UNIVERSITÉ DE TOULON

Contrat doctoral Etablissement 2025/2028
Formulaire de candidature

Titre de la thèse	CROCHET : DEVELOPMENT OF AN AUTONOMOUS UNDERWATER RECOVERY SYSTEM FOR SWARMS AND ITS TECHNOLOGICAL ECOSYSTEM

Ecole Doctorale	ED548
Laboratoire	IMATH/COSMER
Discipline	Mathématiques et robotiques
Directeur(s) de Thèse & Encadrant(s)	ERSOY Mehmet (Directeur de thèse), DUNE Caire (co-encadrante), PENNECOT Yannick (Cosmatech, encadrant industriel)

Description du sujet de recherche

(3 pages maximum - contexte scientifique, objectifs, mots clé, références)

Contexte, originalité et pertinence par rapport à l'état de l'art :

Marine ecosystems are increasingly threatened by climate change, particularly through phenomena like marine heatwaves and ocean acidification. These changes disrupt biodiversity, destabilize ecosystems, and endanger industries reliant on marine resources. To monitor and understand these evolving impacts, innovative technologies are needed to collect and analyze large-scale, high-resolution data from underwater environments. Autonomous Underwater Vehicles (AUVs) and advanced data collection tools, such as photogrammetry and hydrodynamic modeling, are essential for underwater research. However, current systems face significant challenges, including inefficient deployment and recovery processes, difficulties in large-scale coverage, and high operational costs. This thesis addresses these challenges by developing an innovative recovery line system for AUVs, supported by real-time AI-driven navigation and hydrodynamic simulations, aiming to improve operational efficiency and sustainability for large-scale marine monitoring.

State of the Art

Marine monitoring primarily relies on sonar-based systems and surface-deployed technologies. While these systems provide extensive coverage, they lack the resolution needed to identify specific substrates and species. Photogrammetry, which offers high-resolution 3D mapping, requires close-proximity data collection, often using remotely operated vehicles (ROVs), making the process time-consuming and complex. Photogrammetric image collection is typically done using tethered robots operated from surface vessels. These systems require specialized expertise and involve costly equipment, such as large cranes and cages for retrieval. The process is also fuel-intensive, contributing to high operational costs. However, recent advances in mini-ROVs and AUVs have made underwater exploration more accessible. These smaller vehicles can be launched from small boats, reducing crew size and simplifying recovery. Yet, their limited autonomy and slower speeds restrict their operational range COSMA-TECH proposes using a coordinated swarm of mini underwater robots to cover larger areas. Although deploying AUVs is straightforward, recovery remains a challenge, especially in rough seas. The key challenge is automating the retrieval of these robots. COSMA-TECH has developed a novel system for retrieving ROV swarms, which involves deploying a flexible recovery line with intelligent attachment points that allow robots to latch onto it at the end of their mission. Once secured, the system can be reeled back onto the vessel using a simple winch. The next challenge is to develop autonomous control algorithms enabling robots to locate and attach to the recovery line, which will require creating a 3D map of the line and using real-time AI to assist in the process. This recovery line system also provides valuable data about water currents, offering real-time insights into environmental conditions. Combining recovery and environmental monitoring, this approach advances autonomous underwater exploration. AI-driven technologies like Physics-Informed Neural Networks (PINNs) offer new opportunities to enhance the recovery process by predicting currents and optimizing trajectories.

<u>Scientific Question</u>

How can we design and optimize an autonomous recovery system for AUVs that enables large-scale monitoring of dynamic marine environments while minimizing costs and environmental impacts? This central question addresses several challenges:

● Mechanical Design: How to create a modular recovery line adaptable to variable marine conditions?

● Perception-Based Control: How to use swarm sensors to localize and optimize robot trajectories for
attaching to the line?

● Hydrodynamic Modeling: How to improve AUV recovery through real-time simulations?

● AI Integration: How to optimize energy efficiency and navigation within AUV fleets?

● Environmental Impact: How to minimize ecological disturbances from the recovery system?

This interdisciplinary research bridges robotics, AI, and marine science, offering scalable solutions for underwater monitoring and addressing technological and environmental challenges.

