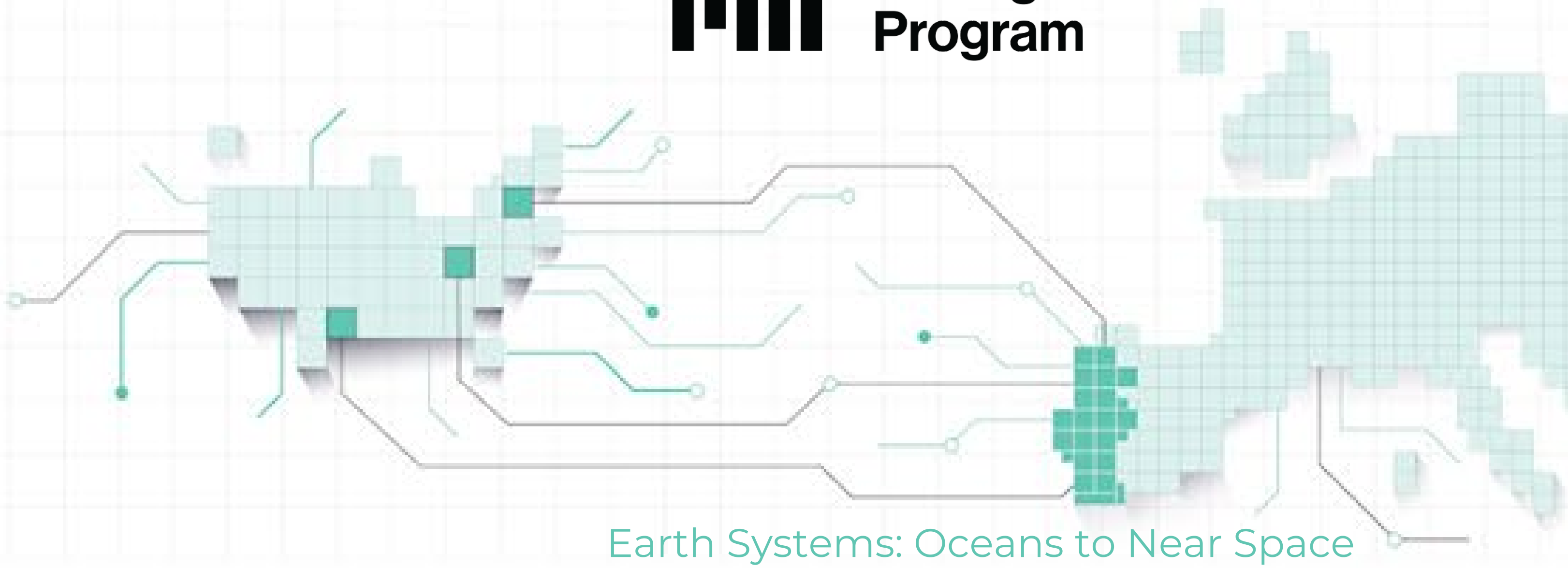


Passive Acoustic Tracking of Small Autonomous Underwater Vehicles with a Large Aperture Linear Array

