Collaborative Research: NRI: INT: Cooperative Underwater Structure Inspection and Mapping

Ioannis Rekleitis, Alberto Quattrini Li, Philippos Mordohai, Srihari Nelakuditi, Jesse Casana
University of South Carolina, Dartmouth College, Stevens Institute of Technology

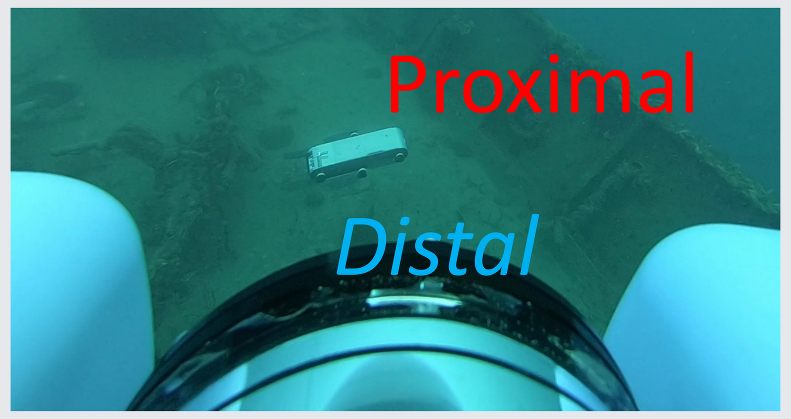
The problem

Underwater structure modeling is crucial for operating in different natural and manmade environments. These environments are diverse and include shipwrecks, oil-rigs and hydroelectric dams, submerged historical sites, and cave systems. Operating in the underwater domain is dangerous, tedious, labor intensive, and physically exhausting for humans. Underwater robots can enable such operations; however, the underwater domain poses unique challenges, including absence of localization systems (e.g., GPS) and communication infrastructure (e.g., WiFi). This collaborative research funded under the NSF-NRI program has the objective to address such challenges, answering to four important Research Questions:

(RQ1) How to robustly achieve cooperative localization with occlusions?
(RQ2) How to fuse the different sources of information on-board in real time for reconstruction?
(RQ3) How should the co-robots cooperate for the mapping task?
(RQ4) How to efficiently and robustly use limited resource communication channels to share information between a team of robots and between robots and operator?

Concept overview

The main idea of our solution is to have a team of co-robots collaborating with a human operator. There are two types of robots: **proximal observer**, which will operate close to the structure to map, and **distal observer**, which will be at distance maintaining the global picture of the structure and the pose of the proximal observer.



Intellectual merits and broader impacts

The **intellectual merits** of this project will be in several areas of computer vision, robotics, learning, and communication, including:

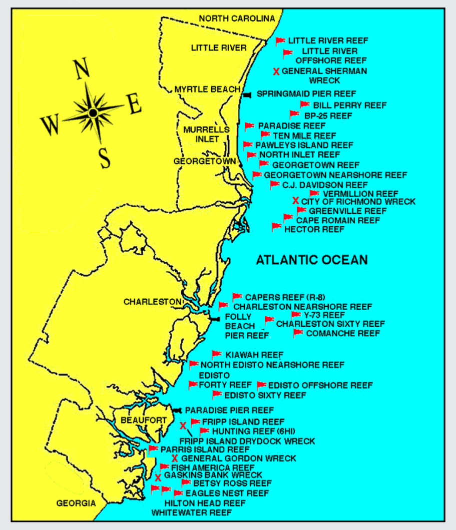
- Robust state estimation and cooperative localization, fusing several sensors.
- Cooperative exploration and planning of underwater vehicles in the presence of obstacles
- Cross-layer optimization approach for transmitting reconstructed models and vehicle positions under limited communication resources.

Having such a team of robots allows for **lowering the barrier to entry in underwater robotics**, as the robot design can be simplified by complementing their capabilities.

This project plans an extensive evaluation and application to underwater archaeology, consisting of

1. tests in a realistic 3-D simulator;
2. data collection in different environments and tests of the algorithms on the collected data;
3. tests directly on the computer onboard of the robot.

