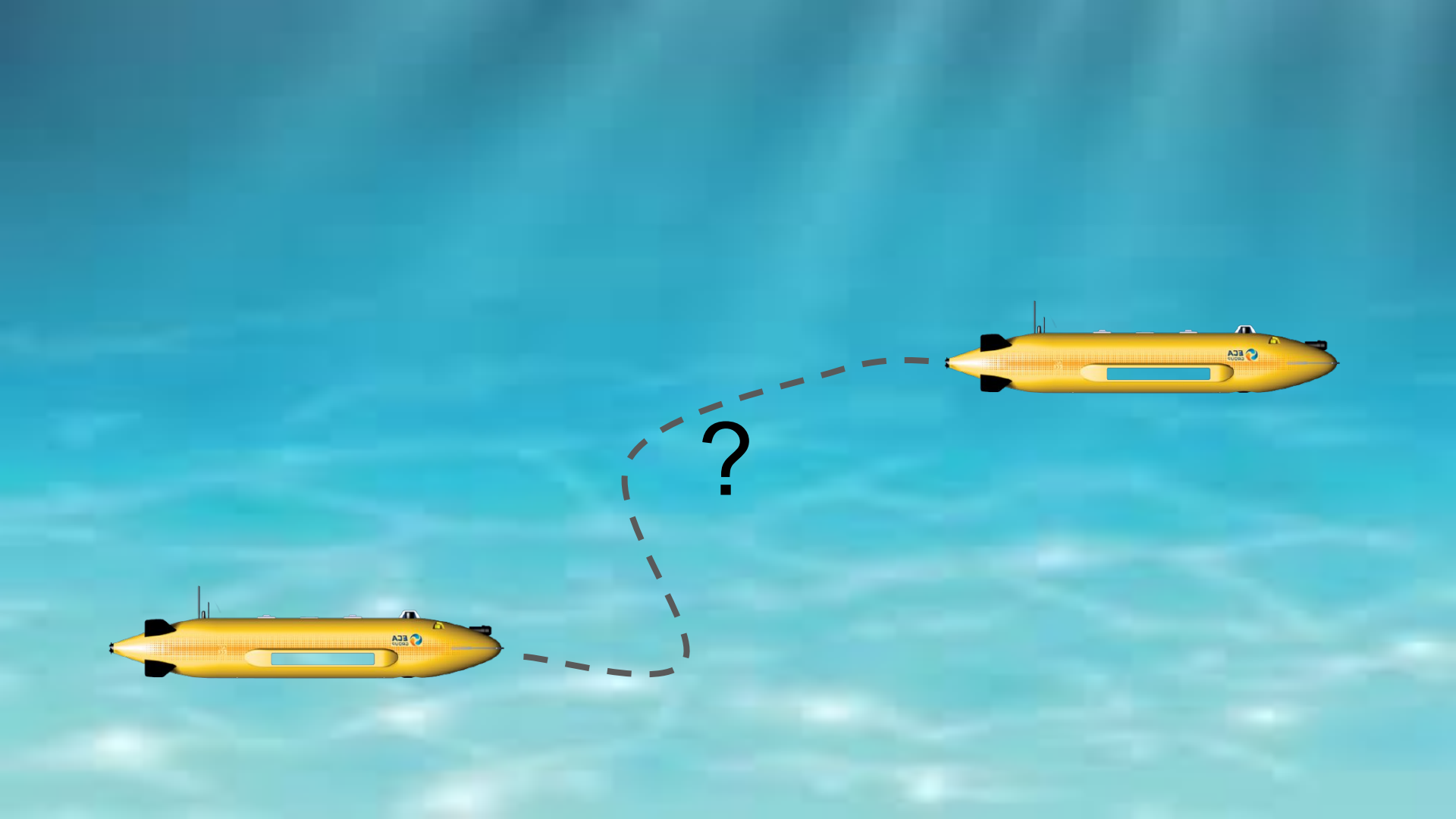
Passive Inverted Ultra-Short Baseline (piUSBL) Localization:
An Experimental Evaluation of Accuracy

Presented by: Laura Dodds

N. R. Rypkema and H. Schmidt, "Passive Inverted Ultra-Short Baseline (piUSBL) Localization: An Experimental Evaluation of Accuracy," 2019 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS), 2019, pp. 7197-7204, doi: 10.1109/IROS40897.2019.8967800.

