Positioning Systems

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Introduction

Problem Statement

- ROV’s as in the name are remotely operated.
- Accurate positioning will help in control of the vehicle and in recording the location of defects observed.

- We need to position an ROV with accuracy comparable to the Waterlinked UGPS robustly in reflective environments.

Traditional Solution

- Optical Positioning
  - Requires Line of Sight
  - Requires Clear water

- Waterlinked Underwater GPS
  - Multiple reflections in closed metallic tanks
  - Difficult to effectively extend the system via adding other sensor sources

Waterlinked UGPS

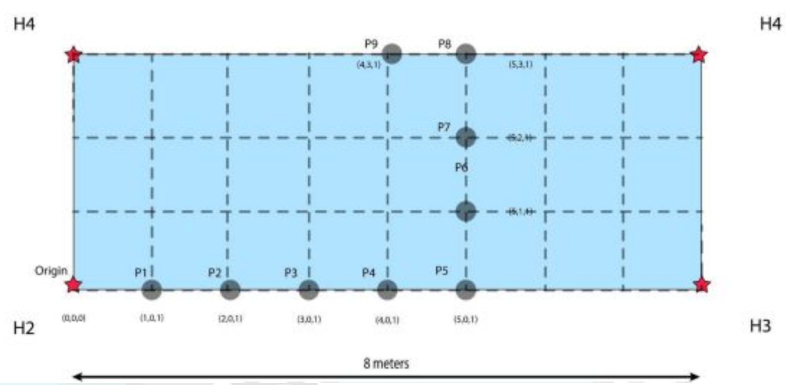
Status as of August 2021

Ashish and Amit Daud (intern, Dec ‘21 - June ‘19) have conducted a set of experiments.

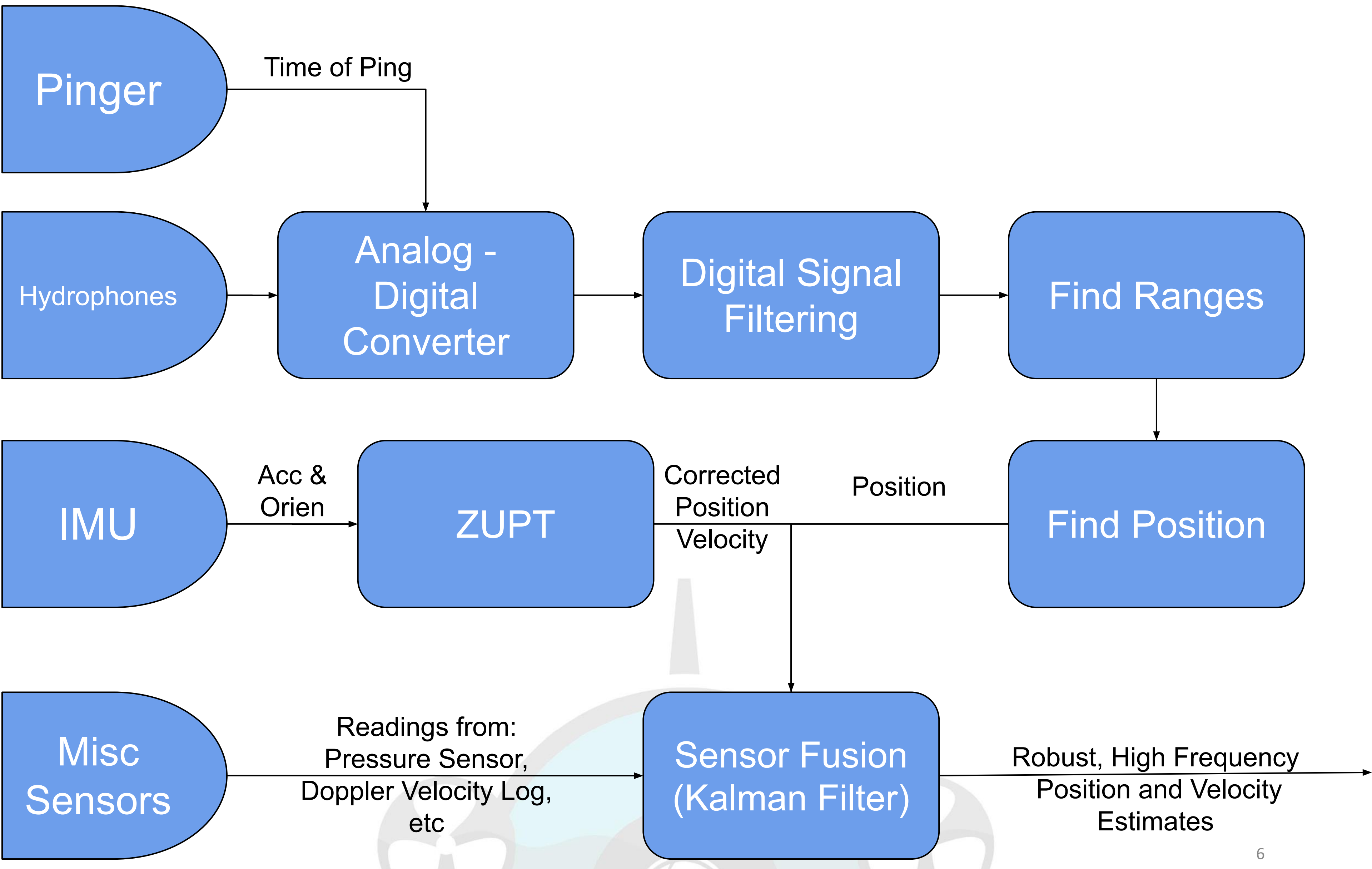
They have achieved the following

- Position a stationary pinger in the test pool
- Fuse a dummy IMU with a series of those positions
- Simulate failure in the IMU or the acoustic system and show how a particle filter is resiliently reacts to that.

We aimed to replicate that progress and build on it. We want to use real-world IMU data and position in real time.



Overall System



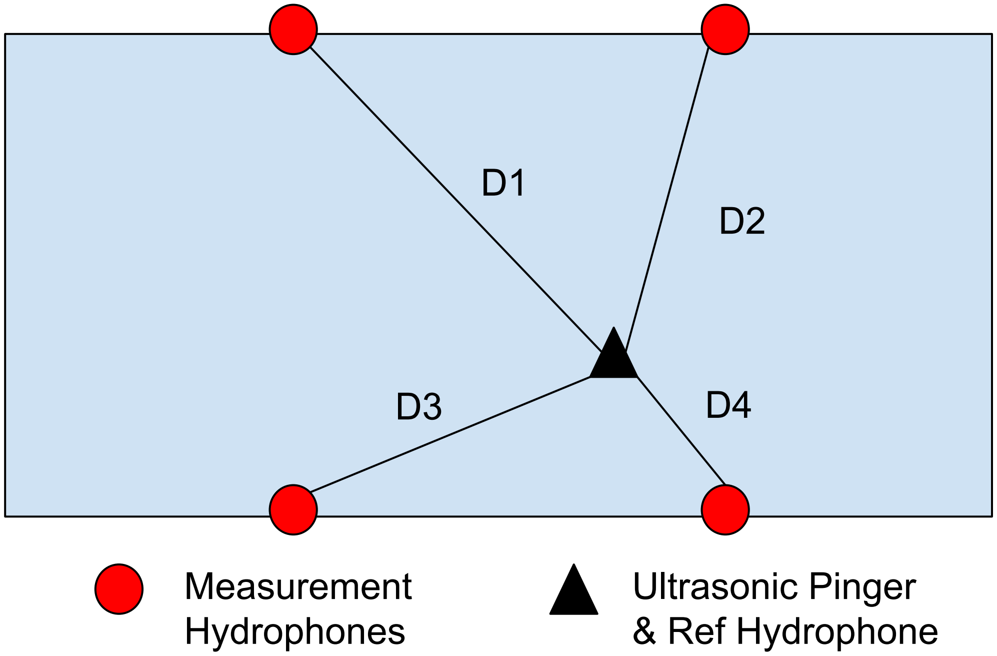
Acoustic System

Acoustic System

3 Step Process

- Acquire and Filter hydrophone data
- Find the time when the ping reaches each hydrophones.
- Using the time difference, find the range of the pinger from each hydrophone.
- Using the ranges, estimate the position of the pinger.

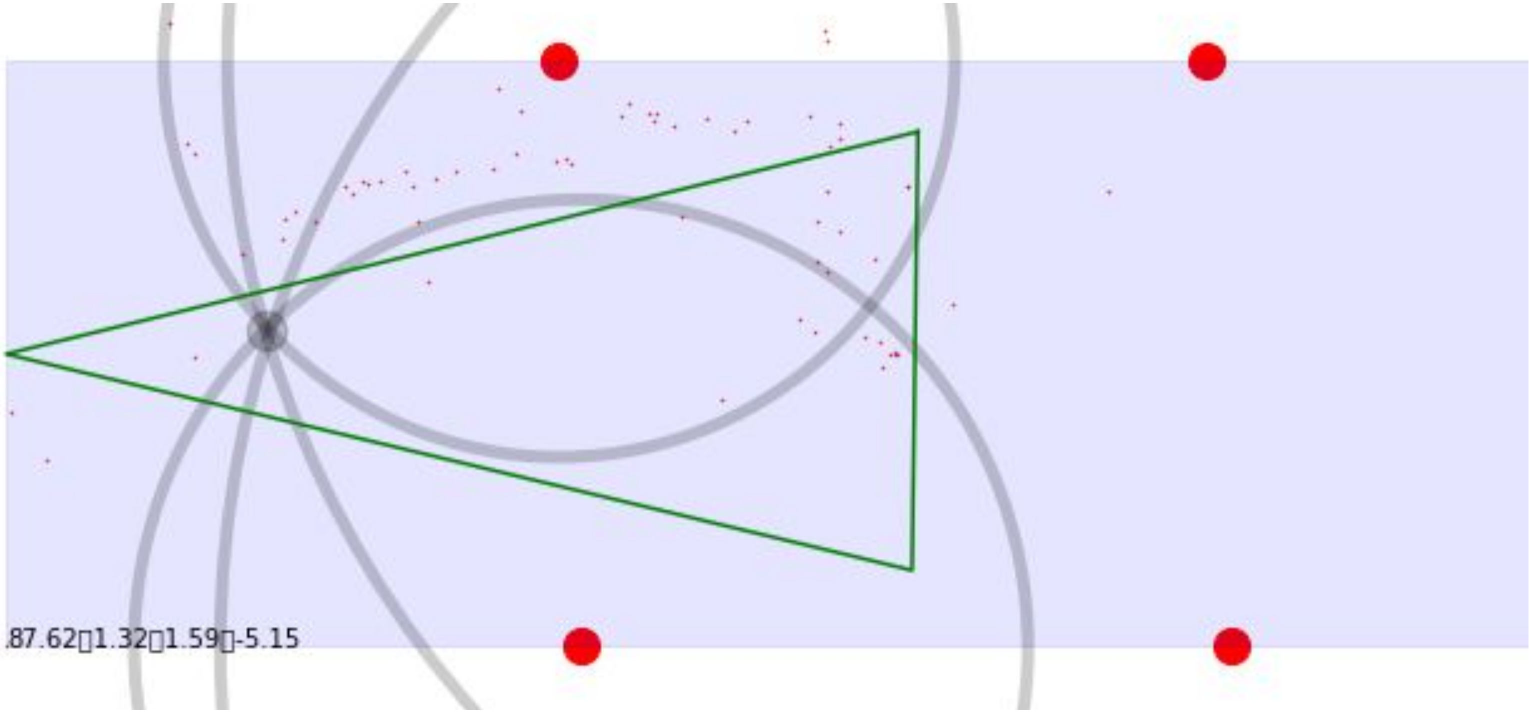
Acoustic System - v1



- We can measure D1, D2, D3 and D4 using the time when
  - The Reference hydrophone receives the ping
  - Each Measurement hydrophone receives the ping

