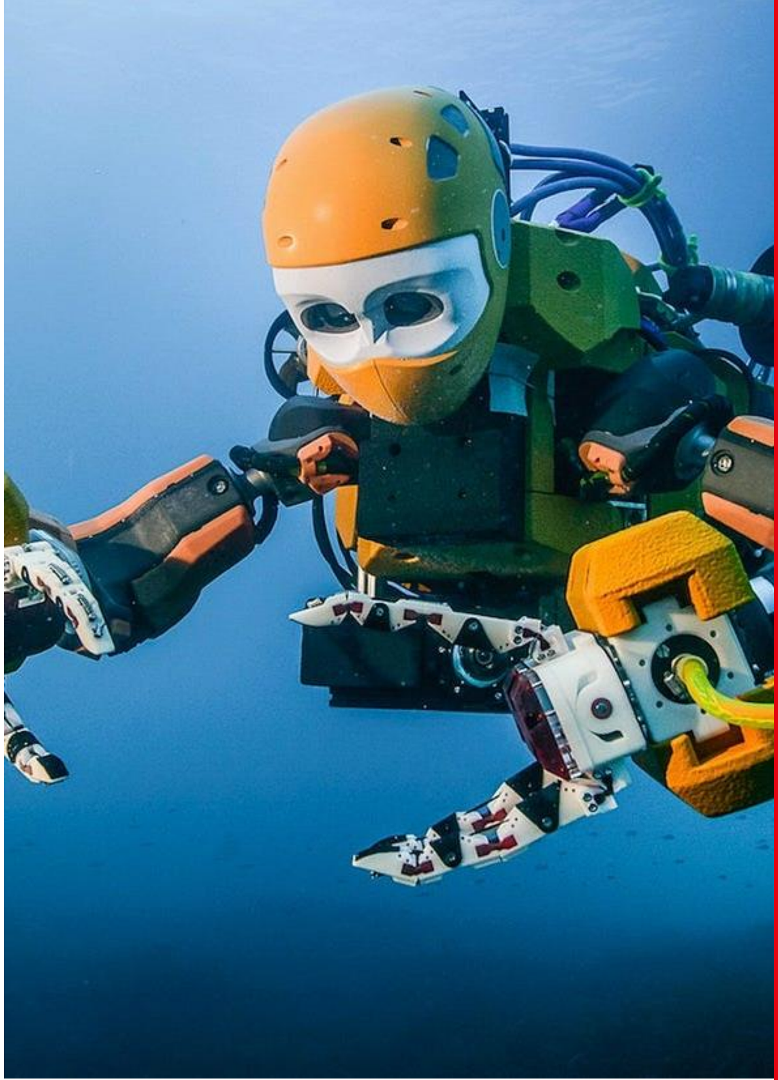

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Underwater Robotics Fundamentals

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Overview of Underwater Robot Types

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Autonomous Underwater Vehicles (AUVs)

- Untethered, programmable robots that follow a pre-planned mission without real-time human input

Remotely Operated Vehicles (ROVs)

- Tethered robots controlled in real-time from a surface vessel. Often used for inspection, repair, and detailed observation

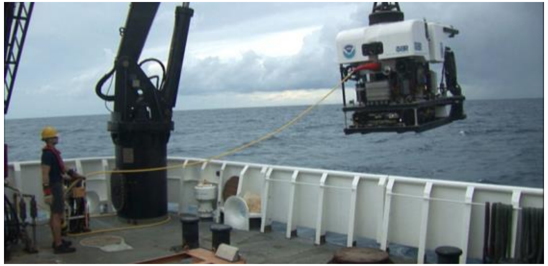
Hybrid Systems

- Vehicles that can operate autonomously or with a tether, combining the advantages of AUVs and ROVs

AUVs

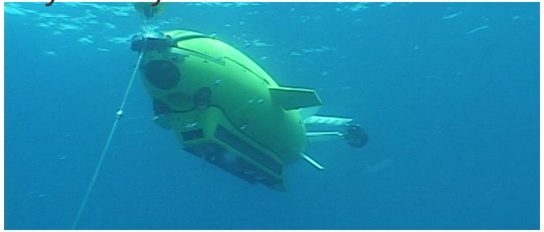
JASCO

ROVs



NOAA Ocean Exploration research

Hybrid systems



Marlin

Comparing AUVs & ROVs in Practice

ROVs

- *Strengths*
  - Real-time control, human-in-the-loop decision-making, high-resolution video feeds
- *Limitations*
  - Tether management constraints, limited operational radius, reliance on a support vessel

AUVs

- *Strengths*
  - Long-range endurance, reduced human supervision, cost-effective for large-area surveys
- *Limitations*
  - Pre-programmed routes, limited ability to adapt on-the-fly without advanced autonomy

Design Considerations – Pressure Housings

Requirements

- Must withstand intense underwater pressure; typically made from titanium, aluminum alloys, or specialized composite materials
- Protects sensitive electronics, batteries, and sensors

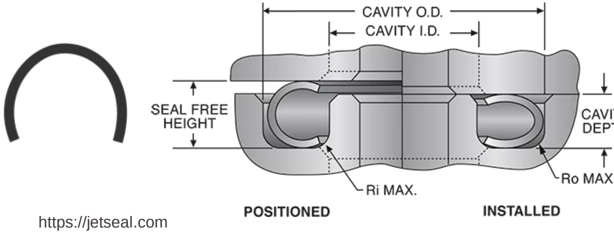
Sealing Mechanisms

- The housing must remain watertight
  - Specialized o-rings
  - Metal o-rings

Spring energied O-ring
(up to 69 MPa ≈ 6900 m deep sea)

https://ahpseals.com/product/vs-prs19-2/

Metal O-ring
(up to 413 MPa ≈ 41300 m deep sea)



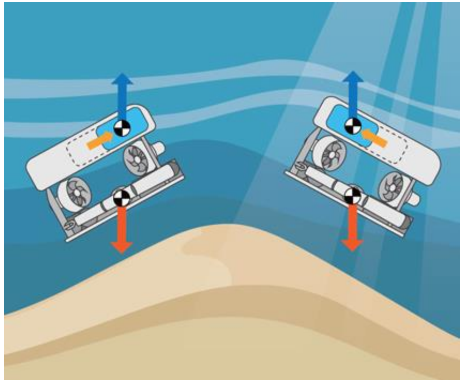
https://jetseal.com

Design Considerations – Buoyancy

Buoyancy Control

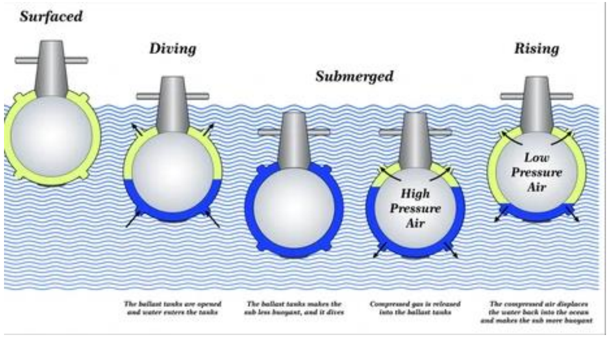
- ❑ **Neutral** buoyancy reduces energy consumption during movement
- ❑ Adjustable **ballast** or foam materials to fine-tune buoyancy
- ❑ External **bladder** systems to shift buoyancy dynamically

ROV control by Buoyancy



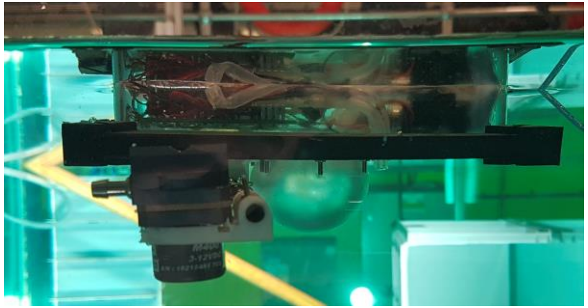
https://global.honda/en/tech/Honda_ROV_Remote_Operation_Vehicle_underwater_robot/

Buoyancy control by ballast water



https://www.shutterstock.com/search/ballast-tank?image_type=vector

Buoyancy control by bladder



Debruyn et al., MEDUSA: A Multi-Environment Dual-Robot for Underwater Sample Acquisition, IEEE RA-L, 2020

Design Considerations – Propulsion & Materials

Propulsion Mechanisms

- Thrusters (electric or hydraulic) for maneuverability
- Underwater gliders
  - Use buoyancy shifts and wings to glide with minimal energy
- Bio-inspired propulsion
  - Fin or undulating foil mimicking marine animals for efficient, quiet movement

Thruster

Blue robotics

Bio-inspired swimming robot

Iguchi, K., Shimooka, T., Uchikai, S., Konno, Y., Tanaka, H., Ikemoto, Y., & Shintake, J. (2024). Agile robotic fish based on direct drive of continuum body. *npj Robotics*, *2*(1), 7.

