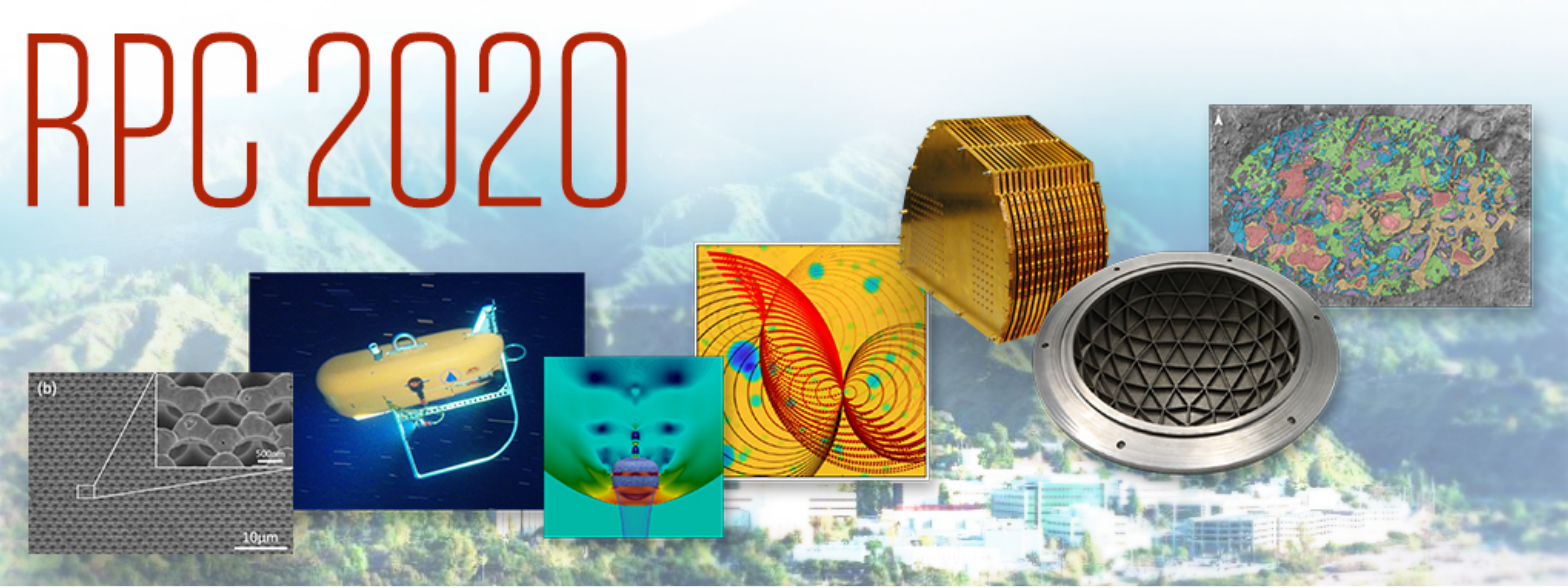

Virtual Research Presentation Conference

Autonomous Operations for An Ocean Worlds Submersible

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Program: Topic

RPC-164

Jet Propulsion Laboratory
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Tutorial Introduction

Abstract

Icy-world oceans such as those on Europa and Enceladus present some of the most promising habitats for discovering exolife in our solar system. Unfortunately, even after transit through the icy shell to access the ocean world, an exploration vehicle would need to operate largely independently from Earth-based ground operations teams. With terrestrial like endurances and speeds, to explore a significant portion of the ocean, the submersible would require excursions involving weeks to months away from communications with Earth in an unknown and dynamic environment. In this project our objective is to develop and validate autonomous operations behaviors for an Ocean Worlds submersible vehicle. These behaviors will enable the study of scientific features of interest and enable navigation to map and hunt for life and habitats from a single base station. Specifically, we were interested in enabling a vehicle to navigate based on a single range-only acoustic beacon and perform autonomous targeting of underwater fronts and hydrothermal venting.