$$D_i = (t_i - t_{ref}) \times v_{sound}$$

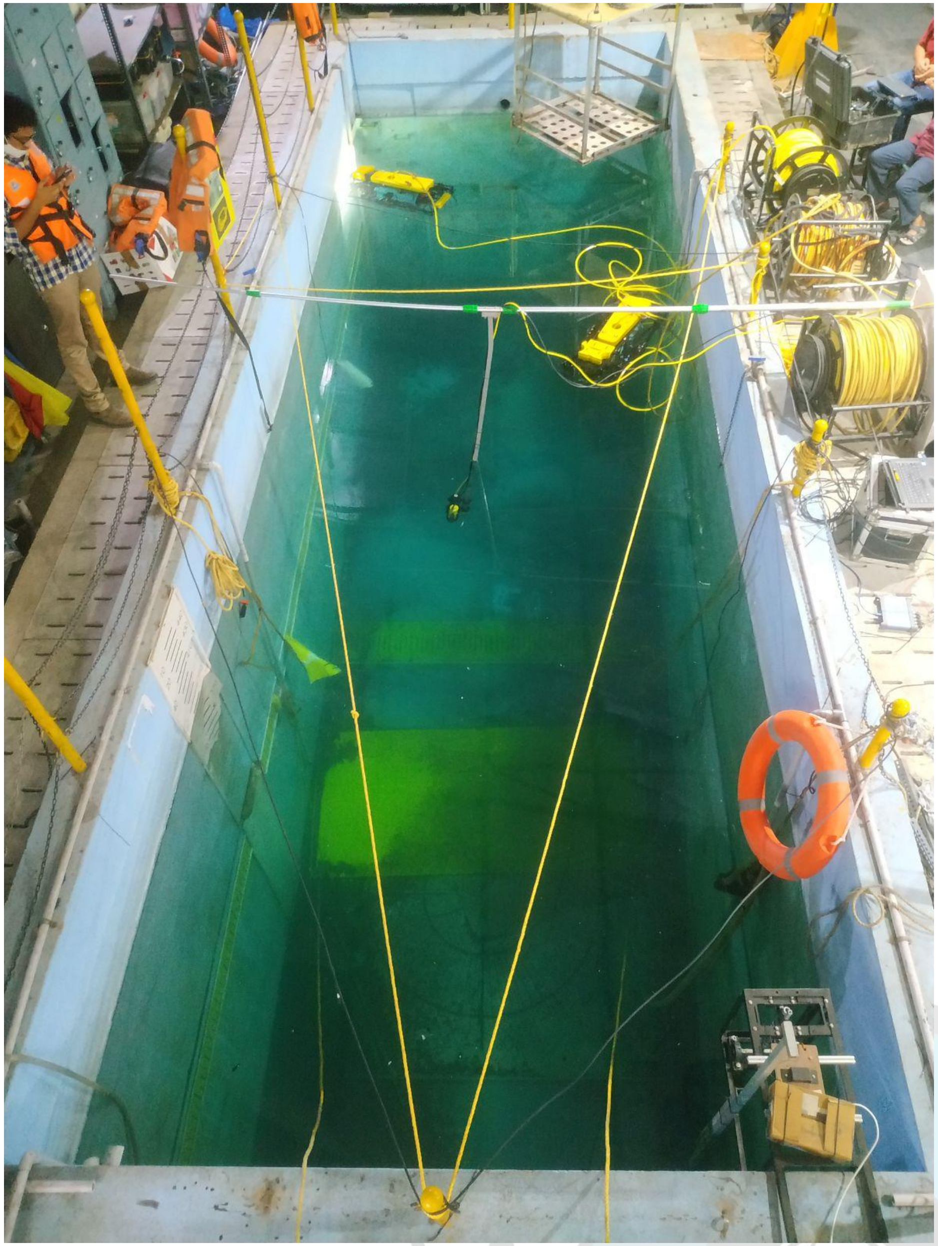
Acoustic System - v1



We use an optimization algorithm to minimize the squared sum of error in dist

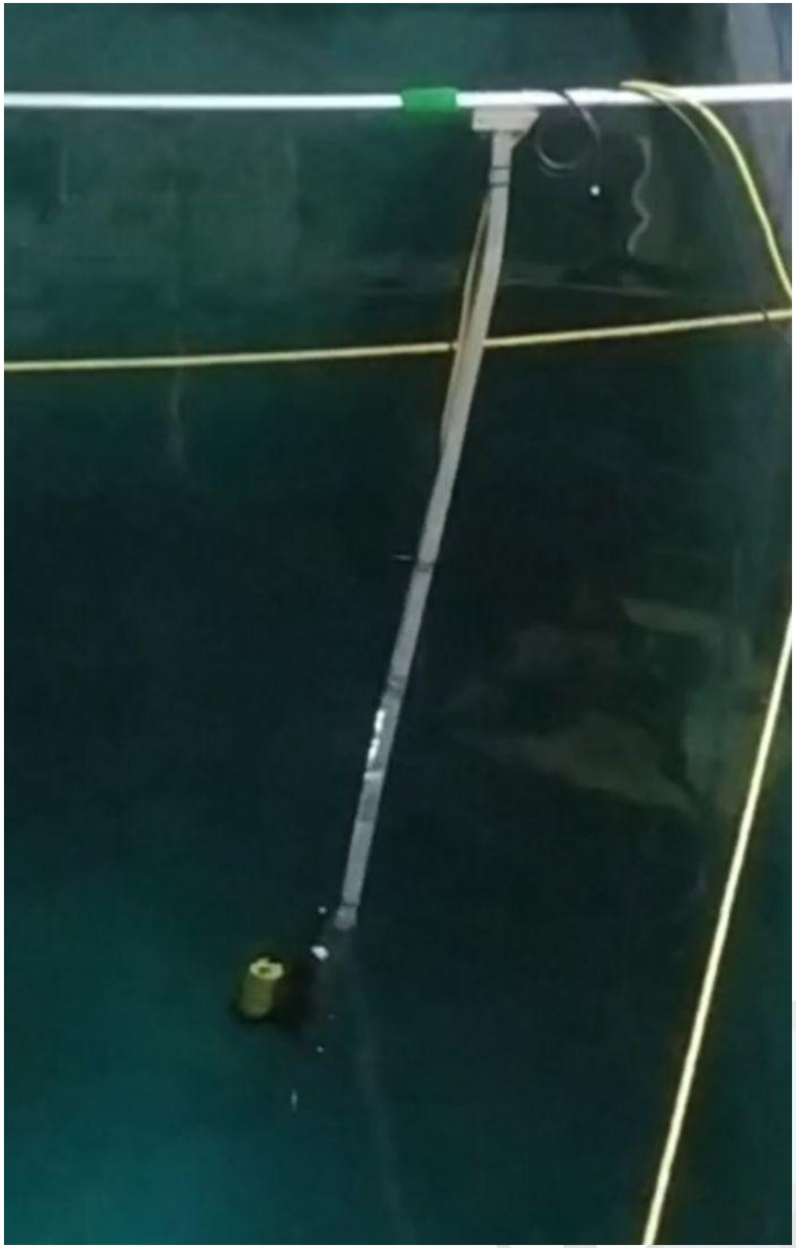
$$f(\vec{r}) = \sum_{i=0}^{4} \left(||\vec{r} - \vec{h_{loc,i}}|| - D_i \right)^2$$

Experimental Setup

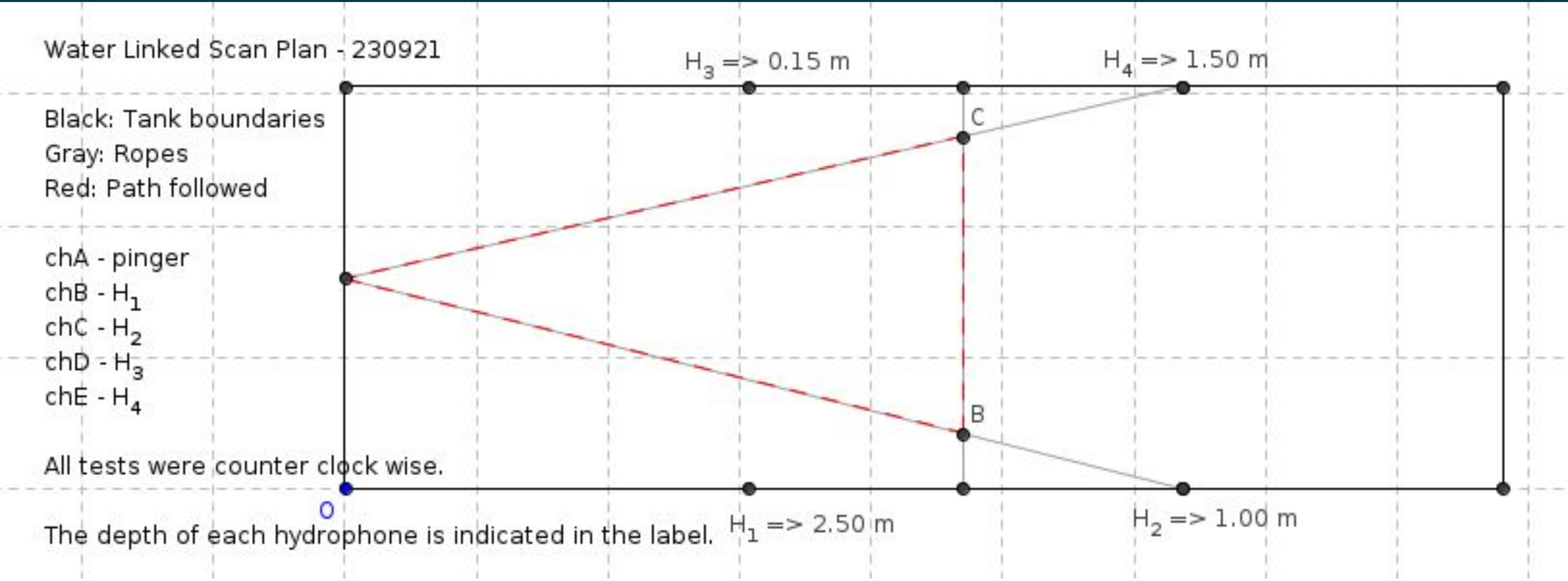


- On Fish-hook
  - 1 Hydrophone
  - 1 Ultrasonic Pinger
  - 1 IMU
  - ~~1 Pressure Sensor~~
- In Pool
  - 4 Hydrophones at various depths

Experimental Setup



Experimental Setup



The pinger + reference hydrophone + IMU were mounted on a fishing hook. The fishing hook was mounted on a telescopic rod.

The entire setup was manually moved along the red triangle starting and ending at C

Results

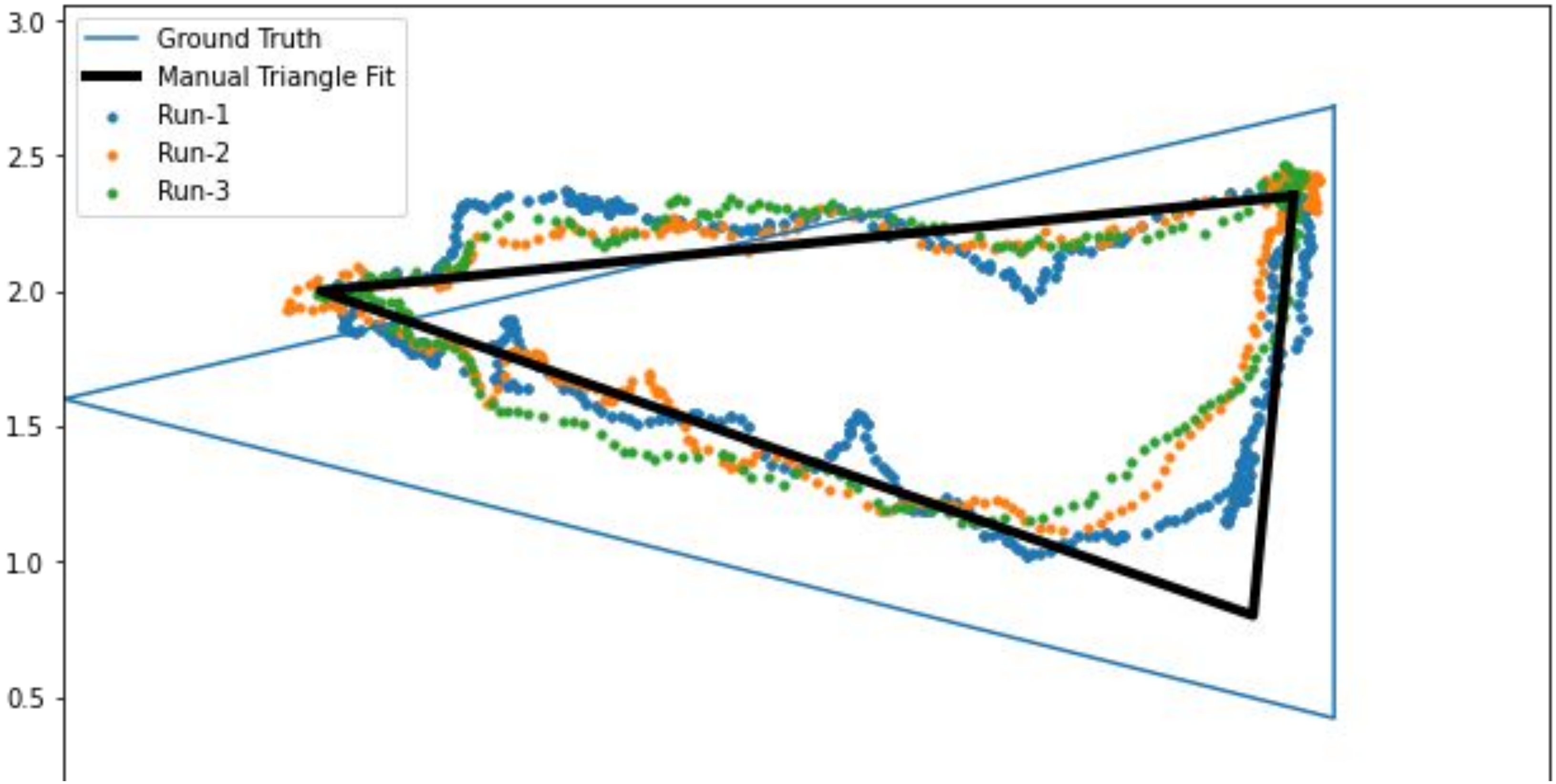
We conducted the above experiment with

- Waterlinked UGPS
- Our System

"Our System" had both an IMU and the acoustic data.

- However the IMU was not well calibrated and the data was not very useful.

