SSSS - SMaRC Sidescan Sonar System

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1 Introduction

We have as our main challenge using sonar to aid navigation. This is of intense interest to MMT, GU, and SAAB. It is also the prize that is within our grasp. We have unique access to resources that will allow us to make large strides here. We need to look at all the sonar types but here I want to talk about a road map for sidescan. The sidescan sonar is particularly difficult due to its lack of a narrow beam giving only 2 of the 3 dof for the terrain. But we have lots of data and are great at machine learning and navigation. So no problem. What we need is plan. A clear idea of how to work on this systematically so that we build up a pipeline that can do it. I have a proposal of some intermediate pieces that can be chained together to get us there. We have a lot of MMT and GU data and can get more of both types of data.

What is needed is some intermediate formats to transform the sonar into that will lead to a representation that is invariant to the sonar pose. That can not be done in one giant step but we must break it down to a series of representations as I will outline below. A similar plan would work for the multibeam but some of the steps below would be much easier.

The idea is that we start with Master thesis students developing these representations with the help of the PhD students. When they have made a start by next summer we will hopefully be in position to have the PhD students step in to integrate and expand on it. Getting it to run on the AUVs themselves.

2 Our Treasures

We have raw sidescan sonar along with Multibeam sonar taken with DVL and a stable platform over the same areas from many angles. Nils and Nacho are working on registering all this ‘perfectly’ to give us essentially ground truth for SS-D-S and IDS Grids for different S’s (see below for that that means). We are taking many thousands of individual cells. This is insanely useful for both place recognition and pose correction using SS (or multibeam).

We should also have some interest from Master students this year if we have the data and tools for organizing it into training data for the projects below.
3 Puzzle Pieces

- Raw-SS, t - These are vectors of intensities separated in to time (or corresponding range distance) bins. They may be somewhat processed, for example, to normalize for transmission losses and sound velocity profile distortions (i.e. make all rays straight according to some assumptions).

- Pose, t - The sonar’s pose at time t interpolated to the time of the pings. These will also normally include altitude (bottom reference) as well as depth (water surface reference).

- SS-D, t - These are Raw-SS along with a second vector of depths corresponding to the bins of the Intensity vector. These depths are relative to some datum that the AUV was using when collecting the data (often the water surface but may be corrected). It can easily have a common offset when compared to data collected at other times. These will normally be also indexed with right or left to remove the ambiguity of two solutions for xy given range and depth.

- SS-S, t - This is a Raw-SS intensity vector along with a corresponding vector of 'S' vectors. S is the vector from the the sonar itself to the point of sonar reflection (for that bin). It is a vector in the sonar frame of reference. The intensities mainly will depend on the direction of this vector but in a generally complex way.

- SS-D-S, t - Obvious.

- IDS Grid - The intensity-depth-direction grid is a regular grid of cells in the horizontal xy plane. Each cell contains a vector of \((I, D, \hat{S}_x, \hat{S}_y, \hat{S}_z)\). \(\hat{S}\) is a unit vector. This might be formed by interpolating the SS-D-S. The grid might therefore be more dense than the SS. It could also be less dense in which case it is more of a averaging grid. These might be arranged in a way analogous to scale space pyramids in computer vision.

- L Grid - A Grid of cells in the xy plane that contain a vector of latent variables that encode a description of how this cell will look from any Pose. We will probably never form such a grid but rather think about it.

- \(\theta\) Grid - A grid of cells that contain latent space distribution parameters, \(\theta\), for example a mean and standard deviation of a Gaussian in the latent space. So an L grid can be drawn from this grid in theory. It is this distribution grid that is actually useful to form.
4 Projects

1. SS-S to SS-S': Investigate small changes in SS-S due to small changes in S. This is actually not obvious that we can use our data as ground truth but we should be able to theoretically transform the intensities of a single scan to account for changing xyz of the sonar by small amounts. This is needed to be able to make a final fine tuning of any SS to SS registrations.

2. Raw SS to SS-D: Various NN or RNN can be tried to learn how to guess depth values for bins in a SS. This might use additional inputs such as altimeter, pose, or even (partially overlapping) multibeam sonar.

3. SS-D-S to IDS Grid: Investigate ways to do this interpolation/averaging and generating SS from the grid. What are the trade-offs and what method to use. This is mainly geometric but can use some learning as a comparison. We want mainly baseline and a good robust method for converting (sparse) scans to (dense) grids.

4. IDS Grid to IDS Grid: Use our data to learn to convert from one set of \( \hat{S} \) to another. This will presumably require us to learn to create a \( \theta \) grid from the IDS grid and back. Variational Auto Encoders are one way to do this. We should make these use CNN ideas as well. (Needs 3)

5. \( \theta \) Grid to \( \theta \) Grid matching: test using the latent space grids to recognize places and to align two trajectories. For example if the distributions are learned as Gaussians the distance between the means weighted by standard deviation can be used for matching and the way that distance varies with sliding the pose in xy will give the precision of the estimate. (Needs 3, 4 and for fine tuning the transformation 1)

These projects have a dependence structure. All depend on Nils and Nacho getting the registration working well. 1,2 and 3 can begin anytime. 4 needs some sort of preliminary 3 in place to get started and then can use the better 3 as it develops. 5 is the pot of gold at the end and will just fall out of the other work when all is in place.