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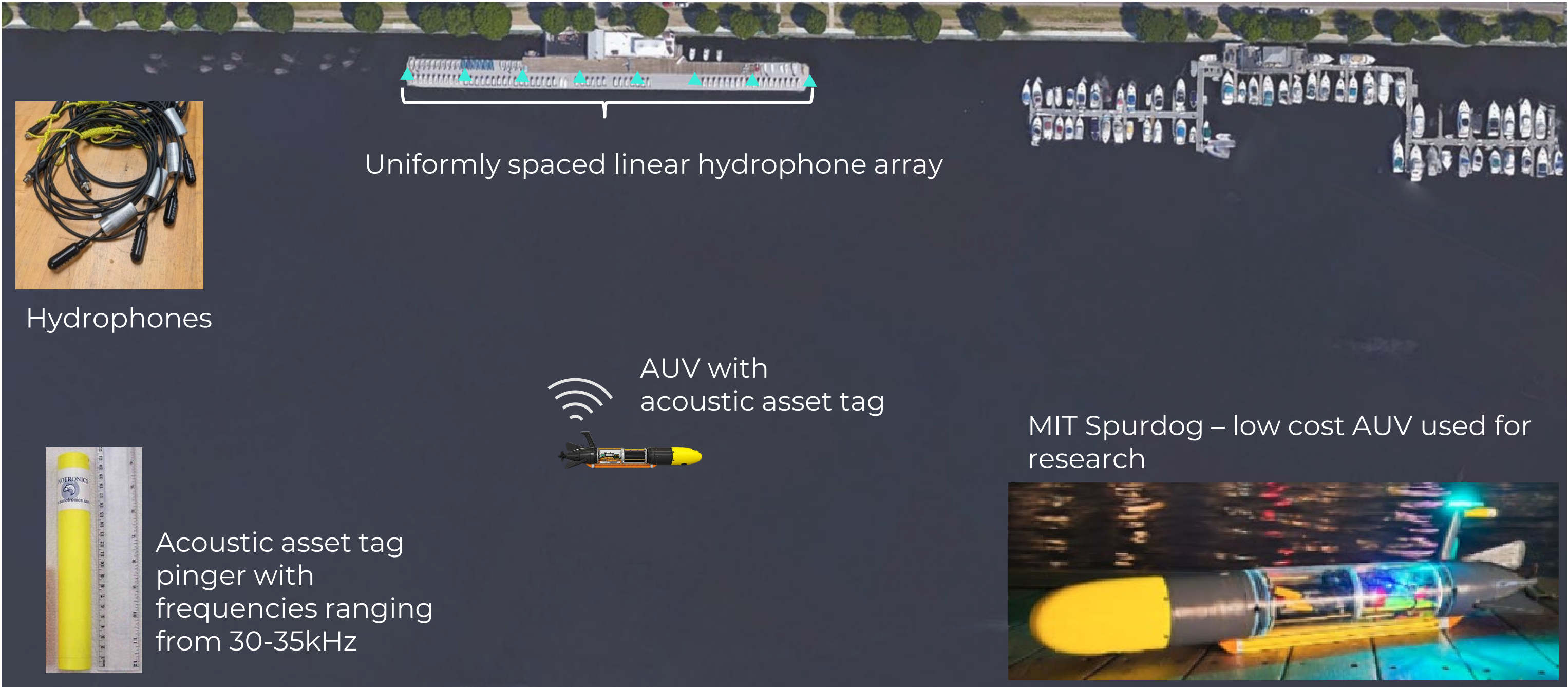
How do you check an underwater robot's navigation without GPS?

Autonomous Underwater Vehicles (AUV) are uniquely suited for underwater environmental research. They can survey and monitor large areas and can achieve spatial and temporal resolution that fixed sensors and ship surveys are incapable of. Improving AUV navigation is critical for these tasks, however AUV navigation research is impossible without ground truth positioning validation.

MIT built an eight-element large aperture sparse array under the MIT sailing pavilion called PAVRANGE for tracking AUVs that are currently used in classroom work and research.

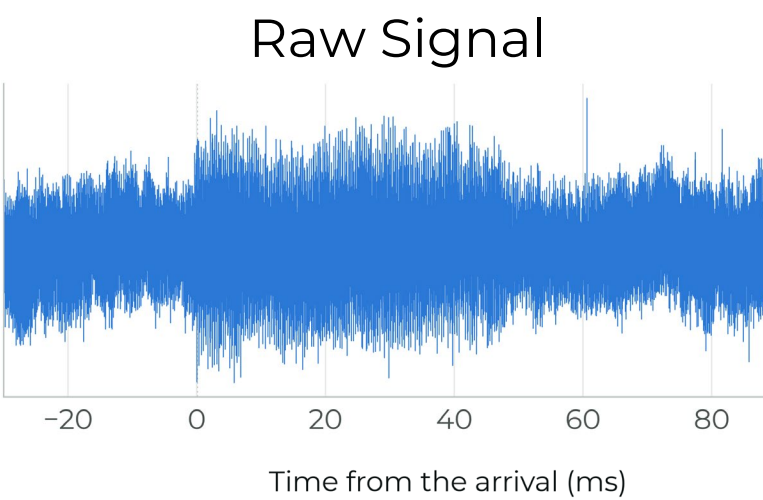
The AUVs are equipped with acoustic asset tag pingers that emit single frequency pings at regular intervals. They are small devices that are easy to temporarily attach to any vehicle.

