Improved Navigation for Long Range Autonomous Underwater Gliders

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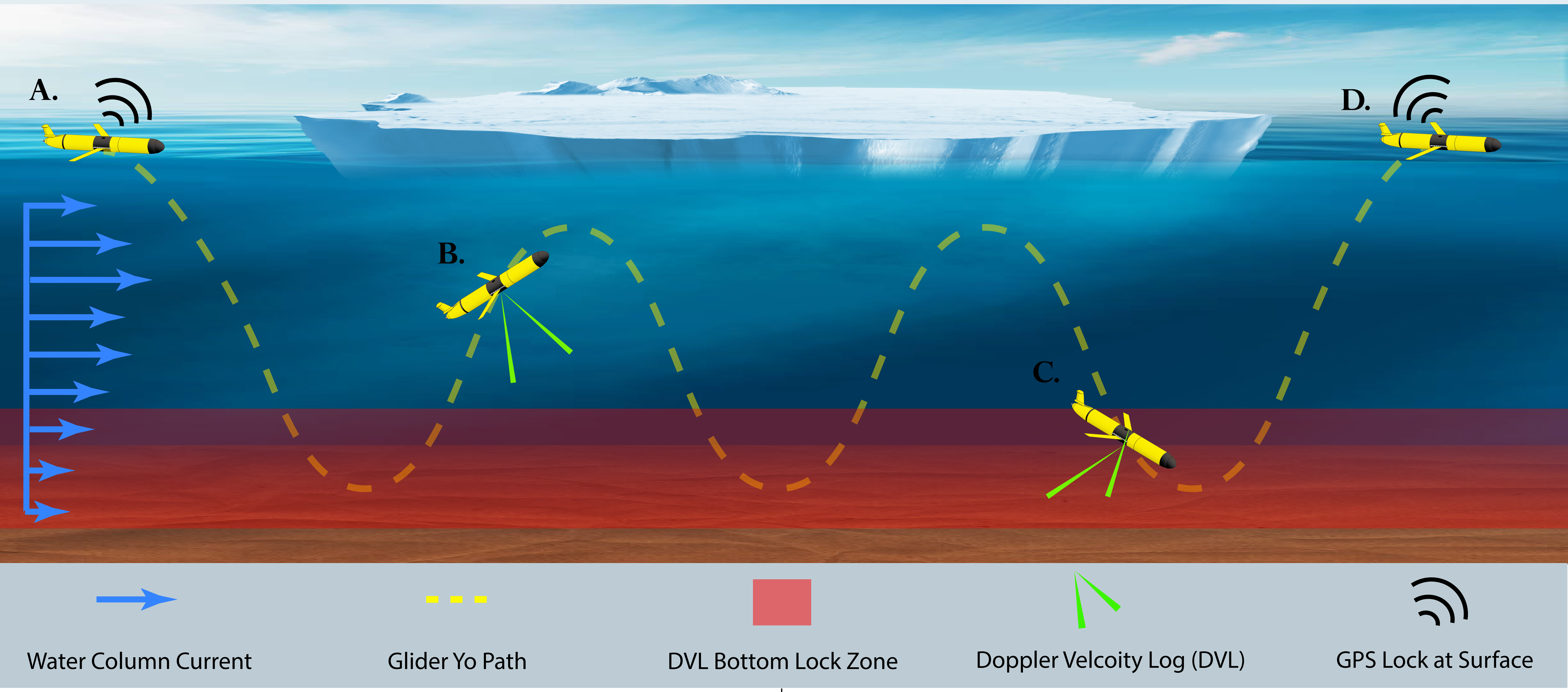
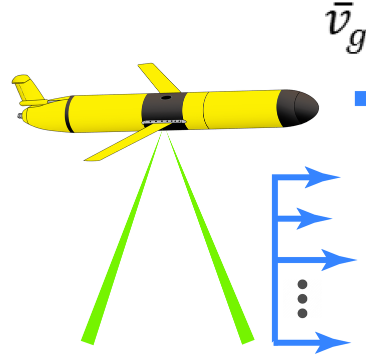


Motivation: Sub-Ice Traversal of Arctic Basin

Autonomous underwater gliders (AUGs) are long range vehicles, capable of traversing basin scale distances. However, AUGs currently lack sufficient navigation accuracy to traverse long distances without periodic surfacing to obtain GPS fixes and constrain the localization drift. We present a method and preliminary results from field trials for improved AUG navigation using a Doppler Velocity Log to dynamically profile water column currents, building on prior literature [1-6]. This improved navigation reduces the AUG localization drift and the need for periodic surfacing, which could enable long range missions beneath arctic ice sheets.

