Jet Propulsion Laboratory
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Golden Selection Search for Single Beacon Homing

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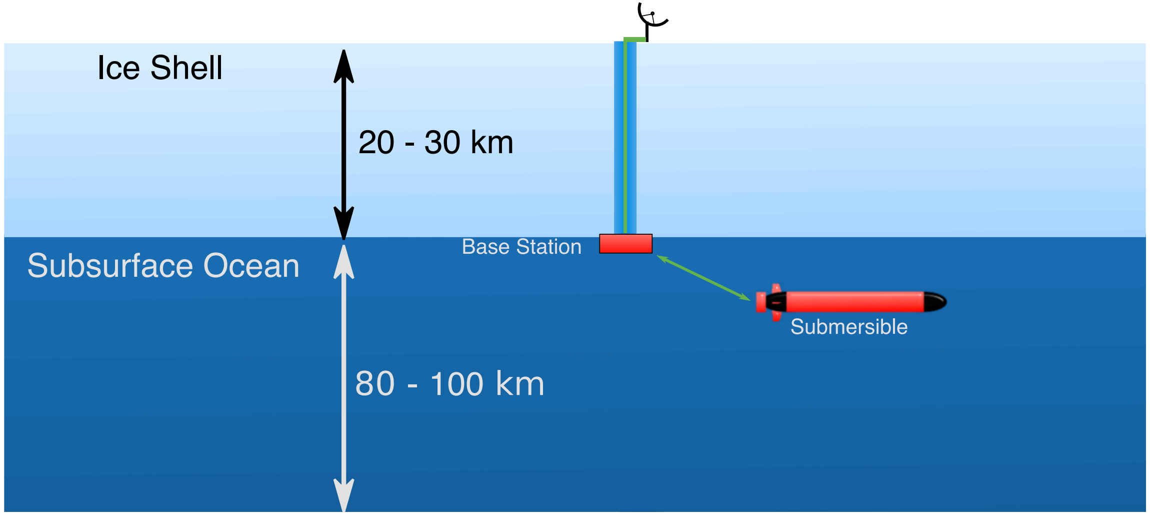
Ocean Worlds AUV Concept Mission

- Long duration mission
  - 1+ years to penetrate ice plus 1 year mission underwater
  - Travel 100's of km from base station
- 3 main components: Surface antenna, under-ice base station, submersible
- Limited communication with Earth due to orbital occlusions and acoustic communication range
- Due to communication constraints, full autonomy is needed for weeks or months at a time.
- Navigation required to return to base station for communication



Navigation Instruments

- Conductivity, Temperate, Depth (CTD)
  - Measures depth via pressure
- Internal Measurement Unit (IMU)
  - Acceleration, rotational velocity
- Magnetic Compass
- Doppler Velocity Log (DVL)
  - Velocity relative to water, surface ice, or seafloor
  - Large power consumption due to active sensor
- Acoustic Beacons
  - Ultra-short baseline (USBL)
    - Single package with multiple receivers determines range and bearing of beacon relative to receivers based on time of arrival phase shift of sound wave
  - Transmitter(s) with single receiver on AUV
    - Time of arrival to calculate range