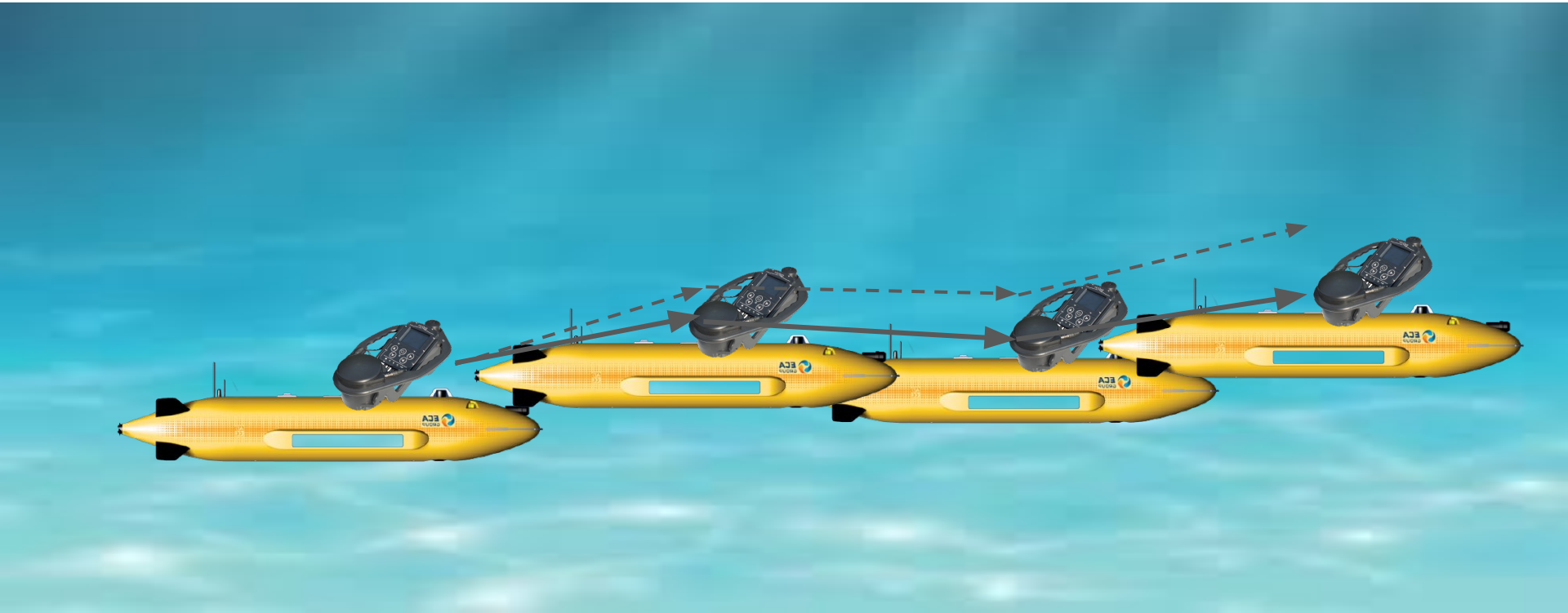


GPS

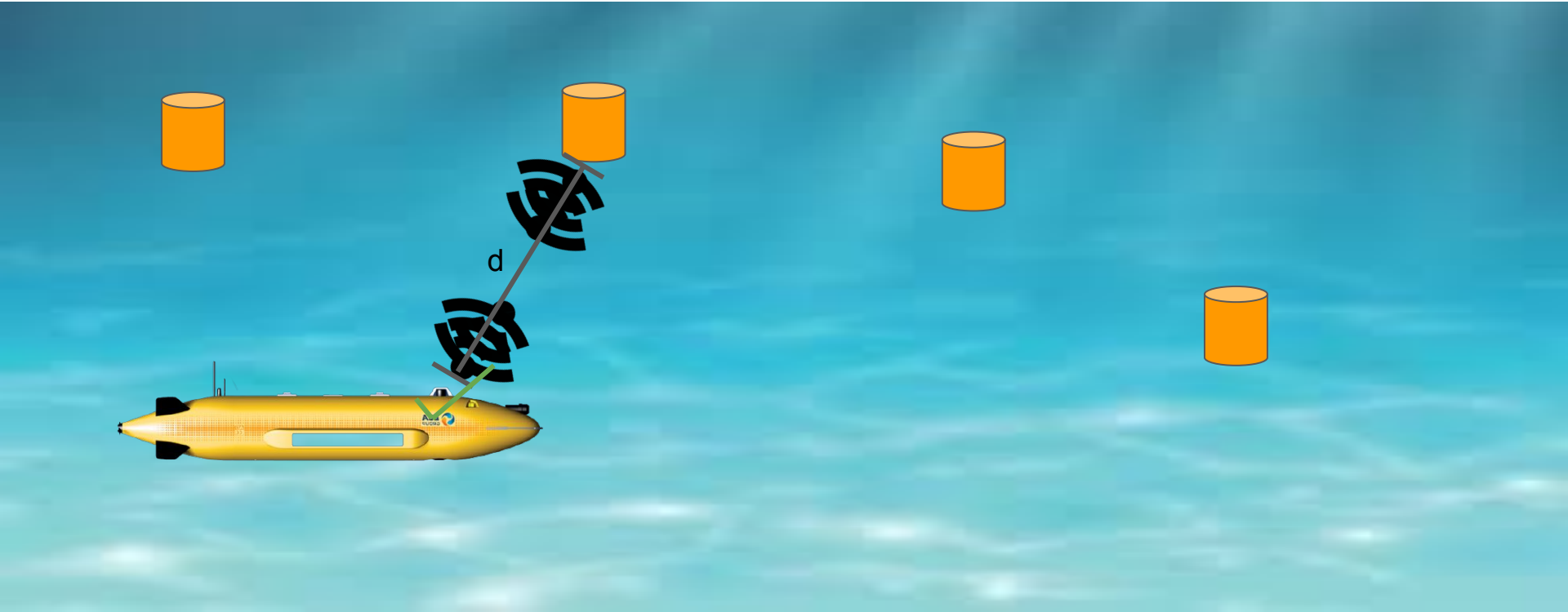
GPS signals will not work underwater

Doppler Velocity Log(DVL) & Inertial Navigation System (INS)

