# IFAC CAMS 2025
# Invited Session Proposal

## *Path-Following and Trajectory Tracking: From Classical Control Methodologies to Artificial Intelligence-based Approaches*

### Code: i18u9

**M. Bibuli** [*] **E. Zereik** [*]

[*] *National Research Council - Institute of Marine Engineering, Italy (marco.bibuli@cnr.it - enrica.zereik@cnr.it)*

**Abstract:** In the scope of advanced and intelligent guidance systems for autonomous marine robots, this proposed Invited Session aims to the gathering of different contribution on the topic of path-following and trajectory tracking, bringing together the employment of classical control methodologies and the exploitation of brand new approaches related to the increasingly growing artificial intelligence. The contribution of both theoretical frameworks and at-field results will arise the consciousness of the state of the art in the proposed topics, leading to an animated discussion on the future developments and further scientific and technological objectives.

## 1. INTRODUCTION

The exploitation of autonomous robotic platforms at sea, both on the surface and underwater, is a consolidated reality. The vision for the next future is to provide more and more advanced capabilities to marine drones, in such a way to let the robots deal with the complex operational environments and unexpected occurrences, which challenge against the completion of the mission targets. In particular, the feature of providing a self-guidance capability to drones has been and remains an objective of interest for scientists and operational personnel.
The field of path-following and trajectory-tracking for autonomous marine vehicles has seen remarkable progress over the past few decades. These control tasks are fundamental for the effective operation of Autonomous Underwater Vehicles (AUVs), Remotely Operated Vehicles (ROVs), and Unmanned Surface Vehicles (USVs), which are increasingly deployed for exploration, data gathering, and intervention in the marine environment. Despite significant advancements, several challenges and open issues remain, necessitating continued research and innovation.

The marine environment presents unique challenges, including dynamic and unpredictable conditions, complex underwater terrains, and the presence of various disturbances such as currents and waves. Traditional control methodologies, while effective in certain scenarios, often fall short in addressing these complexities comprehensively. There is a pressing need for robust and adaptive control strategies that can ensure precise path-following and trajectory-tracking even in the face of significant uncertainties and disturbances.

Some major open issues and future challenges are summarized as follows:

***Environmental Disturbances*** - Developing control algorithms that can effectively compensate for environmental disturbances remains a critical challenge. Future research must focus on enhancing the robustness of control strategies to handle varying and unpredictable marine conditions.

***Underactuation*** - Many marine vehicles are underactuated, meaning they have fewer control inputs than degrees of freedom. This complicates the control design and requires innovative approaches to achieve desired performance.

***Modeling Uncertainties*** - Accurate modeling of marine vehicles and their interaction with the environment is inherently difficult. Addressing modeling uncertainties through adaptive and learning-based control methods is an area ripe for exploration.

***Integration of AI and Machine Learning*** - The integration of artificial intelligence (AI) and machine learning (ML) techniques offers promising avenues for improving control performance. However, the application of these techniques in real-time, safety-critical marine operations poses significant challenges that need to be addressed.

***Experimental Validation*** - While theoretical advancements are crucial, their practical applicability must be validated through extensive experimentation and real-world case studies. Bridging the gap between theory and practice is essential for the successful deployment of advanced control strategies.

This invited session aims to bring together researchers, practitioners, and industry experts to discuss these pressing issues and share the latest advancements in path-following and trajectory tracking for autonomous marine vehicles. By fostering interdisciplinary collaboration and encouraging the exchange of innovative ideas, we hope to address the current challenges and pave the way for future breakthroughs in this vital field.

## 2. THE INVITED SESSION

We are pleased to announce an invited session proposal on "Path-Following and Trajectory Tracking: From Classical Control Methodologies to Artificial Intelligence-Based Approaches" at the 16th IFAC Conference on Control Applications in Marine Systems, Robotics, and Vehicles (CAMS 2025). This session aims at bringing together researchers, practitioners, and industry experts to discuss the latest advancements and challenges in the field.

Path-following and trajectory tracking are critical components in the control of marine robots and related autonomous platforms. These tasks require precise and reliable control strategies to ensure the desired path or trajectory is followed accurately, despite the presence of disturbances and uncertainties, for the objectives of exploration, data gathering and intervention in the marine environment. This session will cover a wide range of topics, including but not limited to:

- Classical control methodologies for path-following and trajectory tracking;
- Robust and adaptive control techniques;
- Model predictive control (MPC) approaches;
- Methodologies for smart and advanced path-planning;
- Intelligent control strategies, including fuzzy logic and neural networks;
- Machine learning and artificial intelligence-based methods;
- Applications in Autonomous Underwater Vehicles (AUVs), Remotely Operated Vehicles (ROVs) and Unmanned Surface Vehicles (USVs);
- Experimental validation and real-world case studies.

We invite researchers and practitioners to submit their original contributions to this session. Papers should present innovative solutions, theoretical advancements, or practical applications related to path-following and trajectory tracking. We encourage submissions that highlight interdisciplinary approaches and novel methodologies.

