Sonar-Aided Manipulation in Low-Visibility Conditions by Novice Users

Amy Phung • MIT-WHOI Joint Program

Co-Authors: Gideon Billings, Richard Camilli

WOODS HOLE OCEANOGRAPHIC INSTITUTION

Massachusetts Institute of Technology

Abstract

Underwater intervention tasks are typically completed with remotely operated vehicles (ROVs) equipped with robotic manipulator arms, and rely on optical-based perception of the scene to guide the manipulation tasks. However, optical sensors perform poorly in turbid water conditions, which can arise from a variety of environmental and anthropogenic causes. This work investigates the use of a wrist-mounted multibeam imaging sonar and doppler velocity log (DVL) close-range scene mapping to enable low-visibility underwater intervention.

Background

- Underwater manipulators complete dexterous tasks in areas inaccessible to human divers
- Existing teleoperated- and autonomy-based control systems rely on optical imagery, which lack robustness in turbid conditions
- Acoustic sensors work well in turbid conditions, but resolving the elevation angle ambiguity in sonar images is difficult

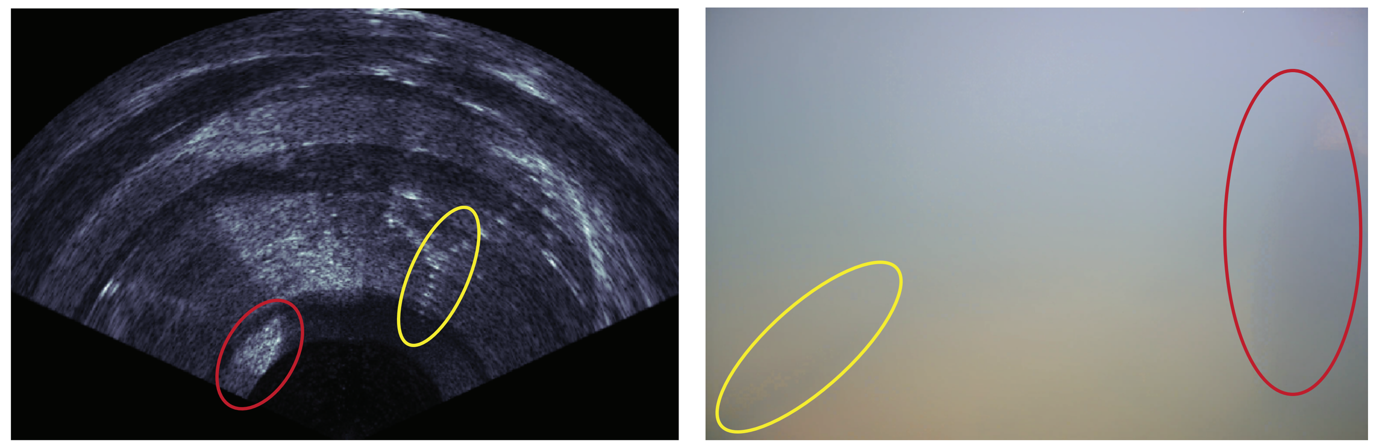


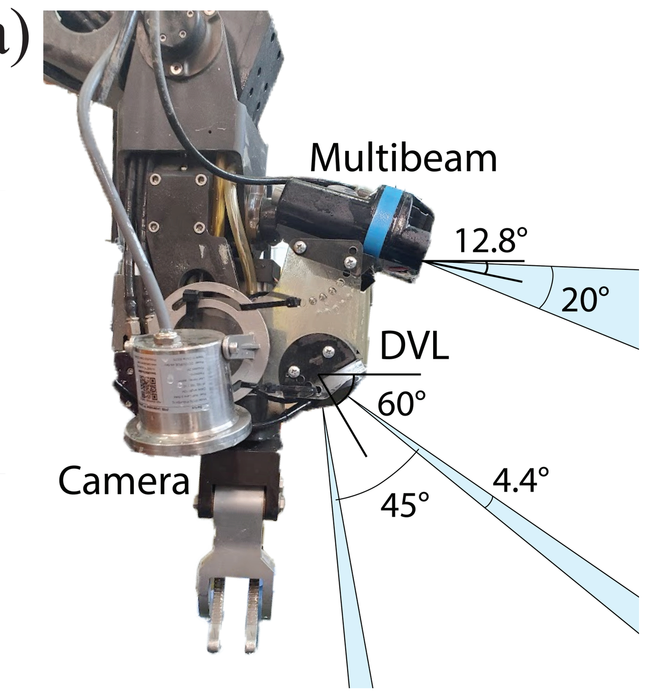
Fig. 1: Rock (red) and chain (yellow) in multibeam sonar image (left) and optical camera image (right)