Underwater glider

JASCO

Design Considerations – Propulsion & Materials

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Thruster

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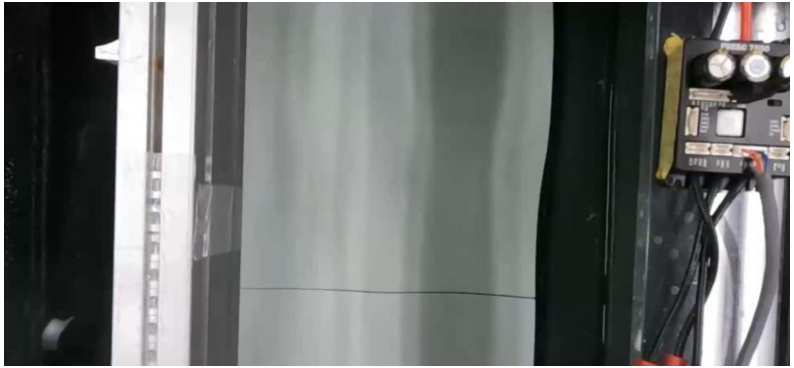
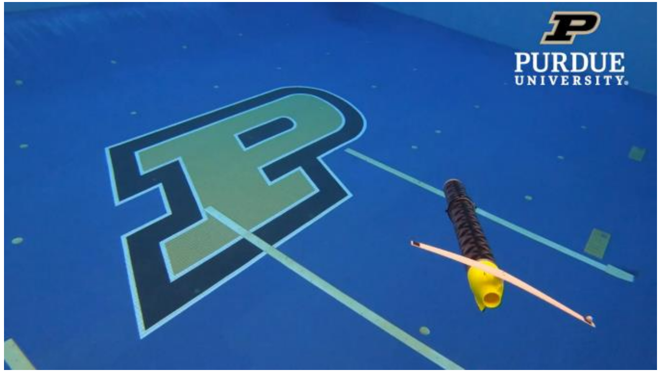


Underwater glider



Purdue Glider

Material Selection for Underwater Robotics

Strength

- **Hydrostatic Pressure**
  - Underwater robotics operate in high-pressure environments, especially at significant depths. Materials must resist deformation or collapse under intense hydrostatic forces
  - Example: At 1,000 meters depth, pressure exceeds 100 atmospheres (~10 MPa)

- **Impact Resistance**
  - The robot may collide with underwater obstacles such as rocks, shipwrecks, or debris. Materials must absorb impacts without cracking or losing functionality

- **Load-Bearing Capacity**
  - Components like frames and joints must support the weight of sensors, electronics, batteries, and tools while maintaining structural integrity.

- **Dynamic Forces**
  - Thrusters, robotic arms, and propellers create mechanical forces that can fatigue materials over time.

Material Selection for Underwater Robotics

Durability

- **Corrosion Resistance**
  - Saltwater accelerates the degradation of materials, especially ferrous metals. Corrosion can weaken components and compromise functionality
- **Wear and Abrasion Resistance**
  - Moving parts (e.g., propeller shafts, hinges) are subject to wear due to friction and abrasive particles like sand. Durable materials reduce maintenance and failure risks
- **Fatigue Resistance**
  - Repeated loading and unloading, such as vibrations from thrusters or pressure cycles, can cause fatigue failures in metals and composites

Worn propellor

https://blog.campingworld.com/marine/how-to-find-the-right-boat-propeller/

Ship floor with biofouling

https://www.european-coatings.com/news/application-areas/marine-anti-fouling-strategies-emerging-opportunities-for-seawater-resource-utilization/

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Material Selection for Underwater Robotics

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Durability

- **Thermal Stability**
  - Underwater robotics may experience temperature variations, especially when transitioning between surface waters and deep-sea environments. Materials must maintain their mechanical properties across temperature ranges
- **Biofouling Resistance**
  - Marine organisms like algae, barnacles, and bacteria can attach to surfaces, impacting hydrodynamics and efficiency

Worn propellor

https://blog.campingworld.com/marine/how-to-find-the-right-boat-propeller/

Ship floor with biofouling

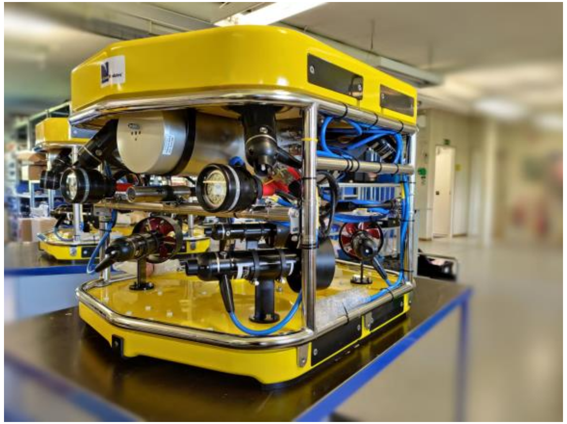
https://www.european-coatings.com/news/application-areas/marine-anti-fouling-strategies-emerging-opportunities-for-seawater-resource-utilization/

Material Selection for Underwater Robotics

Titanium

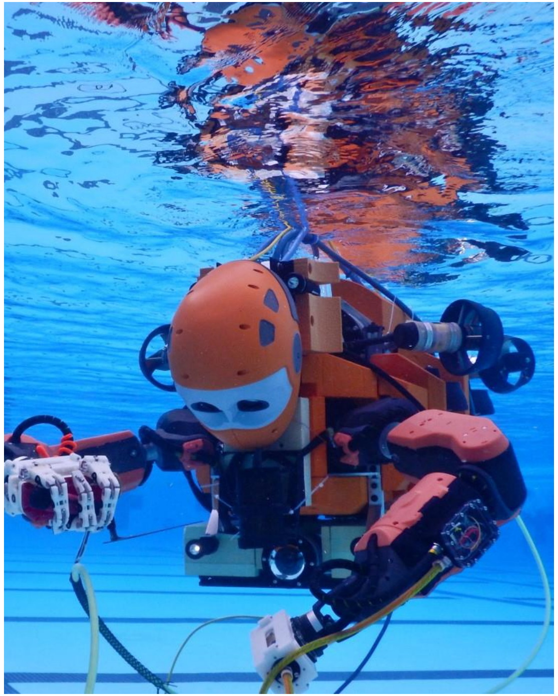
https://www.jamstec.go.jp/mare3/j/ships/deep_sea/kaikou.html

Stainless Steel



https://www.ocean-modules.com/products/v8-m500

Hybrid



https://khatib.stanford.edu/ocean-one.html

Aluminium

https://www.carcinus.co.uk/product/bluerov2-configurable/#bluerov2-base-configuration

Silicone elastomer

Iguchi, K., Shimooka, T., Uchikai, S., Konno, Y., Tanaka, H., Ikemoto, Y., & Shintake, J. (2024). Agile robotic fish based on direct drive of continuum body. *npj Robotics*, *2*(1), 7.

Material Selection for Underwater Robotics

Material	Strength	Durability	Common Use
Titanium	High	Excellent corrosion resistance	Deep-sea pressure hulls, frames
Stainless Steel	High	Good corrosion resistance	Fasteners, external components
Marine-Grade Aluminum	Moderate-High	Moderate corrosion resistance	Vehicle frames, structural supports
FRPs (Composites)	High	Excellent fatigue resistance	Pressure vessels, lightweight parts
HDPE/Polymers	Moderate	Excellent chemical resistance	Buoyancy aids, housings, Bioinspired robots

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Control & Navigation – The Challenge of Underwater Positioning

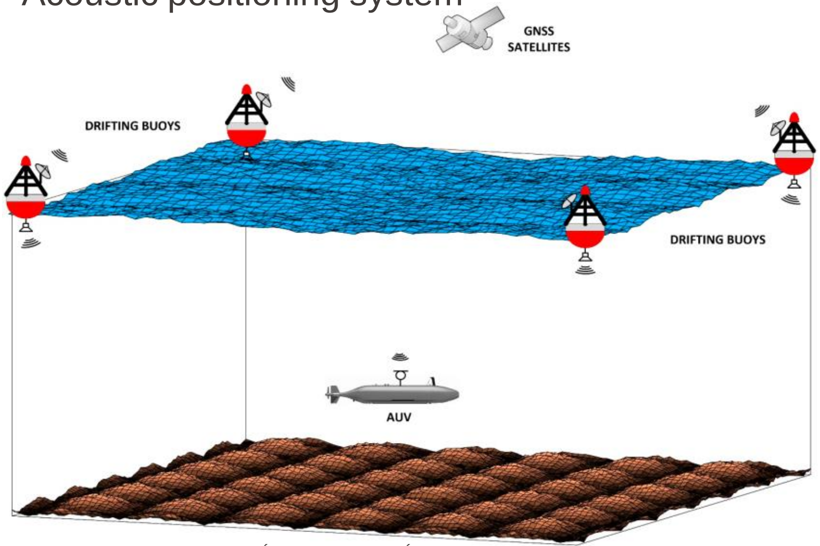
Limited GPS Usage

- ❑ GPS signals cannot penetrate water effectively
- ❑ Robots must rely on other methods for localization once submerged

Acoustic Beacons & Baselines

- ❑ Deploy acoustic transponders on the seabed or on surface buoys
- ❑ The robot triangulates its position based on signal travel times

Acoustic positioning system



Otero, P., Hernández-Romero, Á., Luque-Nieto, M. Á., & Ariza, A. (2023). Underwater Positioning System Based on Drifting Buoys and Acoustic Modems. *Journal of Marine Science and Engineering*, *11*(4), 682.