Results - Waterlinked UGPS

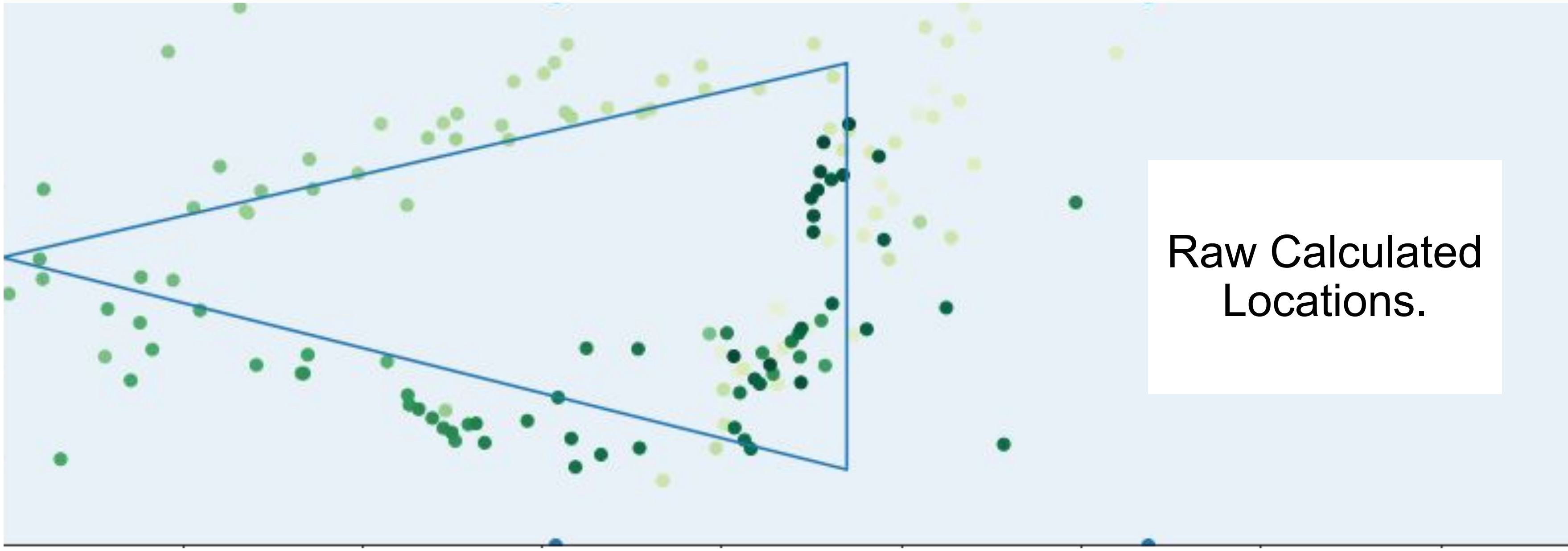


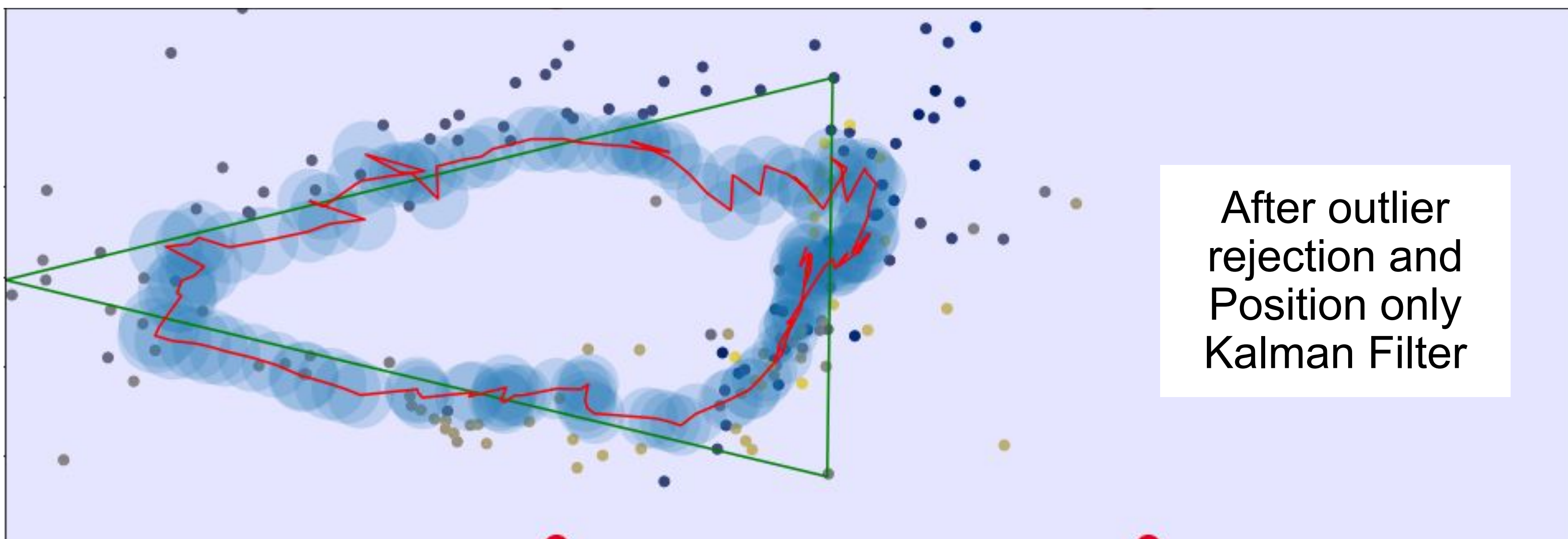
Observations:

- Data seems to be a linear transformation of the ground truth
  - Believe this error is due to inaccurate measurement of hydrophone position
- This received data is after an unknown filtering algorithm, not the raw locations.

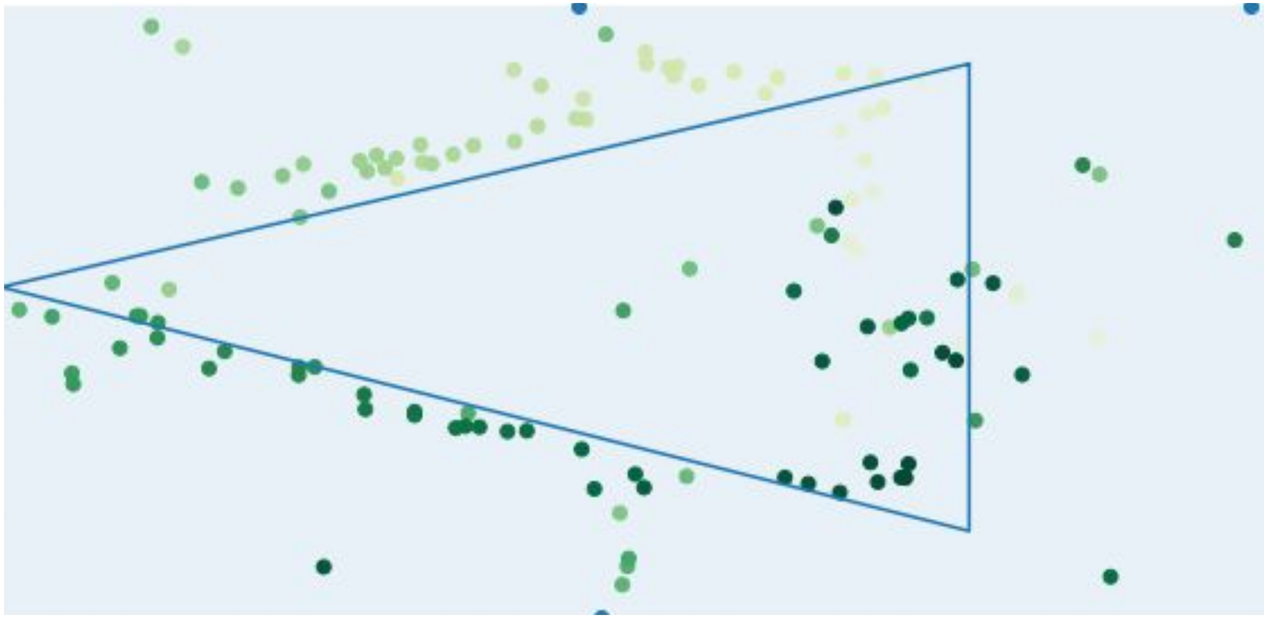
- As discussed earlier, we cannot easily integrate other sensors and compensate for scenarios in a reflecting tank.

Results - Our System

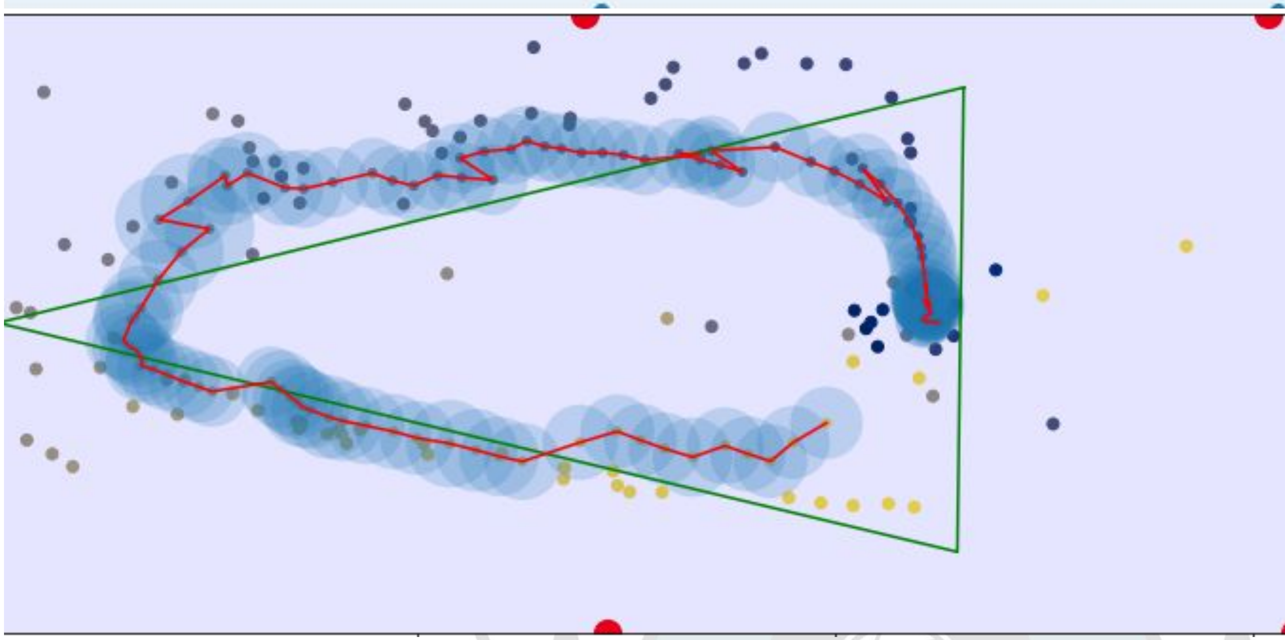




Results - Our System - ZC Algo v2



Raw Calculated Locations.



After outlier rejection and Position only Kalman Filter

Results - Conclusions

The results seem reasonably accurate when compared to the ground truth.

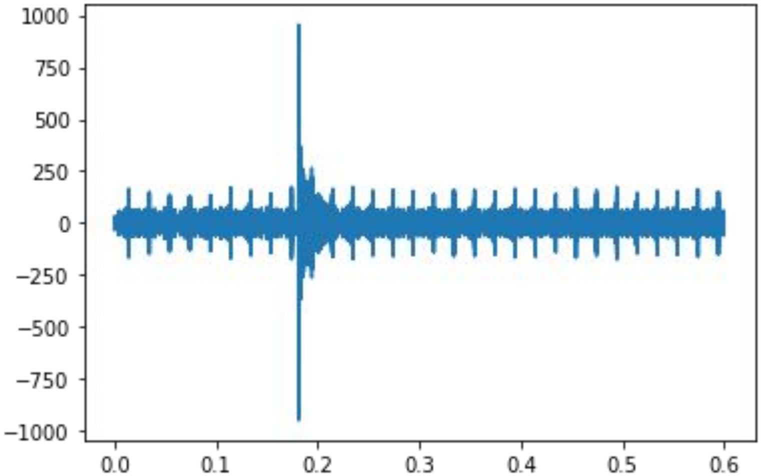
When visually compared with the Waterlinked UGPS there is a significant precision drop.