Key Contribution: Robust, real-time capable method for completing intervention tasks in turbid conditions

Multibeam Mapping: Min-Max Filtering

- a) "Acoustic eye-in-hand" mapping approach
- b) Create "voxel template" to sufficiently represent sonar field-of-view
- c) Project voxel template based on manipulator joint feedback
- d) Observe the **max** intensity value in each voxel to ensure all objects are accounted for
- e) Update the map with the **min** value to resolve elevation angle ambiguity

a)



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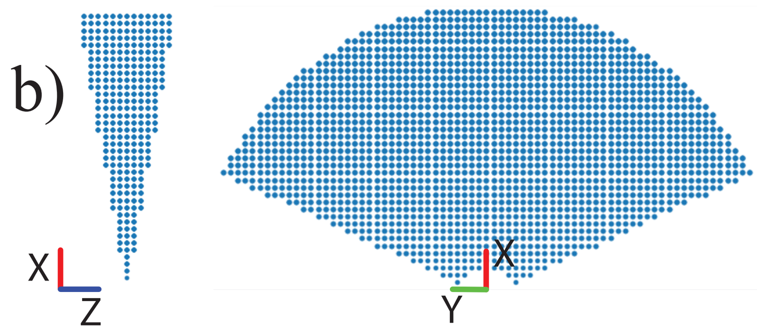
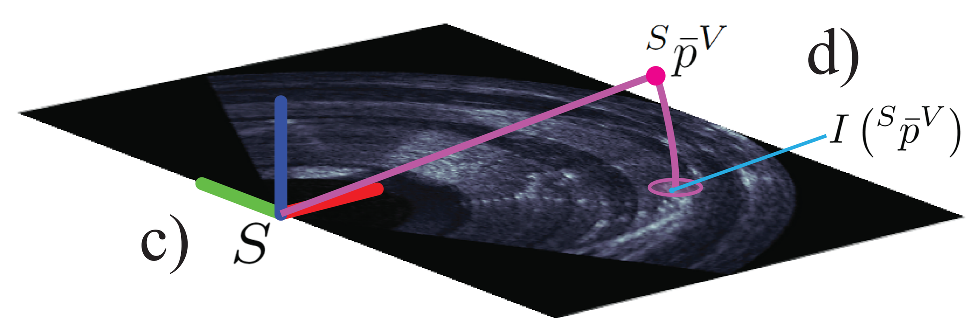
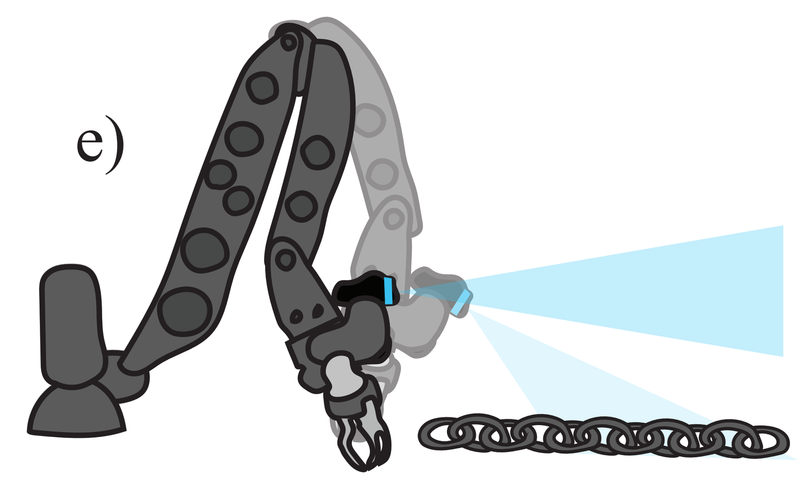




c) d)

e)



Shared Autonomy Framework Integration

- The SHared Autonomy for Remote Collaboration Framework (SHARC) enables novice users to safely control manipulator arms
- Gesture-based controls, a 3D data visualizer, and a VR interface make mapping results usable by novice users
- Integrating sonar-based perception extends its capabilities to low-visibility conditions