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Control & Navigation – Inertial and Vision-Based Methods

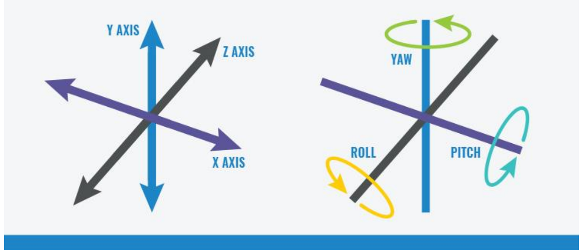
Inertial Navigation Systems (INS)

- Use accelerometers and gyro sensor to track movement from a known starting point
- Can drift over time, requiring periodic correction from acoustic or visual references

Vision- or Sonar-based Navigation

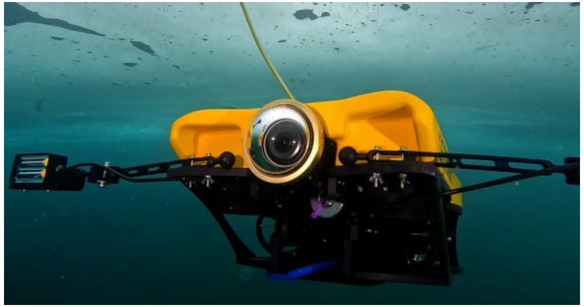
- Cameras and sonar systems identify known landmarks (e.g., seafloor features, artificial markers)
- Simultaneous Localization and Mapping (SLAM) techniques to build maps on-the-fly and update position estimates

Accelerometer   Gyro sensor



https://www.ceva-ip.com/ourblog/what-is-an-imu-sensor/

Vision sensor embedded ROV



https://oceannews.com/featured-stories/an-rov-vision-system-without-compromise/

Sensing & Instrumentation – Core Sensors

Acoustic Sensors (Sonar)

- Imaging sonar for terrain mapping and obstacle detection
- Side-scan sonar for high-resolution seabed imagery

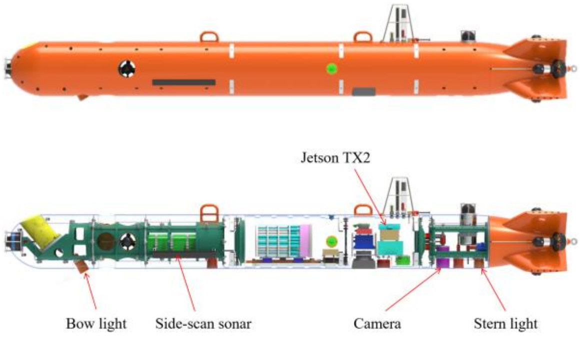
Optical Sensors (Cameras)

- High-resolution cameras for habitat assessment, species identification
- Low-light or infrared capabilities in deep or turbid waters

Chemical & Environmental Sensors

- Conductivity, Temperature, and Depth (CTD) probes for water quality
- Dissolved oxygen, pH, nutrient sensors for ecosystem health monitoring

Integrated sensing system



https://www.frontiersin.org/journals/marine-science/articles/10.3389/fmars.2023.1112310/full

Integration & Data Processing

Sensor Fusion

- Combining data from sonar, cameras, INS, LIDAR, and CTD sensors to form comprehensive environmental pictures

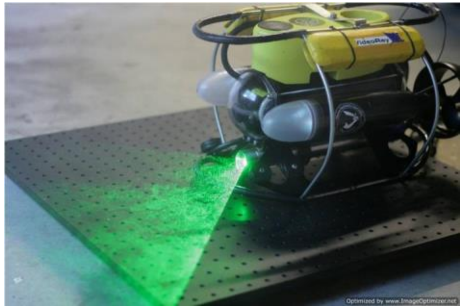
Onboard Data Processing & Storage

- Onboard processors handle raw sensor data, reduce noise, and compress for storage
- Some systems can make autonomous decisions based on sensor inputs (e.g., changing course upon detecting pollution)

Communication & Data Retrieval

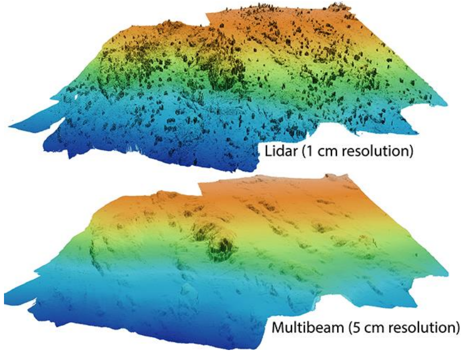
- Acoustic modems or optical communication links to transfer data to the surface
- Post-mission data analysis for generating maps, 3D models, and informed conclusions

LIDAR sensor embedded ROV



https://www.savante.co.uk/micro-rov-laser-inspection

Seafloor mapping



https://www.surveyinggroup.com/next-gen-underwater-lidar-technology-ocean-floor-mapping/

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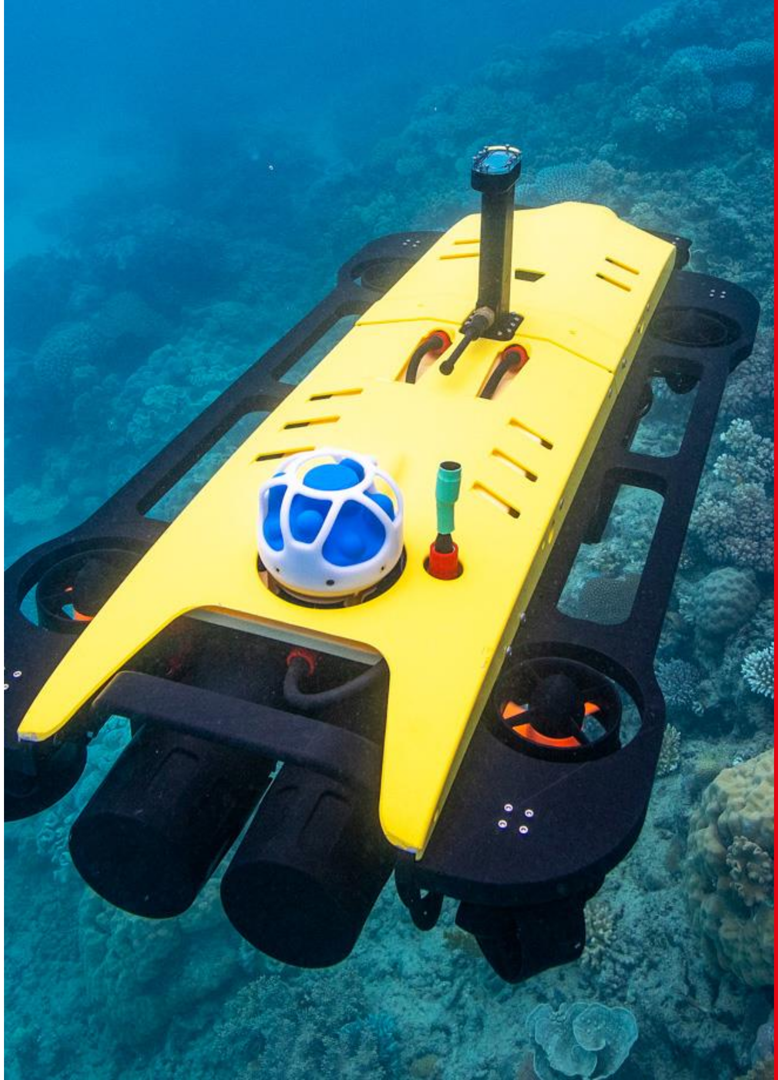

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Environmental Applications

Environmental Monitoring & Data Collection

Coral Reef Surveys

- Underwater drones equipped with high-resolution cameras and multispectral sensors can track reef health, bleaching events, and species diversity
- Long-term reef monitoring helps inform conservation strategies and restoration projects

Coral AUV

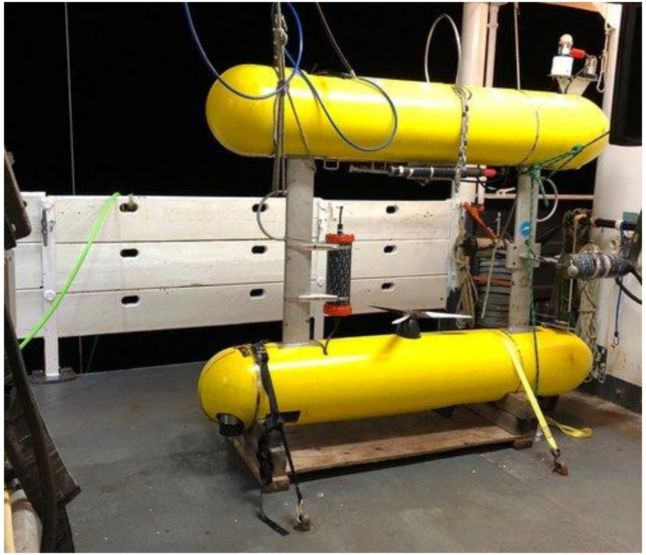
https://www.aims.gov.au/research/technology/reefscan/CoralAUV

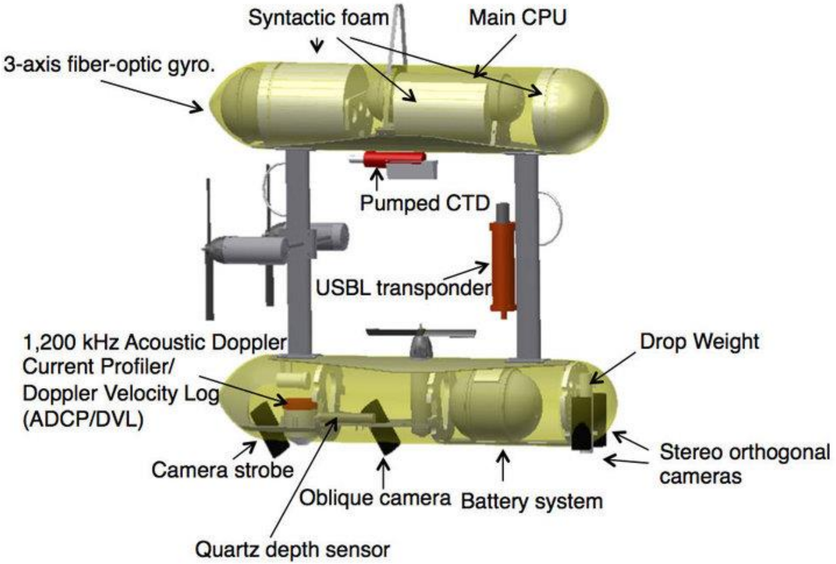
Environmental Monitoring & Data Collection

Ocean Temperature & Nutrient Levels

- AUVs with CTD (Conductivity, Temperature, Depth) sensors measure water column properties over large areas
- Continuous data collection helps scientists understand climate-driven changes, ocean currents, and biological productivity