This can be attributed to two major factors

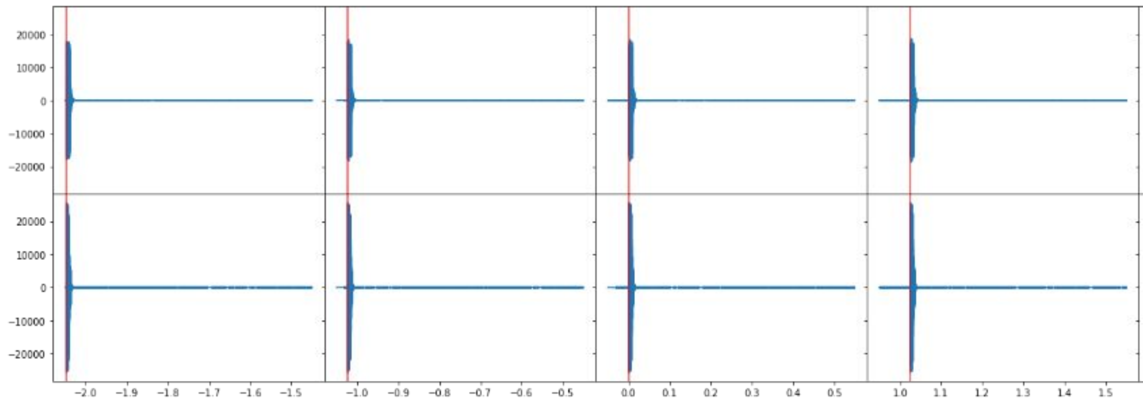
- Significant noise in hydrophones
- When finding position, the optimization algorithm finds an unwanted minima

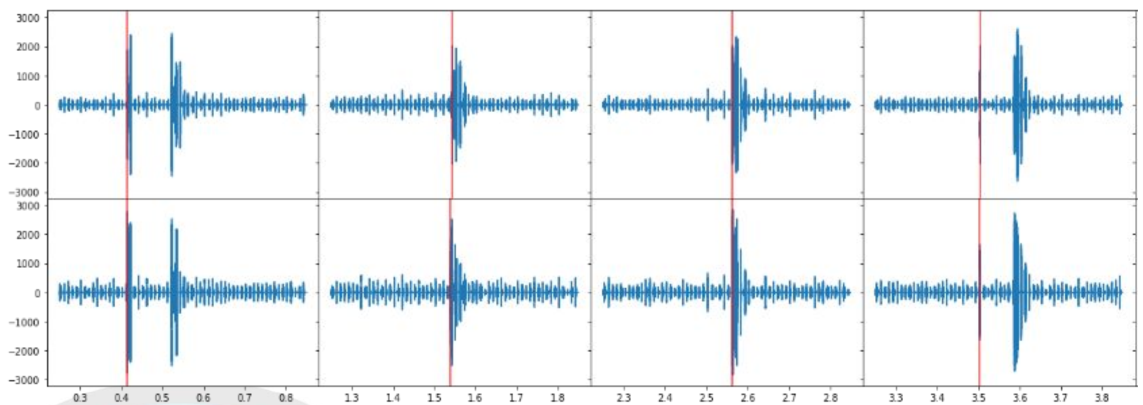
Results - Conclusions - Noise in Hydrophones

Previous Experiments Data



Data Collected from a Bucket





Data Collected in the Test Pool

We faced a lot of noise when testing in the pool:

- Electrical Noise
- Pinger Noise / Malfunction

We were unable to replicate the clean signal that were previously obtained.

Results - Conclusions - Finding Positions

When looking at the range results from hydrophone we sometimes see failure of one channel.

- We can find locations based on 3 correct channels at a time

We often see results at an alternate minima

- We can feed the previous location as the initial estimate

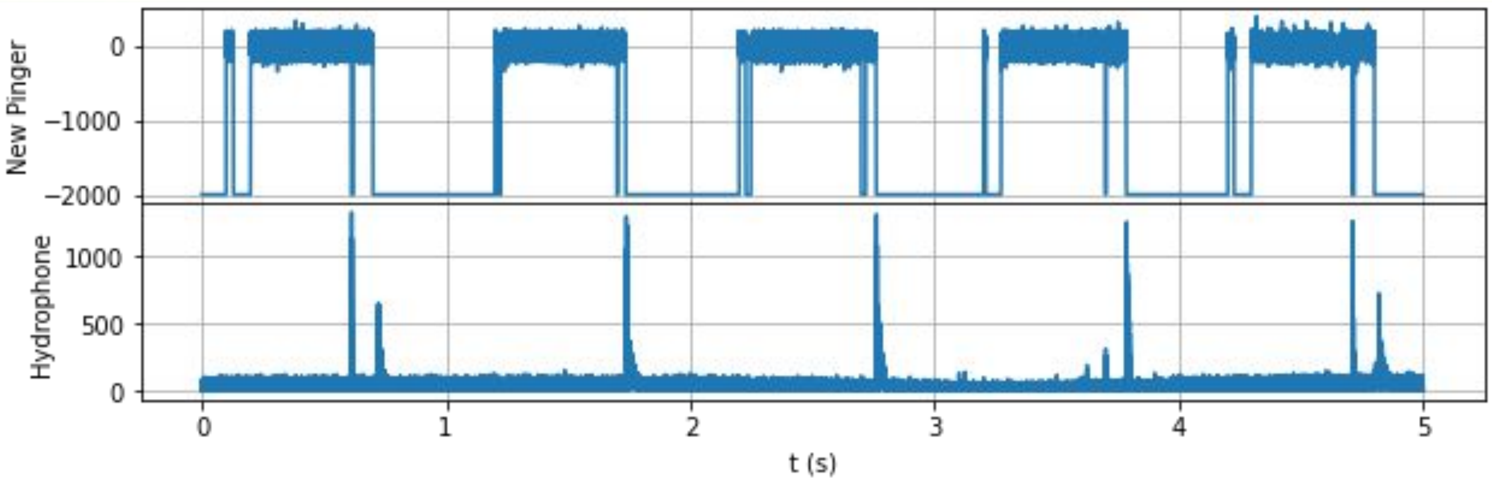
The solver finds minimas (positions) outside of the map bounds

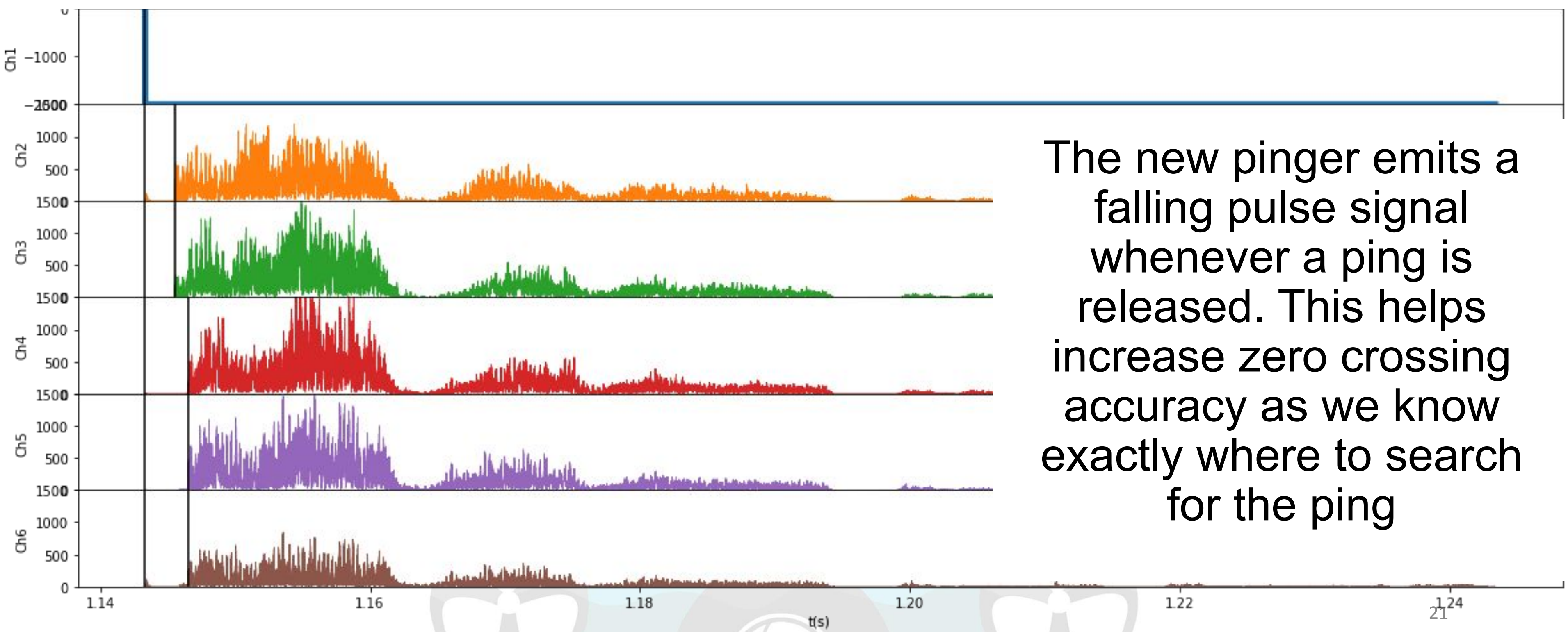
- Use the map bounds directly in the formulation, instead of using it to reject incorrect positions later

Future Improvements:

- Integrate other sources of position at this step, i.e. the pressure sensor, instead of fusing it at the Kalman Filter step.

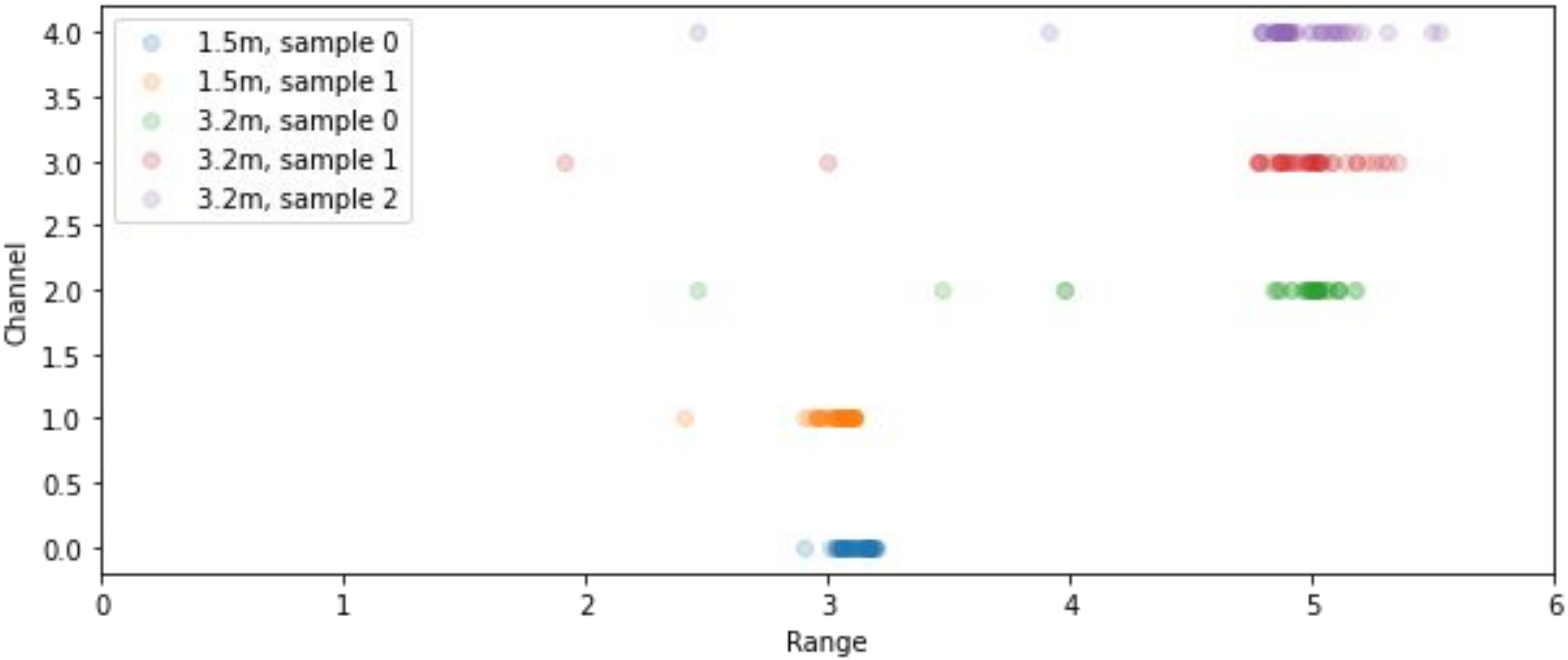
Improvements - New Pinger





The new pinger emits a falling pulse signal whenever a ping is released. This helps increase zero crossing accuracy as we know exactly where to search for the ping

New Pinger - Range Results



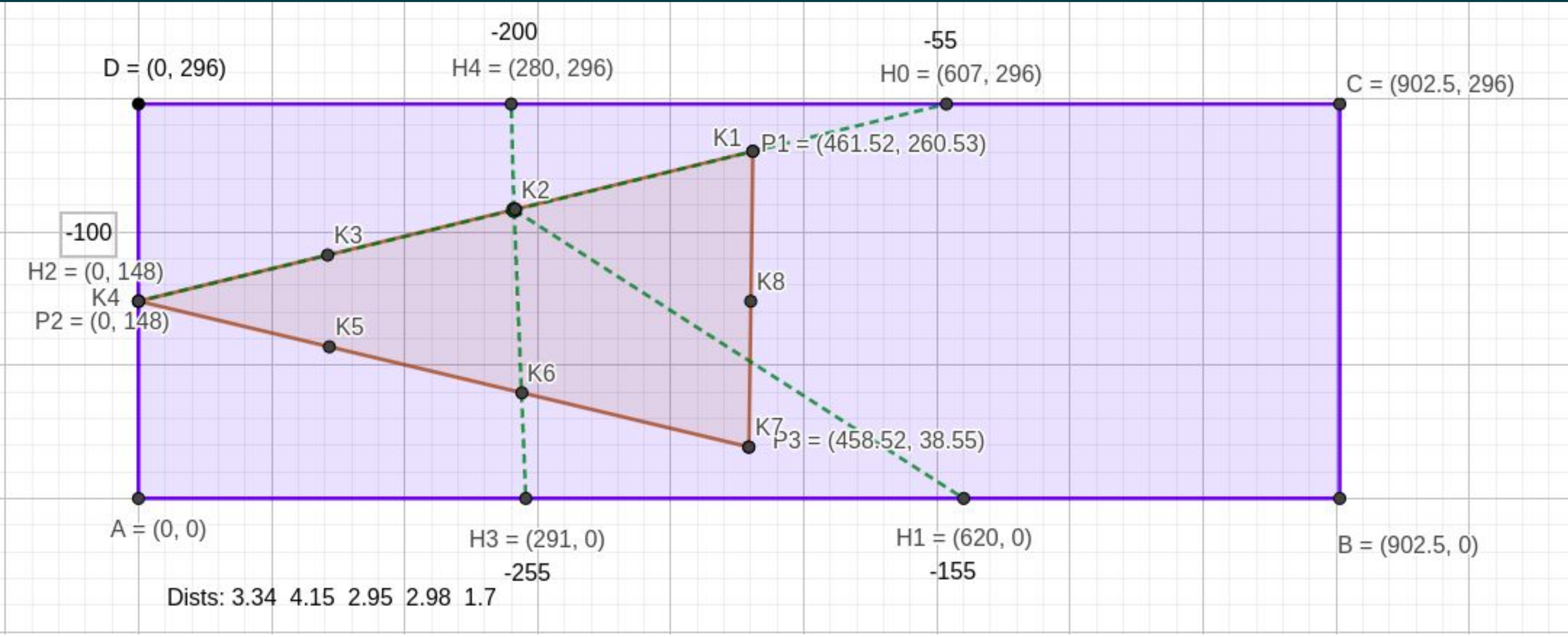
The ranges seem to be accurate within 60 cm

This setup requires only one pinger and one hydrophone.