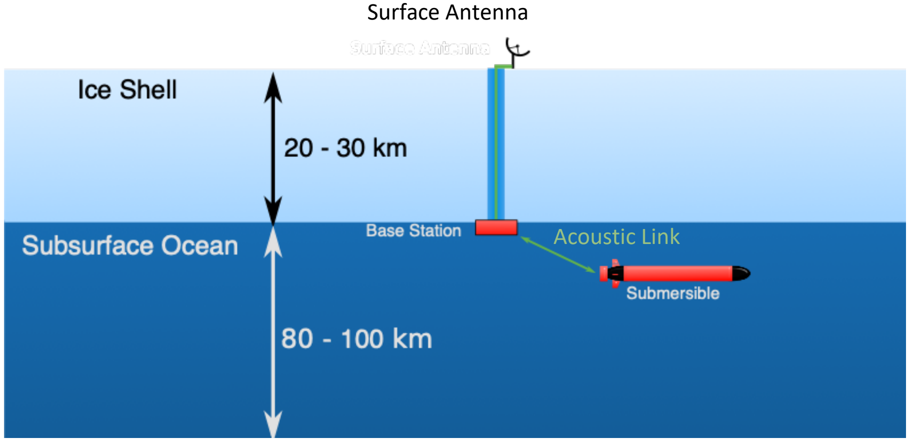


Diagram of notional Ocean Worlds submersible. Three main components are shown, the submersible itself, the under-ice base station, and the surface antenna.

Problem Description

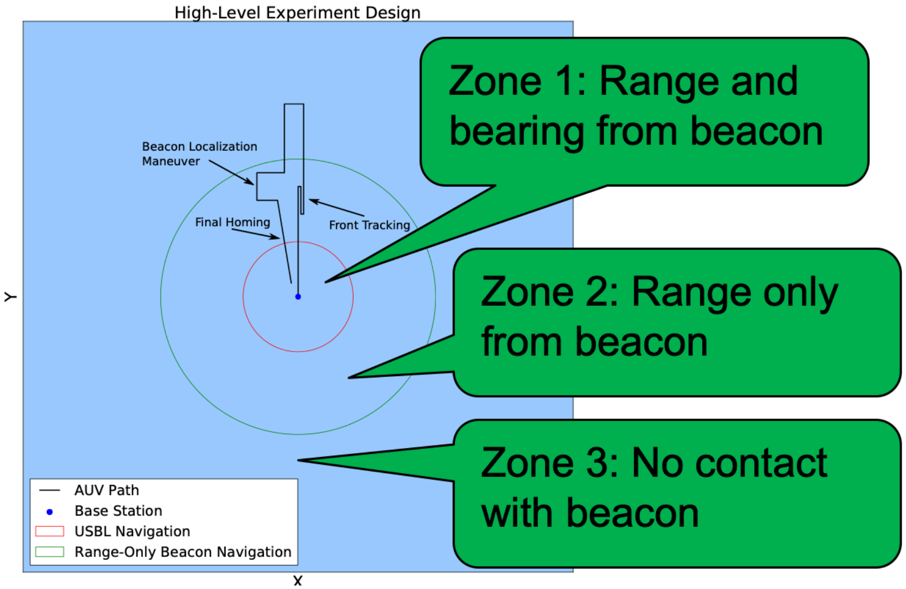
- Ocean Worlds present some of the most promising habitats for discovering exolife in our solar system.
- Autonomous behaviors will be key in maximizing the science return of an Ocean Worlds submersible mission
- Objectives
  - Develop autonomous behaviors to transition between navigation paradigms and techniques for navigation with a single range-only acoustic beacon
  - Develop autonomous behaviors to discover and pursue scientific features of interest while maintaining the ability to return to base station for communication back to Earth.
- Ocean World Constraints
  - Limited communication with Earth due to occlusions by orbital bodies and limited range of acoustics.
  - Single borehole through ice shell due to energy/cost constraints.
  - Potential for limited magnetic navigation due to strong magnetic field at Jupiter and induced magnetic field of Europa.