NOAA Fisheries SeaBED AUV





https://oceanexplorer.noaa.gov/explorations/19express/background/auv/auv.html

Environmental Monitoring & Data Collection

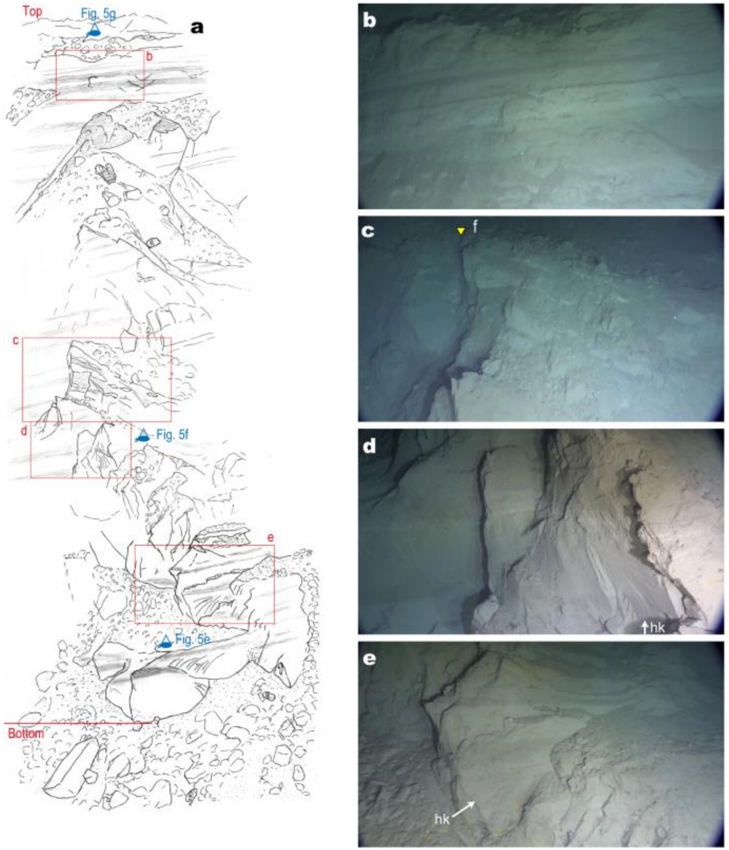
Seafloor Mapping

- ❑Robotic platforms use camera, sonar and LiDAR to generate high-resolution maps of the seabed
- ❑Maps aid in identifying habitats, geological features, and changes over time (e.g., sediment shifts, erosion)

Deep-submergence vehicle

https://www.boatinternational.com/yachts/editorial-features/inside-limiting-factor-the-record-breaking-triton-built-submersible--41923

Fault at seafloor cause by 2011 Tohoku-oki Earthquake

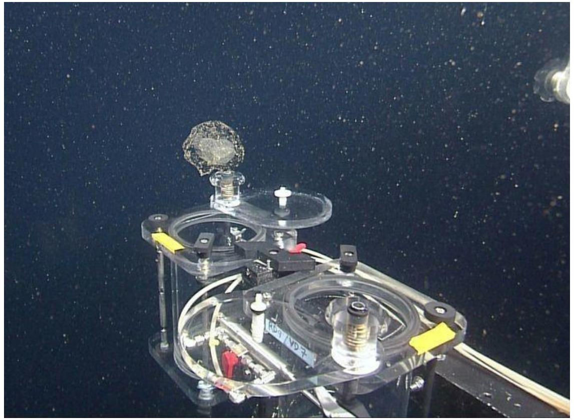


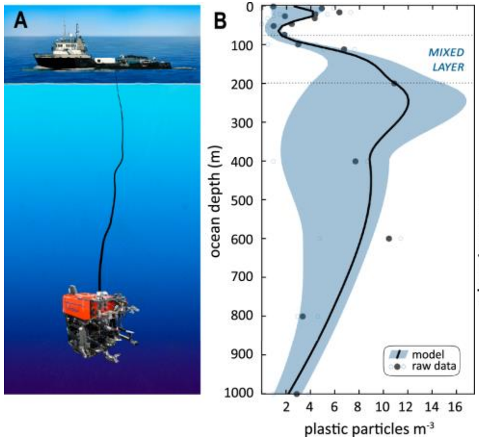
Ueda, H., Kitazato, H., & Jamieson, A. (2023). The submarine fault scarp of the 2011 Tohoku-oki Earthquake in the Japan Trench. *Communications Earth & Environment*, *4*(1), 476.

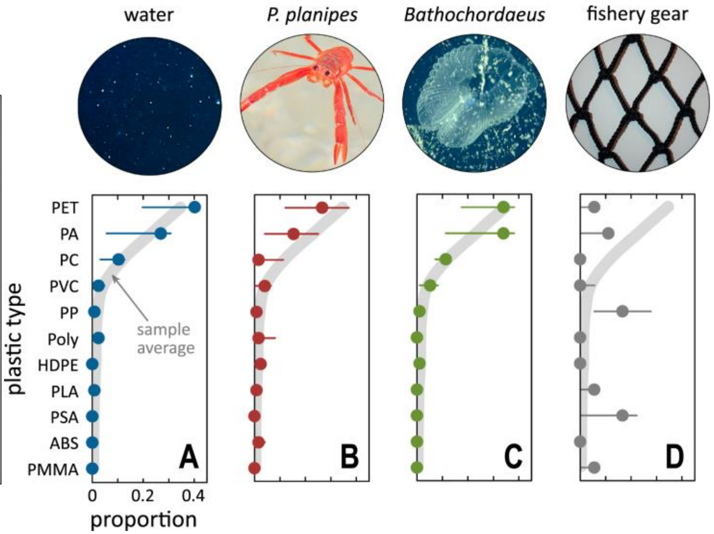
Pollution & Waste Detection

Microplastic Tracking

- Specialized robots equipped with fine filtration systems and optical sensors identify and quantify microplastics in the water







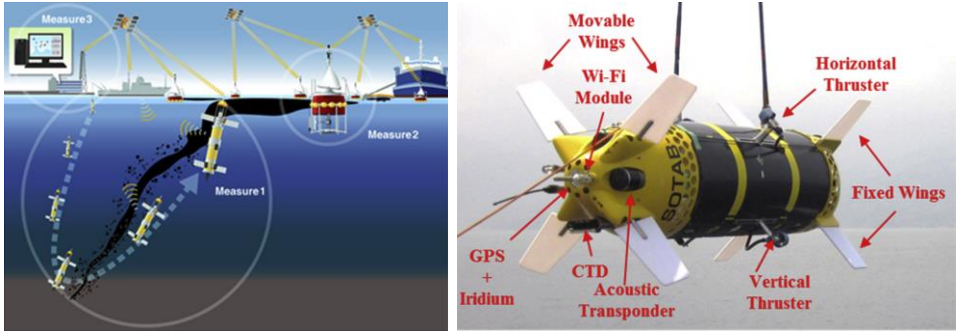
Choy, C. A., Robison, B. H., Gagne, T. O., Erwin, B., Firl, E., Halden, R. U., ... & S. Van Houtan, K. (2019). The vertical distribution and biological transport of marine microplastics across the epipelagic and mesopelagic water column. *Scientific reports*, *9*(1), 7843.

Pollution & Waste Detection

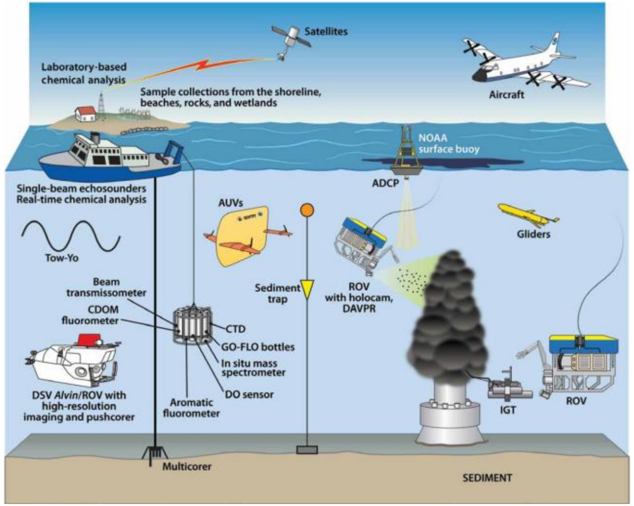
Oil/Hydrocarbon Leak Detection

- ❑ROVs and AUVs fitted with chemical sensors can detect oil plumes, oil spills, gas leak from seafloor, or methane seeps around pipelines and drilling sites
- ❑Early detection reduces environmental damage and guides rapid repair actions

Oil spill and gas leak tracking ROV



Gas leak detection strategy by ROV



Kato, N., Choyekh, M., Dewantara, R., Senga, H., Chiba, H., Kobayashi, E., ... & Short, T. (2017). An autonomous underwater robot for tracking and monitoring of subsea plumes after oil spills and gas leaks from seafloor. *Journal of Loss Prevention in the Process Industries*, *50*, 386-396.

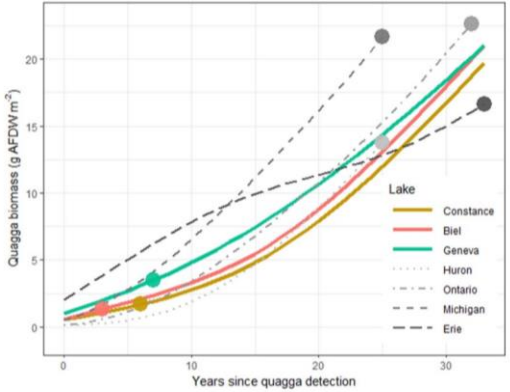
White, H. K., Conmy, R. N., MacDonald, I. R., & Reddy, C. M. (2016). Methods of oil detection in response to the Deepwater Horizon oil spill. *Oceanography*, *29*(3), 76-87.