The project will have **broader impacts** in several high-impact applications, including infrastructure inspection and archaeological sites mapping. The project includes plans for engaging a diverse set of students, for example from Benedict College, the fourth largest Historically Black College or University in the country.

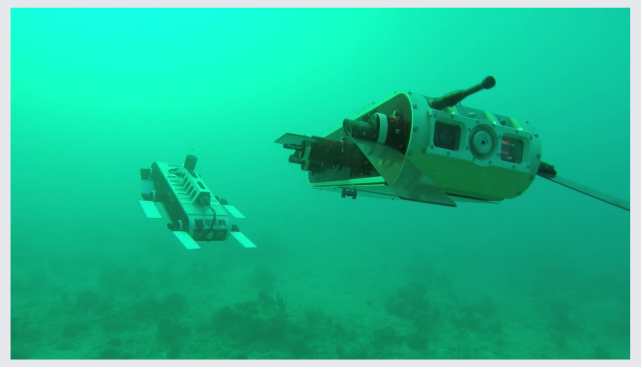


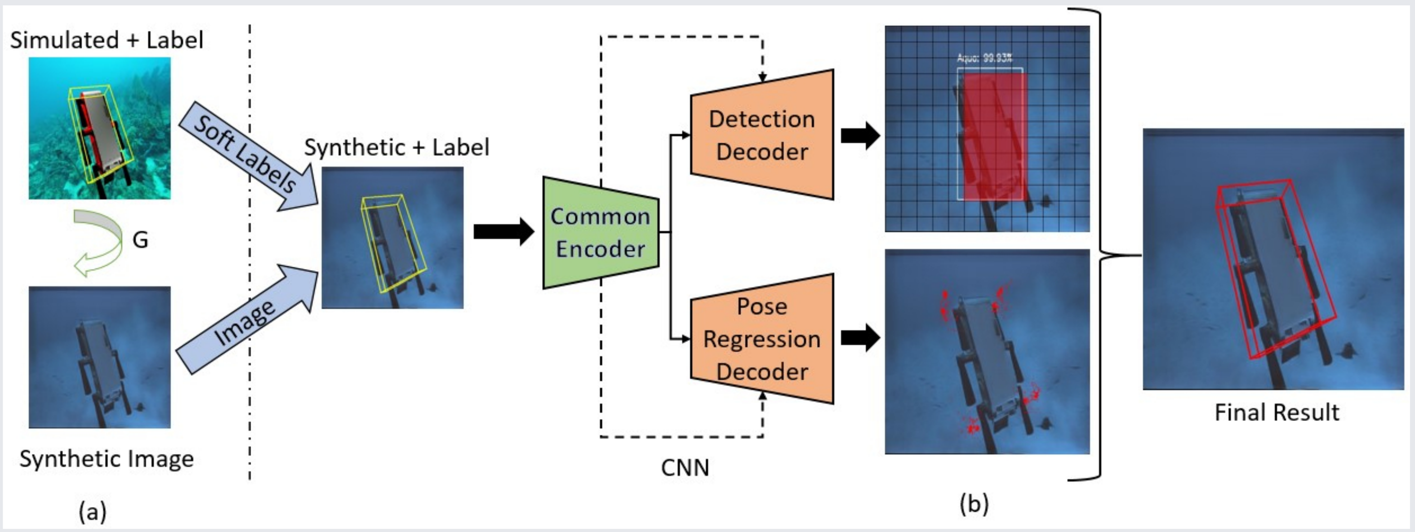
Map of the Carolinas with multiple shipwrecks

Cooperative localization

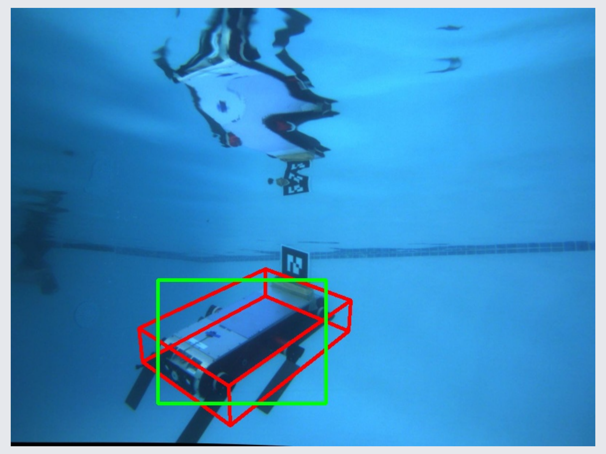
During this first part of the project, we focused on **cooperative localization**, provides the relative pose between *Distal* and *Proximal Observers.*

