National Aeronautics and Space Administration

Autonomous Operations for An Ocean Worlds Submersible

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Program: FY21 R&TD Topics **Strategic Focus Area: Autonomous GNC, planning, scheduling, and execution**

Objectives

The objective of this project is to develop and validate autonomous operations behaviors for an Ocean Worlds submersible vehicle. Due to communication constraints, it is expected that such a mission would require extended periods away from communications with Earth. We are targeting two autonomous capabilities, tracking underwater fronts and hydrothermal venting plumes, to increase the time spent sampling the regions of scientific interest and navigating back to a base station using a single range-only acoustic beacon.

Background

Icy-world oceans such as those on Europa and Enceladus present promising habitats for discovering exolife in our solar system. The communication latency, dropout, and dynamic environment expected on an Ocean World prevents operations similar to that done with terrestrial AUVs and existing planetary surface missions. To achieve the highest science return when such operations paradigms are not possible, the vehicle must have some capability to autonomous detect and collect scientific data of interest. Additionally, the vehicle must be able to return that data to an under-ice base station for transmission to Earth. For navigation, modifications to traditional AUV navigation methods are required on an Ocean World due to environmental, acoustic range, size, and power constraints. Given the cost of reaching the subsurface oceans it is expected that only a single acoustic beacon will be available for navigation. Additionally, the time varying magnetic field of Europa may preclude the use of magnetic navigation.

Approach and Results

In this FY we focused on single beacon navigation. Three different navigation paradigms, depending on the range of the vehicle to the base station, were identified (Figure 1). In close proximity to the base station (<5km), the vehicle is assumed to have the range and bearing to a beacon via an Ultra Short Baseline (USBL) array. Outside of this region only ranging information to the single beacon is available. Finally, when the vehicle is sufficiently far from the beacon (>50km) it will have no acoustic navigation. In this work we primarily focused development on navigation techniques for the middle paradigm, using single beacon navigation methods. We developed a navigation method based on a non-linear least squares filter to localize the beacon position in the vehicle frame based on multiple acoustic range measurements at disparate locations. These ranges and relative position information can be used in a set of non-linear equations to find the location of the beacon relative to the vehicle. See Figure 2 for an example of this method. With that information, the vehicle can be commanded towards the beacon, restarting this process if required. Once USBL fixed are received the vehicle transitions navigation paradigms. This work was deployed with the Monterey Bay Aquarium Research Institute on one of their Tethys-Class Long-Range AUVs (LRAUV) in December 2020 and May 2021. During this field experiment we were able to successfully demonstrate navigation and return to a base station using a single range-only acoustic beacon and no magnetic navigation information. These results can be seen in Figure 3 and Figure 4.

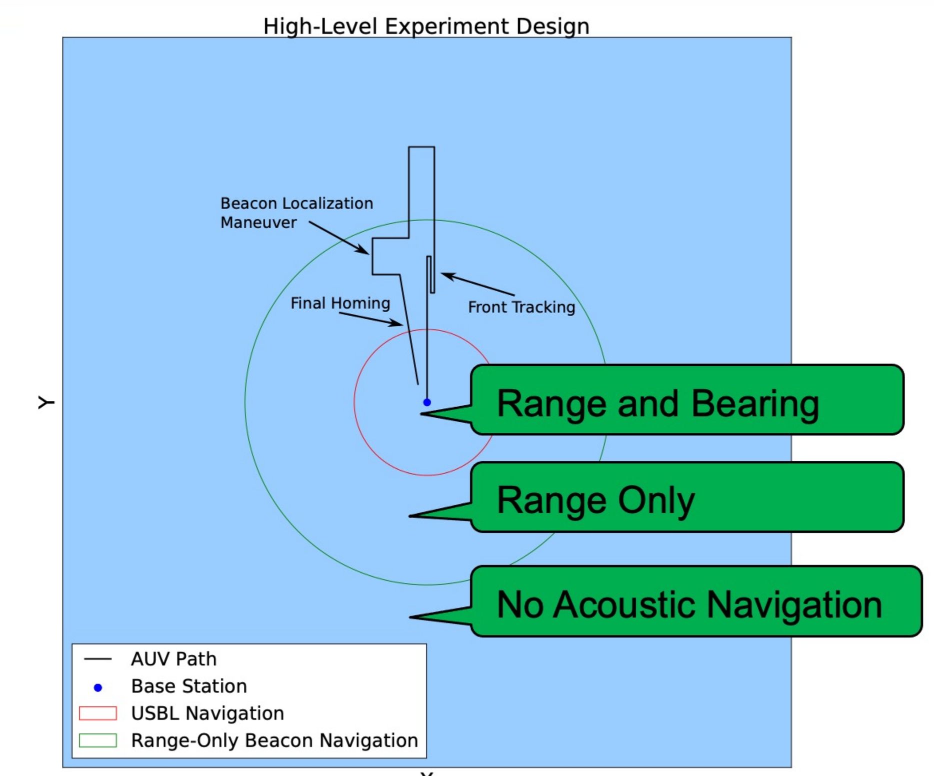

Figure 1: Three navigation paradigms expected for an Ocean World's submersible mission.