Pollution & Waste Detection

Invasive Species & Habitat Monitoring

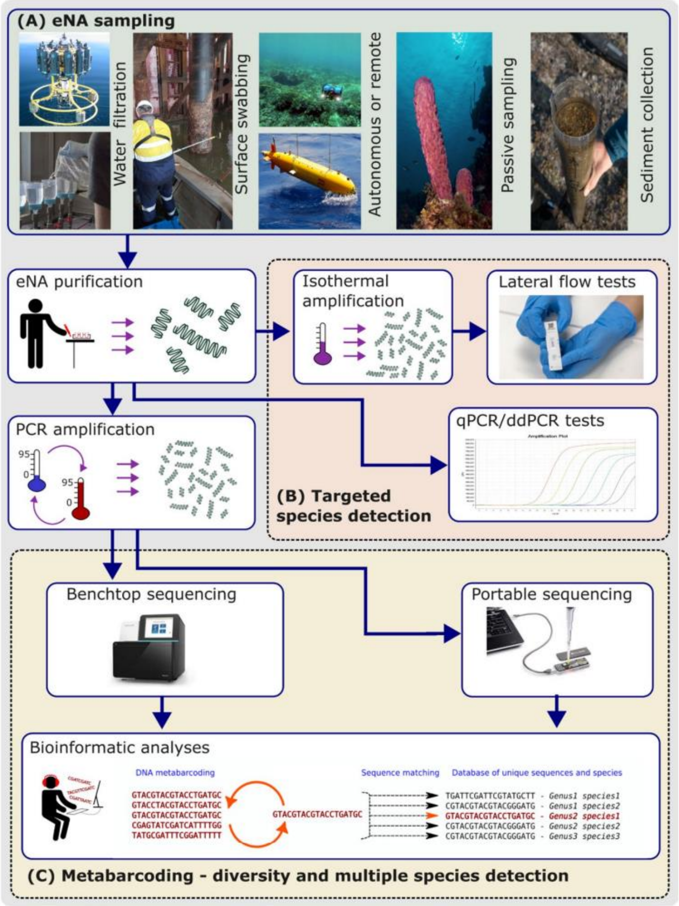
- Robots equipped with cameras, sonar, or DNA-sampling tools identify invasive species such as mussels or jellyfish blooms
- This helps researchers track spread patterns and evaluate eradication efforts

Mussels are spreading over lake in Switzerland



Kraemer, B. M., Boudet, S., Burlakova, L. E., Haltiner, L., Ibelings, B. W., Karatayev, A. Y., ... & Spaak, P. (2023). An abundant future for quagga mussels in deep European lakes. *Environmental Research Letters*, *18*(12), 124008.

eDNA sampling & analysis strategy



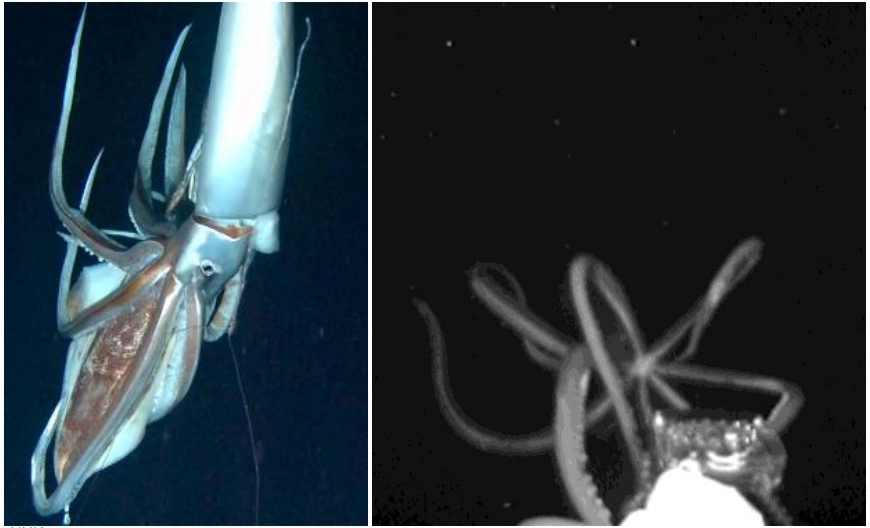
Jarman, S., Ackermann, F., Marnane, M., Berry, O., Bunce, M., Dawkins, K., ... & Harvey, E. (2024). Research horizons for invasive marine species detection with eDNA/eRNA. *Biological Invasions*, *26*(11), 3715-3731.

Deep-Sea Exploration & Conservation

Deep-Sea Biodiversity Assessments

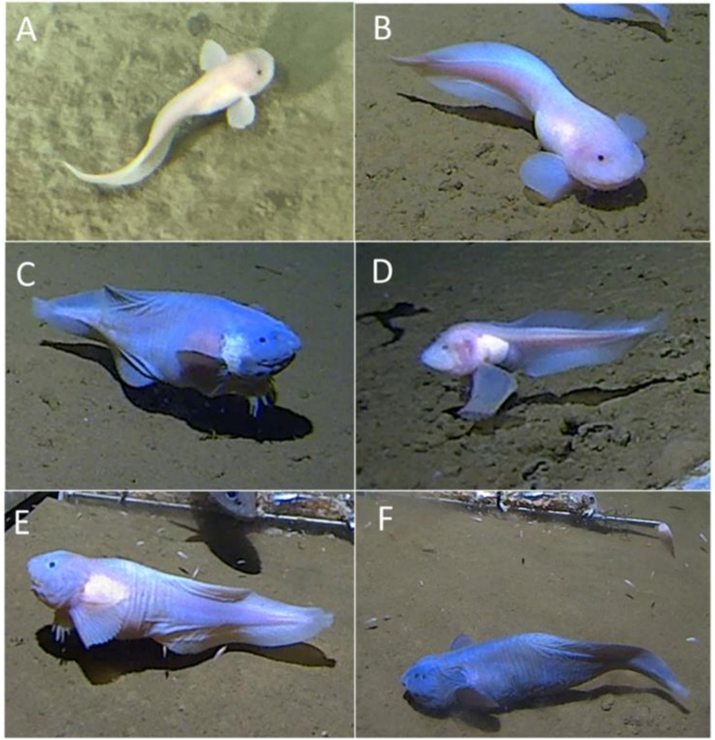
- ROVs operating at deep sea capture high-quality video and sample unique organisms
- Discoveries of new species or habitats inform our understanding of global biodiversity hotspots

Giant squid recorded by electroluminescenced ROV



NHK

Liparidae at deep sea (8336 m)



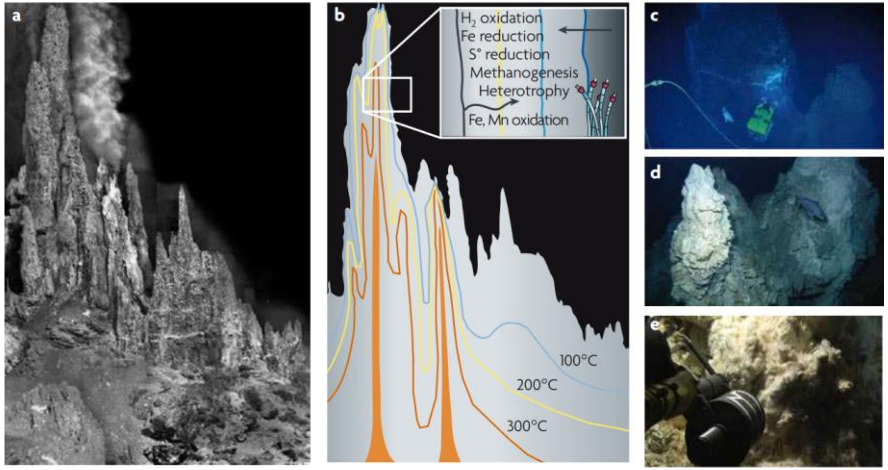
Jamieson, A. J., Maroni, P. J., Bond, T., Niyazi, Y., Kolbusz, J., Arasu, P., & Kitazato, H. (2023). New maximum depth record for bony fish: Teleostei, Scorpaeniformes, Liparidae (8336 m, Izu-Ogasawara Trench). Deep Sea Research Part I: Oceanographic Research Papers, 199, 104132.

Deep-Sea Exploration & Conservation

Hydrothermal Vents & Seamount Studies

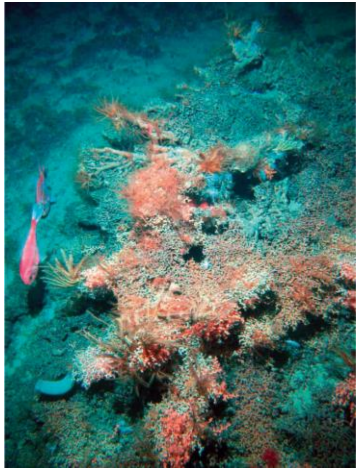
- Robotic explorers collect temperature, chemical, and biological data around vents, revealing how life adapts to extreme conditions
- Understanding these ecosystems contributes to knowledge of biogeochemical cycles and potential biotech resources

Hydrothemal vents with living



Martin, W., Baross, J., Kelley, D., & Russell, M. J. (2008). Hydrothermal vents and the origin of life. *Nature Reviews Microbiology*, *6*(11), 805-814.

Coral at the seamount (950 m)



Clark, M. R., Rowden, A. A., Schlacher, T., Williams, A., Consalvey, M., Stocks, K. I., ... & Hall-Spencer, J. M. (2010). The ecology of seamounts: structure, function, and human impacts. *Annual Review of Marine Science*, *2*(1), 253-278.