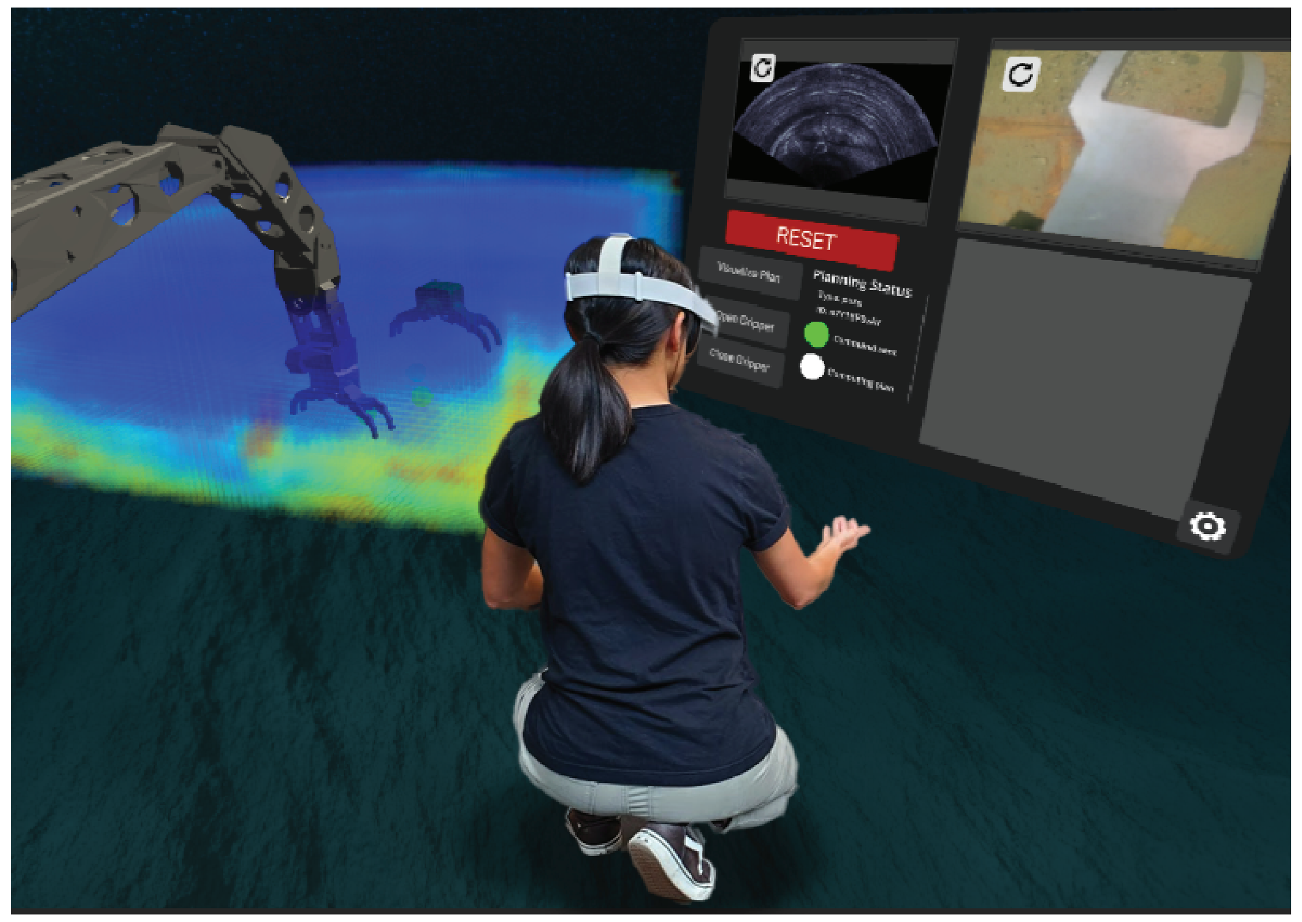


Fig. 2: Mixed-reality view of the SHARC-VR interface with integrated sonar, optical camera, and DVL data

Results

- Multibeam mapping results in turbid test tank demonstrate that the min-max filtering approach resolves elevation angle ambiguity in real-time
- Shared autonomy framework enabled object retrieval from the turbid tank by users without ROV piloting experience

