Approximating the location of underwater sound sources by analyzing acoustic signals

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Motivation & Background

Current methods of surveying the ocean floor are usually *expensive,* since they commonly involve building complex vehicles that are robust to high pressure on the ocean floor. We are interested in developing a *cheap* ocean surveying method by ***utilizing noise already present in the ocean*** to determine the approximate location of marine life, such as snapping shrimp, remotely with sensors placed meters below the ocean surface.

Problem

Our goal is to determine the location of a snapping shrimp, located on the ocean floor, by using ***time differences between signal arrivals*** of a snap from the same shrimp recorded by multiple Autonomous Underwater Vehicles (AUV).

Data Collection

- 20 small-sized AUVs with hydrophones were deployed into the water as a swarm along with buoys that emit pings.
- The hydrophones attached on AUVs picked up the pings from the buoys along with other ocean noises, including snapping *shrimp snaps*.
- Since GPS is not available underwater, AUVs localize themselves via the measurement of time differences that pings were received.

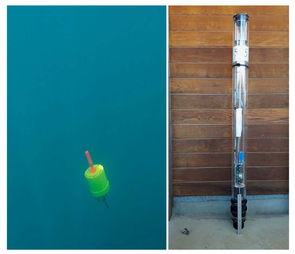


Fig 1.
Left: An AUV in the ocean.
Right: Pinger of buoy with a built-in GPS. [1]

Solution

Step 1 Data Filtering and Snap Classification

- Extract loud sound signals through amplitude threshold filtering.
- Filter out the snaps based on their special range of frequencies.
- Record the arrival time of snaps.

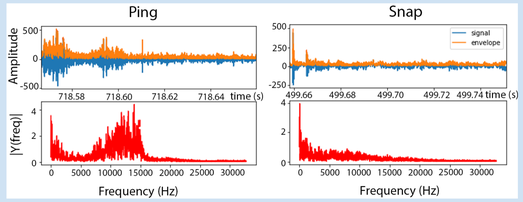


Fig 2. Plots of the amplitudes (top) and frequencies (bottom) of a ping and a snap. The ping has a longer duration and its frequency and amplitude has more tumultuous peaks comparing to that of the snap.

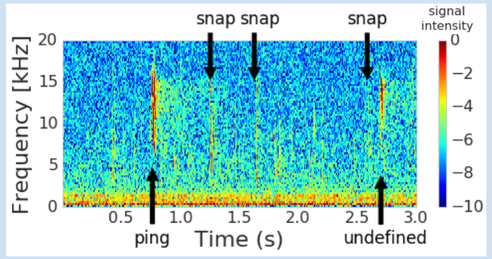


Fig 3. Spectrogram of a sound file recorded by an AUV. We can determine whether a signal is a snap or a ping by examining the **duration** and **span** of frequency.

Step 2 Cross-AUV Snap Detection

- Use filtering and classification algorithm from step 1 to verify the existence of a snap throughout 4 AUVs whose relative positions are in a quadrilateral formation.

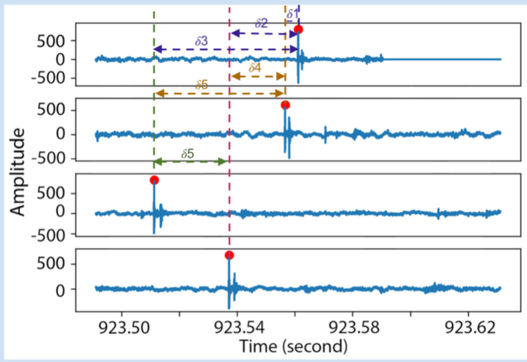


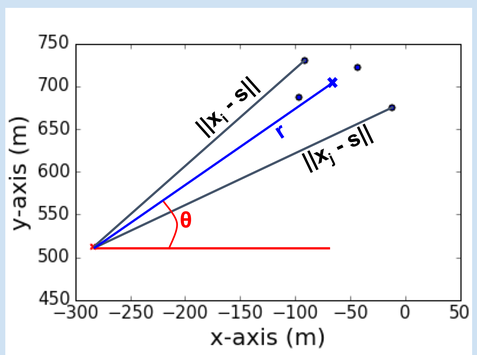
Fig 4. A snap that is consistently picked up by four AUVs that are roughly in a square formation. By having the arrival times of a snap across all four AUVs allows us to estimate the direction the snap is coming from in relation to the four AUVs by using the time differences that the direct arrivals reach each AUV.

Step 3 Direction Estimation

- We derive a system of nonlinear equations to find the direction of the signal through analyzing the time difference of arrivals between four AUVs.

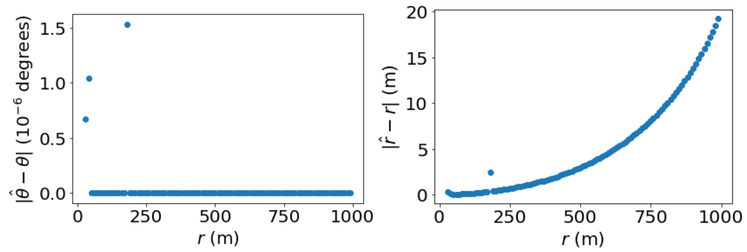
$$loss(s) = -\delta_{i,j} + \|x_i - s\| - \|x_j - s\|$$
$$i, j = 1, ..., 4$$

- We are able to stably retrieve the direction of a signal coming to the AUVs, and approximate the location of the shrimp.

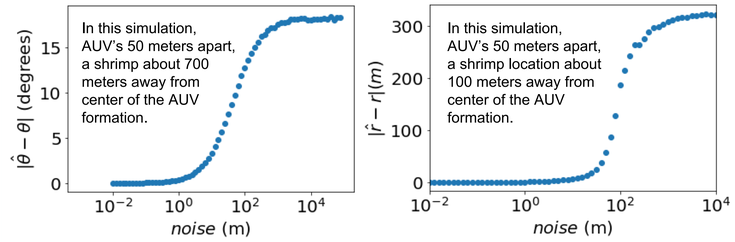


Results

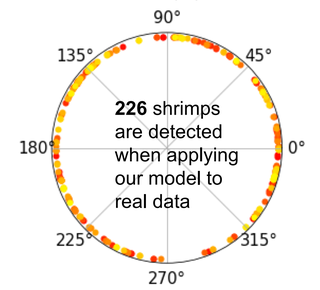
Error in the direction angle(θ) v.s. Error in the radius(r) for signals at different distances from the AUVs



Error in the direction angle(θ) v.s. Error in the radius(r) when noise is added to the arrival times of a signal



In determining the ***direction*** of the shrimp location relative to our frame of reference, the results were numerically stable and accurate. However, when recovering the ***precise shrimp location***, the results were relatively unstable.



Conclusion

The use of time differences between arrivals of the same signal recorded by different AUV's makes it possible to estimate the direction of underwater sound sources. Since the location approximation has poor accuracy, our future work will be concentrated on refining our algorithms by making use of reflected arrivals to make the approximations more precise.

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Literature Cited:
[1] Jaffe, Jules S., et al. "A swarm of autonomous miniature underwater robot drifters for exploring submesoscale ocean dynamics." Nature communications 8 (2017): 14189.