DVL & INS are too expensive and drift over time

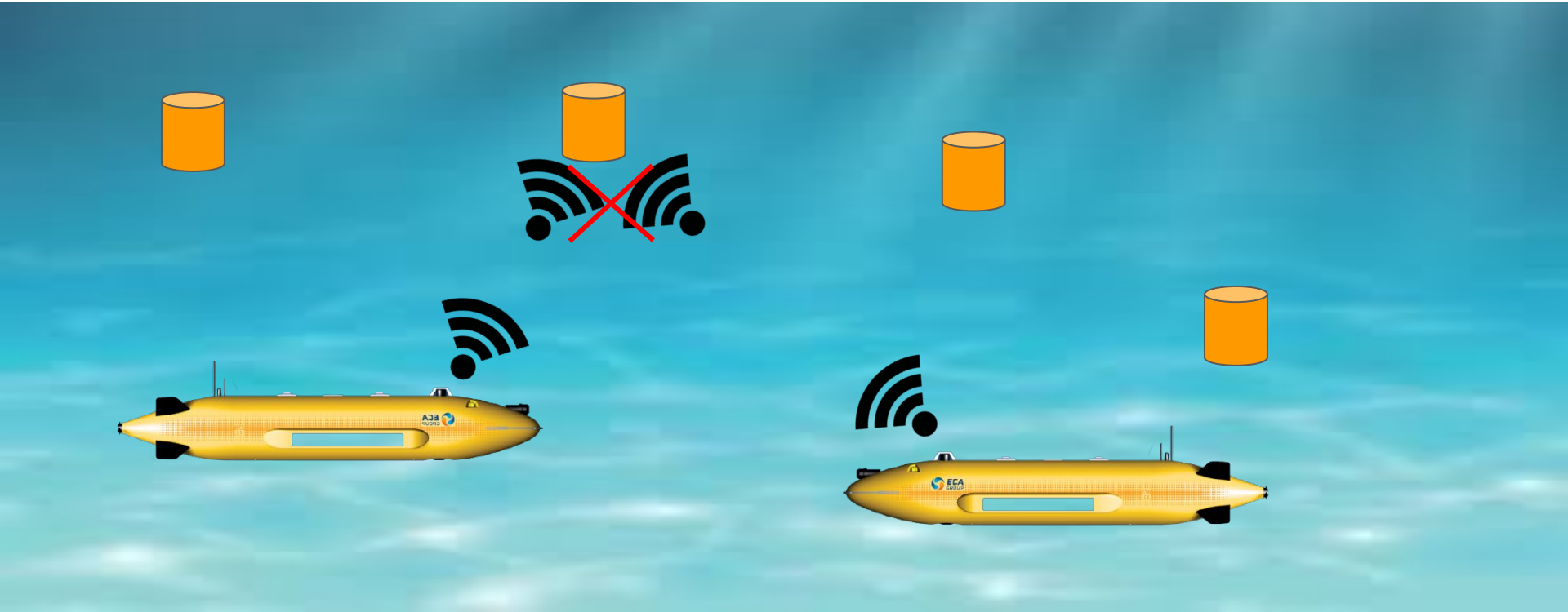


Long Baseline (LBL)



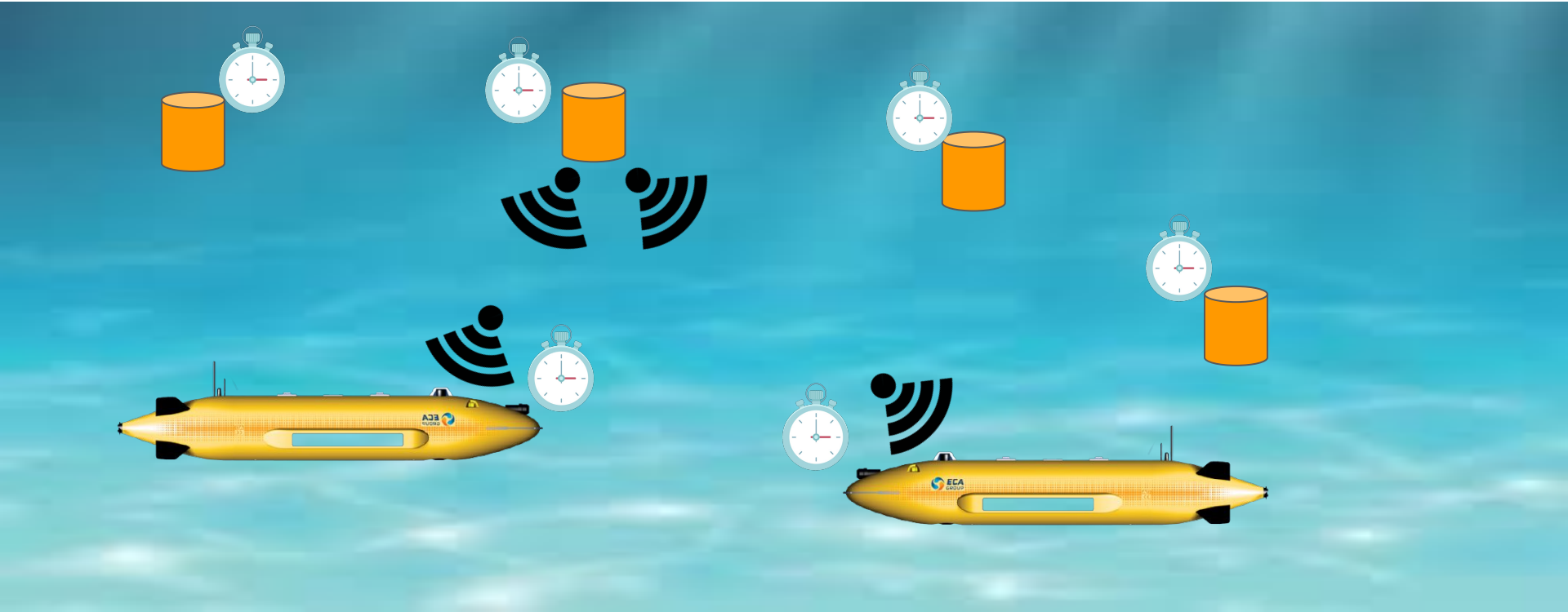
Long Baseline (LBL)