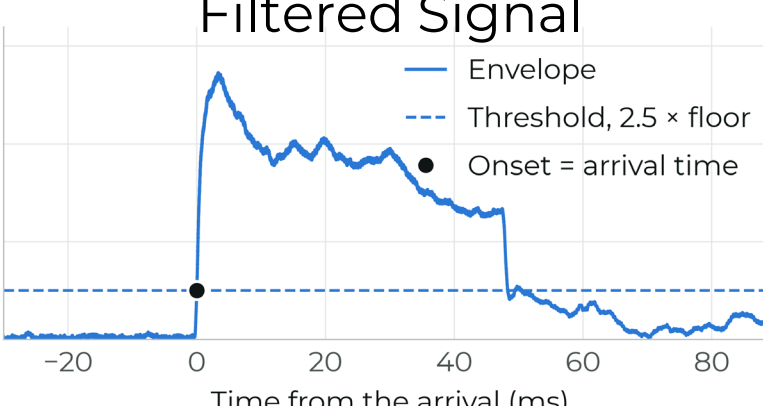
- Goals of this research**
- 1. Be able to track any type of vehicle
 - 2. Robustly track vehicles at large distances from the array
 - 3. Require no prior synchronization or calibration of vehicle equipment



Data Processing Pipeline

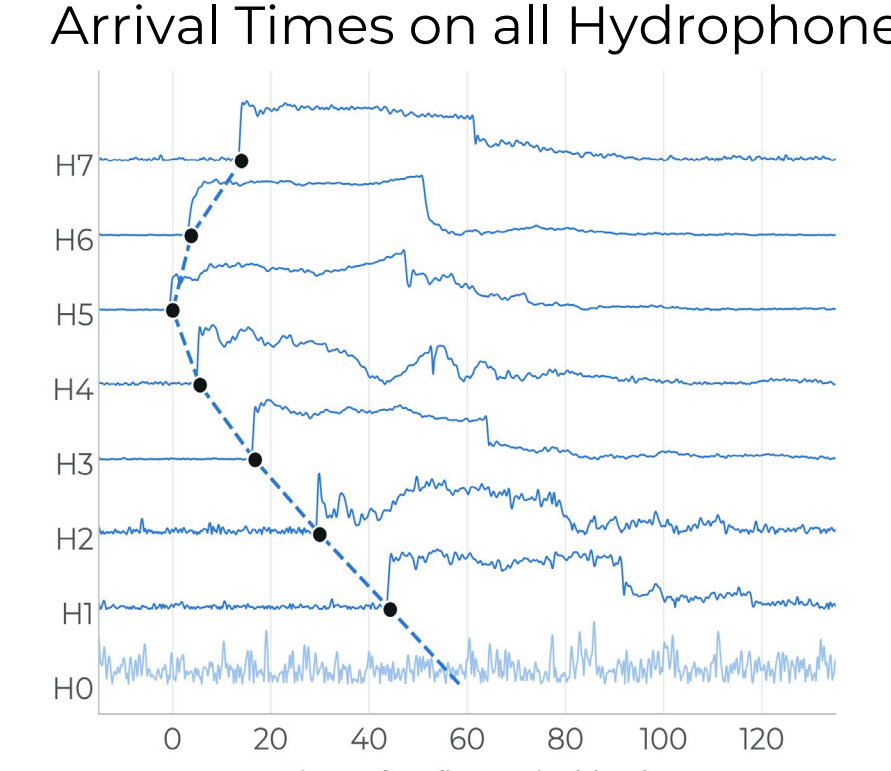
I. Filtering

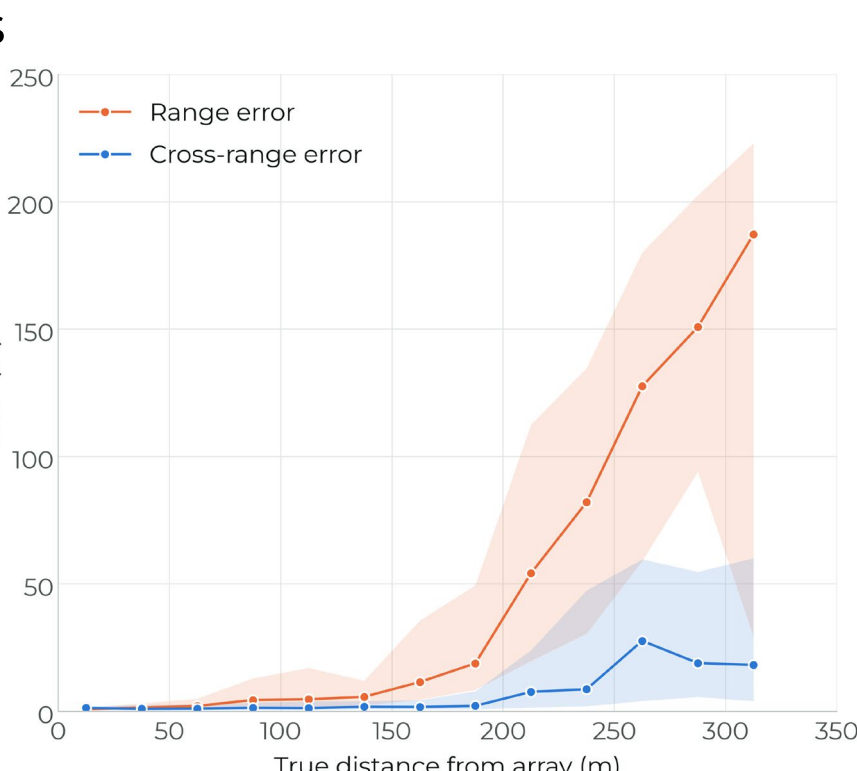

Raw Signal


Filtered Signal

The raw input signals are filtered around the pinger frequency then a quadrature envelope is applied to improve the arrival time estimates.