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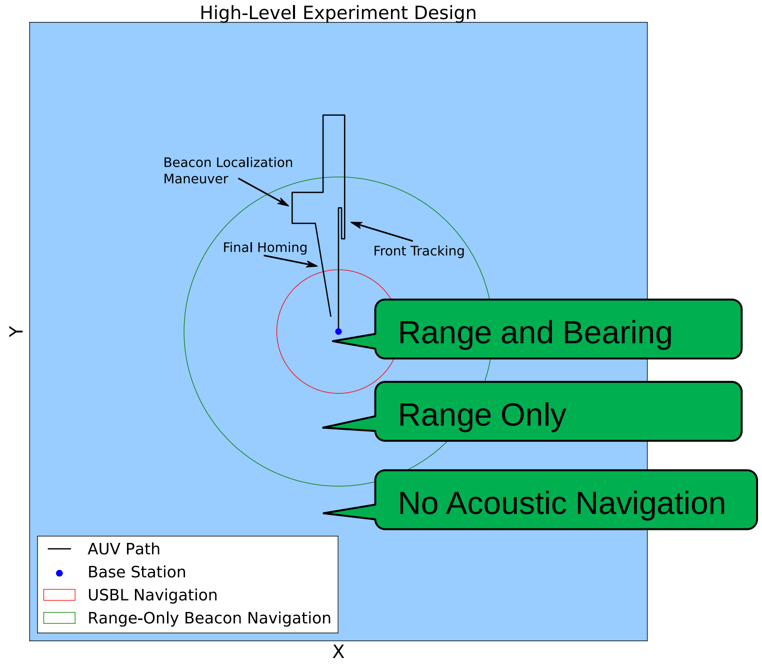
Navigation Paradigms

- Less than 10 km: Range and Bearing from single acoustic beacon
  - Inverted Ultra-short baseline (iUSBL)
    - Beacon on base station, receiver on AUV
  - Range and bearing of base station via iUSBL
- ~10 km to ~100 km: Range only from single acoustic beacon
  - Range from base station via acoustic beacon. Need to determine bearing to base station via other means
- Greater than ~100 km: No contact with single acoustic beacon
  - Navigate solely based on vehicle dead-reckoning
  - Only feasible for short durations while still being able to return to acoustic range



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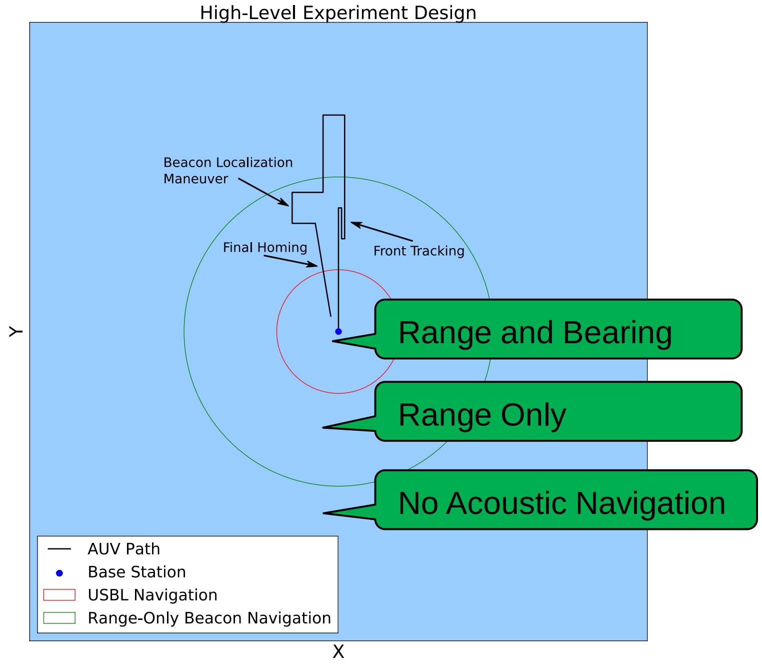
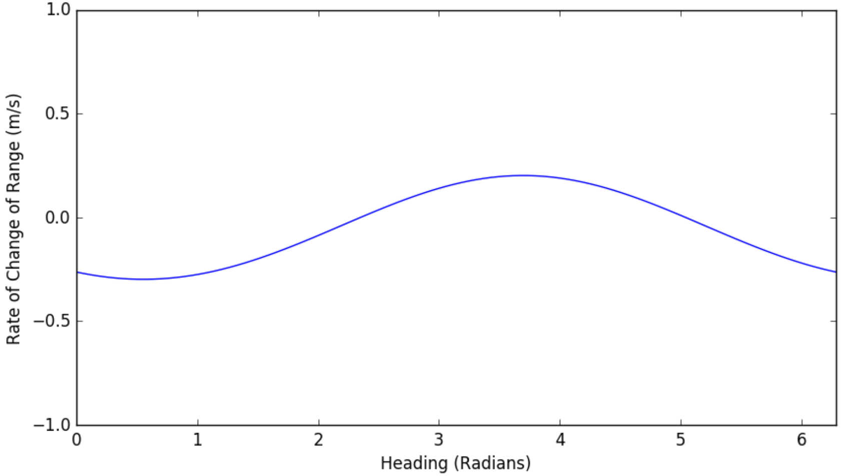


