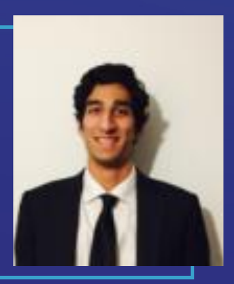
Dimensional Inference Method for Degeneracy Aware Underwater Simultaneous Localization and Mapping



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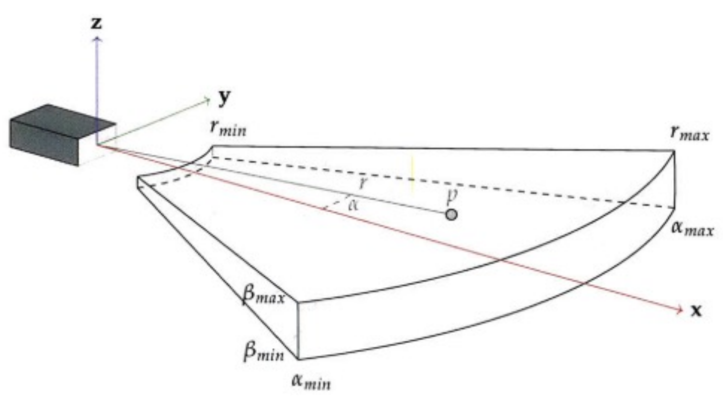
Objectives

- Perform 3D underwater mapping by merging monocular camera data with sonar data
- Mitigate sensor limitations by using *inferred* monocular depth to find correspondences between sonar and camera data and thus fully constrain observed landmarks in 3D space.

Challenges

- GPS-denied environment, low-cost vehicle (no DVL, noisy IMU)
- Sensor modalities do not provide full 3D points from environment
- Lack of underwater training data leads to unreliable inferred monocular depth
- Appropriate noise models for learned models still an open research question



Figure[1] (above): A model of the multibeam sonar geometry. For each return, we lose β, i.e. the 3D point in the real world $\{r, \alpha, \beta\}$ is only represented by $\{r, \alpha\}$, thus making the recovery of the full 3D point location a *degenerate* problem.

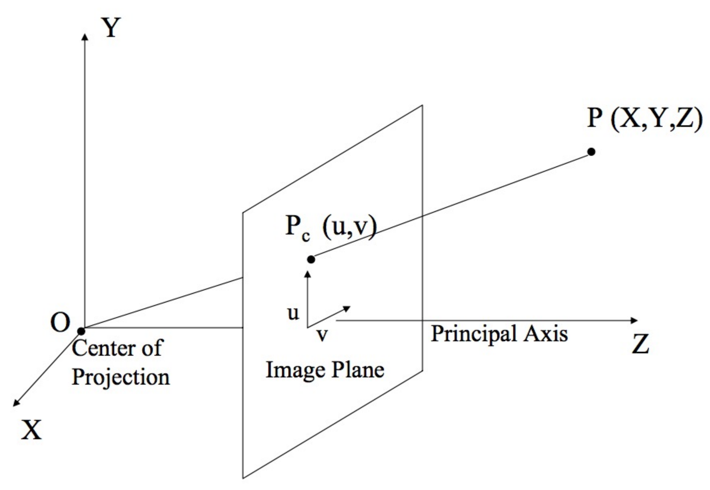
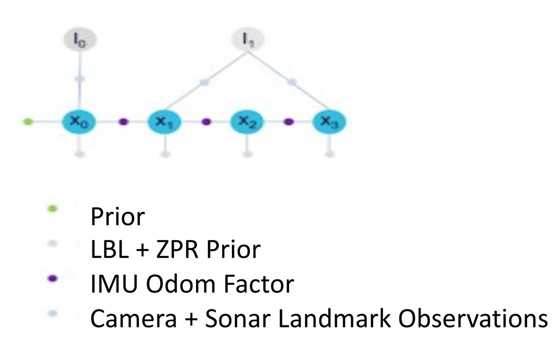


Figure (above): A pinhole model for a monocular camera. Similarly to the sonar model above, the camera sensor projects 3D points {X, Y, Z} = $\{r, \alpha, \beta\}$ in the world to 2D points $\{\alpha, \beta\}$ in the image. For each image, we lose the range/depth measurement, again making 3D recovery underconstrained.

Proposed Method

- Utilize monocular camera depth estimation neural network MiDaS[2] to infer depth/range from camera data.
- Address inherent errors in inferred depth model usage with out-of-training datasets through novel method
  - Frame-to-frame inferred depth consistency and camera-to-sonar consistency used for *dynamic covariance scaling (DCS)*, thus providing a feasible noise model
- Incorporate DCS into probabilistic graphical model for mapping known as a *factor graph*.
- Inferred depth is used as an *initialization* for alignment with sonar data, and through an iterative optimization process, we refine the sonar/camera alignment to get an optimized 3D position of points seen by both sensor modalities.