LBL is difficult to deploy and not scalable

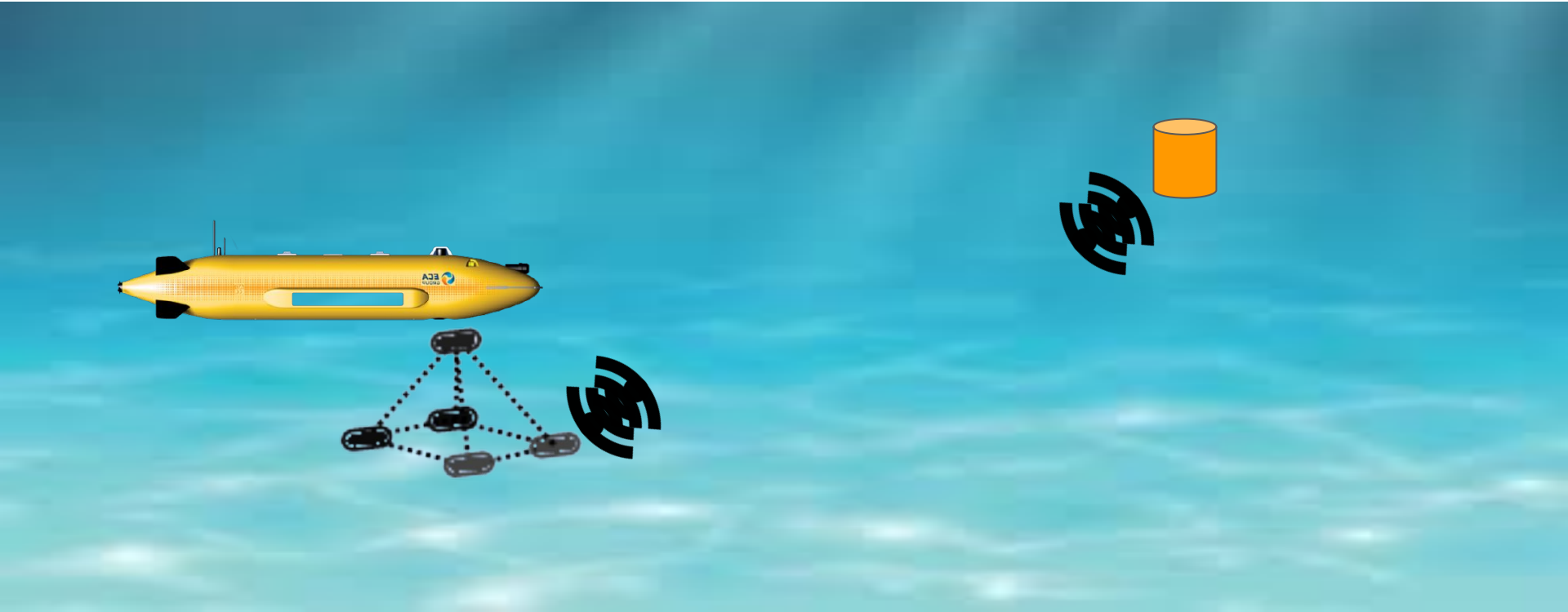


Passive Long Baseline (pLBL)

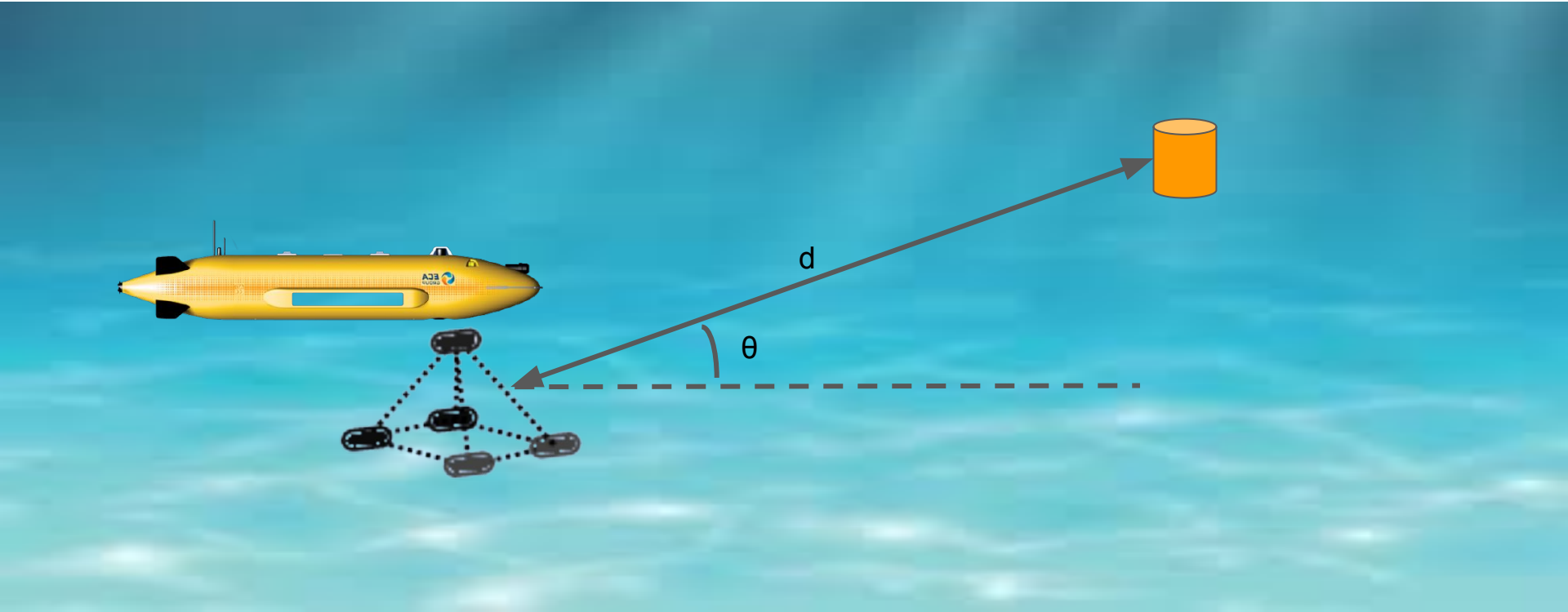
Passive LBL is difficult to deploy



Ultra-Short Baseline (USBL)

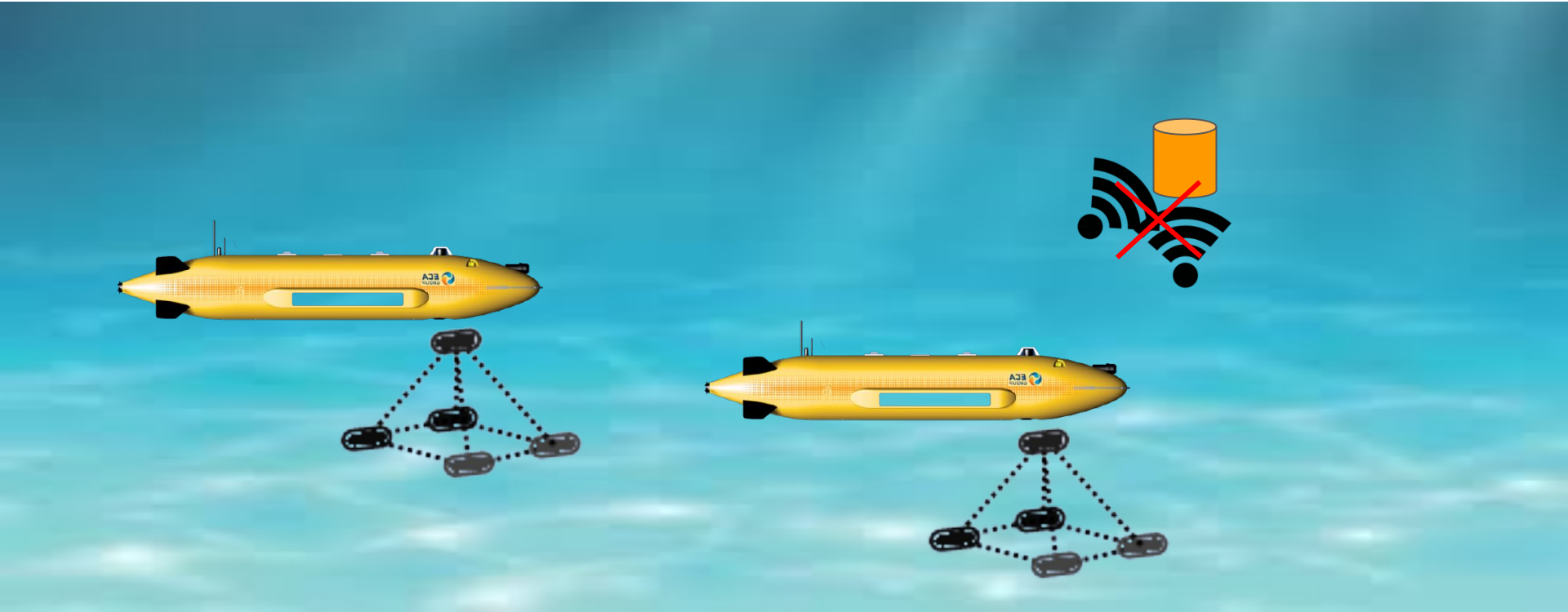


Ultra-Short Baseline (USBL)