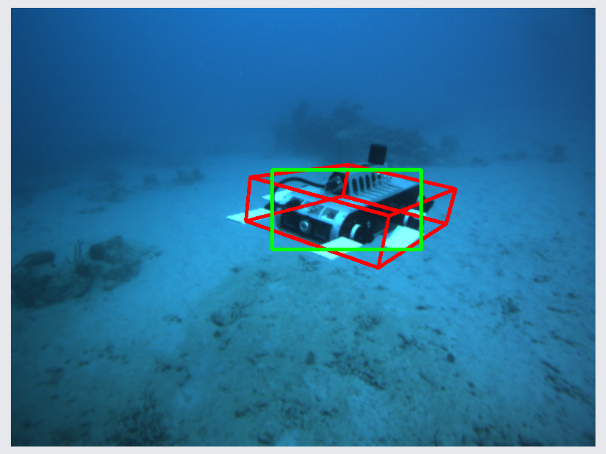
We recently proposed a deep learning framework for detecting the relative pose between the two robots [2].





The CNN is trained on simulation, with a translation network to bridge the gap between simulated and real images, and then tested it on real images. Results showed high robustness and accuracy.





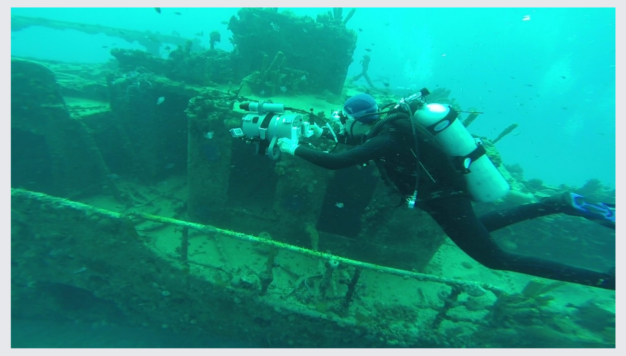
To improve the estimate, we are currently fusing other sensor data, e.g., IMU and pressure-based depth sensor.

Proximal observer: active exploration

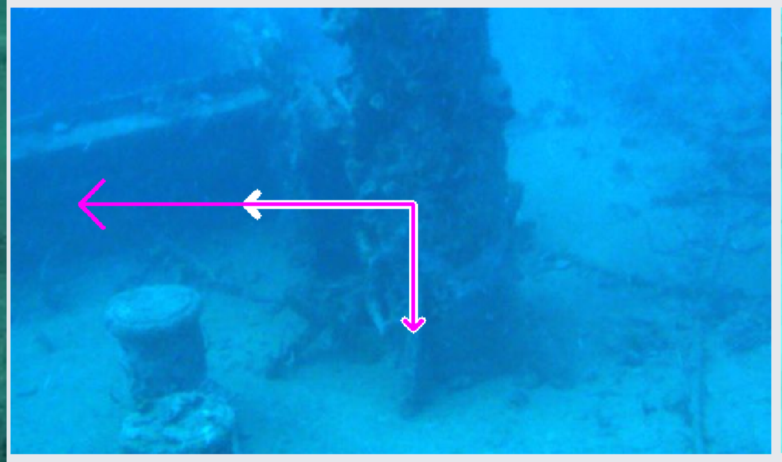
Recently, we proposed a CNN framework [3] which is trained based on the way that human divers collect data.

Annotations were made to mark the best direction of motion and the to guide the autonomous underwater robot to cover a shipwreck.

