Experimental Evaluation of Vision-Based Formation Control for Underwater Robots

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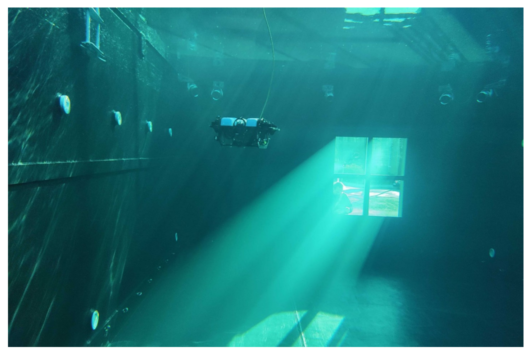
Context & Motivation: KTH has recently built a new underwater robotics testing facility (see Fig. 1a), featuring a dedicated water tank and three BlueROV2 underwater vehicles (see Fig. 1b). This setup opens the door to experimental research in cooperative multi-robot systems in underwater environments, where traditional communication and sensing modalities are highly constrained.

(a) Experimental facility consisting of a $9 \times 5 \times 3m$ swimming pool with motion capture system.



(b) BlueROV2 underwater vehicle.

Research Problem Statement.

The goal of this thesis is to implement and experimentally validate a vision-based formation control strategy for underwater robots, using RGBD cameras as feedback for the relative positions among the robots. Given the underwater environment's communication limitations, formation control will be implemented over directed sensing graphs without inter-robot communication. The approach could draw inspiration from [1], specifically using Barrier Lyapunov Functions (BLFs) [2] to guarantee collision avoidance, connectivity maintenance, and convergence to a desired formation, even in the presence of directed interaction topologies.

As a possible extension, if time allows, the thesis may also explore formation control using only RGB-based bearing measurements, i.e., relative direction without depth information [3]. This scenario introduces additional theoretical and practical challenges, which could involve the design of an observer and the satisfaction of necessary observability conditions [4].

The key objectives of this thesis include:

1. Adapt and implement BLF-based formation controllers using onboard vision (RGBD) on BlueROV2 platforms.
2. Evaluate system performance through experiments in the underwater tank.
3. Analyze the robustness and limitations of using vision-only sensing underwater.
4. (Possible extension) Investigate theoretical and practical challenges of formation control using only RGB-based bearing measurements.

Expected workload: The work will include:

1. Familiarization with ROS2, PX4 and the BlueRov2 platform.
2. Literature review on multi-robot formation control in the presence of constraints.
3. Implement vision and stereo-based detection methods for neighboring robots.
4. Integration of collision avoidance and connectivity maintenance through BLFs.
5. Experimental validation using multiple BlueRovs 2 inside the water tank.

Prerequisite: Willingness to dive into rigorous mathematics and do real experiments. Proficiency in ROS2 and prior hands-on experience with mobile robots are highly appreciated. A solid background in multi-robot systems and control theory is also desirable.

Type of work: 50% theory, 50% implementation.

References

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