Factor Graph Formulation



Experimental Setup

- Modified BlueROV in an outdoor tank
- Tank has several object placed around perimeter such as a ladder, pipes, and other manmade structures

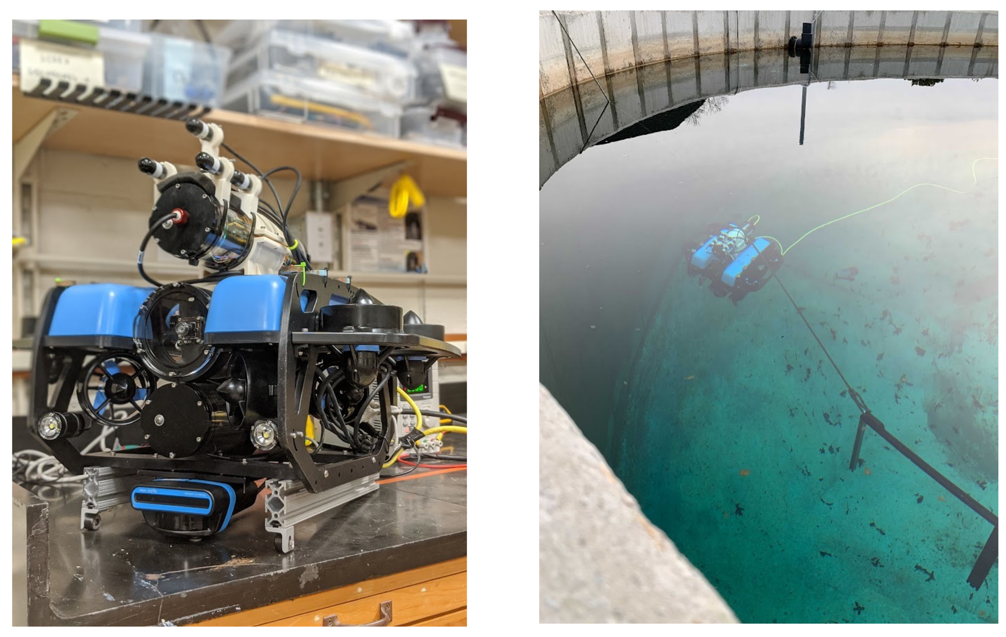


Figure: (left) The modified BlueROV used for data collection. (right) The BlueROV pictured in the tank environment collecting data.

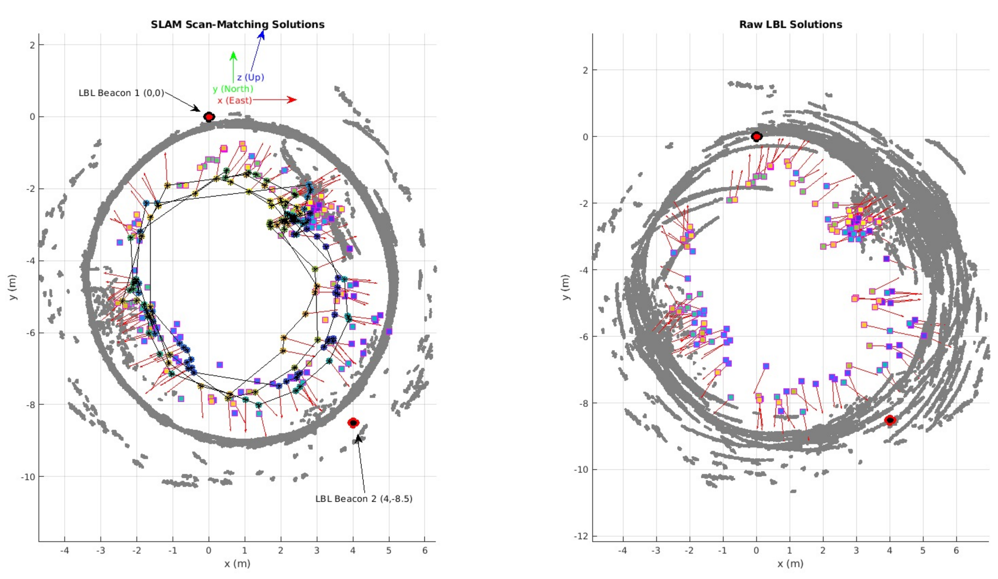


Figure: The sonar-only mapping result (with ICP alignment left, without right) is limited to mostly 2D representations of the tank. The same limitation applies to a camera-only photomosaic, albeit with a different missing dimension, thus motivating the use of the proposed method.