DVL Odometery with Real-Time Current Profiling



$$\bar{v}_g = \bar{v}_w + \bar{v}_c^i$$

$$\bar{w}_t^{i+2:i+n} = \bar{z}_t^{2:n} - \bar{v}_w$$

$\bar{v}_g$ – vehicle estimated velocity over ground
$\bar{v}_w$ – vehicle estimated velocity through water
$\bar{v}_c^i$ – water column velocity at depth bin i
$\bar{z}_t^j$ – DVL bin j measured water relative vehicle velocity at time t

**Note that all velocities are transformed to an East-North-Up reference frame using onboard AHRS measurements*

$$W = \begin{bmatrix} \bar{w}_1^0 & \cdots & \bar{w}_K^0 \\ \vdots & \ddots & \vdots \\ \bar{w}_1^N & \cdots & \bar{w}_K^N \end{bmatrix}$$

Water column matrix represents N eqaul size depth bins and stores last K velocity measurements and associated timestamps for each depth bin.

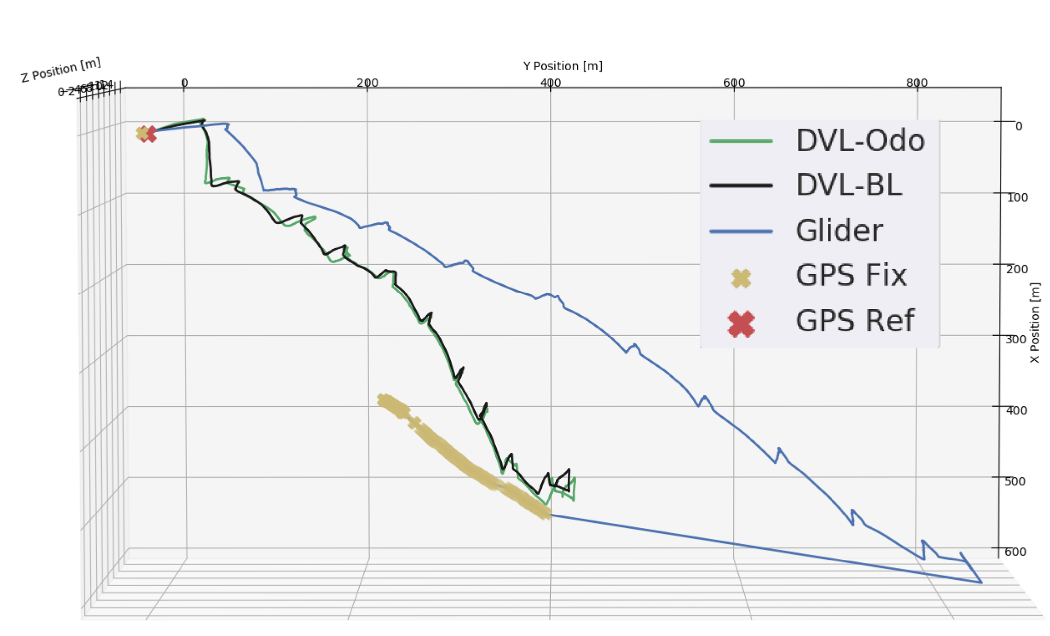
$$\bar{v}_c^i = median(\bar{w}_{1:K}^i)$$

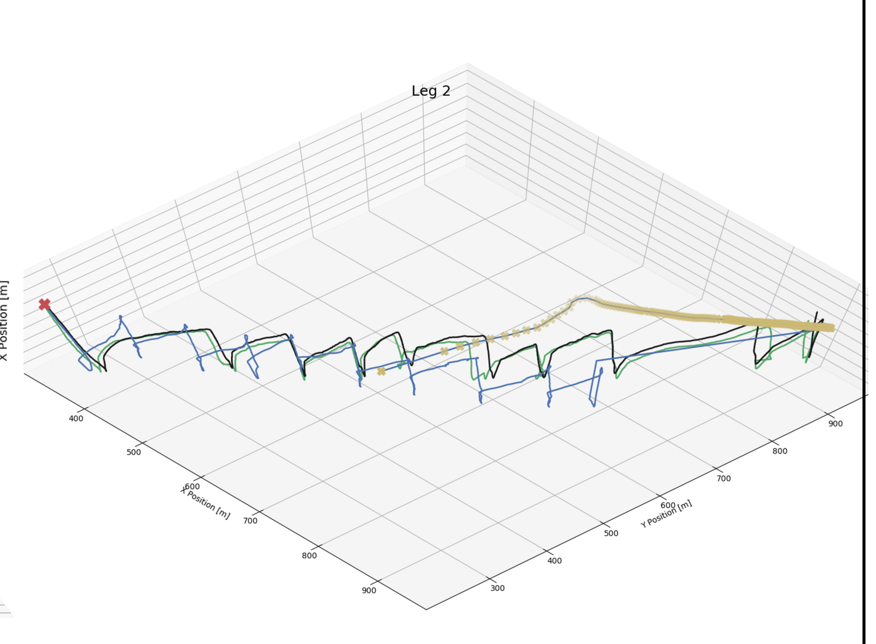
Median filter empirically gives better results than mean