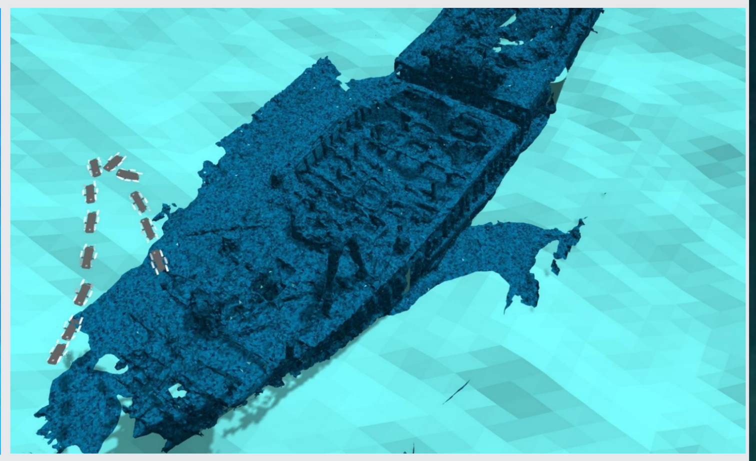
Currently, we are looking at metrics to guide the next-best view process.



Diver collecting images



Direction determined by the CNN

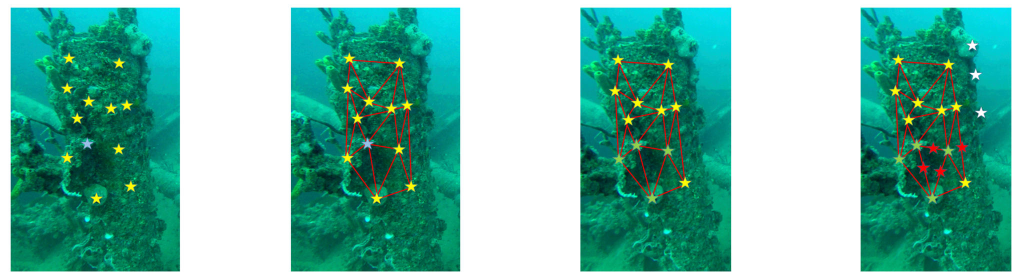


Test in simulation.

Photo-realistic reconstruction

Currently, we are working on creating a photorealistic reconstruction, based on a pipeline where:

a) Keypoints (in yellow in the figure) are detected in the reference image of the first stereo pair and reconstructed in 3D.
b) An initial mesh is generated based on those keypoints, to determine the keypoint that has higher error than a specified tolerance (in blue).
c) New additional images are acquired guided by b) to lower the error.
d) New keypoints are generated in the previously unseen parts of the image.



(a) Initial keypoints (b) Mesh and active keypoint (c) Explained keypoints (d) Generation of new keypoints

This pipeline ensures high-quality image data collection allowing for a reconstruction that can help humans to understand underwater structures.

Distal Observer: Active Positioning

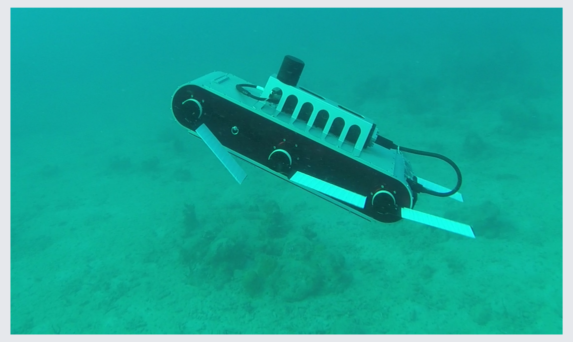
We are also working on the tight coordination of the proximal and distal observer, so that the distal observer has the general structure in view, as well as at least one proximal observer.

This step is to reduce the uncertainty of both the reconstruction and the cooperative localization process.

Low-Bandwidth Communication

The underwater domain is a very harsh environment for communication, which is primarily based on acoustic devices characterized by very low data rate (tens of kb), high packet loss, and distance-dependent performance.

We are investigating compact data representations and the optimal utilization of the communication channel. We are evaluating the acoustic channel performance with the real robot.



AUV with acoustic modem

Acknowledgments and References

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