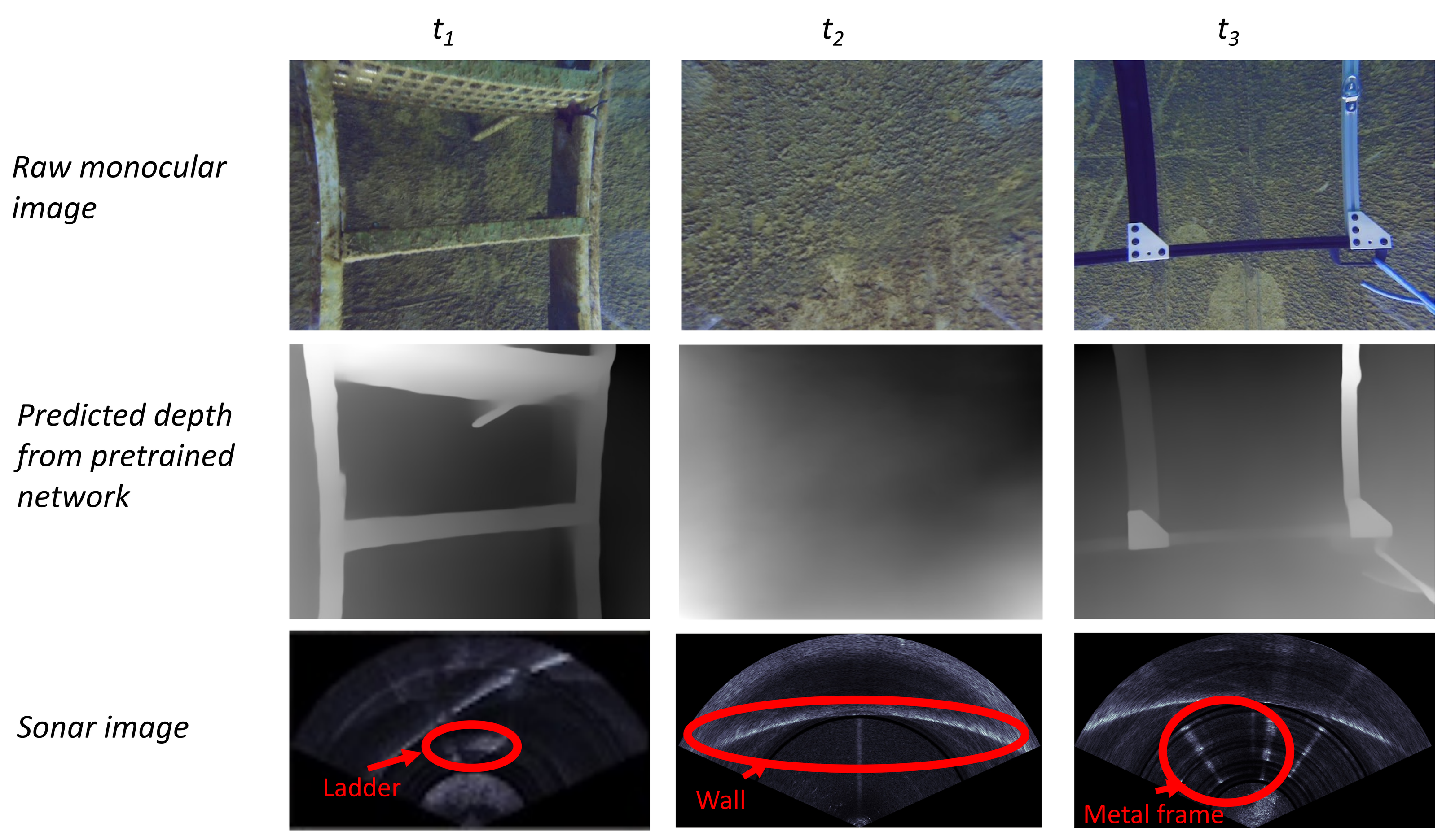


Figure: Three representative frames illustrating the challenges of inferred depth, and the need of a probabilistic method to incorporate such models.
(leftmost column) The predicted depth image for the ladder is accurate, and can easily be linked to the corresponding sonar image.
(middle column) The predicted depth inaccurately varies throughout the image despite only a curved wall in sight, as the depth network outputs varied depths from the wall texture.
(rightmost column) The depth of the structure is mostly inferred correctly, but the differing colors of the two beams cause the network to guess a closer range for the silver beam.

References

1. Vaz Teixeira, Pedro & Hover, Franz & Leonard, John & Kaess, Michael. (2018). Multibeam Data Processing for Underwater Mapping. 1877-1884. 10.1109/IROS.2018.8594128.
2. René Ranftl, Katrin Lasinger, David Hafner, Konrad Schindler, & Vladlen Koltun (2022). Towards Robust Monocular Depth Estimation: Mixing Datasets for Zero-Shot Cross-Dataset Transfer. *IEEE Transactions on Pattern Analysis and Machine Intelligence, 44(3).*

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