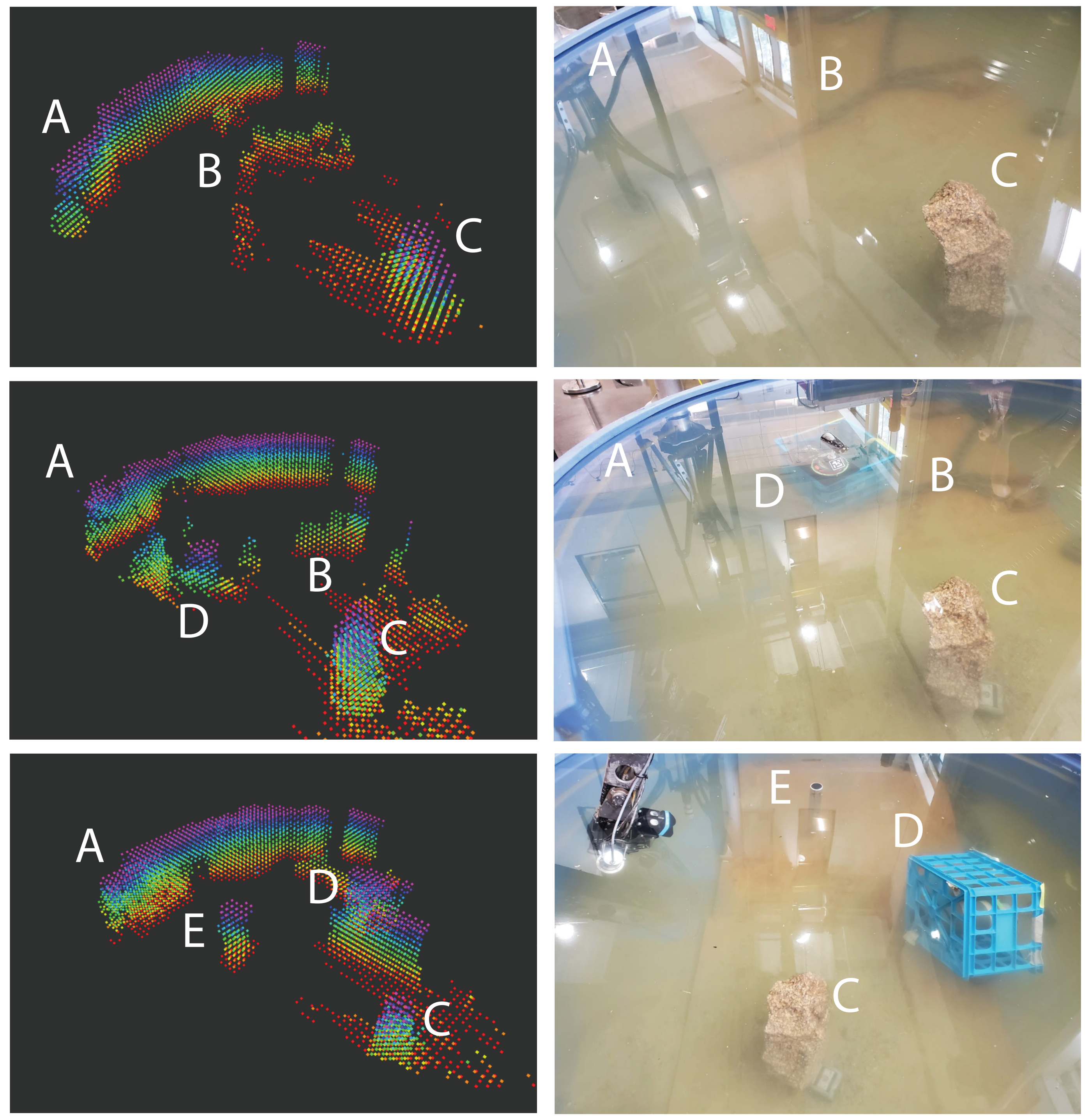


Fig. 3: (A) Tank walls, (B) chain, (C) rock, (D) tool crate, and (E) metal pipe are recognizable in the reconstructed data

Future Work

- Current implementation lacks robustness to dynamic obstacles
- Issues with navigation drift and map scalability need to be addressed for free-floating manipulation

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