Correlating Sidescan Sonar with Bathymetry for AUV Navigation

Padial, J., Dektor, S., and Rock, S.M.

Introduction

Terrain-Relative Navigation (TRN) is an emerging technology for localization of autonomous underwater vehicles (AUVs). TRN solutions rely on the correlation of a bathymetric terrain map with downward-looking range measurements, typically using the four ranging beams of a doppler velocity log (DVL), and have been demonstrated successfully in the field with meter-level accuracy. However, when flying over terrain low in information, e.g. flat, accurate navigation with TRN can be challenging. The incorporation of side-looking information presents a potential solution to this challenge in areas where there is bathymetric information port or starboard. Several types of sensors exist which can measure side-looking information, including multibeam sonars, simple acoustic ranging devices, and sidescan sonars.

This work is exploring the incorporation of sidescan sonar data into a TRN filter. Sidescan sonar is chosen due to its low cost, low power and because it is a sensor commonly found on operational AUVs.

Sidescan Sonar

Sidescan sonar systems emit a fan-shaped pulse of acoustic energy into the water and record energy intensity return from the seafloor as a function of time of flight. Return intensity is in general a complex function of terrain grazing angle, terrain surface composition, and water properties. Unlike multibeam sonars, sidescan sonar measurements do not provide range along beam directions, and as such there is an ambiguity in extrapolating terrain geometry from sidescan returns.

Figure 1 provides a depiction of typical sidescan sonar usage. As the vehicle moves forward, returns from each timestep fan are stitched into a 2D image. In order to create a spatial image from time of flight data, a flat seafloor assumption is typically employed.

The method of approach is to correlate acoustic shadows in a measured sidescan signal with shadows predicted based on vehicle pose relative to a bathymetry map. The process of estimating and measuring acoustic shadows is shown in Figure 3. The alignment of expected and measured acoustic shadows drives measurement weighting, which is used in non-parametric filtering (e.g. particle filter or point mass filter) to determine the confidence in a given pose estimate.

Acoustic Shadows

Acoustic shadows are significant drops in sidescan sonar intensity signal, and are determined primarily by line of sight occlusion due to the geometry of ensonified terrain relative to the sonar transducer. As such, these features allow for correlation with a bathymetry map.

Figure 2 highlights acoustic shadows in real sidescan sonar data. The left image shows an AUV trajectory over a bathymetry map in red, while the right image provides the corresponding sidescan sonar time of flight intensity returns, with each timestep (fan) laid in a row of the 2D image. The black lines between the left and right images highlight acoustic shadows and the terrain features from which they are derived.

Approach

The method of approach is to correlate acoustic shadows in a measured sidescan signal with shadows predicted based on vehicle pose relative to a bathymetry map. The process of estimating and measuring acoustic shadows is shown in Figure 3. The alignment of expected and measured acoustic shadows drives measurement weighting, which is used in non-parametric filtering (e.g. particle filter or point mass filter) to determine the confidence in a given pose estimate.

Terrain bathymetry profile extracted. Occluded terrain identified by line of sight.

Terrain visibility projected into time of flight domain and interpolated for expected shadow identification.

Shadows detected in sidescan sonar measurement by thresholding.

Results

The viability of sidescan sonar bathymetry-based correlation in TRN was demonstrated using field data from Monterey Bay Aquarium Research Institute (MBARI) Dorado-class AUV runs.

A point mass filter was implemented as the TRN estimator using sidescan sonar acoustic shadow data as measurements. A point mass filter is a non-parametric filter that propagates discrete state hypotheses. The estimated states were East and North vehicle position, where depth, altitude, and attitude were treated as known quantities from the pressure sensor, altimeter, and INS/DVL (doppler velocity logger).

Figure 5 shows a TRN result for a run of roughly 500m distance traveled. This dataset comprises the mapping run used to generate the bathymetry map, and thus the “Mapping Trajectory” shown is essentially true, shown red. The weighted mean TRN estimate (SS-TRN) is shown in blue, along with confidence ellipses. The convergence of the SS-TRN estimate highlights the promise of the sidescan sonar correlation method for TRN.

Conclusions

The viability of sidescan sonar use in a TRN filter has been demonstrated with AUV field data. Acoustic shadow information in sidescan sonar returns has been shown to be usable for correlation with a bathymetry map.

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Further Information

For further information please contact Jose Padial at jpadial@stanford.edu or Shandor Dektor at sgd@stanford.edu.