Ultra-Short Baseline (USBL)

USBL is not scalable



Can we create a scalable, low-cost underwater localization system?

Passive Inverted Ultra-Short Baseline(piUSBL)

Scalable

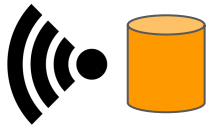
Passive

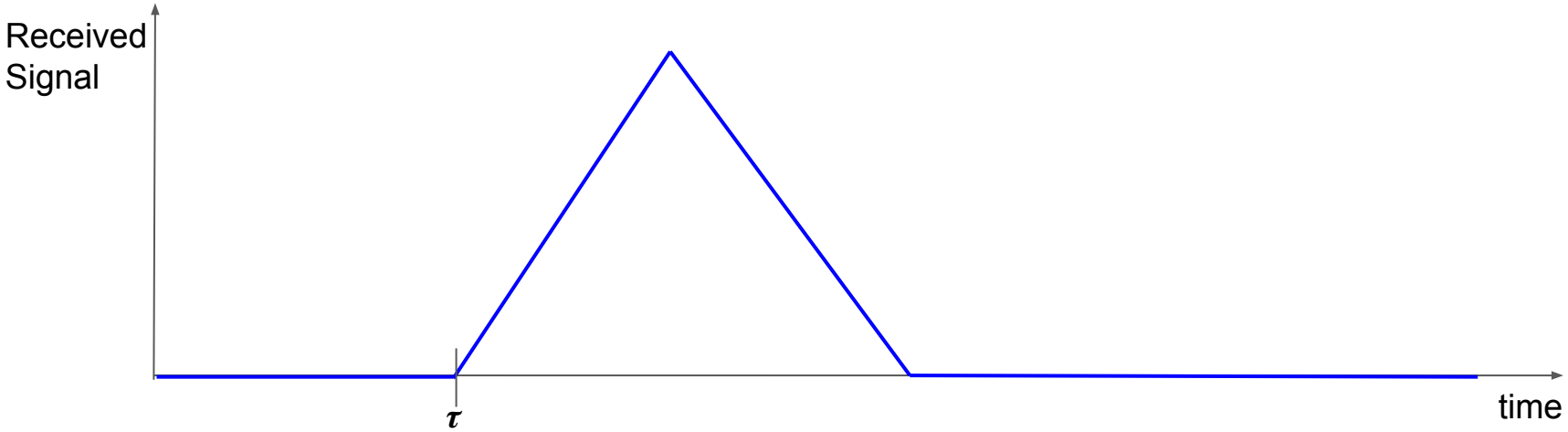
Low Cost

One beacon

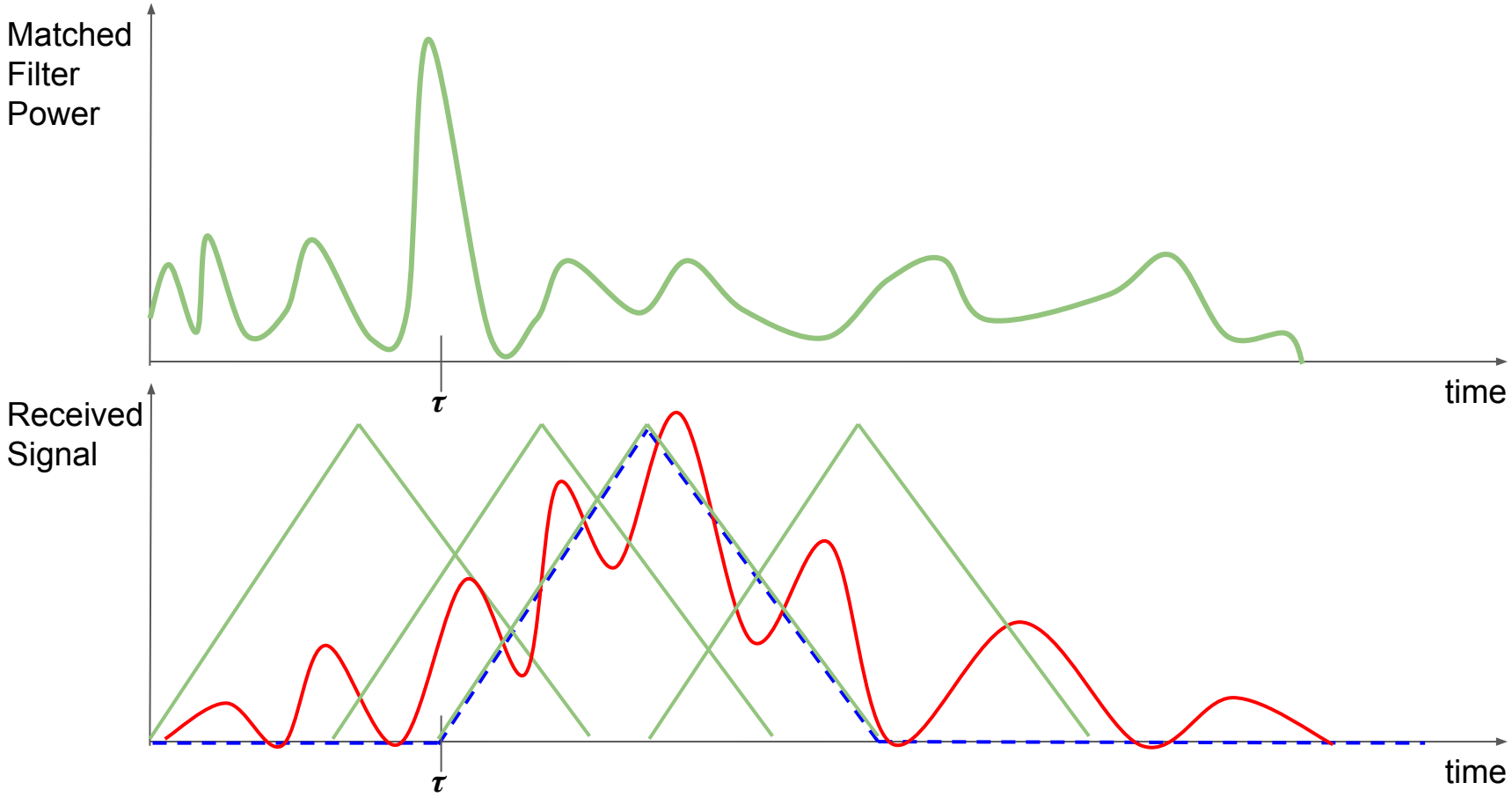
Pre-Filter

Measuring Range



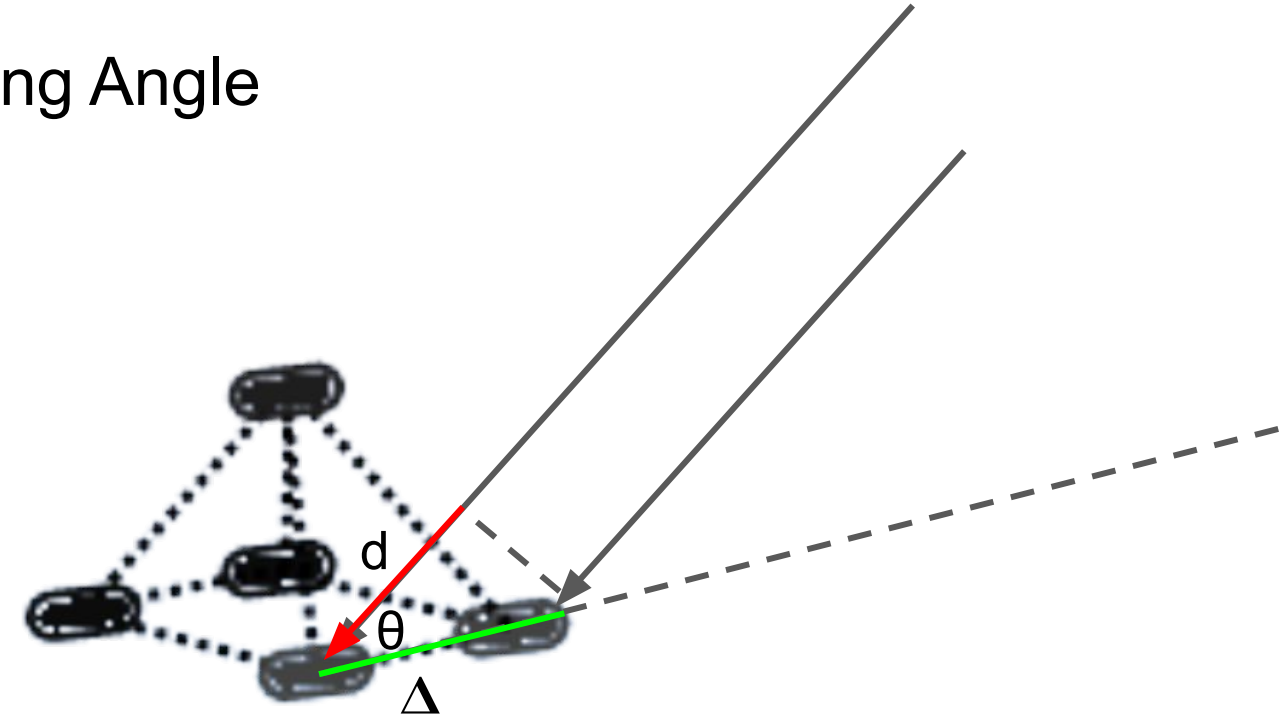


Measuring Range



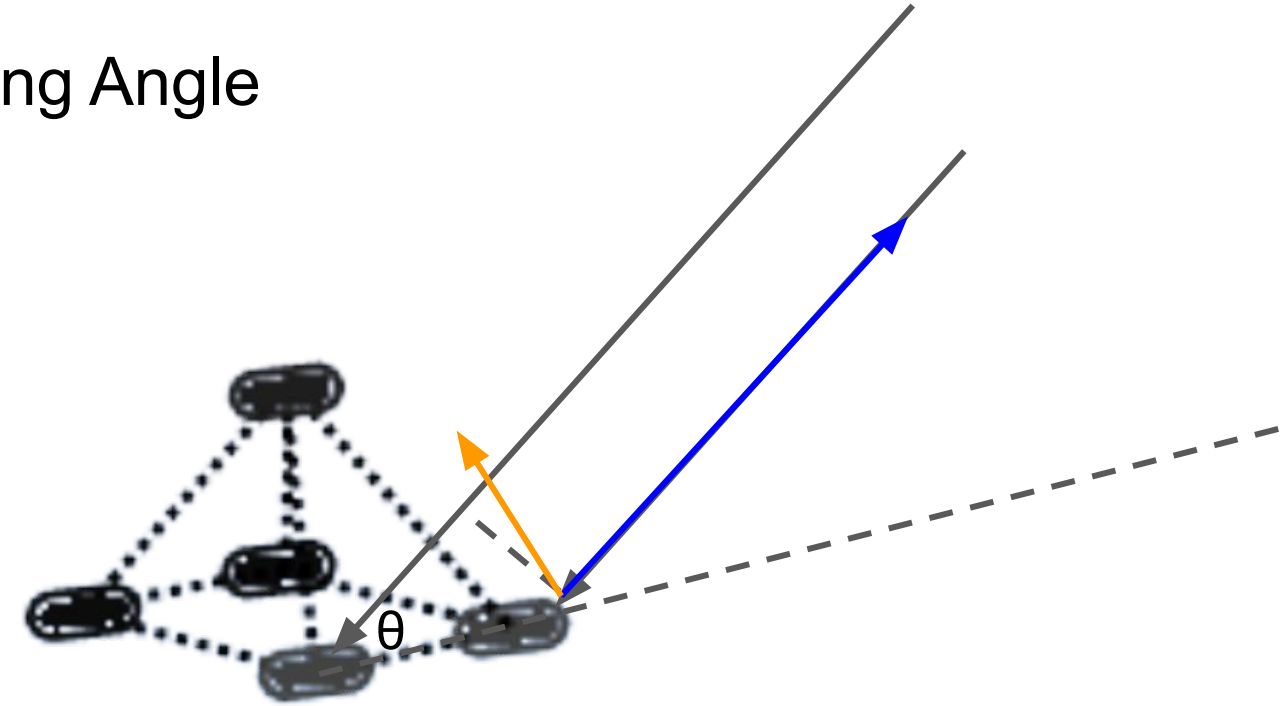
Range - Speed of Sound