Single Beacon Range-only Homing

- Orient AUV to the heading resulting in the minimum rate of change of range
- Heading vs. Rate of change of range is sinusoidal for fixed parameters
- Function changes over time based on vehicle location and currents
- A modified golden-selection search algorithm can locate the heading corresponding to the minimum rate of change of range

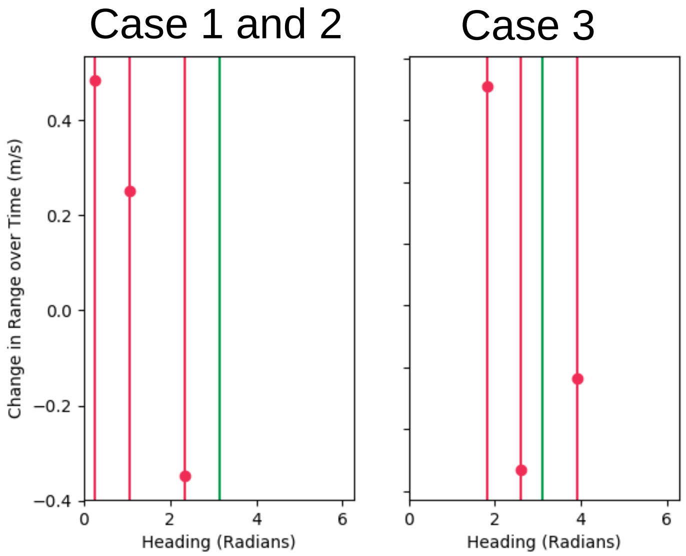


Rate of change of range over headings for a given vehicle location, beacon location, vehicle velocity, and constant currents

Kiefer, J. (1953). Sequential minimax search for a maximum. *Proceedings of the American mathematical society*, *4*(3), 502-506.

Golden Selection Search Algorithm

- Travel along three relative headings measuring delta range
  - When a range is received calculate delta range as the slope of the least squares fit of range measurements
  - Continue on heading until variance of the last N delta range calculations is below some threshold
- Based on three data points determine one of three cases
  - Case 1: Min of data points is the largest heading. Move interval to larger headings.
  - Case 2: Mirror of Case 1
  - Case 3: Min of data points is the middle heading. Perform additional measurements in current interval.
- Next heading location is selected to maintain the golden ratio spacing