Deep-Sea Exploration & Conservation

Cultural Insights

- ROVs help locate and document shipwrecks, aiding marine archaeology and history

Antikythera Shipwreck (Greece)

https://whyathens.com/events/antikythera-shipwreck/

Shipwrecks founded by ROV (battleship Musashi)

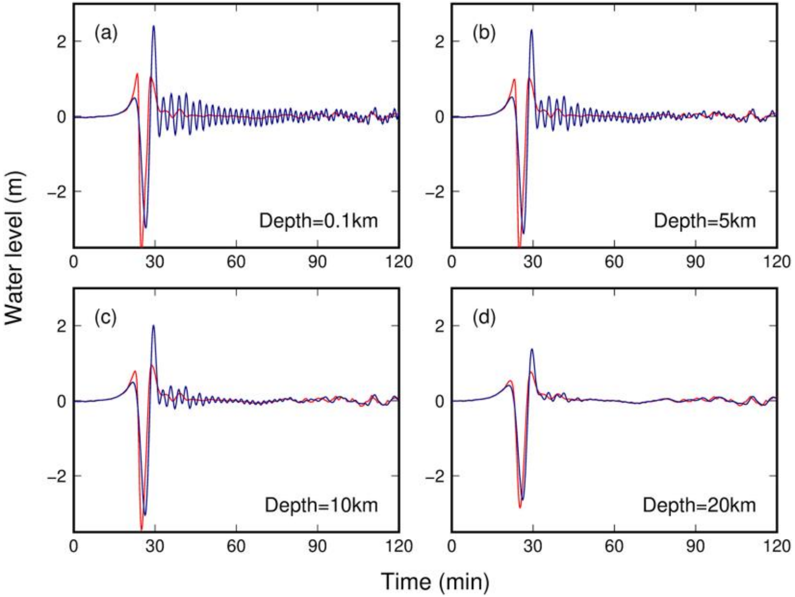
https://www.washingtonpost.com/news/morning-mix/wp/2015/03/04/huge-wwii-japanese-battleship-musashi-has-been-found-billionaire-paul-allen-says/

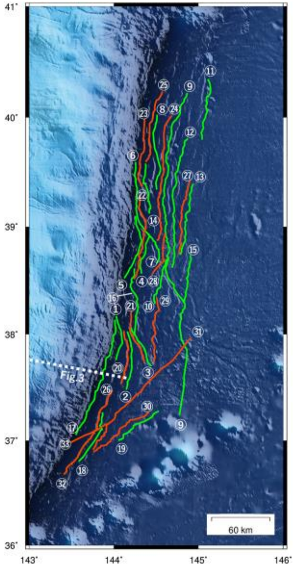
Deep-Sea Exploration & Conservation

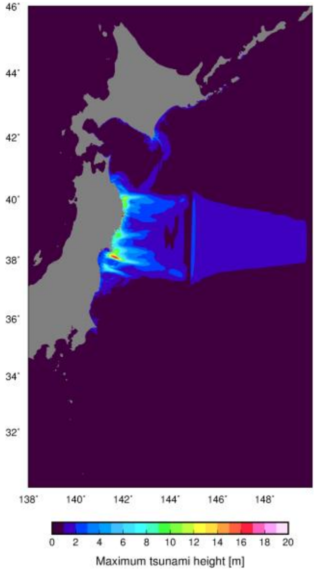
Geological Insights

- Geological surveys inform earthquake and tsunami modeling, enhancing disaster preparedness

Tsunami modeling of Tohokuoki-earthquake based on observation of slided fault







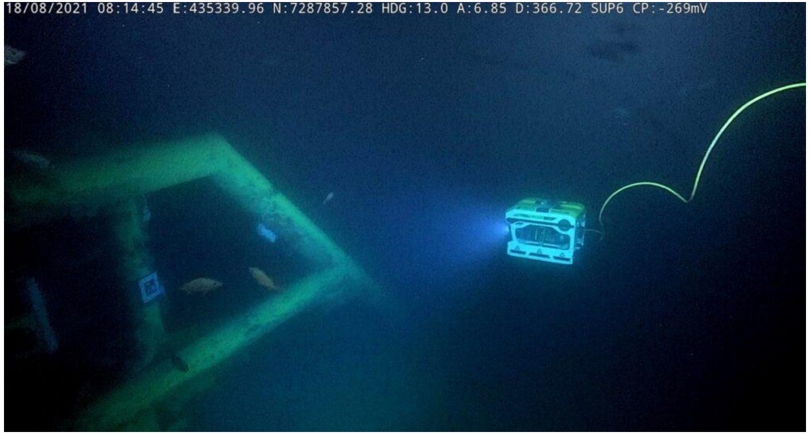
Baba, T., Chikasada, N., Nakamura, Y., Fujie, G., Obana, K., Miura, S., & Kodaira, S. (2020). Deep investigations of outer-rise tsunami characteristics using well-mapped normal faults along the Japan Trench. *Journal of Geophysical Research: Solid Earth*, *125*(10), e2020JB020060.

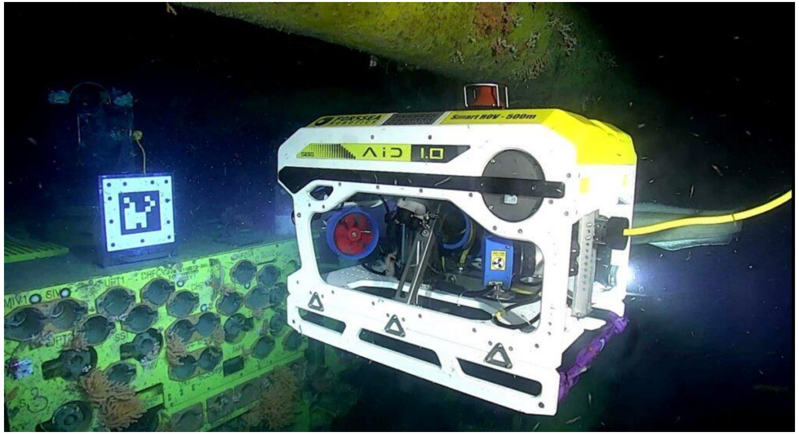
Renewable Energy Support

Offshore Wind Farms

- Underwater robots inspect turbine foundations for corrosion, biofouling, and structural integrity
- Routine inspections ensure efficiency, extend asset life, and reduce maintenance costs

Wind farm inspection by ROV





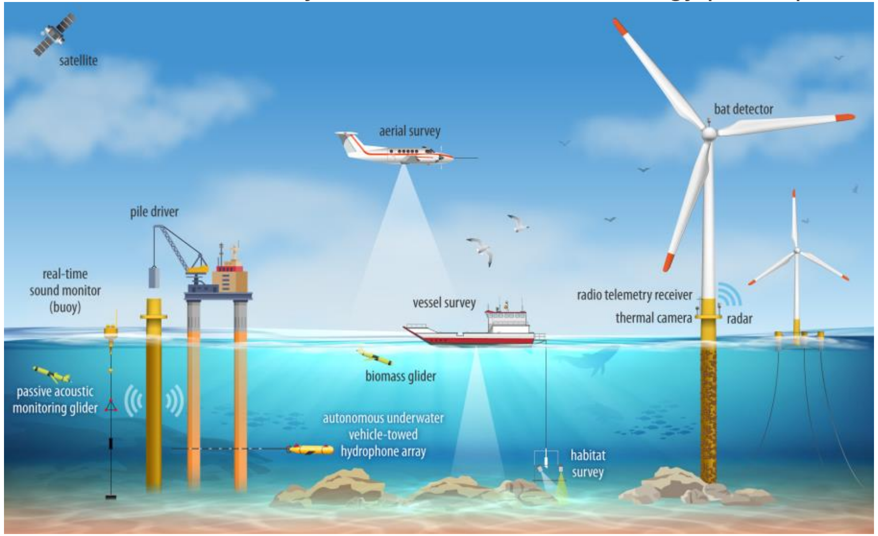
https://www.ixblue.com/north-america/customer-story/powering-autonomous-subsea-inspection-for-offshore-wind-farms/

Renewable Energy Support

Tidal & Wave Energy Converters

- Robotic surveys monitor seafloor impacts of tidal turbines and wave energy devices
- Data helps optimize placement, design, and environmental compatibility of renewable installations

Robotic observation systems with renewable energy power plant



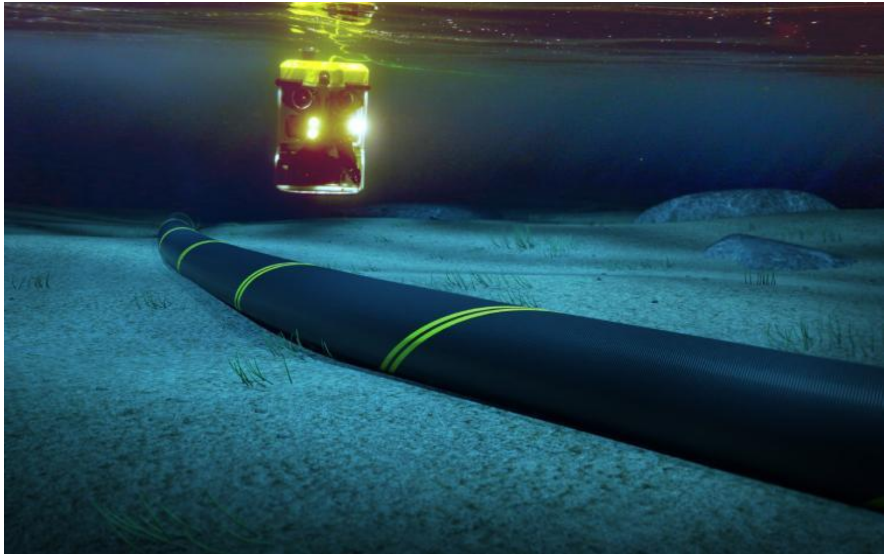
https://issuu.com/journaloceantechnology/docs/v18n1_book_march_30_2023_-_interactive

Renewable Energy Support

Underwater Cable Inspections

- AUVs/ROVs ensure undersea cables (connecting offshore installations and grids) remain intact and safe
- Early detection of damage prevents costly failures and energy supply disruptions

Underwater cable inspection by ROV



https://www.ecagroup.com/en/solutions/cable-inspection-and-monitoring-rov

Applications for a Sustainable Future

Combining Data Layers

- Data from pollution surveys, biodiversity assessments, and energy infrastructure inspections can be combined to form a holistic marine management strategy