There is a linear error in the hydrophones due to the pinger zc. This can be easily removed.

	Median, std dev (m)
1.5m, sample 0:	3.12, 0.06
1.5m, sample 1:	3.05, 0.11
3.2m, sample 0:	5.00, 0.52
3.2m, sample 1:	4.98, 0.59
3.2m, sample 2:	4.90, 0.42

Final Fishhook Tests



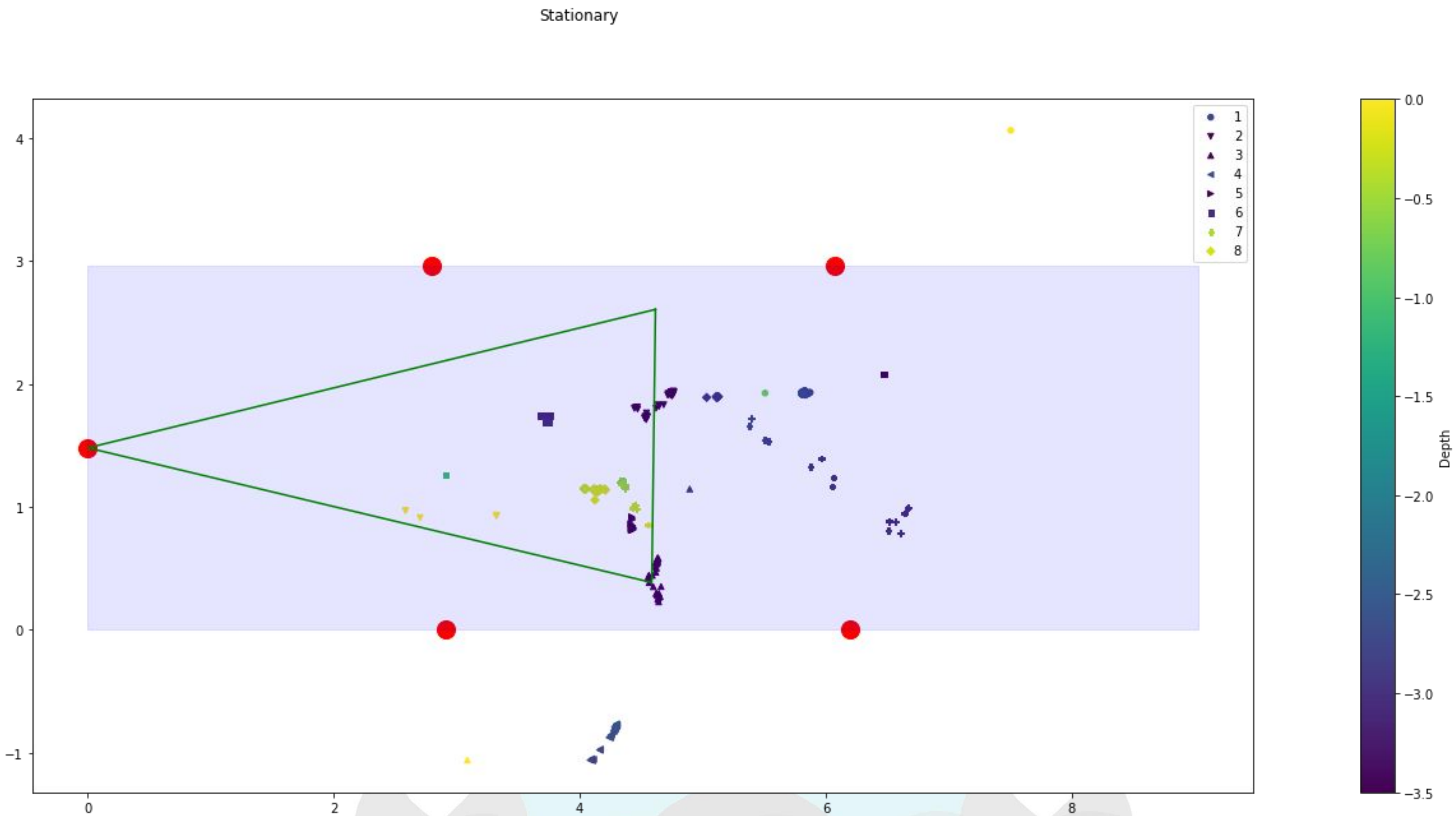
Final Fishhook Test:

- ‘New Pinger’ - 1
- Hydrophones - 5
- IMU - 1

We tried to replicate the first set of fishhook experiments with the new pinger setup and a calibrated IMU.

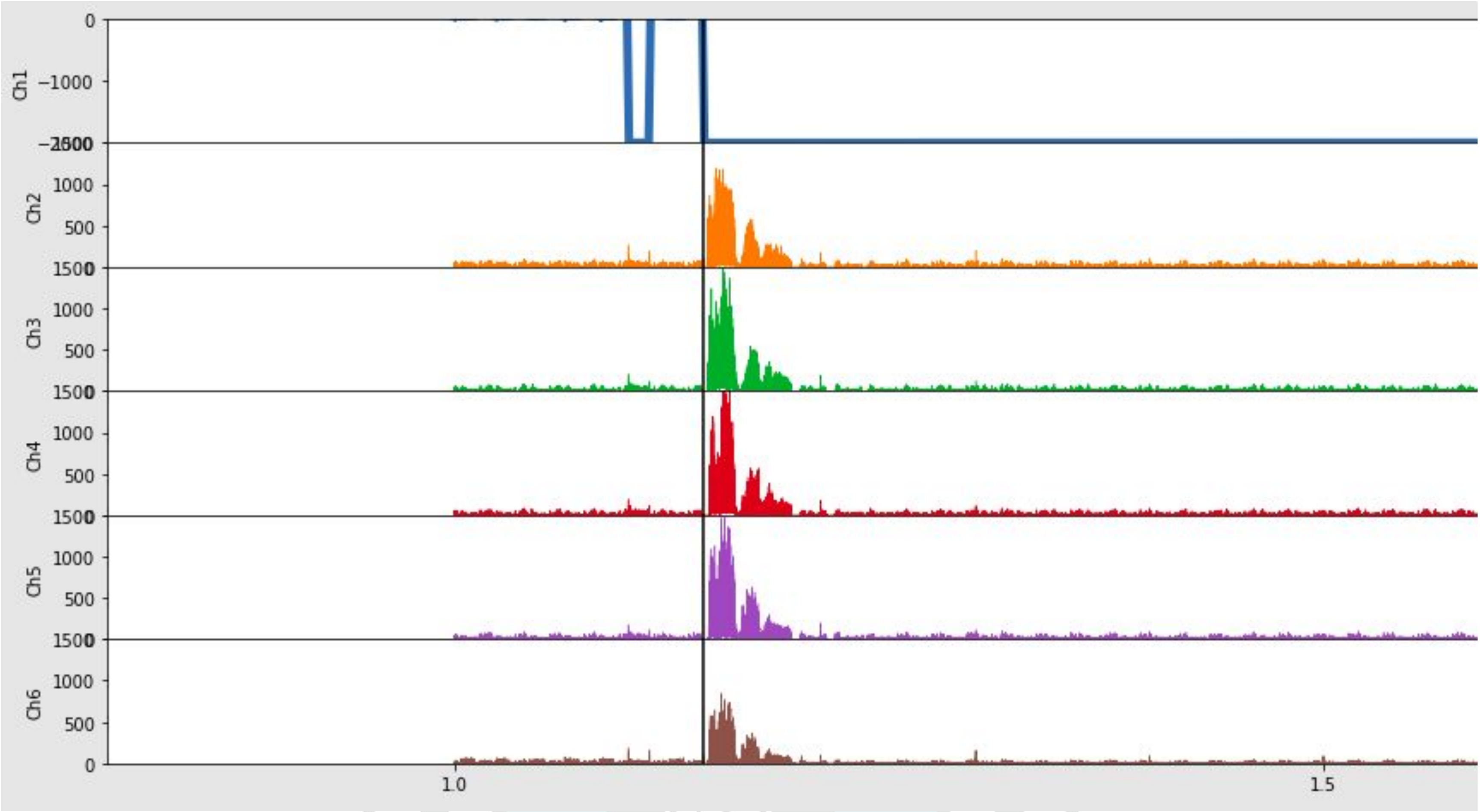
Final Fishhook Tests

- The Acoustic range results were very precise.
- However they did not match the ground truth at all
- For this test the ground truth should be on the triangle.



Final Fishhook Tests

- The ping data looked clean.
- We visually verified that the zero crossing module was working properly.

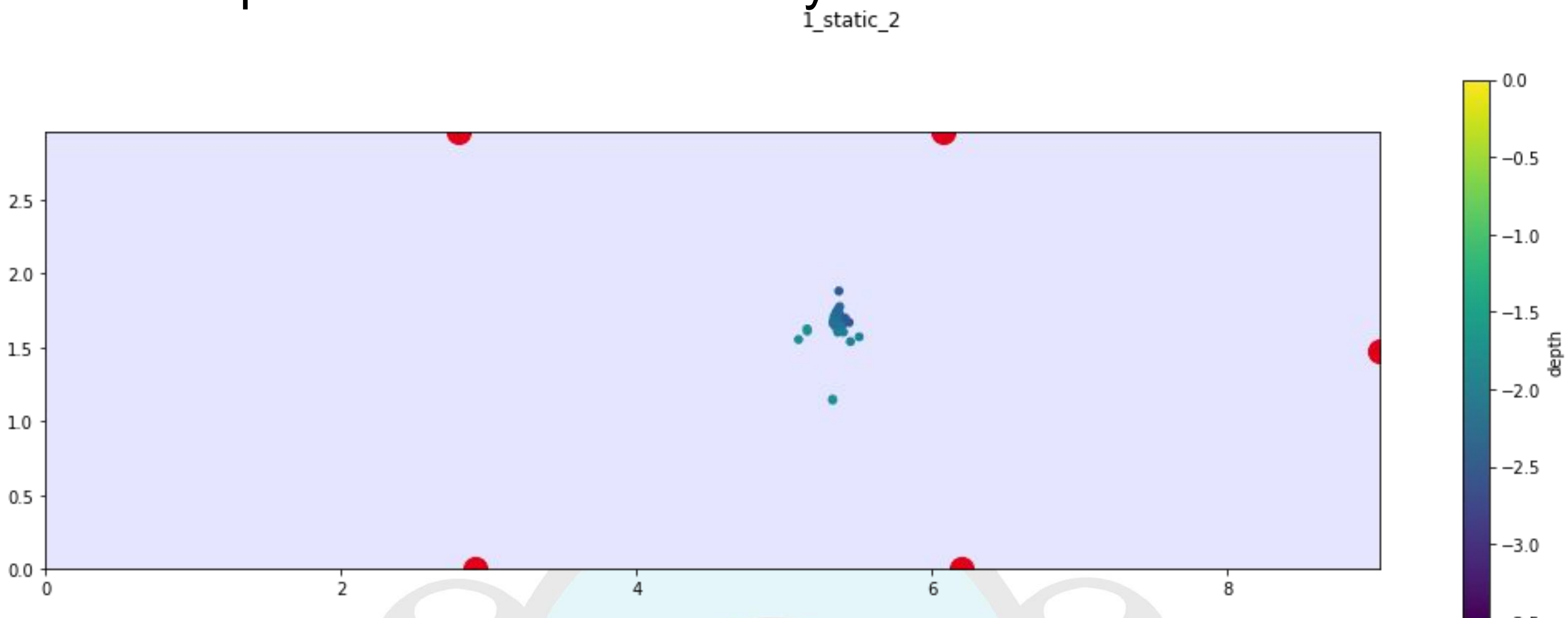


Final Fishhook Tests

- However as seen in the plot, the results were not matching with the ground truth, and we could not isolate the source of the error.