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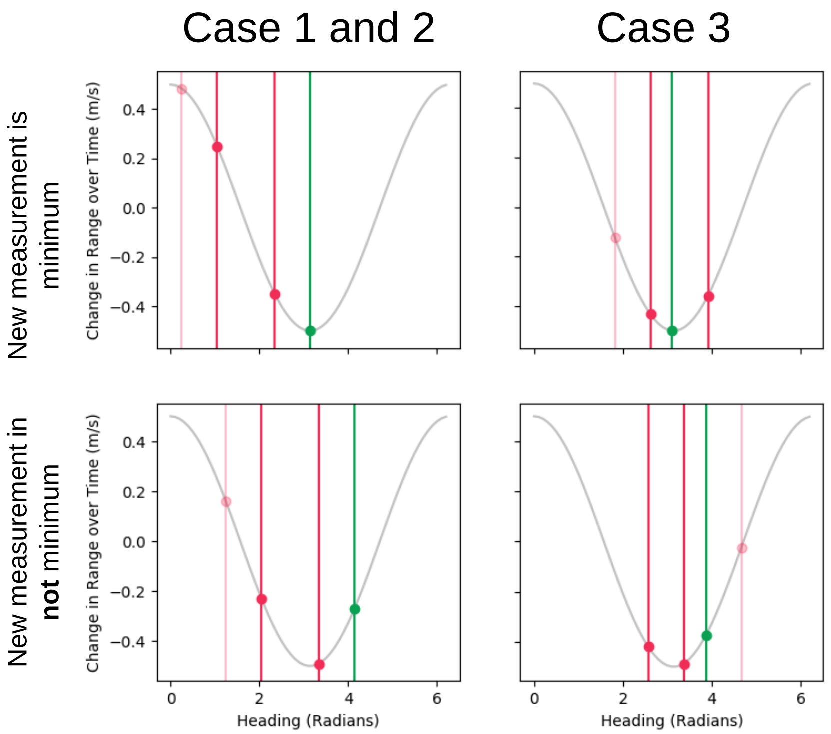
Golden Selection Search Algorithm

- Select minimum measurement and two closest neighbors as next search interval
  - The golden ratio spacing guarantees that the next search interval will be a fixed size, independent of the new measurement
  - Otherwise, repeatedly selecting the "wider" interval could slow convergence
- Iterate
- Finish when interval size reaches some threshold
- Travel along heading until delta range drops below a percentage of the originally measured value
- Restart Golden Selection Search



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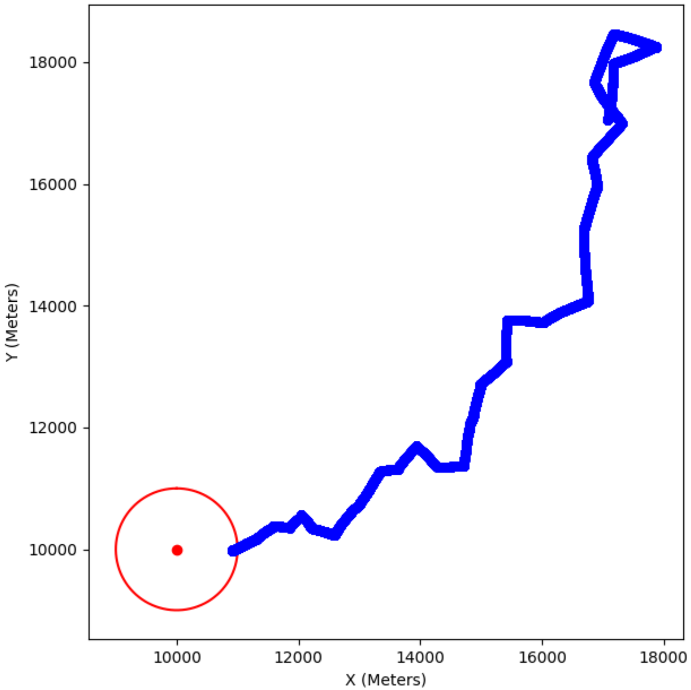
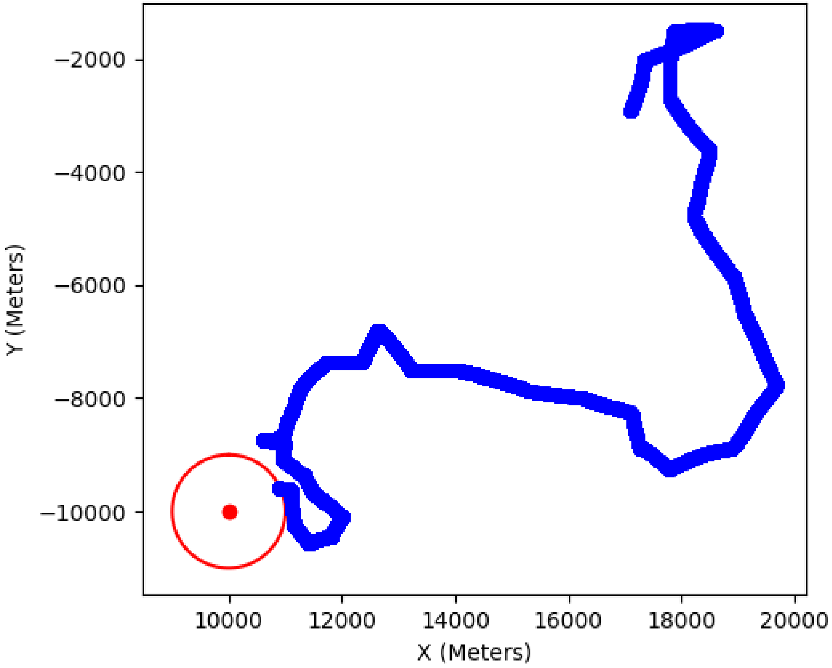
Experiment Setup