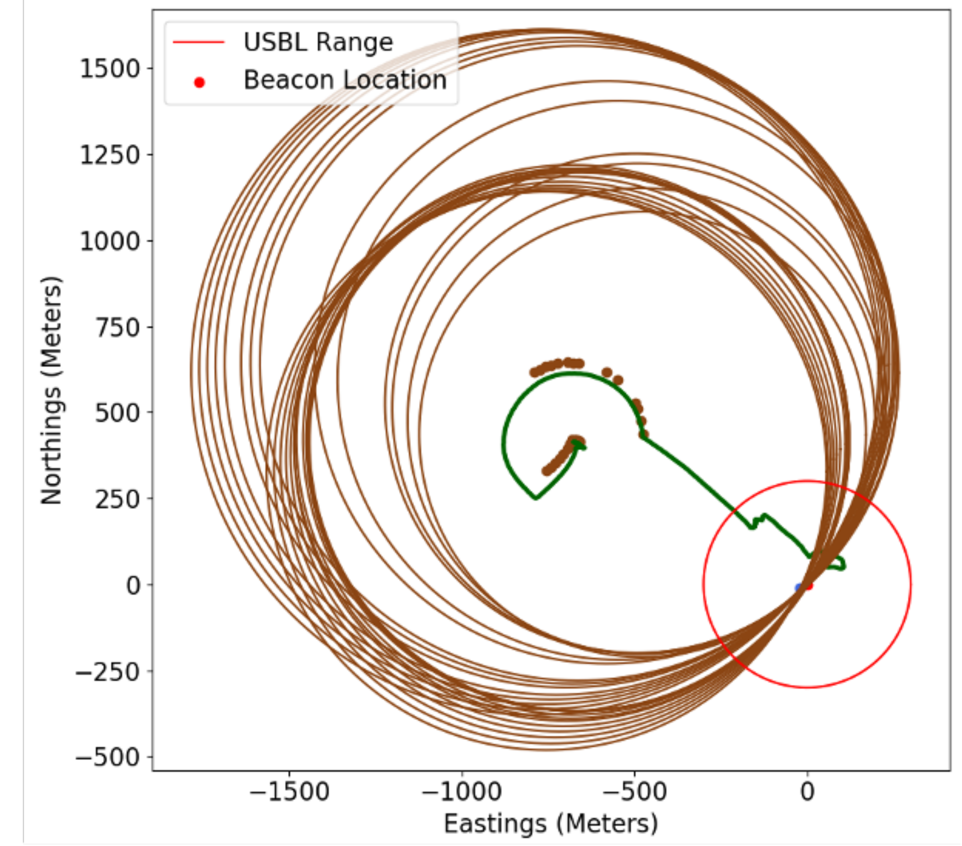

Figure 2: Example on non-linear filtering method for the localization of a beacon. Range rings are shown in brown, all converging at the beacon location.

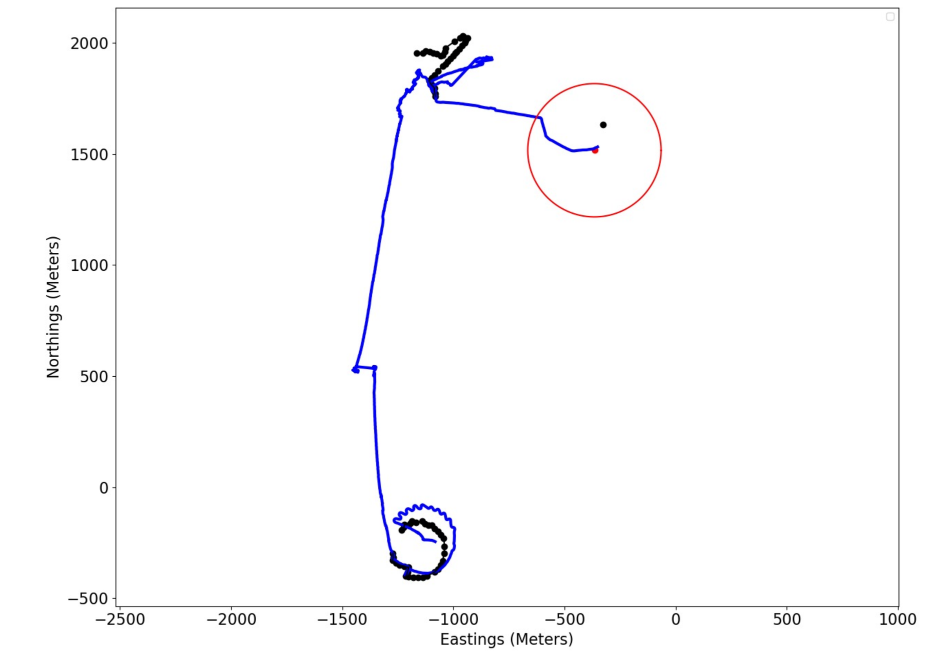

Figure 3: Beacon homing example run from the May 2021 field experiment. In this run heading data was not used in estimating the beacon location, with the vehicle still successfully homing towards to the beacon.