<u>Objectifs</u> :

The project aims to develop a lightweight recovery system for AUV fleets to enable efficient, sustainable monitoring of marine environments. Specific objectives include:

- Design a modular, adaptable recovery line system for varying marine conditions.
- Develop a perception-based control system for AUV swarms to locate and attach to the recovery line.
- Integrate advanced hydrodynamic models using PINNs for current prediction and trajectory optimization.
- Develop AI-driven navigation and fleet coordination algorithms to optimize efficiency.

- Minimize environmental impact through reduced acoustic and electromagnetic emissions.
- Test the system in controlled and real-world conditions.
- Disseminate findings to industrial and scientific communities and support global climate change efforts.

Méthodes :

The research follows an interdisciplinary approach, combining robotics, AI, hydrodynamics, and environmental
science. Key phases include:

- Mechanical Design: Model the recovery system's behavior under hydrodynamic loads and test materials for durability and flexibility.
- Perception-Based Control: Implement visual servoing techniques to optimize robot trajectories.
- Hydrodynamic Modeling: Use PINNs and CFD tools for real-time modeling of wave-current interactions.
- AI-Driven Navigation: Use reinforcement learning and decentralized algorithms to enhance fleet operations.
- Environmental Impact: Assess acoustic and electromagnetic emissions and use eco-friendly materials.

Planning
Year 1: Local Development

- Design a patented cable attachment system.
- Simplify control with rectilinear cable modeling.
- Develop robust local control for moderate sea states (1–3).
- Begin marine current rejection for higher sea states (>3).
- Validate through tank tests and simulations.

Year 2: Optimized Global Approach

- Optimize planning to minimize energy use.
- Model advanced hydrodynamic effects for stability.
- Create decentralized multi-robot coordination.
- Validate in open-sea experiments.

Year 3: AI-Based Predictive Approach

- Use AI to estimate real-time marine currents.
- Design semi-active control for all sea conditions.
- Test autonomous robots in dynamic environments.

Retombées attendues :

This technical solution is designed for direct transfer to the industrial sector, with COSMA-TECH serving as both the ambassador and the initial user. Additionally, the project will contribute to scientific advancements through high-impact publications and presentations at leading conferences. By integrating robotics, AI, and marine science, this project provides scalable and sustainable solutions for ocean monitoring. It aligns with the United Nations Sustainable Development Goal 14 (Life Below Water), contributing to marine ecosystem conservation and restoration. The outcomes will transform underwater data collection methods, advancing our understanding of ocean health and responses to global environmental changes, while supporting efforts in biodiversity conservation and sustainable resource management.

Mots clés : Digital Twin, SWARM of AUV, Autonomous docking, Hydrodynamic modeling, Artificial Intelligence (AI)

Références :

1. J. Kim, "Cooperative Localization and Unknown Currents Estimation Using Multiple Autonomous Underwater Vehicles," IEEE Robotics and Automation Letters, 2020.
2. Zhou et al., "Estimation of Ocean Current Using Dynamic Underwater Acoustic Sensor Network," IEEE CYBER, 2023.
3. Chu et al., "Path Planning Based on Deep Reinforcement Learning for AUVs," IEEE Transactions on Intelligent Vehicles, 2023.
4. Shi et al., "Cooperative Flow Field Estimation Using Multiple AUVs," IEEE Conference on Decision and Control, 2020.
5. Chen et Zhu, "Optimal Time-Consuming Path Planning for AUVs," IEEE Transactions on Vehicular Technology, 2020.
6. Qin et al., "Fast In-Motion Alignment for INS/DVL in Rough Sea Conditions," IEEE Transactions on Instrumentation and Measurement, 2024.
7. Lakshminarayanan et al., "Estimation of External Force Acting on Underwater Robots," IEEE CASE,2024.

Encadrement et conditions matérielles pour le doctorant

→Computer

Compétences attendues et personnes à contacter

Compétences attendues : A Master's degree (or equivalent) in a relevant field such as robotics, mechanical engineering,computer science, or applied mathematics.

● Solid knowledge of numerical modeling, hydrodynamics, or artificial intelligence is highly desirable.

● Oceanography knowledge and interest for environmental monitoring will be appreciated

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