- ROS simulation with ocean currents from a realistic ocean model
- Vehicle is using simple dead reckoning navigation without a compass
- 3 different base station locations with 8 starting locations per base station
- Starting locations were 10 km from base station at 45 degree intervals
- Initial headings are always 0 degrees
- Success when vehicle is within 1km of base station
- Fail after 48 hours
    - The vehicle can travel approximately 86.4 km in this time
- Varied individual error parameters for rotational velocity and range.
    - Bias and Standard Deviation

Results

Example Runs

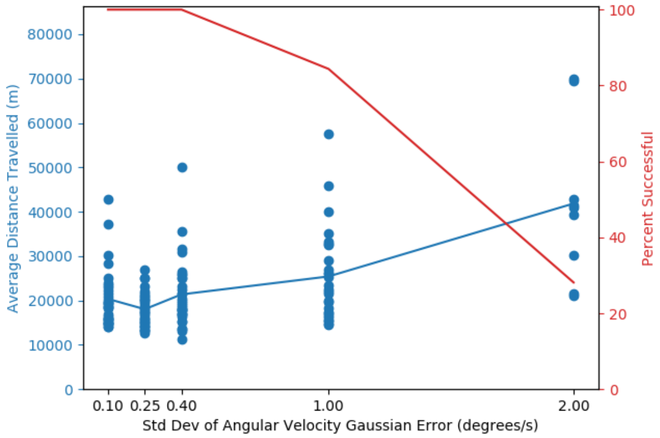


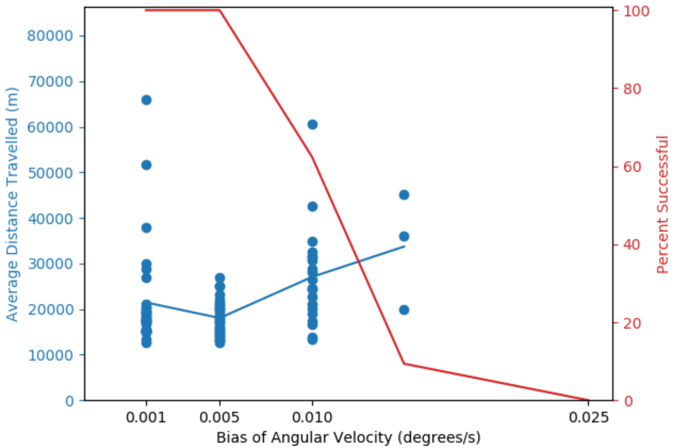


Results

Varying Error in Angular Velocity

- The fixed error parameters are as follows
  - range standard deviation = 5%
  - range bias = 5%
  - angular velocity standard deviation = 0.25 degrees/s
  - angular velocity bias = 0.005 degrees/s