$$\bar{v}_w = mean(\bar{z}_{t:t-5}^1) - \bar{v}_c^{i+1}$$

Velocity through water estimated from smoothed first DVL bin with current compensation

Preliminary Results Demonstrate Improved Odometery





A. Water Column Initialization from Surface Drift

$$W = \begin{bmatrix} \bar{w}^0 & \cdots & \bar{w}^0 \\ \vdots & \ddots & \vdots \\ \bar{w}^{N-n} & \cdots & \bar{w}^{N-n} \\ & \bar{0} & \end{bmatrix}$$

Water column matrix is initialized from GPS measured surface drift and running average of DVL measured water column bin velocities down to the max bin range of the DVL.

B. Odometery & Current Profiling Without Bottom Lock

$$W^{i+2:i+n} = \begin{bmatrix} \bar{w}_2^{i+2} & \cdots & \bar{w}_K^{i+2} & \bar{w}_t^{i+2} \\ \vdots & \ddots & \vdots & \vdots \\ \bar{w}_2^{i+n} & \cdots & \bar{w}_K^{i+n} & \bar{w}_t^{i+n} \end{bmatrix}$$

Water column matrix is updated by shifting over old measurements in all observed bins and appending the new DVL measurements.

**Note that new measurements are filtered for outliers*

$$\bar{p}_t = \bar{p}_{t-1} + \bar{v}_g * \Delta t$$

Odometery update step

C. Odometery & Current Update With Bottom Lock

$\bar{v}_{bg}$ – DVL bottom lock velocity over ground

$$\bar{v}_{err} = \frac{1}{T}\sum \bar{v}_{bg} - \bar{v}_g$$

Difference between bottom lock velocity and estimated velocity over ground is cumulated as running average.

$$\bar{w}_t += \bar{v}_{err} \mid t > (prev.\,bottom\ lock\ time)$$

If enough bottom lock measurements, update water column measurements stored since the last bottom lock update.

$$\bar{p}_{err} = \bar{v}_{err} * (time\ since\ last\ bottom\ lock)$$

Pose error update applied to odometery

$$\bar{p}_t = \bar{p}_{t-1} + \bar{v}_{bg} * \Delta t + \bar{p}_{err}$$

Odometery update step

**Note some work is still being done on the associated pose uncertainty, which will be addressed in the publication of this work*

D. Opportunistically Surface for GPS Update & Reset

- Can be triggered when pose uncertainty exceeds threshold, if area is safe for surfacing.
- Reset water column and re-initialize odometery from GPS fix, restarting process from A.

Relevant Literature

1. Medagoda, L., et al. (2016). Mid-water current aided localization for autonomous underwater vehicles. Autonomous Robots.
2. Visbeck, M. (2002). Deep velocity profiling using lowered acoustic Doppler current profilers: Bottom track and inverse solutions. Journal of atmospheric and oceanic technology.
3. Todd, R. E., et al (2017). Absolute velocity estimates from autonomous underwater gliders equipped with Doppler current profilers. Journal of Atmospheric and Oceanic Technology, 34(2), 309-333.
4. Woithe, H. C., et al. (2011, September). Improving slocum glider dead reckoning using a doppler velocity log. In OCEANS'11.
5. Duguid, Z. (2020). Towards basin-scale in-situ characterization of sea-ice using an Autonomous Underwater Glider (Doctoral dissertation, Massachusetts Institute of Technology).
6. Kinsey, J. C., & Whitcomb, L. L. (2003). Preliminary field experience with the DVLNAV integrated navigation system for manned and unmanned submersibles. IFAC Proceedings Volumes, 36(4), 79-84.