II. Geometry from arrival pattern

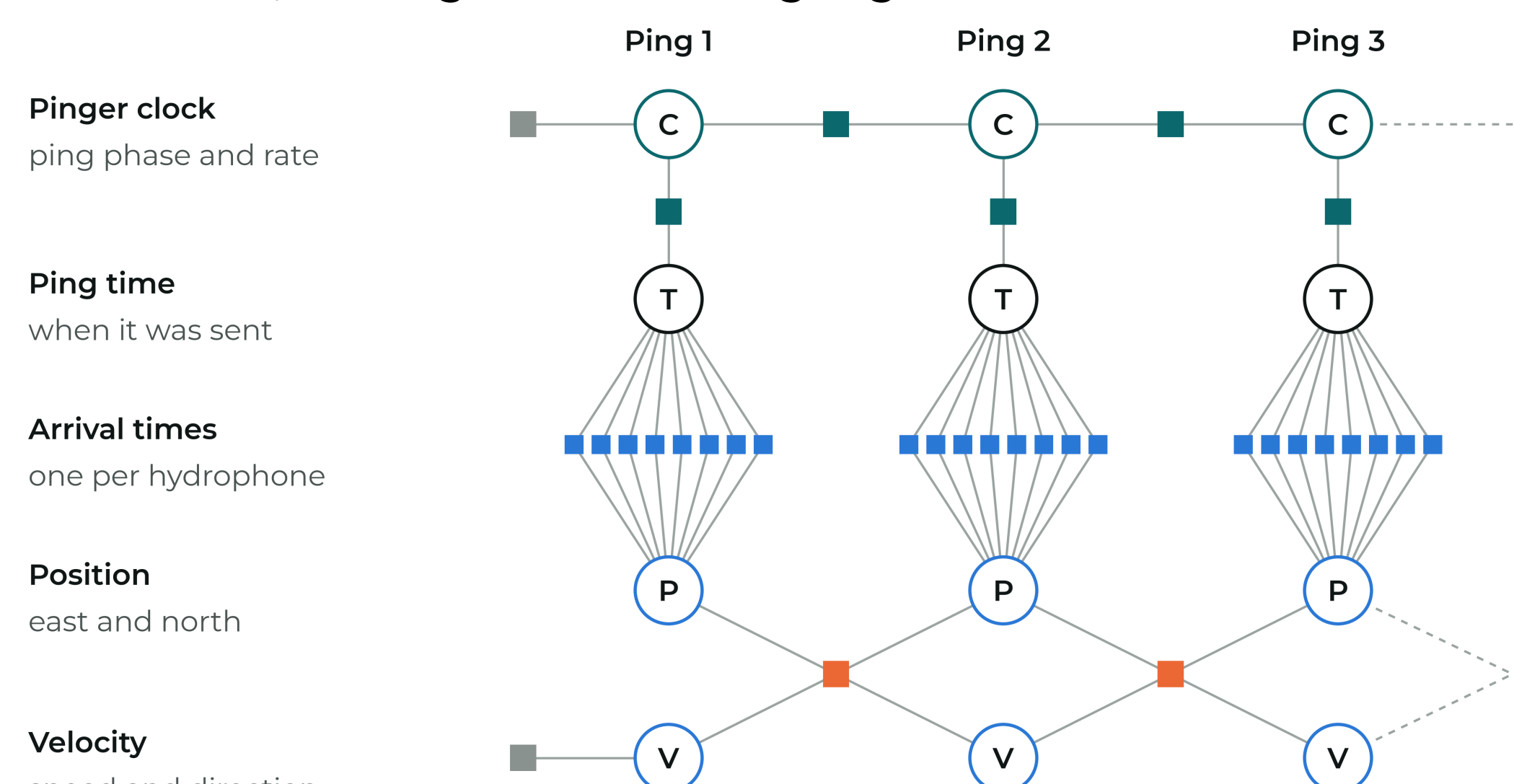

Arrival Times on all Hydrophones


Error (m)

The pattern of arrival times across all eight hydrophones determines the pinger's location. However, because the array is linear, range error grows rapidly as the AUV moves farther from the array. Distance can only be inferred from the slight curvature of the wavefront across the 158 m aperture, and that curvature fades with range, so range error grows roughly with the square of the distance while the cross-array error remains small.