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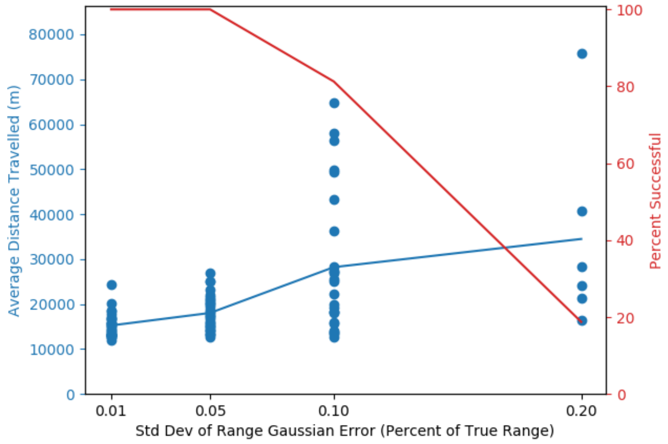

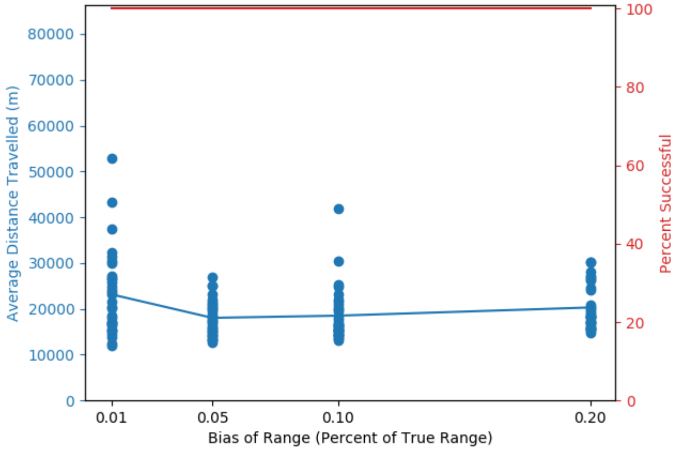

Discussion

- Expected degrading of homing performance as errors increase
  - Fixed range bias does not degrade performance as we are only concerned with delta range

- Performance of algorithm depends on inter-related parameters
  - Dead reckoning performance
  - Frequency and quality of range measurements

- Specific testing is necessary for individual vehicles/use cases

Related Work

- Baccou, P., and Jouvencel, B. 2003. Simulation results, post-processing experimentations and comparisons results for navigation, homing and multiple vehicles operations with anew positioning method using on transponder. InProceedings 2003 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS 2003)(Cat. No. 03CH37453),volume 1, 811–817. IEEE.
- Webster, S. E., Freitag, L. E., Lee, C. M., & Gobat, J. I. (2015, May). Towards real-time under-ice acoustic navigation at mesoscale ranges. In Robotics and Automation (ICRA), 2015 IEEE International Conference on (pp. 537-544). IEEE. doi:10.1109/ICRA.2015.7139231
- Webster, S. E.; Eustice, R. M.; Singh, H.; and Whitcomb,L. L. 2012. Advances in single-beacon one-way-travel-time acoustic navigation for underwater vehicles. The International Journal of Robotics Research 31(8):935–950.
- Kiefer, J. (1953). Sequential minimax search for a maximum. *Proceedings of the American mathematical society*, *4*(3), 502-506.
- LaPointe, C. E.2006.Virtual long baseline (vlbl) autonomous underwater vehicle navigation using a single transponder. Technical report, Massachusetts Inst of Tech Cambridge.
- Scherbatyuk, A. P.1995.The auv positioning using ranges from one transponder lbl. In ‘Challenges of Our Changing Global Environment’. Conference Proceedings. OCEANS’95 MTS/IEEE, volume 3, 1620–1623. IEEE.

Future Work

- Use synthetic multilateration to determine the relative location of the base station as a pre-cursor step to Golden Selection Search

- Develop algorithm for navigation and return when completely out of acoustic beacon range

- Combine with autonomous science algorithms such as ocean front tracking

- In water testing with the Monterey Bay Aquarium Research Institute.
    - Planned for October/November 2020.

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