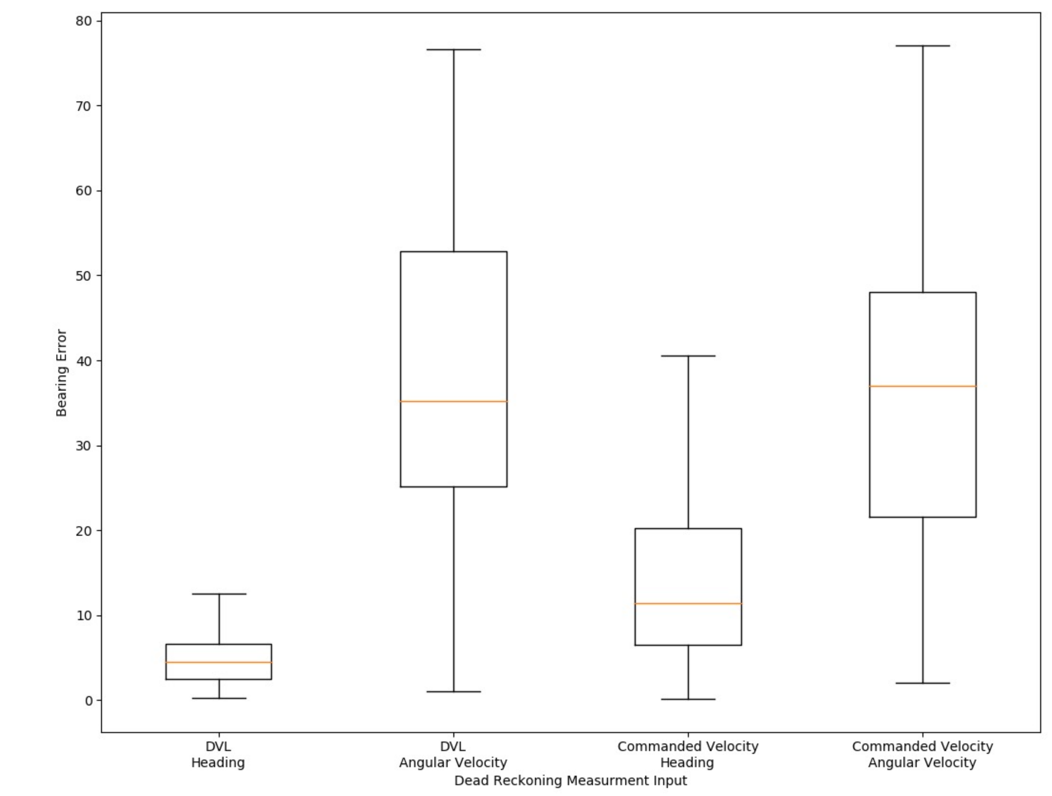

Figure 4: Summary of the error in bearing between the true beacon position and the estimated beacon position from non-linear filtering. Each column represents a different combination of inputs into the dead reckoning system used when performing non-linear filtering.

Significance/Benefits to JPL and NASA

Autonomous operations are crucial on the path to enable direct study of the subsurface oceans on Ocean Worlds. The abilities being developed here support **JPL Quest 4**: "Had there ever been life in our solar system and is it there today?". Enabling under-ice exploration on Earth also supports **JPL Quest 1**: "What changes are happening on our own planet?". These initial collaborations with other oceanographic institutions provide pathways for more involved deployments to test these autonomous systems in under-ice locations on Earth as an analog for sub-ice oceans on Ocean Worlds.

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Publications

Branch, A.; Mason, J.; Chien, S.; Hobson, B.; Raanan, B. Y.; McMahon, J.; German, C. R.; Xu, G.; and Jakuba, M. V. **Onboard Autonomy Requirements for an Ocean Worlds Submersible Mission.** In *Flight Software Workshop (FSW 2021)*, February 2021.

Branch, A.; McMahon, J.; Xu, G.; Jakuba, M. V.; German, C. R.; Chien, S.; Kinsey, J. C.; Bowen, A. D.; Hand, K. P.; and Seewald, J. S. **Demonstration of Autonomous Nested Search for Local Maxima Using an Unmanned Underwater Vehicle.** In *International Conference on Robotics and Automation (ICRA 2020)*, June 2020.

Branch, A.; Mason, J.; and Chien, S. **Golden Selection Search for Single Beacon Homing.** In *Workshop on Planning and Robotics, International Conference on Automated Planning and Scheduling (ICAPS PlanRob 2020)*, October 2020.

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