III. Factor graph estimation

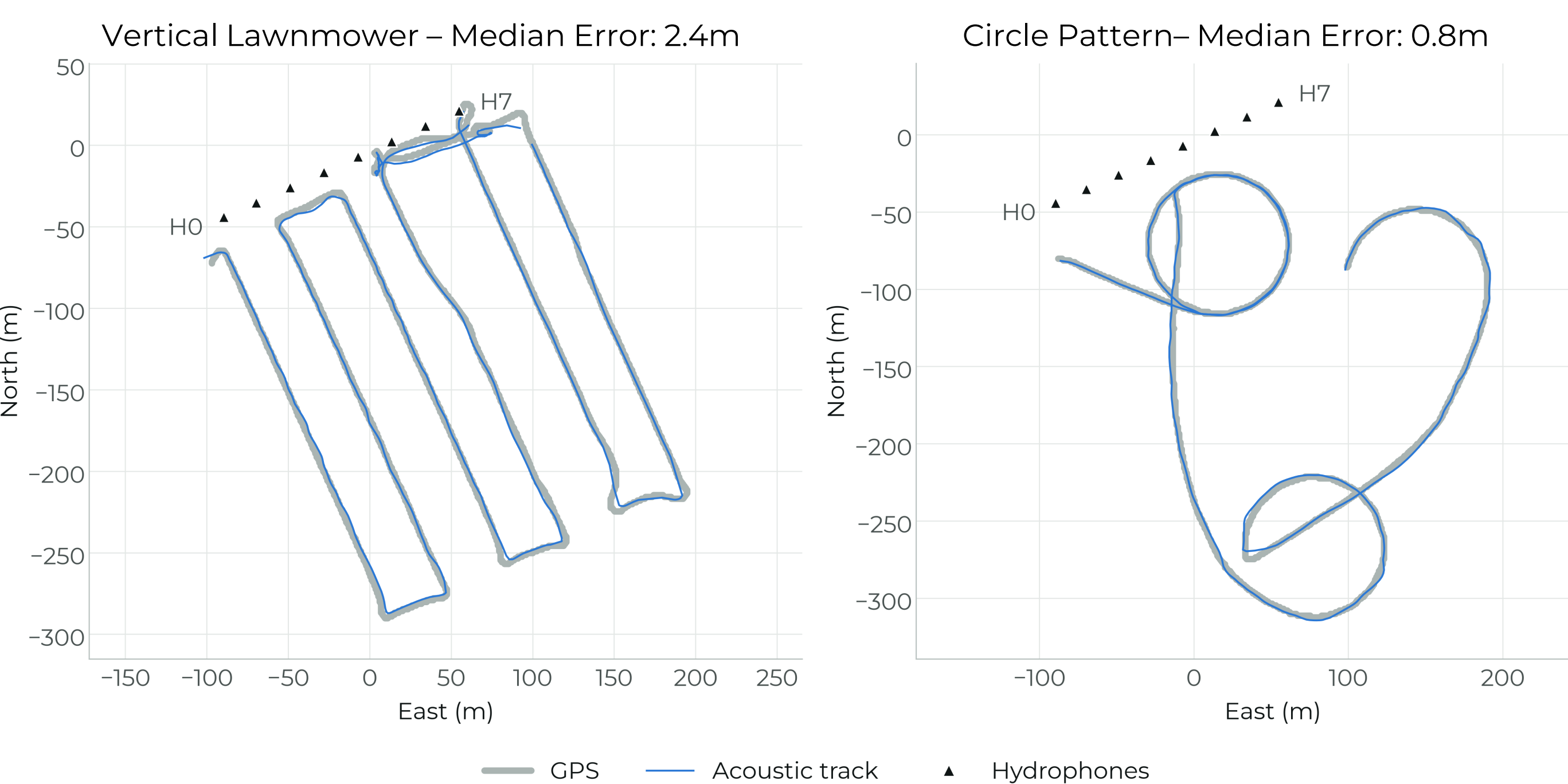
All pings are solved together in one factor graph: circles are unknowns and squares are measurements and constraints. Each arrival time is weighted by its SNR, and consecutive pings are linked by a constant-velocity motion model. Because the pinger repeats steadily, the graph learns its clock from pings near the array and uses it to turn far-field arrivals into direct range measurements, so range error no longer grows with distance.



- Pinger clock**
ping phase and rate
- Ping time**
when it was sent
- Arrival times**
one per hydrophone
- Position**
east and north
- Velocity**
speed and direction

- Steady ping rate, drifting slowly
- Each ping is sent on the clock's beat
- Arrival = ping time + distance / sound speed
- Smooth motion, small random accelerations
- Starting values