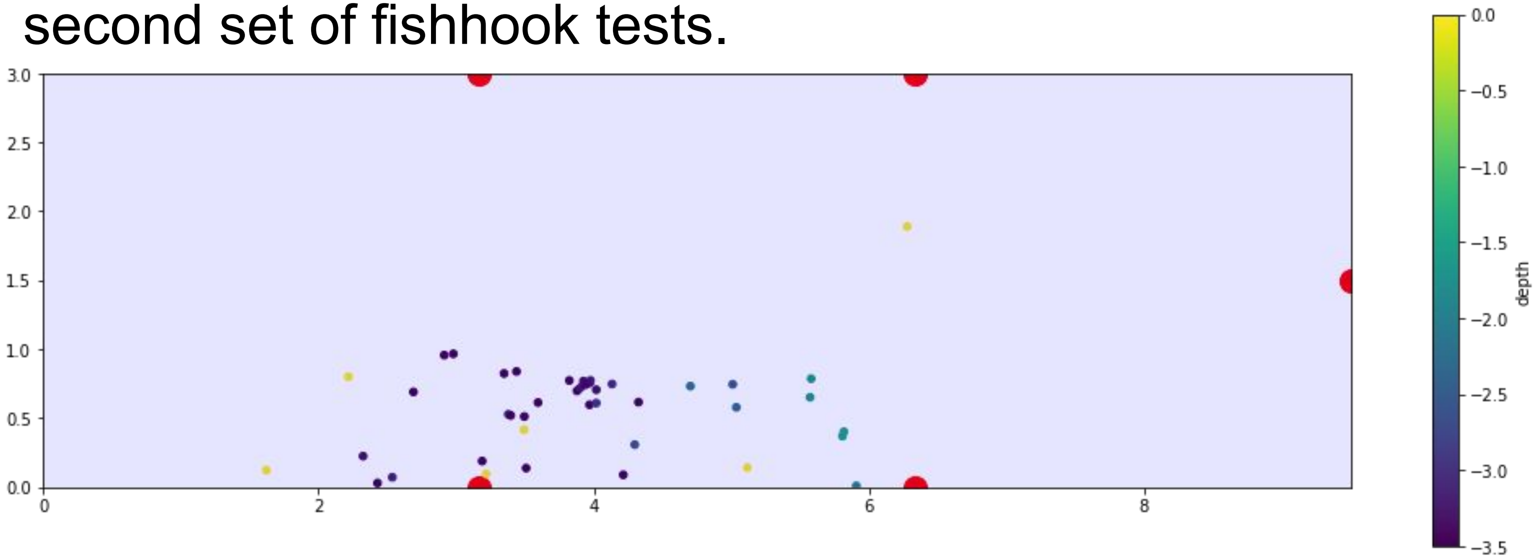
ROV Tests

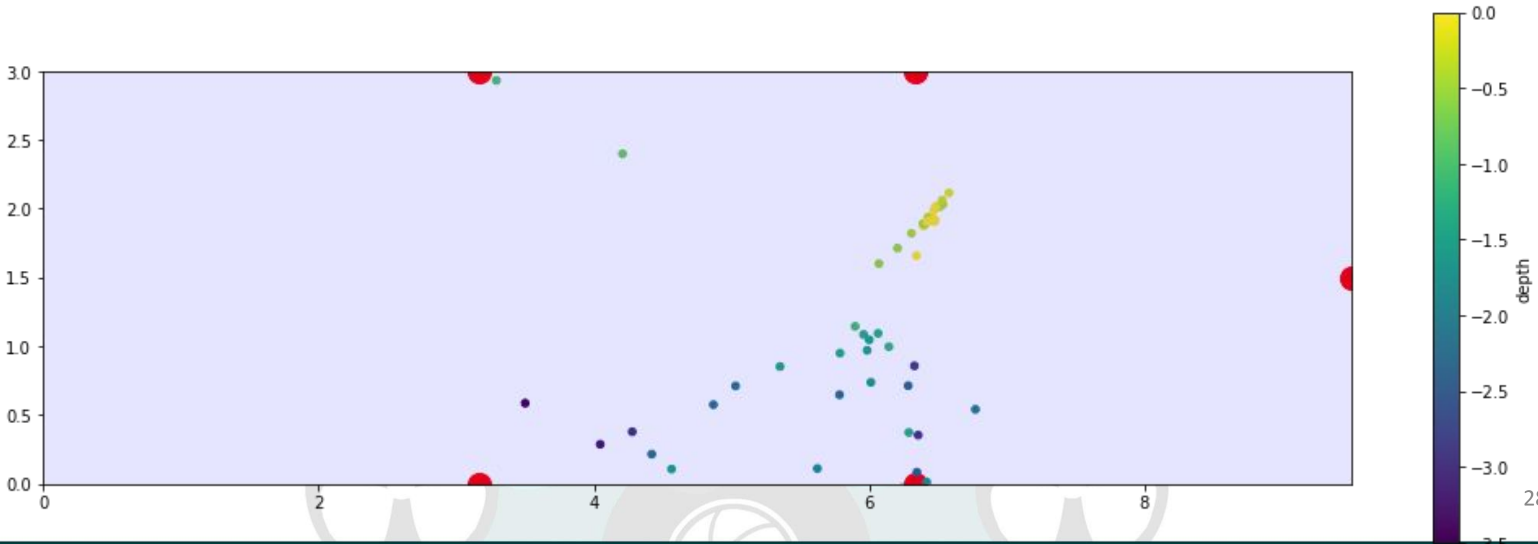
- As a test of the acoustic system at different depths, and to gather domain appropriate data for the IMU ZUPT algo, we mounted the system on mikros and performed some basic maneuvers.
- Below is the result from of acoustic data from a test where we kept the the ROV stationary.



ROV Tests

- Alas, further tests gave inaccurate results, similar to the second set of fishhook tests.





Acoustic System - Next Steps

- We can make attempts to reduce noise at the hardware level. Try to understand why there is so much noise in the pool. Figure out why the pinger malfunctions and causes double pings when it is in the pool.

- As discussed earlier, improvements can be made at the optimization problem step (ranges -> positions)

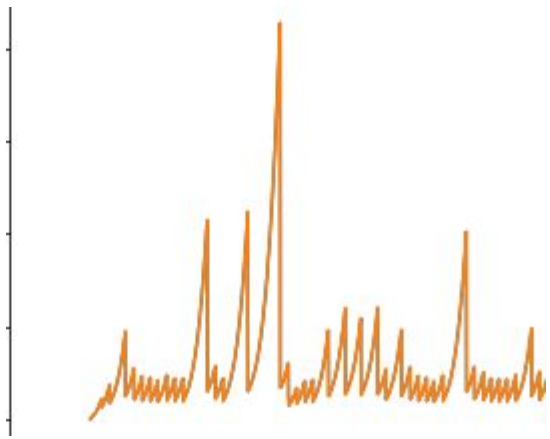
- The last set of results (fishhook and ROV) were very unexpectedly wrong. Further tests need to be done to isolate the problem.

Inertial Measurement Unit

Inertial Measurement Unit

Why do we need the IMU:

- Acoustic Positioning Data:
  - Low Interval
  - Medium Variance
  - Constant Variance with Time
- IMU
  - Very High Interval
  - Initially very low Variance
  - Variance increases polynomially with Time



The IMU alone cannot position alone, as its velocity and position estimate will increase without bounds.

Inertial Measurement Unit

In land vehicles, IMU - GPS fusion is a very common scenarios.

GPS provides **position and velocity** fix with a similar error type to our acoustic system.

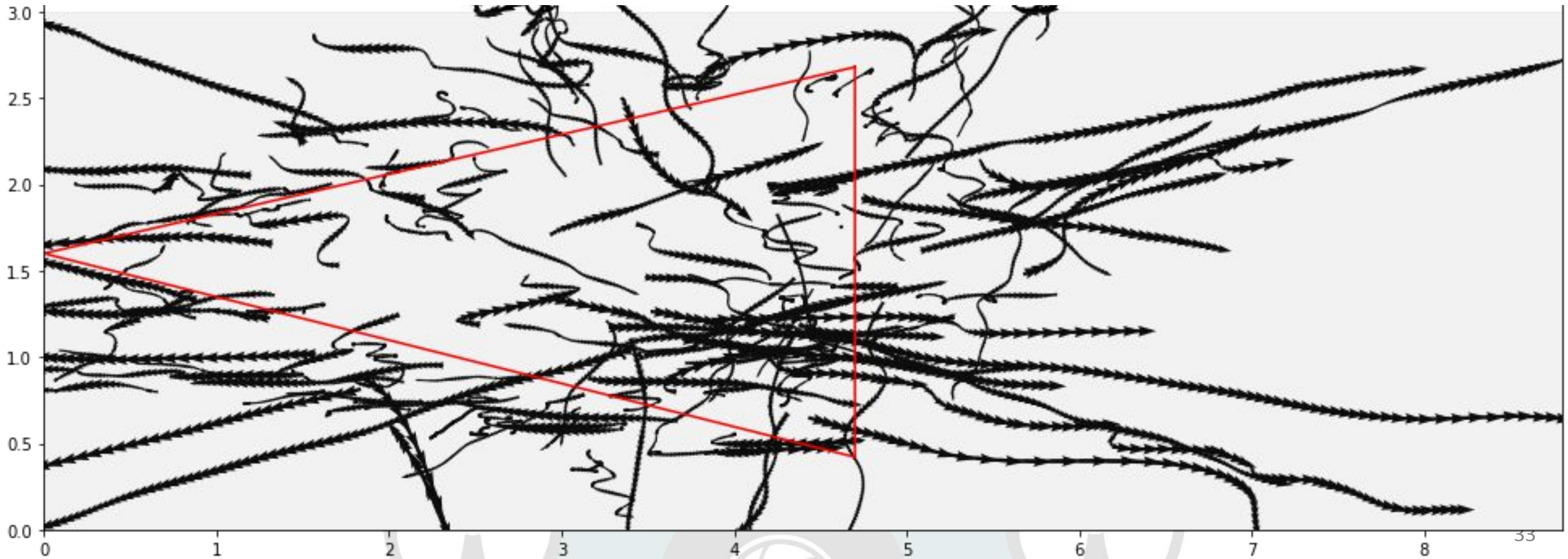
The GPS fixes are used to correct the errors in dead reckoning via the IMU data.

Our scenario is similar to this; however, our low frequency acoustic data does not provide a good velocity estimate.

Initial Attempts

- Initially, we tried direct fusion of the IMU and the Acoustic data
- Even over shorter time intervals, the velocity and position estimate exploded

- Next we attempted to improve this by getting a very coarse velocity estimate from differentiation in acoustic position data
- The results were not satisfactory.

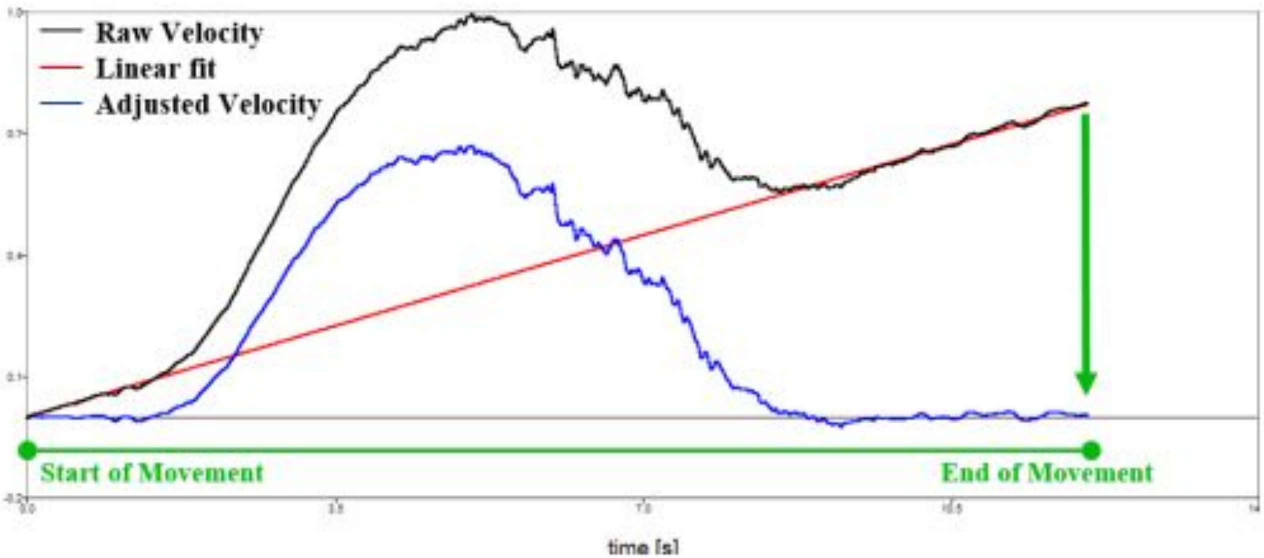


ZUPT - Zero Velocity Potential Update

- It estimates the binary question of: Is the IMU in motion?
- Then method of estimation depends on the specific implementation platform (the vehicle/device on which the imu is mounted)

- It is commonly used in tracking human motion via an imu mounted on a shoe
- It has also been used in tracking a handheld electric angle nutrunner.