Measuring Angle



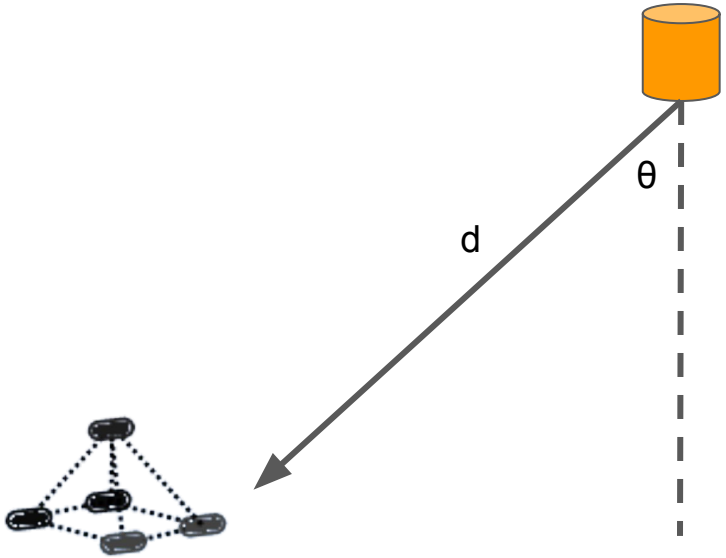
$$d = \Delta\cos(\theta)$$

Measuring Angle

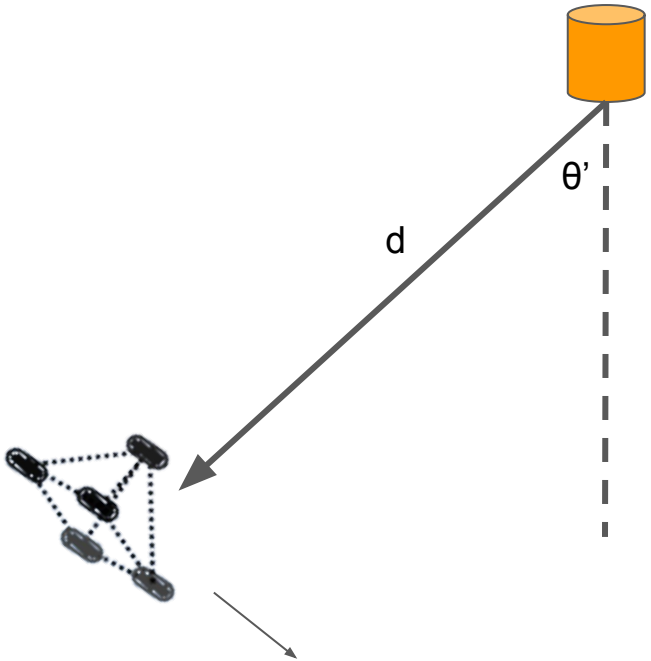


Angle - Azimuth Bias

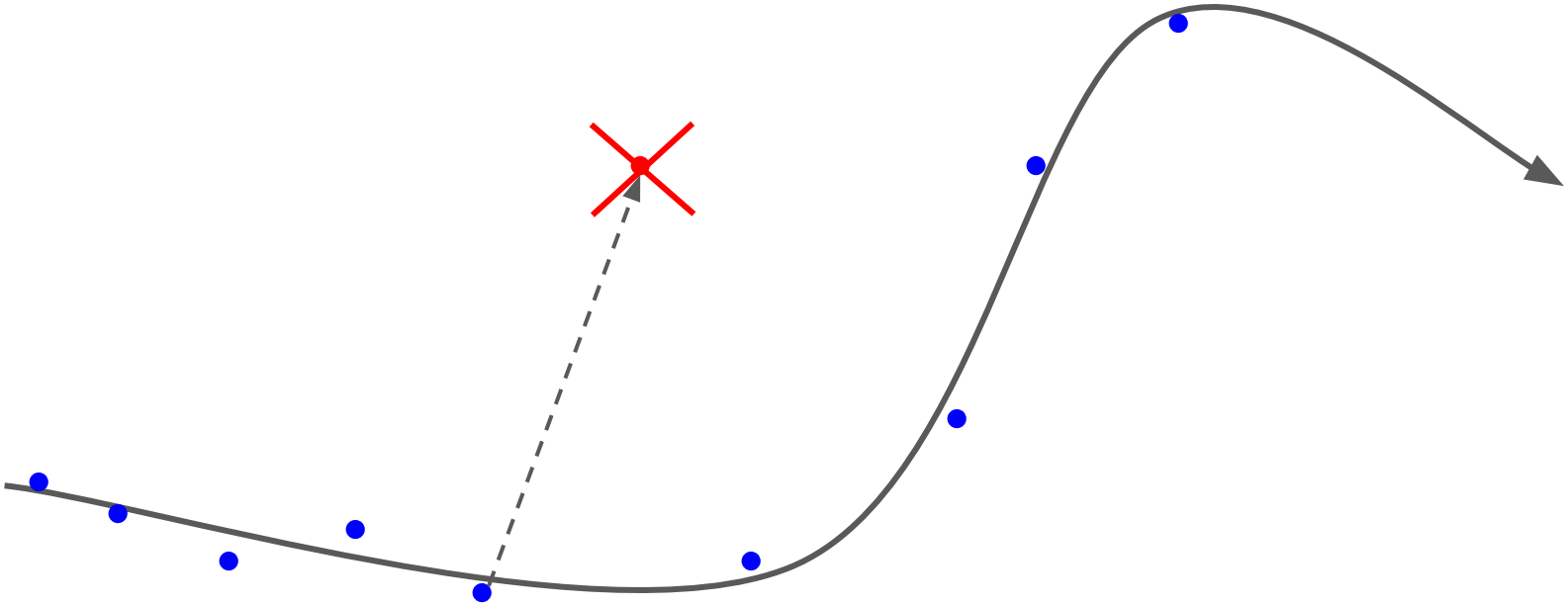
Combining Angle and Range