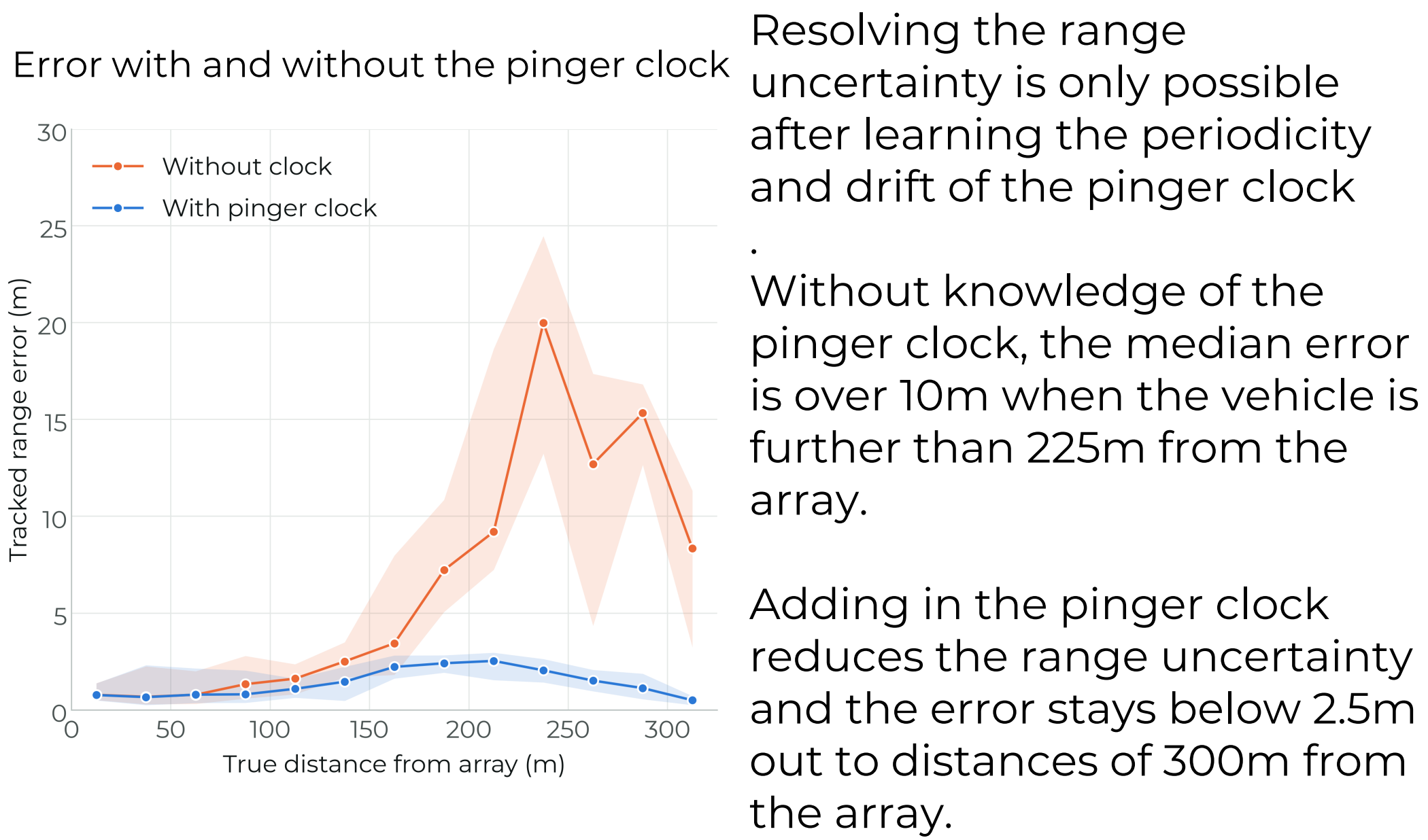
Results



Two experiments were run using a surface vehicle equipped with GPS and an acoustic asset tag. The vertical lawnmower tests the array's range resolution, and the circle pattern tests both the array's bearing and range accuracy. These results show the following:

This system can achieve meter-level tracking to a range of ~300m

The pinger's clock is calibrated while the vehicle is near the array, then keeps range error small far from it, with no prior synchronization.



Impact

- Ground truth without GPS** – This array is able to provide meter level tracking accuracy for underwater vehicles operating in an environment where ground truth GPS validation is impossible.
- Low-cost and minimal infrastructure** – The pingers used for the tracking are low cost, can easily be attached to any vehicle, and no prior synchronization is required.
- Affordable AUV research** – This array allows low-cost vehicles like the MIT Spurdog to be tested and validated without expensive navigation sensors.
- Transferable to other environments** – This same approach could be used in different environments and with different array geometries and can be applied wherever tagged vehicles or instruments need to be tracked.

Conclusion

- Accurate tracking at long range** – Using knowledge about the pinger's period keeps error low at long ranges. The array is able to track vehicles at ranges of ~300m
- Leveraging the pinger periodicity is key** – The pinger's clock drift is small enough that it can be used at large ranges to estimate the range and reduce error.
- No prior synchronization or calibration** – The system can learn the pinger's period and drift at close ranges. This information is carried forward when the vehicle moves away from the array.

Future Work

- Real time tracking** – Implementing real time tracking would allow people on the dock to see what the vehicles are doing underwater.
- Multi-AUV Tests** – Low cost AUV navigation typically involves multiple vehicles working together. Future tests will involve anywhere from 2-4 AUVs.
- Joint calibration** – Currently the water sound speed and hydrophone geometry are assumed to be constant. Future will involve estimating these parameters along with the vehicle positions.