Preliminary results on terrain-aided localization algorithm for glider AUV

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Abstract— **Glider class autonomous underwater vehicles operate and collect water column data for long periods of time, even weeks, before the need for recovery. However, they possess only rudimentary navigation and localization capabilities. Gliders are under-actuated vehicles and prone to water currents disturbances hence their localization error increase significantly while dead-reckoning underwater. In this workshop, we present preliminary results of a localization algorithm aided by existing seafloor map bounding dead-reckoning drift. The glider is equipped with mechanical scanning imaging sonar producing bathymetric patches of the seafloor, which are compared with existent bathymetry of the area. Glider data were collected in a field survey at Scott Reef, Australia.**

I. INTRODUCTION

Glider class autonomous underwater vehicles (AUVs) are increasingly popular oceanographic platforms because of their ability to collect water column data for extend periods of time and over long ranges. Furthermore, because these platforms can operate unattended, they require a fraction of the cost compared to standard ship-based surveys.

The endurance of these vehicles have been achieved by eliminating continuous actuation, such as thrusters, with a buoyancy engine that normally operates for a fraction of mission time. Glider energy requirements are further reduced by their being equipped with a modest suite of sensory hardware that collects data in periodic schedule to minimize energy consumption. This minimalist approach has many benefits, however it creates a tradeoff in localization accuracy.

Gliders perform dead-reckoning while underwater using information only from low resolution heading, depth, and attitude sensors. With the influence of water currents their localization error increase significantly and the only solution is to surface regularly to obtain GPS fix. For this reason, gliders are typically used in open ocean environments,restricting their utility in more confined areas, such as under ice or in regions with significant bathymetric relief.

In this workshop, we present preliminary results of a localization algorithm aided with an existing seafloor map to bound the dead-reckoning drift, allowing operations in a coral reef with significant water column currents and bathymetric relief. In our approach a glider was equipped with mechanical scanning sonar produce bathymetric patches of the seafloor, which are compared with existent bathymetry of the area.

II. PRIOR RELATED WORK

Since the inception of AUVs, there has been a continuous effort to minimize localization drift. Techniques such as path planning to correct for previous drift are commercially available with Slocum glider which calculate positioning error from dead-reckoning estimated surface point to the actual surface GPS point, and adds this error as a bias to the next planned path, assuming constant currents direction and velocities [1]. More sophisticated algorithms also take into account ocean models to predict currents evolution with much better results [2], [3]. However, these techniques do not bound the localization drift until the glider surfaces.

Other approaches seek to better estimate the gliders actual trajectory while underwater. In [4], added a Doppler velocity log (DVL) to improve vehicle's location estimate. Although DVL addition can give better dead-reckoning results, localization drift remains unbounded and significantly increases energy consumption. More recently [5], glider altimeter and existing bathymetry from mission's area have been applied for terrain aided navigation (TAN), wherein an algorithm utilizes a digital elevation map along with a jittered bootstrapping particle filter (PF). Results from two field trials of 12 and 91 km trajectories indicate that TAN localized the glider within an average RMS error of 33 and 50 m. The authors in [6], present a TAN algorithm that traced the path performed by the glider within a known bathymetry, using least squares minimization with a model-free approach for several linear possible paths. Results showed an average of 55 m total navigation error over 4.54 km trajectory.

The aforementioned TAN works utilize the native glider's altimeter sensor for range measurements. The low temporal and spatial measurement updates from this sensor suggests that long paths are required before TAN algorithms converge toward the real trajectory. Our research builds on these previous works with the addition of a small low power mechanically scanning imaging sonar. This sonar rotates perpendicularly to glider's forward motion providing adequate range measurements to characterize local slopes during each glider descent. Although the addition of the sonar increase vehicle's power consumption, our results indicate

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that this configuration enables the algorithm to converge faster, enabling glider operation in confined environments.

III. SONAR BASED TAN FOR GLIDER AUV

A. Slocum Adaptations

A Tritech Micron DST sonar has been installed in the front of a Teledyne Webb Slocum glider, as can be seen in figure 1. A *Raspberry Pi A+* was installed in gliders science bay, gathering data both from the glider science processor and the sonar.

