Online Seabed Estimation for Terrain-Aware Underwater Navigation

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TL;DR: In this project you will design and implement an online estimator that uses forward-looking underwater sensors to predict the seabed directly beneath an AUV in real time. The main challenge is to recover the dominant terrain shape while rejecting rocks, isolated objects, and acoustic outliers, so that the estimate becomes useful for terrain-aware guidance and control.

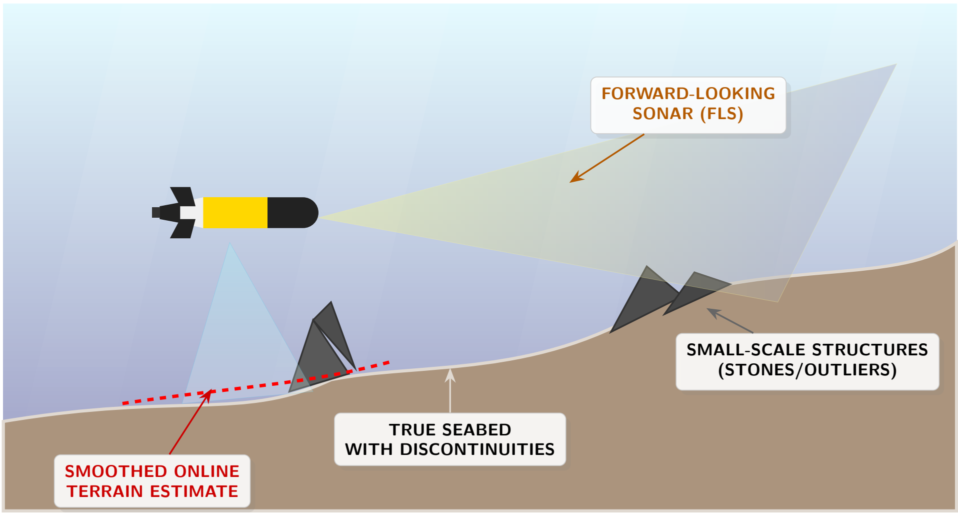

Figure 1: Conceptual overview of the proposed seabed estimation pipeline. Forward-looking sensors perceive the upcoming terrain, allowing the system to compute a smoothed, outlier-rejected estimate of the seabed directly beneath the vehicle for real-time control.

Description

Autonomous underwater vehicles (AUVs) are increasingly used for seabed inspection, marine science, and subsea infrastructure operations. Yet near-bottom navigation remains difficult when visibility is poor and GPS is unavailable. A reliable estimate of the terrain directly beneath the vehicle can improve safety margins and make guidance and control significantly more robust [1, 4, 9, 16].

In this thesis, you will design and implement an online seabed estimator that uses forward-looking sensing (forward-looking sonar and/or forward-looking altimeter) to predict the dominant terrain shape under the vehicle in real time. A key research and practical challenge is to suppress rocks, isolated objects, and acoustic outliers while preserving the large-scale terrain structure relevant for control [6, 7, 11, 14]. Depending on scope and student interest, optional extensions can include data-driven perception methods (e.g., neural networks) for object identification in complex FLS imagery [15]. However, the core project remains fully feasible with model-based estimation and robust filtering.

Project relevance and learning outcomes

- **Application context:** The topic addresses a concrete need in autonomous subsea operations, where near-bottom navigation quality affects safety and control performance.
- **Technical content:** The work combines estimation, geometry, point-cloud processing, and real-time algorithm design [2, 3, 13].
- **Methodological emphasis:** The thesis includes implementation, quantitative evaluation, and discussion of robustness and limitations.
- **Scope flexibility:** The work can be adjusted from a focused one-semester project to a full master's thesis with more advanced terrain models.

Suggested work packages

1. Review sensor measurement geometry, coordinate frames, and relevant literature on terrain-aided navigation and seabed mapping.
2. Build a preprocessing pipeline that transforms raw sonar/altimeter measurements into a local geometric representation for estimation [2, 6, 13].
3. Design an online estimator (e.g., local plane or low-order surface fitting) for the seabed directly below the vehicle [3].
4. Add robust spatial filtering/outlier handling to reject small objects and spurious returns while preserving dominant terrain trends [7, 11, 14].
5. Use forward-looking measurements predictively so that observations acquired ahead of the vehicle improve the current under-keel estimate [5, 10].
6. Evaluate accuracy, smoothness, latency, and computational load in simulation and/or logged data, and discuss effects on downstream guidance and control [1, 4].

Expected deliverables

- A documented seabed-estimation pipeline suitable for online use.
- Quantitative evaluation with clear metrics and controlled comparison studies.
- Reproducible code and experiments.
- A well-structured thesis/report with discussion of limitations and future work.

Scope options

Project thesis: Focus on local planar/low-order seabed estimation, robust filtering, and validation in simulation or selected logged data.

Master's thesis: Extend to richer terrain representations (e.g., Gaussian-process-based models) [16, 17], uncertainty quantification, state-estimate fusion, and tighter integration with guidance/control [8, 12, 1].

Practical Information

The report should be written in English and structured as a research report (motivation, methodology, experiments, discussion, and conclusion). Source code, experiment settings, and key implementation details should be delivered with the report to ensure reproducibility.

Recommended background

Background in estimation, signal processing, geometry, and control is helpful. Experience with robotics, marine sensors, and scientific programming is an advantage, but motivation and willingness to experiment are equally important. Relevant courses may include TTK4190 Guidance, Navigation and Control of Marine Craft, Aircraft and Drones, and related courses in estimation, robotics, or perception.

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