## 3. EARLY-PROPOSED PAPERS

(1) "*An event-triggered tunable predefined-time control method for path following of marine vehicles*", Guo Ying, Yu Caoyang, Zhong Yiming, Lian Lian, School of Oceanography, Shanghai Jiao Tong University (Shanghai, China)
Abstract: In this paper, taking into account both convergence time and update frequency of onboard actuators, a path following controller based on an event-triggered tunable predefined time method for marine vehicles is presented. Tunable predefined-time Lyapunov stability theory is utilized to ensure the heading tracking error converges within a predefined time that can be further adjusted through a tunable parameter. In addition, by combining with the switching threshold strategy-based event-triggered mechanism (ETM), the actuator is only updated when the triggering condition is satisfied, thereby significantly reducing energy consumption and actuator wear. Finally, comparative numerical simulations are conducted, which indicate that path following errors could converge within the predefined time under the action of the designed controller and the number of triggers has been reduced by 90% with the help of the switching threshold strategy-based ETM.

(2) "*State-Constrained Finite-Time Guidance System Design for Depth Tracking Control of Underactuated AUVs*", Qu Yang, Duan Yu, Yang Shaolong, Xiang Xianbo, School of Naval Architecture and Ocean Engineering, Huazhong University of Science and Technology (Wuhan, China)
Abstract: Autonomous Underwater Vehicles (AUVs) have been widely used in diverse marine applications. Although previous studies have investigated various guidance system designs for underactuated AUVs, compensation for sideslip motion remains a a critical and under-explored challenge, particularly in the presence of time-varying disturbances. Inspired by the principle that a system's position and velocity changes are uniquely determined by its acceleration, we develop a finite-time guidance law design. This guidance law design incorporates a planning-time-based acceleration constrained by the tracking errors of position and velocity to realize depth-tracking control for underactuated AUVs. Simulations were conducted to verify the effectiveness of the proposed finite-time guidance law design. Compared to the selected methods, our proposed method can rapidly and accurately compensate for sideslip effects in the estimation of sideslip angle, resulting in precise depth-tracking performance.

(3) "*System Architecture and Implementation of Global Vessel Path Planning Based on ROS2 Framework*", Krizman Enio, Kapetanovic Nadir, Nad Dula, Norwegian University of Science and Technology (NTNU, Norway), University of Zagreb Faculty of electrical engineering and computing (FER, Croatia)
Abstract: This paper presents a system architecture

for global path planning developed within the ROS2 framework for Unmanned Surface Vehicles (USVs). The system is structured into three key stages: generating a cost map through geographic feature extraction, managing start and goal coordinates, and executing path planning using the D* Lite algorithm with interpolation techniques. The cost map, based on OpenStreetMap data, provides a detailed representation of the operational environment, while RViz2 is used for interactive setting and visualization of start and goal coordinates. To address the sharp path transitions produced by the D* Lite algorithm, this paper introduces a path interpolation model that consists of coordinate resampling and curve fitting techniques. The hypothesis is that, with correctly configured cost settings and interpolation parameters, these methods can support real-world vessel path planning. Simulation tests on navigational maps validate this approach, demonstrating its suitability for further development and integration into USV system architectures.

(4) "*Disturbance Compensation for a 3D Virtual-target based Path-Following Guidance System*", Bibuli Marco, National Research Council (CNR, Italy)
Abstract: The paper focuses on the analysis of the effect of environmental disturbance to a 3D virtual-target based path-following guidance system. The evaluation of the disturbance effect aims to define the operational limits of the exploitation of the guidance system, with respect to the degradation of the path-following capability. Based on the available measurements, a feedforward control signal is added to compensate for the disturbance, thus increasing the guidance performance. The theoretical framework and simulation results are provided.

(5) "*Adaptation of virtual target-based path-following to conventional guidance and control architectures: performance evaluation and procedures for replicable experiments*", Caccia Massimo, Bibuli Marco, National Research Council (CNR, Italy)
Abstract: Virtual target based path-following is a consolidated methodology able to be easily extended to design cooperative guidance systems for unmanned marine vehicles (UMVs) at the kinematics level. Although the generation of reference yawrate as control output is compatible with advanced UMV guidance and control (GC) systems, specific formulations tailored to integrate the concept of virtual target-following path-following with conventional autopilots, providing heading control, and guidance systems providing line-following, are implemented and validated. To this aim suitable procedures to execute replicable experiments are defined as well as quantitative metrics to evaluate performance. Results obtained at field with CNR SWAMP ASV will be presented and discussed in the final version of the paper.

(6) "*Adaptive Reference Management and Model Predictive Control for Near-Surface Operations of Autonomous Underwater Vehicles*", Hammond Maxwell, MacLin Gage, Cichella Venanzio, University of Iowa (USA)
Abstract: Low speed near surface operations for autonomous underwater vehicles (AUVs) provide unique challenges as a result of significant forces from suction and waves as well as reduced control authority from control surfaces. This fact, coupled with potential danger of detection in the event of an unexpected surface breach create strict constraints on the problem. This work focus on the problem of tracking desired depth and pitch profiles of the Joubert BB2 submarine. A model predictive controller (MPC) is presented based on the linearized ROM and an L1 adaptive control algorithm is used to modify the MPC reference commands to overcome nonlinearities and uncertainties within the problem. The efficacy of this methodology is demonstrated with results from the Joubert BB2 ROM.