ZUPT - Zero Velocity Potential Update



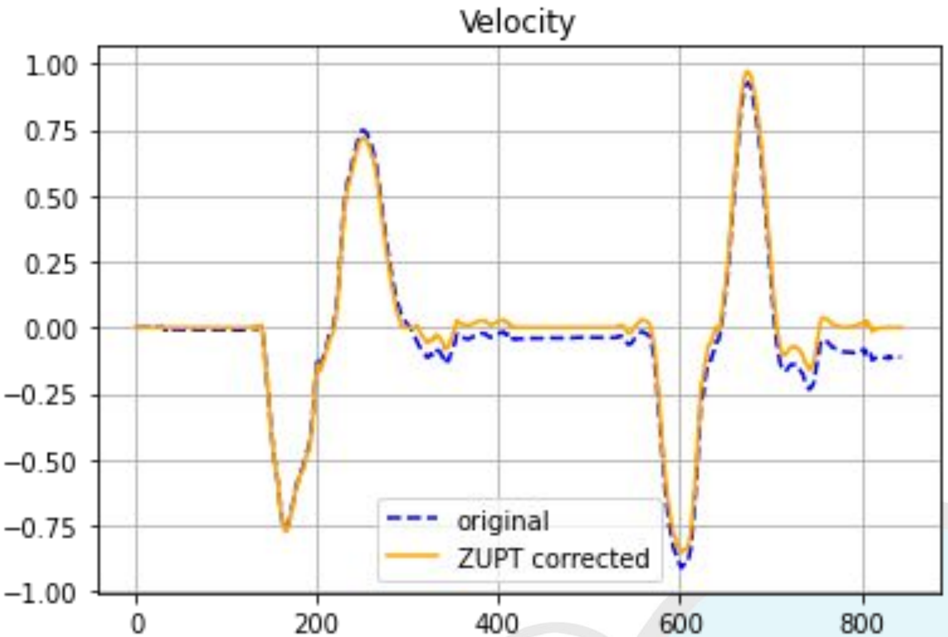
And IMU has a constant error in acceleration (the bias)

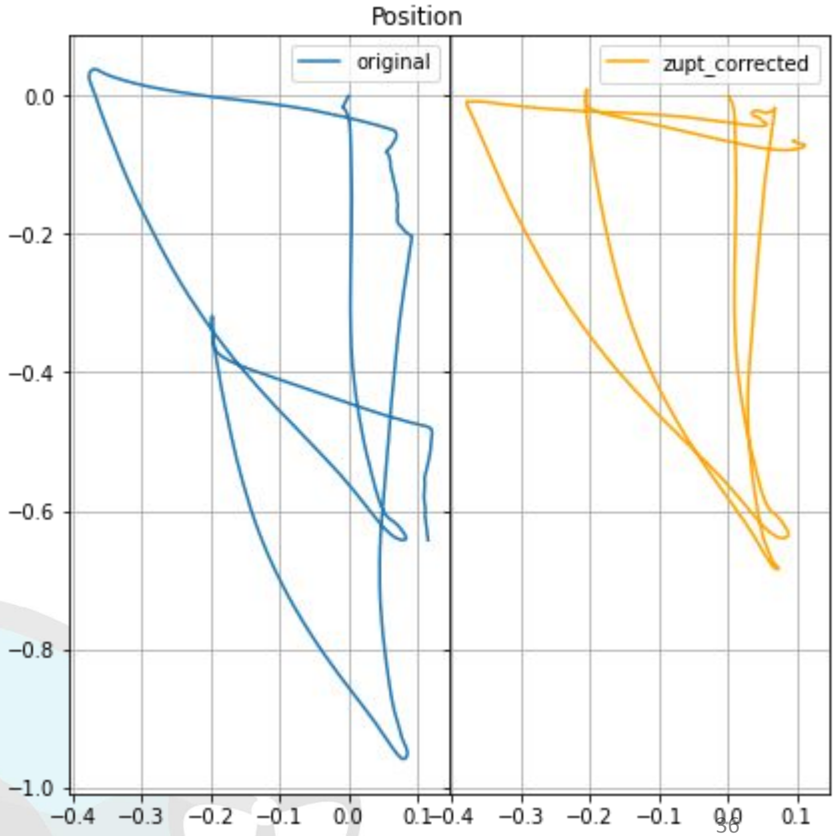
Thus the Velocity will have a linear error.

As we know the Start and Stop of a motion, we can retroactively correct the estimated velocity and the position calculated from that

ZUPT - Zero Velocity Potential Update

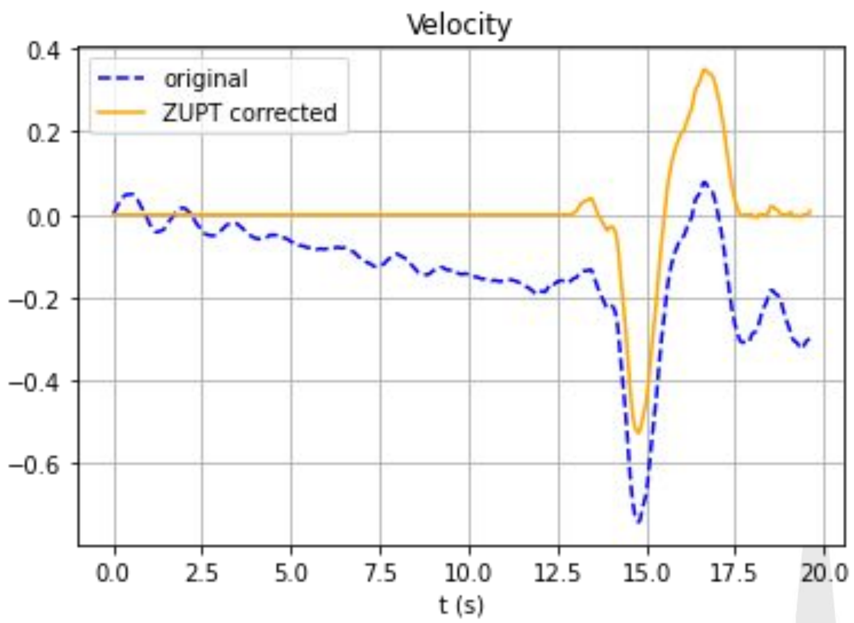
- This method was first attempted on hand-held imu movement
- A combination of **variance of acceleration** and **change in orientation** was used to decide whether the IMU was in motion

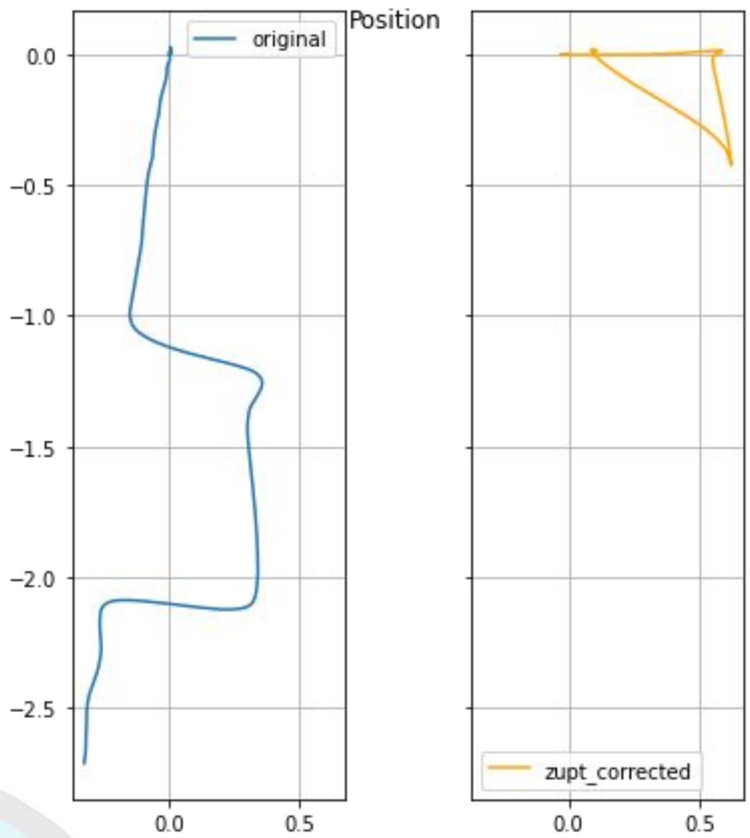




ZUPT - Zero Velocity Potential Update

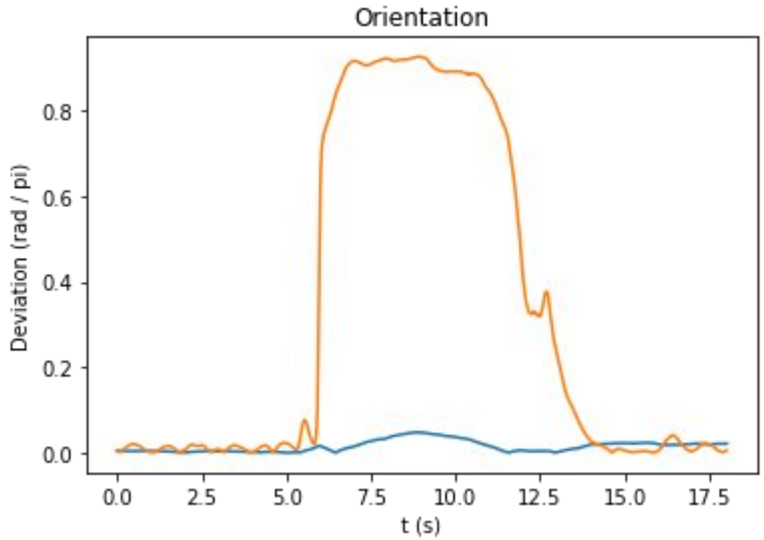
- A second example, which is over a longer timeframe (20s)

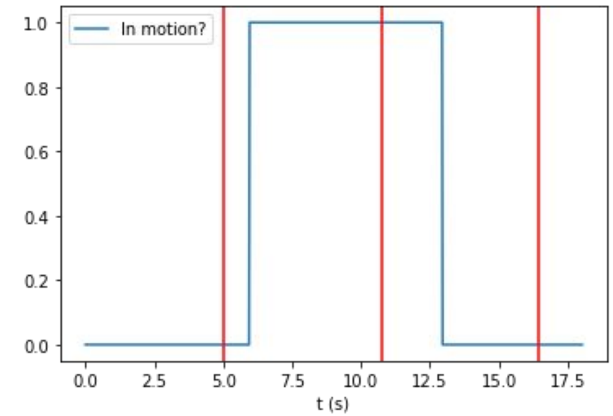




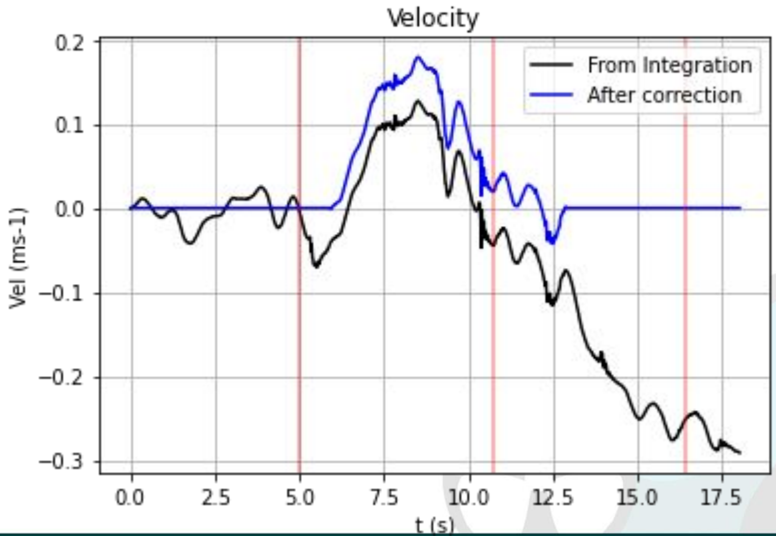
ZUPT - On Fishhook

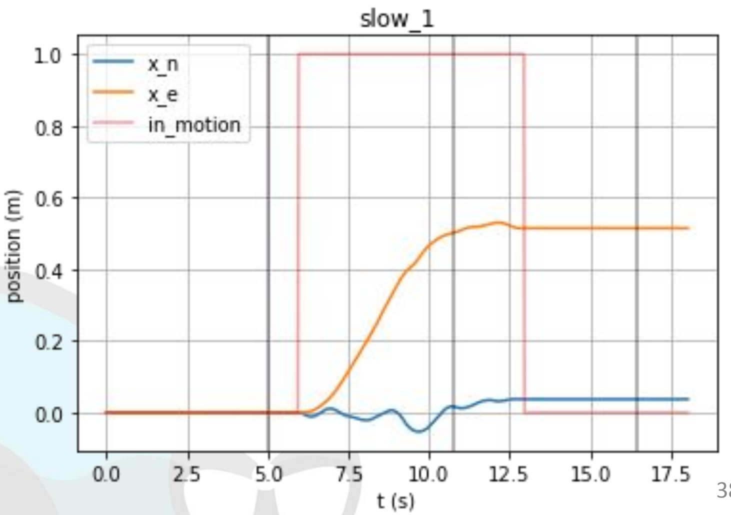
- In this experiment, we moved a fishhook in a straight line.
- We are using an IMU only to find the results