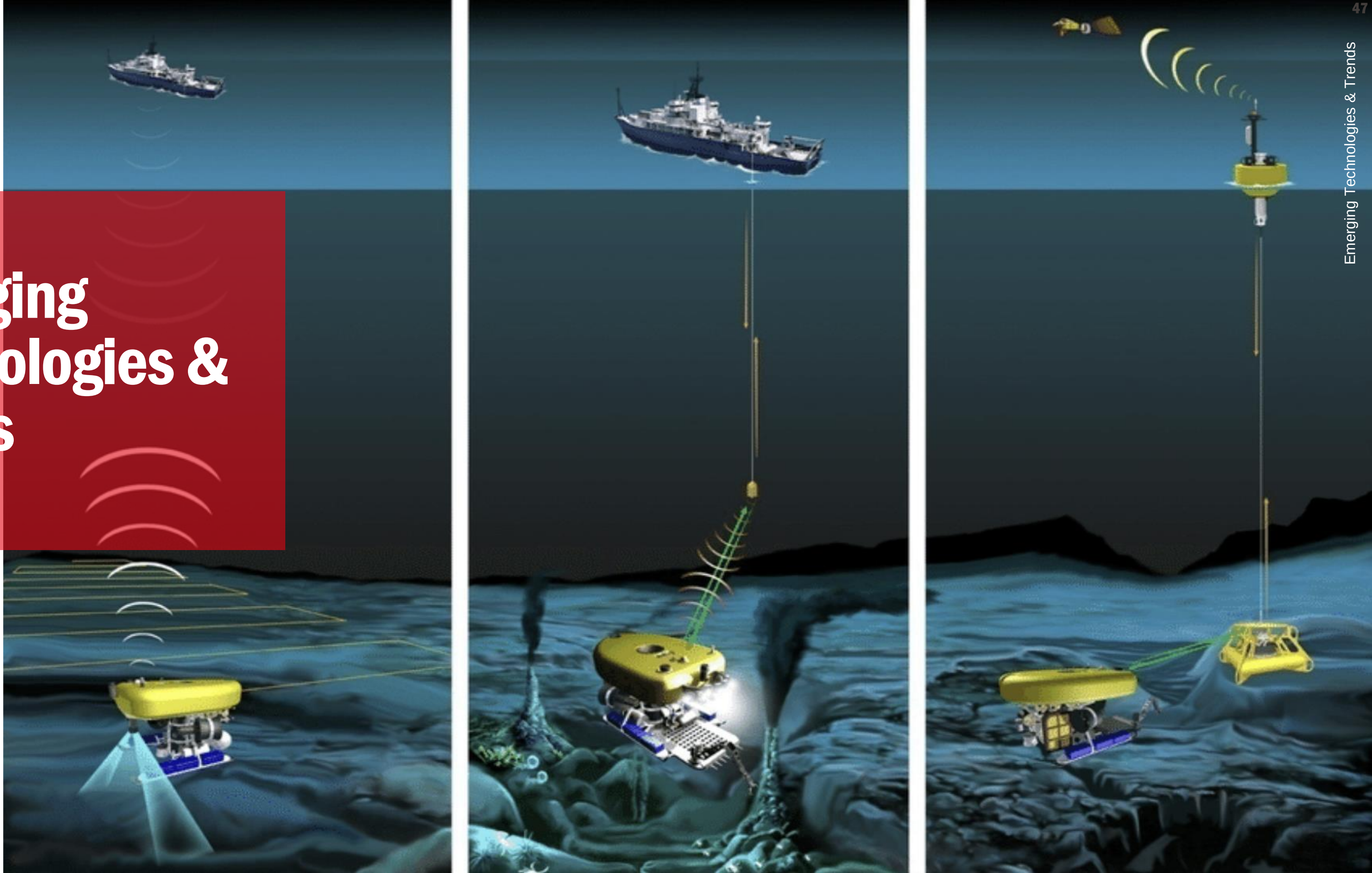
Real-World Case Study

- Briefly mention a case (e.g., a marine protected area that uses robotic data to enforce no-fishing zones while ensuring turbines are sustainably managed)

Policy & Collaboration

- Encourage multi-sector collaboration: environmental agencies, energy companies, research institutions working together with robot-collected data

Emerging Technologies & Trends

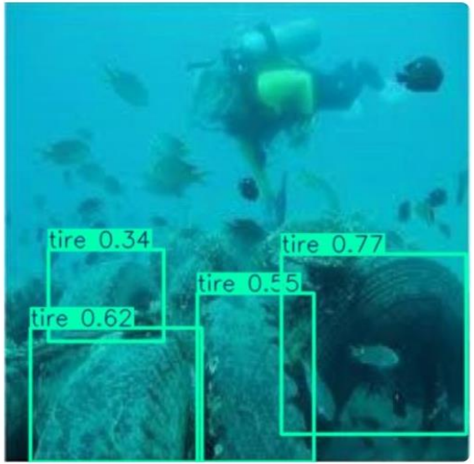


Advancements in AI & Autonomy

Machine Learning for Adaptive Missions

- ❑ Algorithms enable vehicles to detect objects, change course, sample rates, or depth based on **real-time** sensor inputs
- ❑ Example: AUVs adjusting their path when **detecting** unusual temperature anomalies or pollution hotspots

Machine learning based AUVs with object detection functionality



https://viso.ai/computer-vision/autonomous-underwater-vehicles/

EPFL

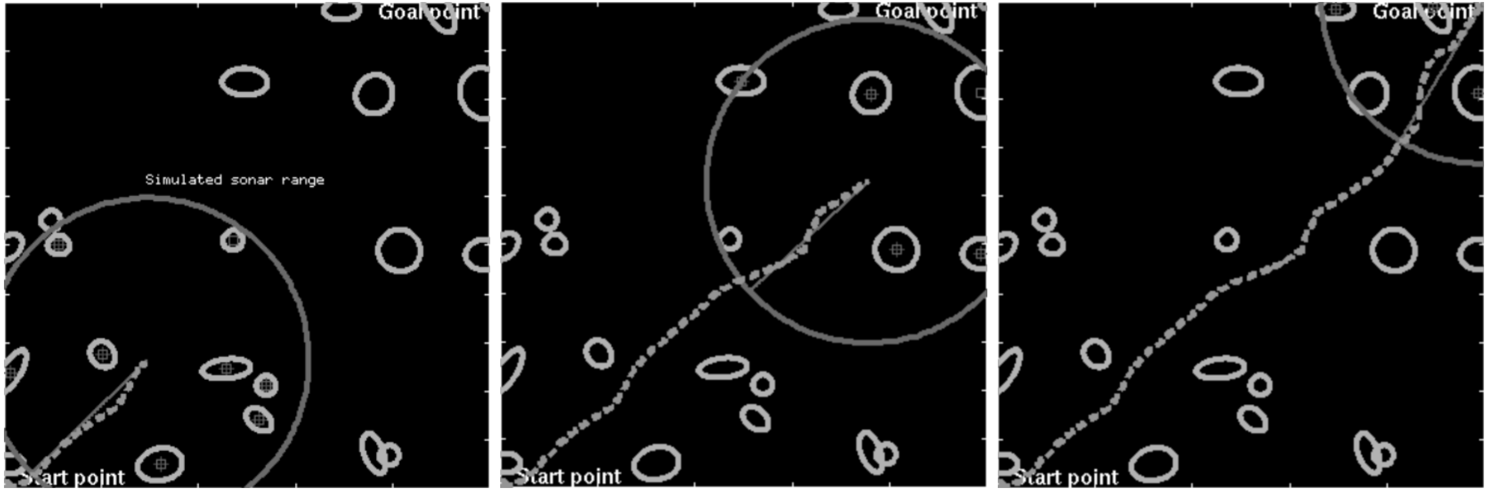
Empa

Advancements in AI & Autonomy

Obstacle Avoidance & Path Planning

- Sonar or camera-based detection combined with AI ensures robots safely navigate around rocks, coral structures, or other vehicles
- Reduced human intervention lowers operational costs and increases the feasibility of long-duration missions

Obstacle avoidance path generate by machine learning based AUVs



Petillot, Y., Ruiz, I. T., & Lane, D. M. (2001). Underwater vehicle obstacle avoidance and path planning using a multi-beam forward looking sonar. *IEEE journal of oceanic engineering*, *26*(2), 240-251.

Advancements in AI & Autonomy

Intelligent Data Analysis Onboard

- On-vehicle processing **identifies species** in real-time, improving efficiency in dynamic environments
- Classifies **substrates** quickly without external or surface-level analysis delays
- Flags anomalies in **chemical** readings, enabling immediate detection and faster intervention
- Enhances operational **efficiency** in fields like environmental monitoring, robotics, and industrial inspections

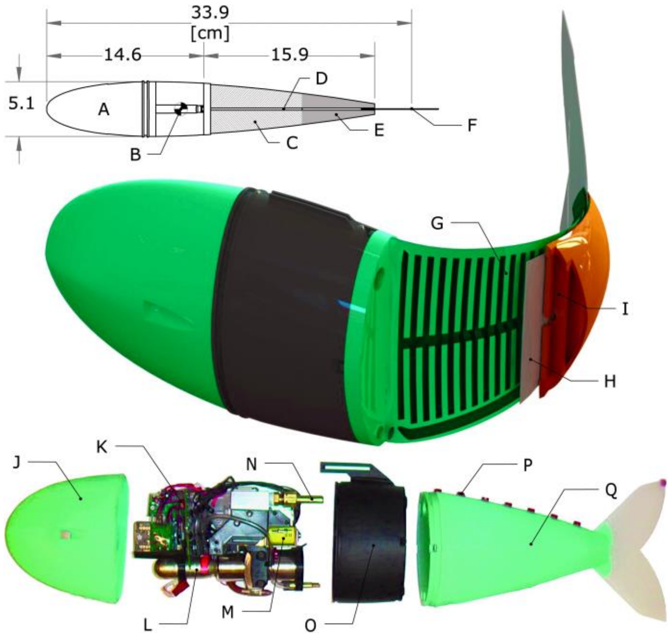
Bio-inspired Robotics

Biomimetic Propulsion & Locomotion

- Robots designed with flexible fins or undulating bodies move more efficiently, quietly, and with less energy
- Mimicking fish or eel swimming patterns reduces disturbance to marine life and improves maneuverability in tight spaces