SOA Comparison, Benefits

- State of the Art
  - Current approaches to AUV autonomy generally use fixed transect with humans in the loop to identify and target scientific features of interest.
  - Few methods have enabled an AUV to autonomously identify and track various oceanographic features
    - Upwelling Fronts [2,3,4]
    - Hydrothermal Venting Plumes (in simulation and post-processing) [5,6]
  - Underwater acoustic navigation traditionally uses multiple acoustic beacons paired with multi-lateration [1] and Ultra Short Baseline (USBL) arrays. Cost and acoustic range limitations prevent the sole use of these methods.
  - Limited study of navigation with single range-only beacon [7], however not under Ocean World constraints
- Relevance to NASA and JPL
  - These technologies enable an Ocean Worlds submersible mission and further under-ice exploration on Earth by allowing the pursuit of unscripted science features.
  - Collaborations performed through this work 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.

Methodology

- Developed notional, high-level conops to establish key autonomous capabilities related to our focus
  - Submersible starts next to the base station
  - Travels away from the base station, autonomously targeting science features
  - Returns to base station to transmit data to Earth
  - Repeat
- Identified 3 major navigation paradigms
  - “Zone 1”, range and bearing to the beacon via USBL
  - ”Zone 2”, range only from beacon via traditional acoustic beacon
  - “Zone 3”, no contact with the beacon, expect navigation to diverge.
- The autonomous behaviors must be able to transition between these navigation paradigms and perform autonomous science



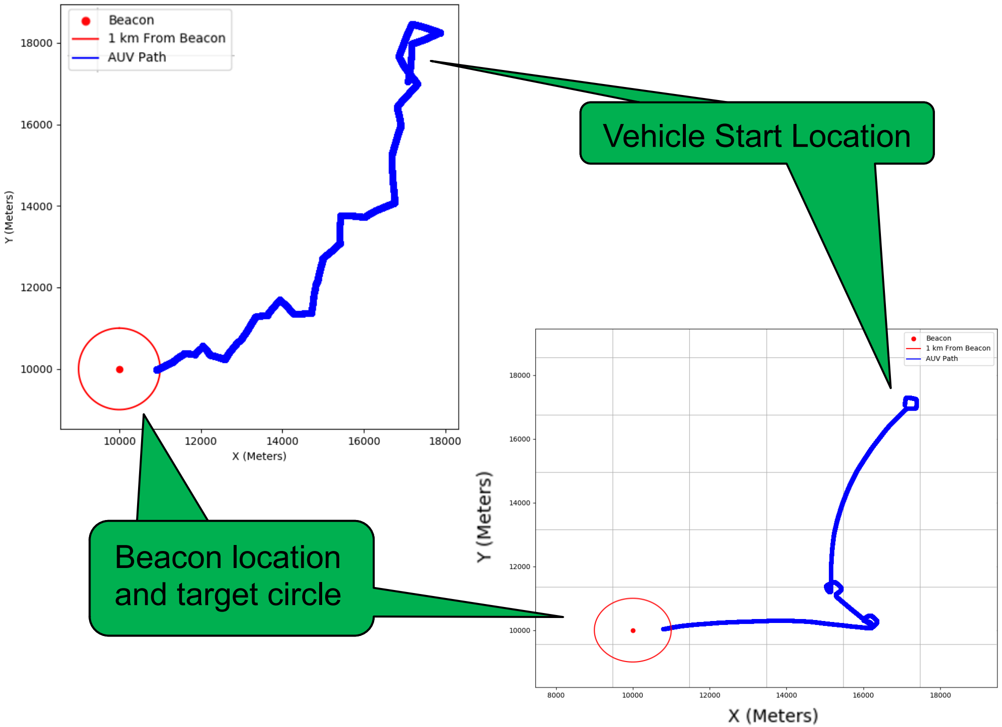
Notional high level conops for Ocean Worlds submersible

FY20 Milestone Progress

Milestone	Status/Progress
FY19 ICRA Publication [B] (Q2)	Completed
Develop and do in simulation navigation algorithm testing (Q3)	Completed
ICAPS publication of navigation algorithm testing [A] (Q3)	Submitted, Conference in October 2020
Prepare for Deployment with Monterey Bay Aquarium Research Institute (Q2)	In Progress. Working with MBARI to integrate with the Tethys LRAUV.
FY20 deployment to test navigation algorithms (Q2)	Planned for October 2020. Delayed due to COVID-19
FY20 Journal Publication (Q4)	Planned