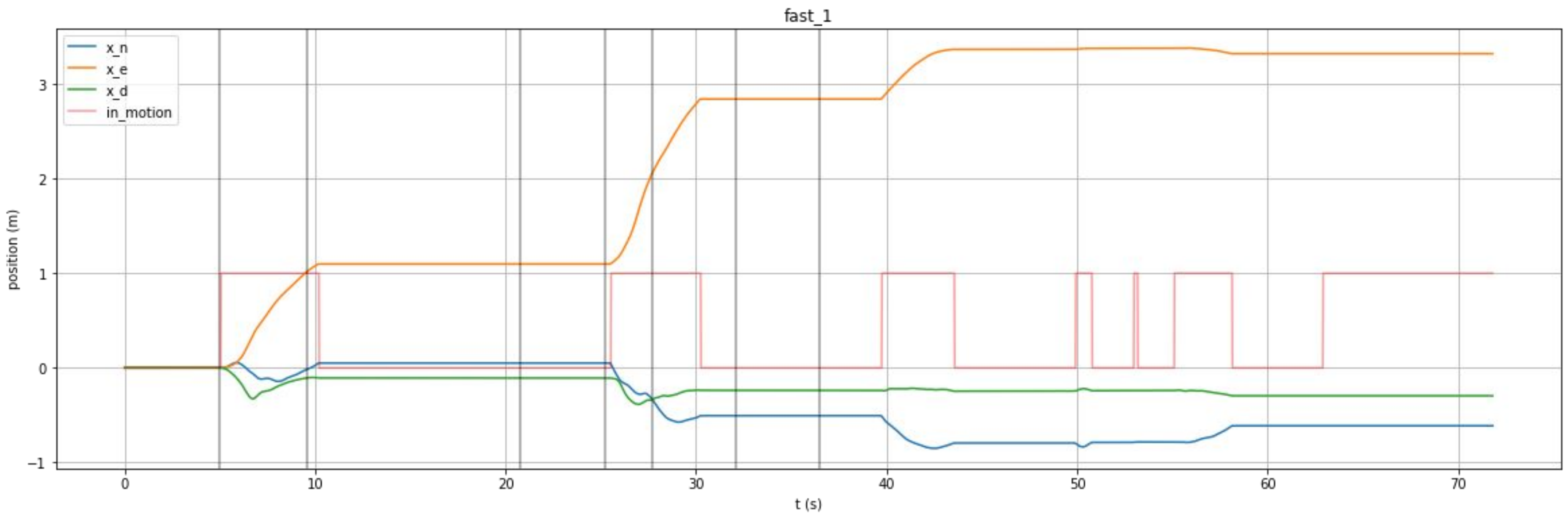


The first and last red lines are the start and end of the motion





ZUPT - On Fishhook



Another example with multiple start-stop motions.

For this technique, the more the start-stop motions, the better the accuracy gains.

ZUPT - On New Fishhook Tests

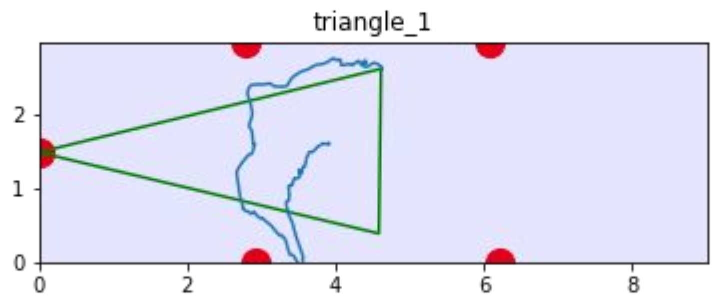
- The following data is from the second set of fishhook test
- They are preliminary results with only IMU data.

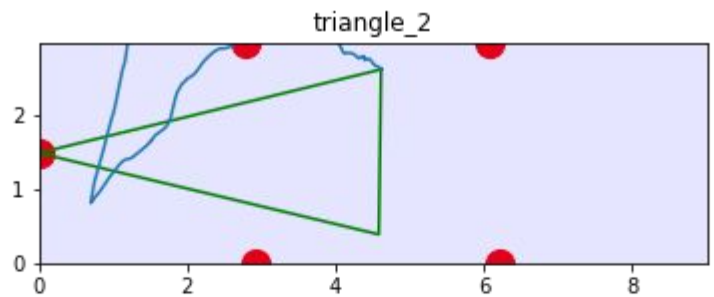
- These results require much tuning of the thresholds

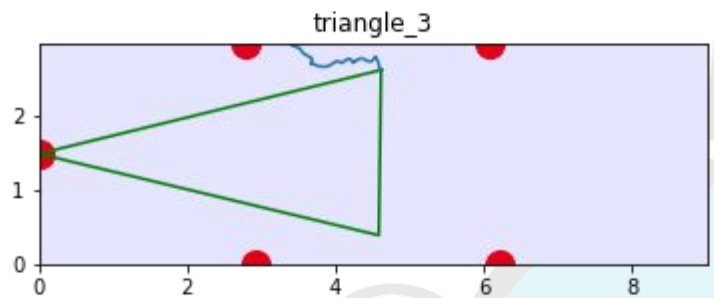
- The IMU requires position data to correct it at intervals.
- We can see that in <u>the initial time interval the performance is good</u>
- It then degrades without a position fix

ZUPT - On New Fishhook Tests

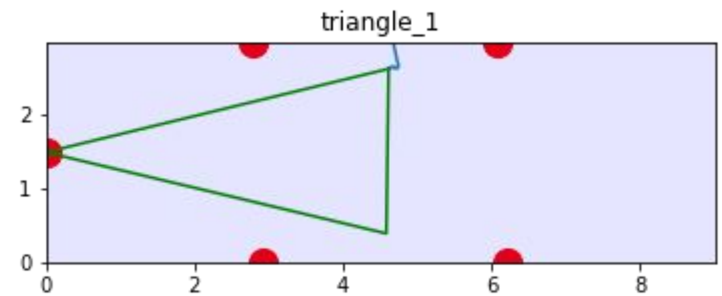
With ZUPT

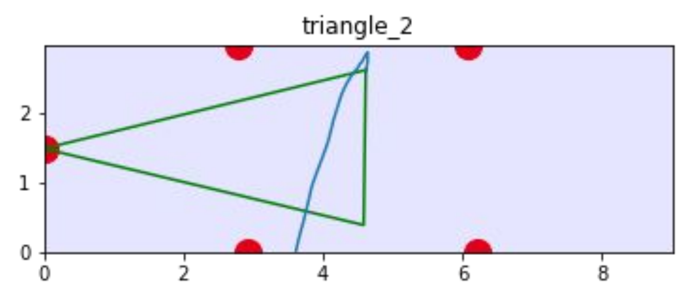


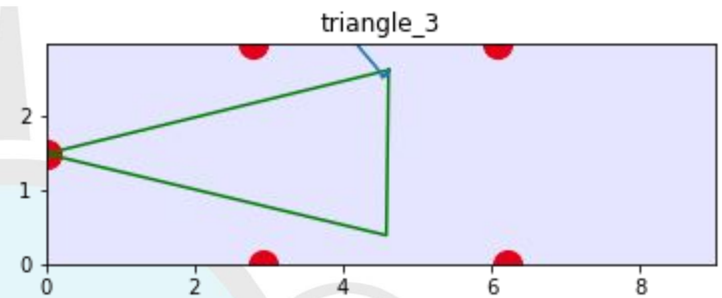




Without ZUPT







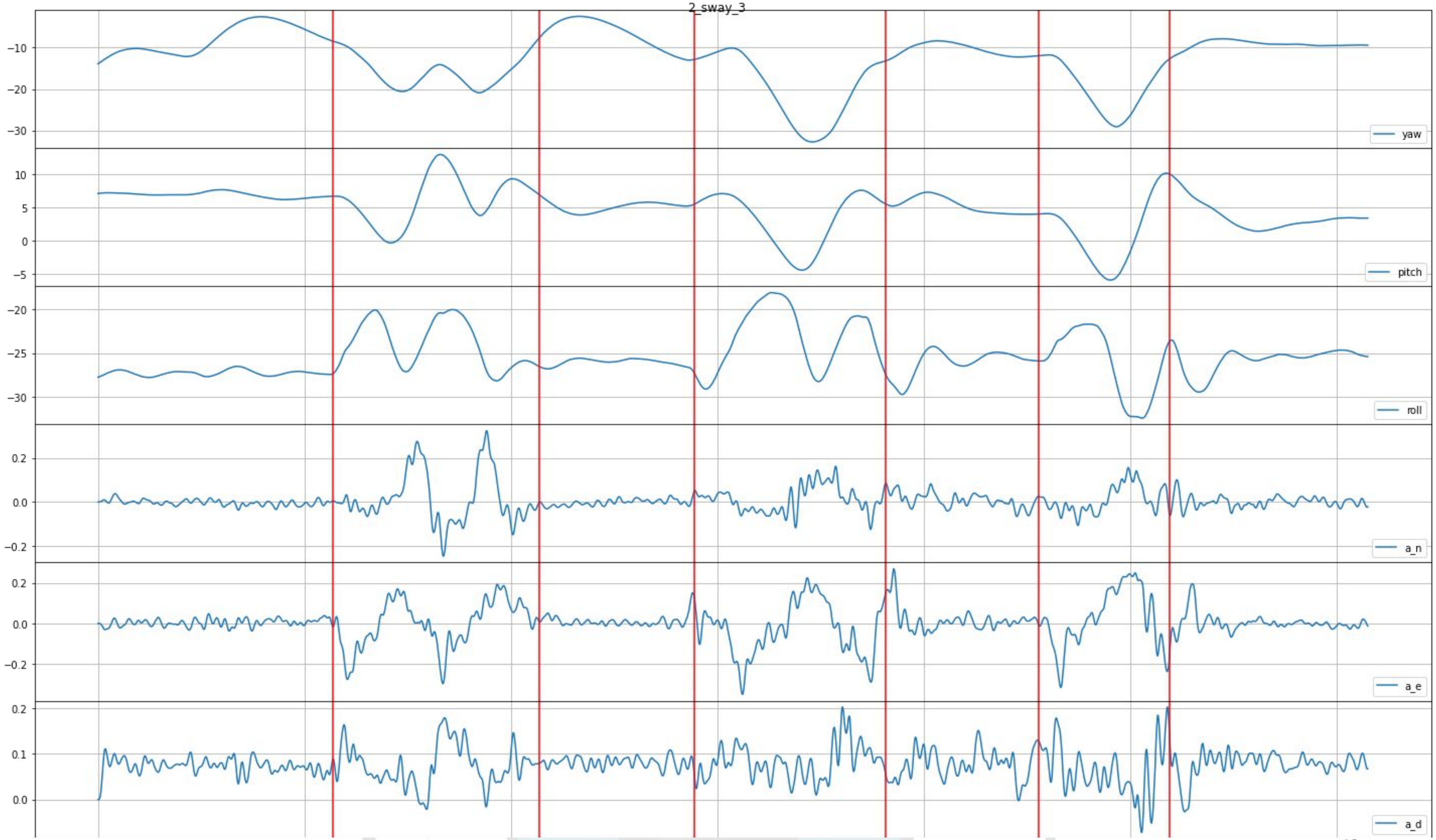
ZUPT - On the ROV

- As mentioned above we conducted test on mikros in the pool
- The bellow plots show the data collected from that run

- The red lines indicate the ground truth of start and stop of the motion.

ZUPT - On the ROV

- Via visual inspection, we noticed that there is deviation in the roll pitch yaw angles when the ROV is in motion.



ZUPT - Zero Velocity Potential Update

- A couple of toy metrics to detect motion that show promise

ZUPT - Zero Velocity Potential Update

- Our experiments have only reached a proof of concept stage. However they have verified that this technique is suitable for our problem.

Next Steps:

- We need to collect more data to choose a metric for the `in_motion` step
- We need to gather data from a better tuned ROV
- It may be profitable to train a small network to take orientation, acceleration, and output the `in_motion` state.

- The algorithm needs to be modified to work one sample at a time to work with the filtering algorithm.

Probabilistic Filtering

Probabilistic Filtering

There are two main types of filtering algorithms:

- Kalman Filters
- Particle Filters

They both have similar principals but different ways to represent the current distribution of probable states.

Particle Filters provide support for more complex distributions via an approximation, however we do not require those distributions.

Probabilistic Filtering - Kalman Filter

How it works.

Probabilistic Filtering - Kalman Filter

- As seen in the earlier section, Kalman Filtering with just acoustic results shows good results
- We were not able to properly test acoustic + IMU fusion as the ZUPT algorithm is not ready yet.

Probabilistic Filtering - Kalman Filtering

- There are multiple types of Kalman filters. We currently implemented a vanilla Kalman filter.

- In the future, when adding sensors with more complex measurement models, or to get better numerical fidelity
  - Specifically, we need to switch to an Error-State Kalman filter
  - For complex sensors we can integrate the Extended or Unscented propagation.

Extensibility of the Filtering

- With a Kalman filter, new sensors can be added as just another step in the measurement stage.
- All that needs to be known is the “measurement model” and the variance of the sensor’s data

- The Depth Sensor and the Doppler Velocity Log (DVL) are two very easily integrable sensors.

Kalman Filter - Next Steps

- To progress on this front, we need to receive reasonably accurate position, acceleration, and ZUPT data.

- The ZUPT model needs to be worked upon
- Small tests need to be performed to isolate the problem in the last set of acoustic data

- A new set of full tests need to be conducted to provide data on which we can test and iterate our kalman filter parameters.

PLANYS
TECHNOLOGIES

Positioning Systems

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