Advantages of Bio-inspired Approaches

- Lower power consumption, extended mission durations
- Enhanced ability to closely observe marine life without altering their natural behavior

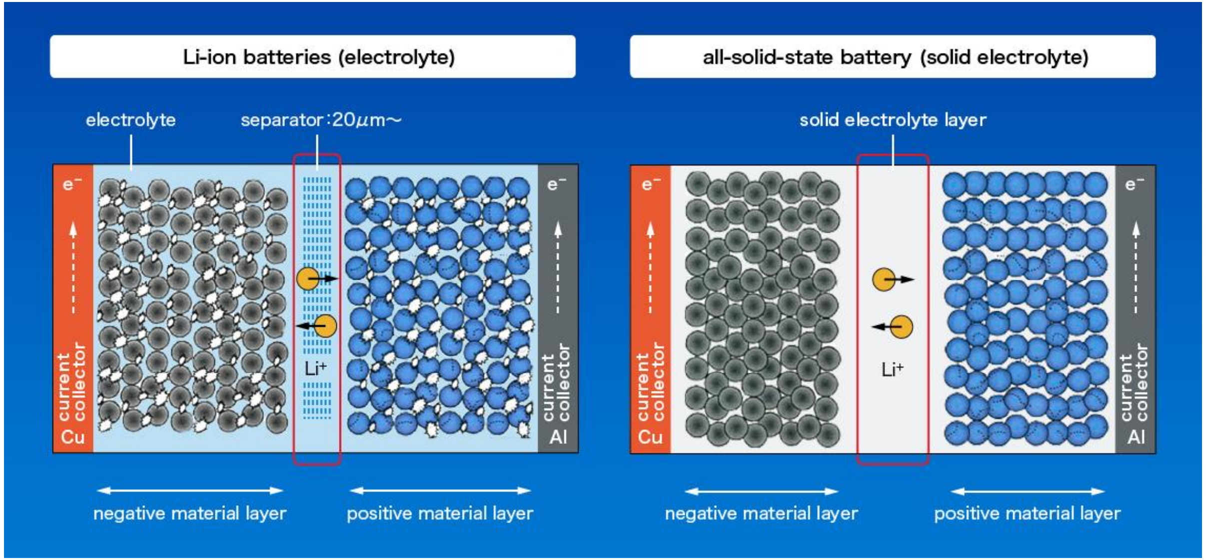


Marcheseandrew, D., & Onalcagdas, D. (2014). Autonomous soft robotic fish capable of escape maneuvers using fluidic elastomer actuators. *Soft robotics*.

Long-Lasting Power Sources

- New **battery** chemistries (lithium-sulfur, solid-state) offer higher energy density and longer operational times
- Fuel cells and underwater **docking** stations extend mission durations, enabling weeks or months of continuous surveying

Comparison of all-solid-state battery with Li-ion battery



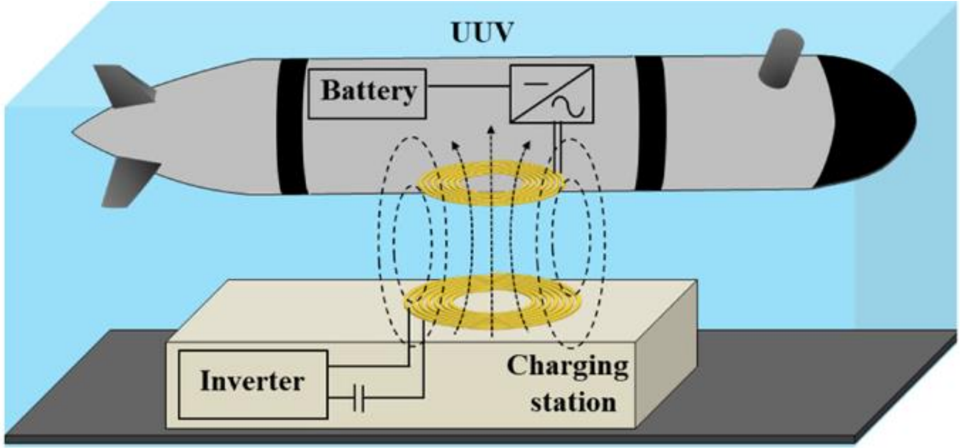
https://www.fdk.com/research-and-development-e/new-battery/all-solid-state/

Energy & Power Management

Wireless Charging Underwater

- Inductive charging or through-water power transfer systems let robots recharge without returning to the surface vessel.
- Combined with moored charging buoys or seabed “charging stations,” reducing downtime

Concept of wireless charging UUV



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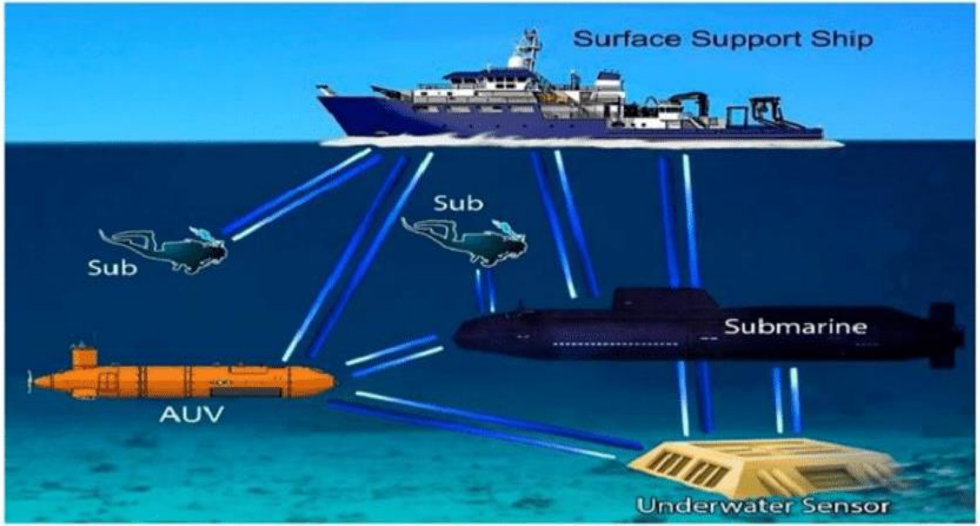
Connectivity & Communication

Optical Communication Systems

- Underwater "Li-Fi" (light-based data transfer) can achieve higher data rates over short distances, enabling HD video streaming or rapid data dumps
- Perfect for ROV-to-AUV communication during inspection tasks that require detailed imagery

Concept of "Li-Fi" communication



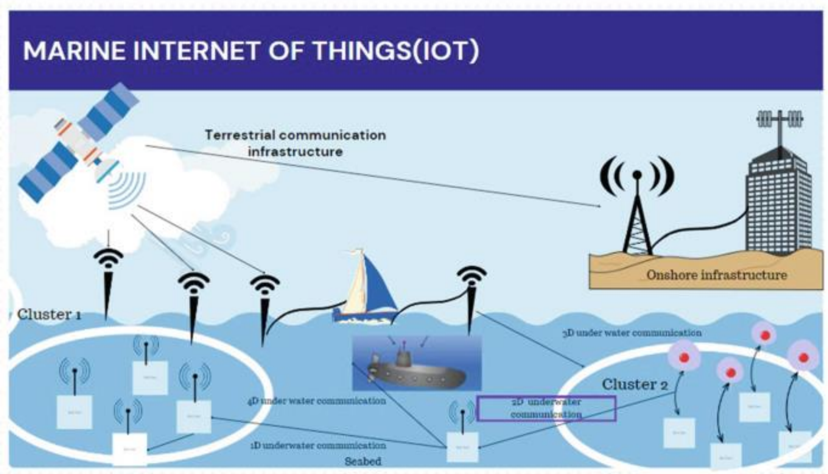
Sanjay, V Manikanta & Indra Kumar, Ankith. (2021). A Review on Li-Fi: The Next Generation Wi-Fi. International Journal for Research in Applied Science and Engineering Technology. 9. 11. 10.22214/ijraset.2021.38814.

Connectivity & Communication

Integration with Surface & Satellite Links

- Robots relay data to surface buoys equipped with satellite transmitters, bridging the gap between underwater observations and global data networks
- Supports near real-time decision-making, allowing for dynamic mission updates based on fresh insights

Concept of satellite link with ROV



Chaithra, N., Jha, J., Sayal, A., Priya, M. S., Allagari, N., Chandana, K., & Aggarwal, N. (2024). Enhancing Underwater Imagery with AI/ML and IoT in ROV Technology. In *Artificial Intelligence and Edge Computing for Sustainable Ocean Health* (pp. 311-342). Cham: Springer Nature Switzerland.

Humanity in water?

“What we are trying to do here is prove that the seas are actually a viable environment for human expansion,”

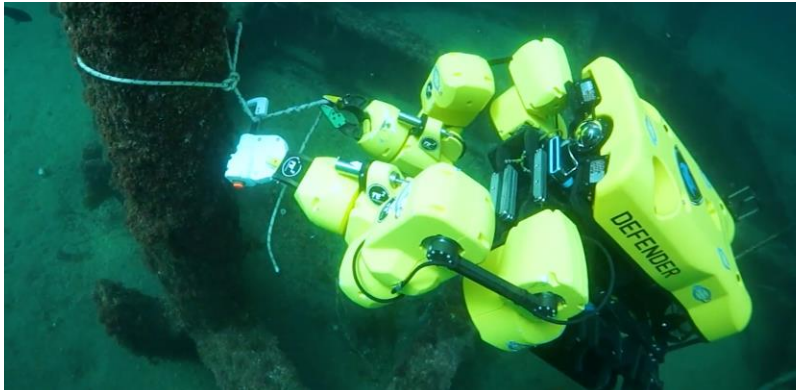
Which rule robotics should play?

120 days: German man sets world record for living under water

Learning Goals revisited

- ❑ *Why should we use robotics for underwater monitoring?*
- ❑ *How would one construct an underwater robot?*
- ❑ *What are emerging technologies can help underwater robot development?*

McGill University



SARCOS Robotics, Inc.