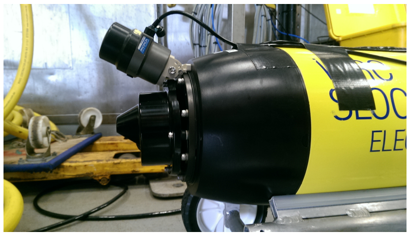
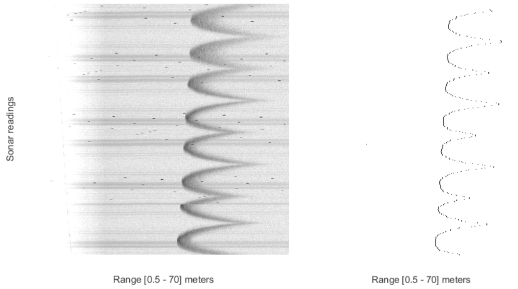


Fig. 1: Sonar installation on Slocum glider.

B. Sonar data processing

The sonar produces 8 bit resolution images with configurable beam ranges and number of intensity bins. Raw images are noisy due to floating particles in the water or fishes. To extract reliable seafloor ranges, first a thresholding is performed based on the histogram information of every beam (Fig. 2), following by sound velocity correction.



(a) Raw image (b) Processed image

Fig. 2: Sonar image process example.

C. Particle Filter

Particle Filters (PF), also called sequential Monte-Carlo methods, are recursive filters for solving the Bayesian estimation problem which can deal with nonlinear motion and measurement models without relying on linearization techniques. A set of random samples, “particles”, are used to represent the probability density.

PF for TAN takes the measured seafloor depth for every sonar reading and compare it with the depth returned by the bathymetry map for every particle position. The similarity between these data assigns weights to every particle which will make some of them to be discarded or replicated using resampling function and Gaussian noise is added to the remaining particles. Finally, the weighted sum of the particles position is the estimation of the real trajectory.

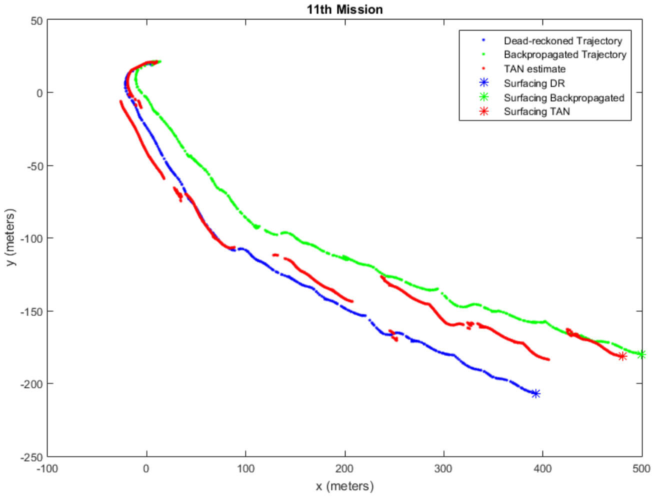
IV. FIELD TRIALS PRELIMINARY RESULTS

A. Dataset

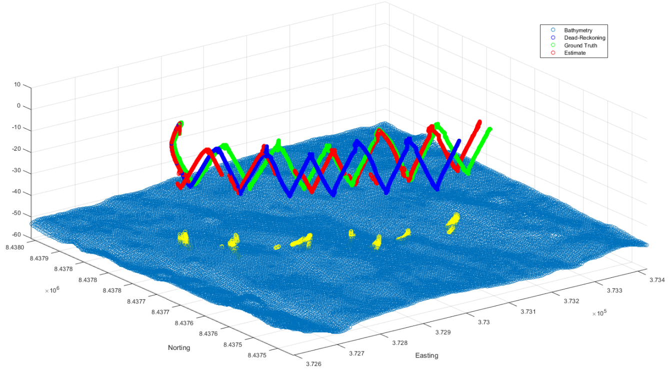
Between the 1^{st} and the 4^{th} of April 2015 in the framework of Coordinated Robotics research cruise at Scott Reef, Australia, several glider missions were performed with the modified Slocum glider from Woods Hole Oceanographic Institution. The confined area of the reef and the sharing of the glider for other engineering trials did not allowed for long trajectories (e.g., > 10 km), however the glider collected sufficient data for proof of concept. Mission 11 was chosen because it had the larger dead-reckoning error due to strong water currents.

B. Results

Preliminary results from the sonar-based TAN algorithm can been seen in figure 3. With blue is the dead-reckoning estimated trajectory, with green the GPS back-propagated corrected trajectory used here as ground-truth, and with red the TAN estimated trajectory. The final errors at the end of the mission are 110 meters for the dead-reckoning, and 18 meters for TAN algorithm. These preliminary results indicate our algorithm potential for better estimating gliders trajectory while underwater in relatively confined environments.



(a) Trajectories comparison.



(b) 3D view. In yellow are scan points projected from PF trajectory estimation.

Fig. 3: Results from the proposed TAN algorithm.

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