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

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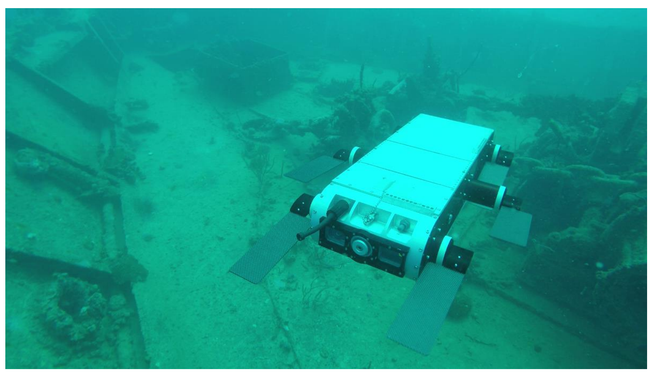
High-level Objectives

The overarching goal of this project is to enable underwater structure mapping at different scales utilizing a team of cooperative robots, while addressing specific challenges of the underwater domain such as the lack of a localization system and communication infrastructure.

Real-Time Dense 3D Mapping of Underwater Environments

- Combining SVIn2, a robust VIO method, with a real-time dense 3D reconstruction pipeline based on fusion of stereo depth maps
- Comparable reconstruction with COLMAP at high frame rates on a CPU
- Paper in upcoming ICRA



Challenges

- Power, computation and communication limitations
- No global positioning system
- Online depth estimation required for obstacle avoidance and to guide coverage or exploration operations

Solution

- Estimate UAV pose from cameras, IMU, sonar and pressure sensor using SVIn2
- Compute dense depth maps using optimized binocular stereo leveraging calibration to obtain scale
- Fuse depth maps to improve accuracy and reject outliers
- Compare depth maps and 3D point clouds to COLMAP
  - Use discrepancy between models in the absence of ground truth
  - COLMAP is between 27x and 60x slower on 4 underwater datasets

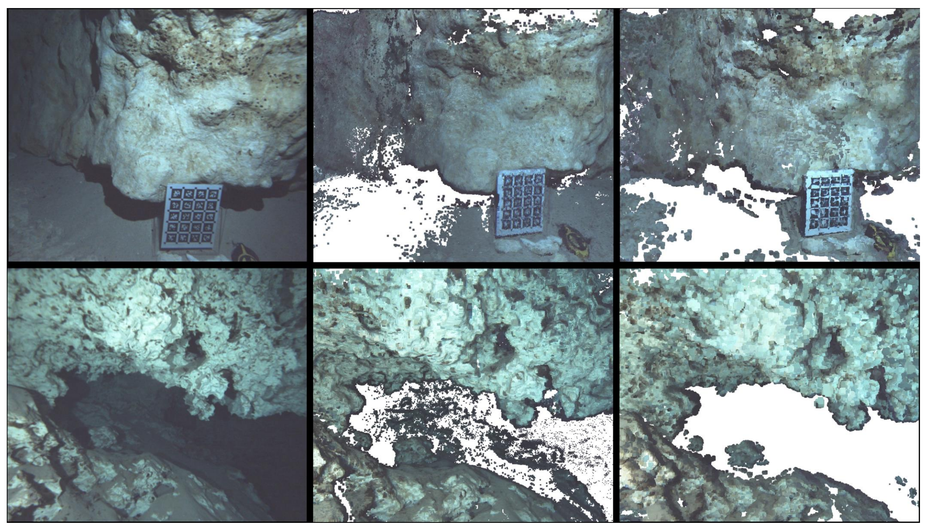


Image COLMAP Pipeline
Ginnie Ballroom (top), and Cenote (bottom)

Dataset	pipeline-to-colmap		colmap-to-pipeline	
	Precision (%)	Accuracy (m)	Recall (%)	Completeness (m)
Ginnie Ballroom	96.9	0.029	97.5	0.019
Cenote	94.4	0.037	92.4	0.047
Coral Reef	52.3	0.109	60.3	0.114
Stavronikita	43.6	0.134	40.2	0.143

Dataset	COLMAP			Pipeline			
	stereo pairs	vertices	MVS (min)	total time (min)	vertices	Stereo (ms/frame)	Fusion (ms/frame)	total time (min)
Ginnie Ballroom	1519	8,056,361	607.61	858.10	54,034,304	398.88	374.93	22.36
Cenote	1401	8,909,774	568.52	1250.53	91,036,005	360.49	418.71	20.92
Coral reef	631	3,833,107	254.31	337.99	66,733,182	369.35	677.65	12.44
Stavronikita	897	4,552,326	367.17	482.57	29,851,344	323.57	553.37	14.95

Broader Impact on Society

The project may reduce the cost and risk of having the same tasks performed by divers

Robots can make covering larger areas practical

Applications in archaeology, infrastructure inspection

Broader Impact on Outreach and Education

Three PhD students involved at Stevens

Four high school students mentored by PI on programming and scientific simulation

Broader Impact on Research Community

The project has generated over 10 papers including several in top-tier venues such as ICRA and CVPR

Most software components have been open-sourced

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