

## Robust Path Planning and Trajectory Optimization Framework for Tethered ASV-AUV

Markus Buchholz<sup>1</sup>, Zebin Huang<sup>2</sup>, Ignacio Carlucho<sup>1</sup>, Yvan R. Petillot<sup>1</sup>

<sup>1</sup> *School of Engineering and Physical Sciences, Heriot-Watt University,  
{m.buchholz, ignacio.carlucho, y.r.petillot}@hw.ac.uk*

<sup>2</sup> *School of Mathematical & Computer Sciences, Heriot-Watt University, zh2027@hw.ac.uk*

**Abstract** – This paper introduces a novel framework for path planning and trajectory optimization for a tethered multi-robot system consisting of an Autonomous Surface Vehicle (ASV) and an Autonomous Underwater Vehicle (AUV). The framework addresses the challenges of coordinating and navigating these robots, including the dynamic behavior of the tether within the robot team and environmental obstacles. The findings hold promise for future research and practical deployments in areas requiring precise coordination and movement, such as underwater inspection and maintenance.

**Keywords** - path planning, multi-agent systems, coordination

### I. INTRODUCTION

In recent years, Autonomous Surface Vehicles (ASVs) and Autonomous Underwater Vehicles (AUVs) have emerged as valuable tools for exploration, monitoring, and research. Their ability to operate collaboratively in the surface and the underwater domains has revolutionized marine operations, enabling scientists and researchers to gain deeper insights into the marine world. One key challenge in utilizing these vehicles lies in coordinating their movements, particularly when they are tethered together. The tether, while providing fast and reliable communication between the platforms, introduces a unique set of constraints and dynamics that demand careful consideration for safe and efficient operation.

Previous work has focused on addressing the coordination problem of multi-robots [1]. However, the specific issue of coordinating tethered vehicles has not received significant attention. A recent study demonstrated a method for achieving safe path planning between a tethered unmanned ground vehicle and a drone [2]. While this approach appears promising, it's important to note that some challenges still persist. For example, it is not clear how to coordinate and navigate these robots in a constrained environment, while ensuring safety and entangled free trajectories.

In this work, a novel methodology has been developed for path planning and trajectory optimization in tethered multi-robot systems, specifically targeting ASV-AUV pairs. This approach integrates advanced pathfinding algorithms, dynamic tether modeling, synchronization techniques, and Bezier curve interpolation for efficient and collision-free navigation. The ASV's path is determined using a modified A\* algorithm, while the AUV's path takes into account tether dynamics and obstacle avoidance. Adaptive tether length optimization has been incorporated to enhance safety and practicality. This research contributes to the advancement of technological capabilities in individual ASVs and AUVs and extends opportunities for their collaborative applications across various domains, including marine research, underwater exploration, and surveillance operations. The findings hold substantial implications for future research and practical deployments, particularly in domains such as underwater inspection, maintenance, and coordinated environmental surveillance, where precise coordination and movement are paramount.

### II. METHODS

This section presents an overview of our methodology for path planning and trajectory optimization. Our innovative approach combines advanced pathfinding algorithms, catenary curve modeling for tether dynamics.

To achieve efficient path planning, and ensure safety for the ASV-AUV systems, the A\* algorithm is adapted for tether-constrained systems. This modified algorithm acknowledges the unique challenges posed by environmental obstacles and the dynamic behavior of the tether, which is accurately modeled using catenary curves.

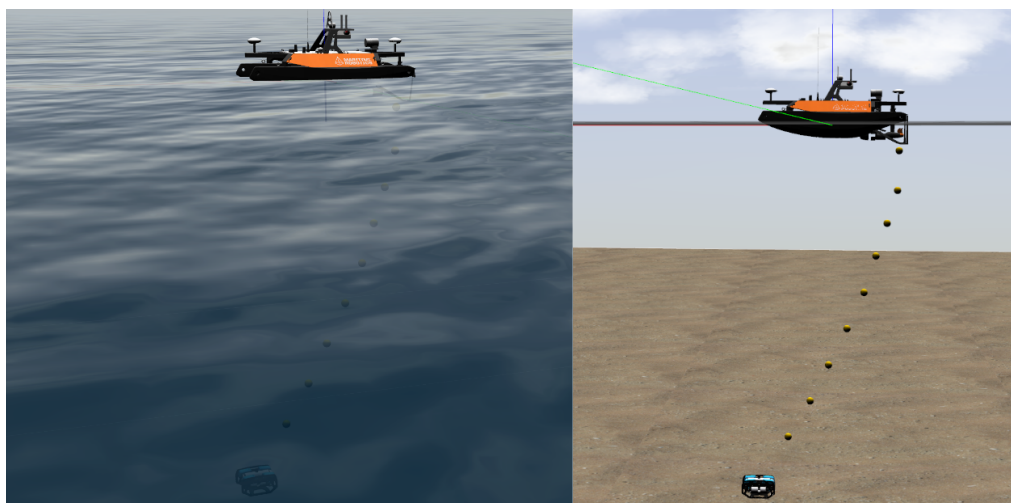


Fig. 1. Simulation environment for the tethered ASV-AUV platforms

Bezier curve interpolation is applied for trajectory smoothing, combined with linear movement between closely spaced waypoints. This hybrid strategy balances the computational efficiency and simplicity of linear paths with the smooth transitions of Bezier curves. It effectively approximates curved paths in densely waypointed regions, ensuring computational efficiency while maintaining the accuracy of the planned path. Furthermore, the synchronization mechanism plays a crucial role in the field of tethered multi-robot systems. It adjusts the robots' velocities to ensure simultaneous arrival at corresponding waypoints. This synchronization is critical for maintaining the tether's integrity and the system's overall stability.

Our methodology was evaluated in a simulated environment consistent with an ASV-AUV platform as shown in Fig. 1. The simulation utilises the UUV simulator [3]. To emulate tether dynamics and potential collisions, a tether modelled by spheres has been developed. This provides a streamlined yet adequately precise simulation environment to evaluate our proposed methodology. Our preliminary results show the advantages of our method.

### III. CONCLUSIONS

In this work, we present a novel path planning and trajectory optimization algorithm for tethered multi-robot systems, specifically for tethered AUV-ASV systems. Our approach combines advanced pathfinding algorithms, dynamic tether modeling, synchronization techniques, and Bezier curve interpolation to overcome the challenges of navigating in complex environments while maintaining the stability and integrity of the tethered system. Overall, our work represents a significant advancement in the field of tethered multi-robot systems, opening up new possibilities for collaborative applications in marine research, underwater exploration, and surveillance operations. The proposed framework has the potential to revolutionize the way tethered robots are deployed and operated, enabling more efficient, safer, and more sophisticated missions in challenging underwater environments.

### REFERENCES

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