Results

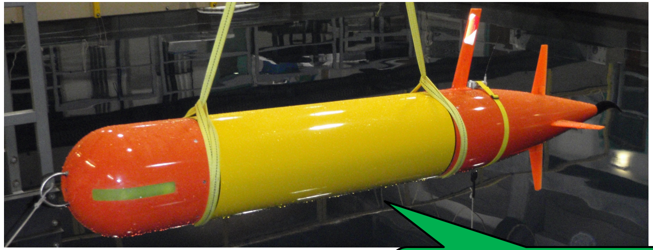
- Developed two methods for vehicle homing to a single range-only acoustic beacon without high powered navigation instruments (i.e. Doppler Velocity Log or other bottom following capabilities) or absolute heading information
- Tested algorithm in simulation using realistic currents and error characteristics of simulated sensors
- The simulated vehicle was able to home from 10km to within 1km of the beacon
- Results show that the vehicle is able to do this reliably and within a reasonable time frame



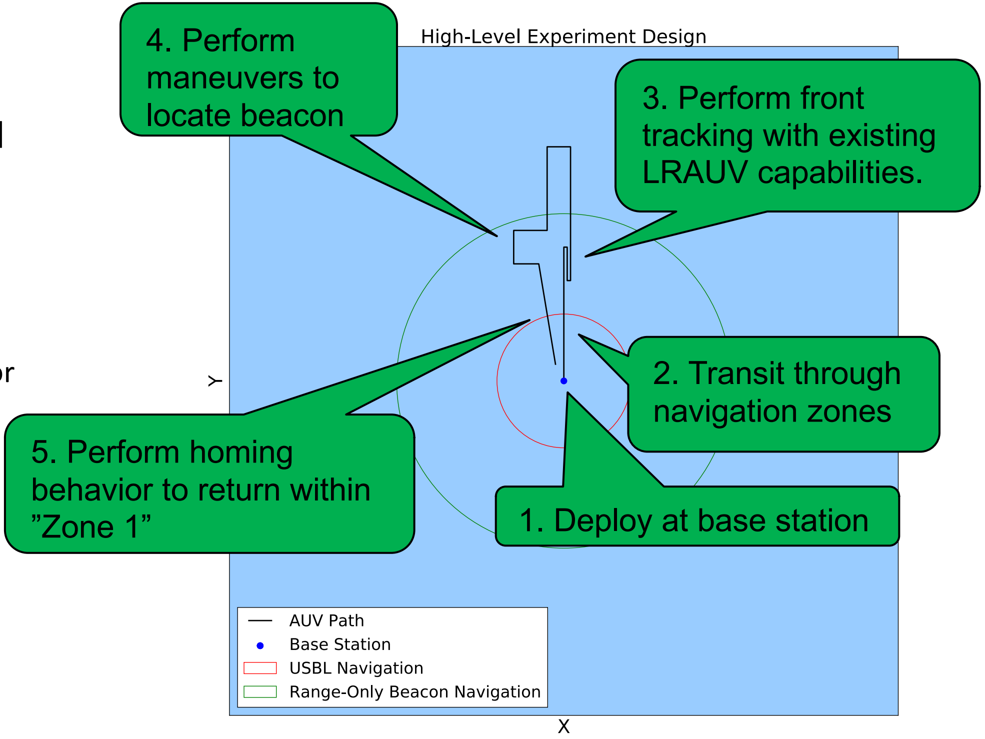
Examples of the two single range-only acoustic beacon navigation/homing algorithms

Next Steps

- Deploy the autonomous capabilities developed here on a Long-Range AUV with the Monterey Bay Aquarium Research Institute in October 2020.
- Potential Follow-On Work
  - Deploy these autonomous behaviors under sea-ice or an ice-shelf.



Tethys-Class Long Range AUV



MBARI Experiment Overview

Publications and References

Publications

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