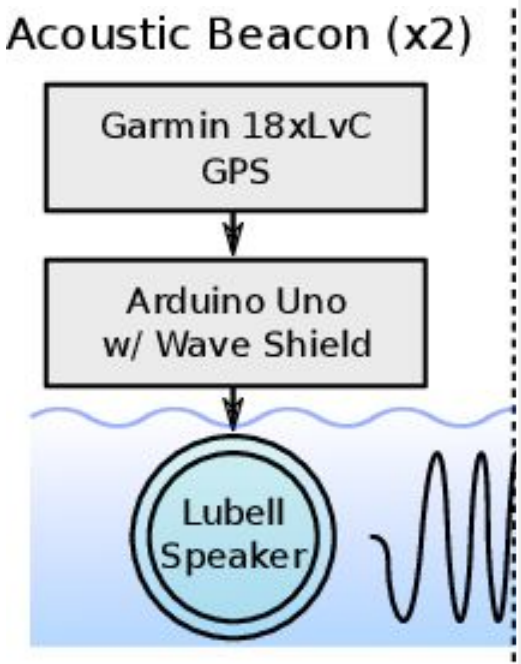


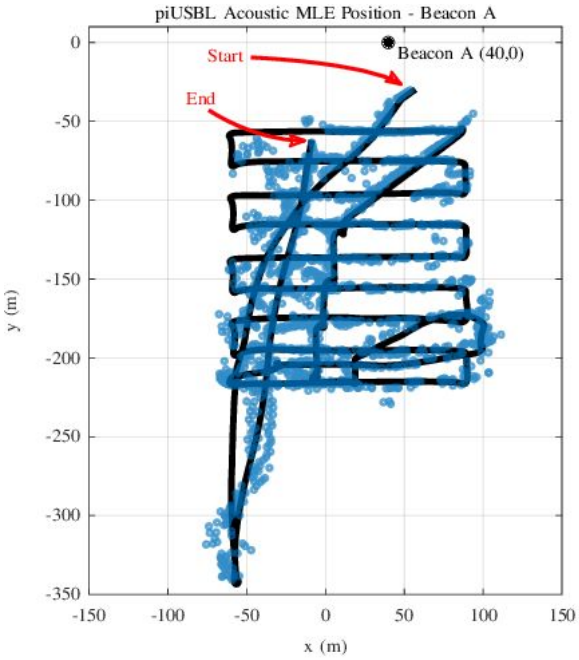
Combining Angle and Range

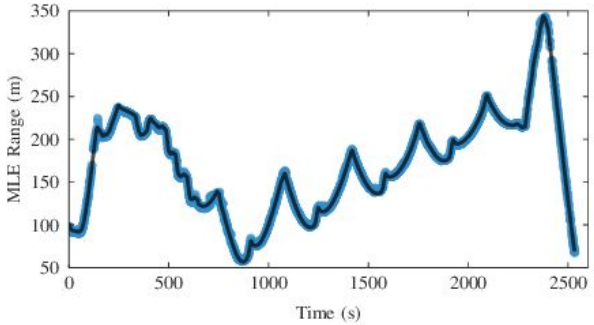


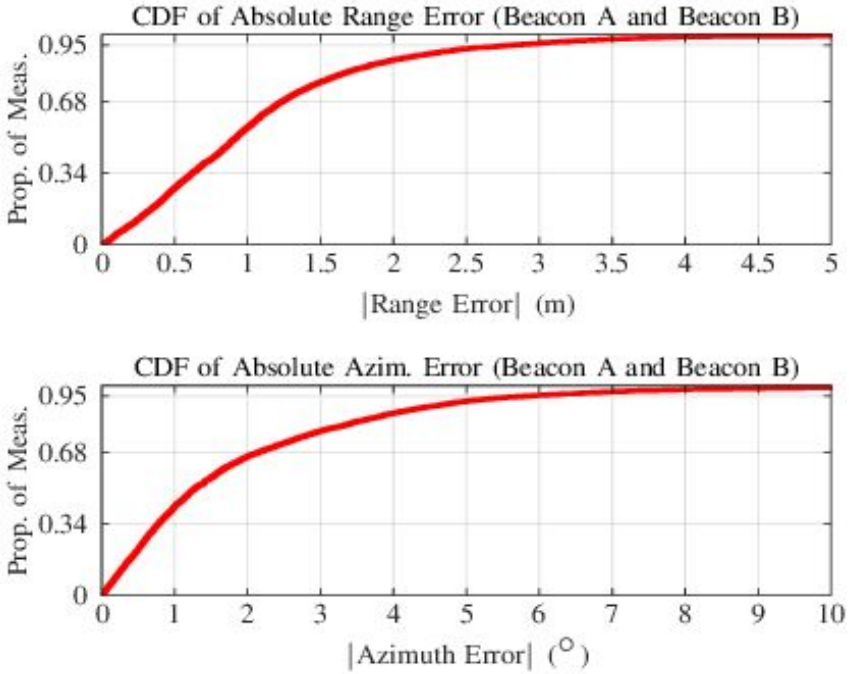
Outlier Rejection

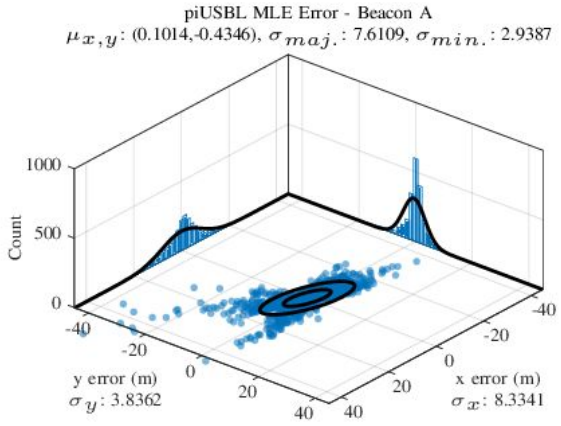


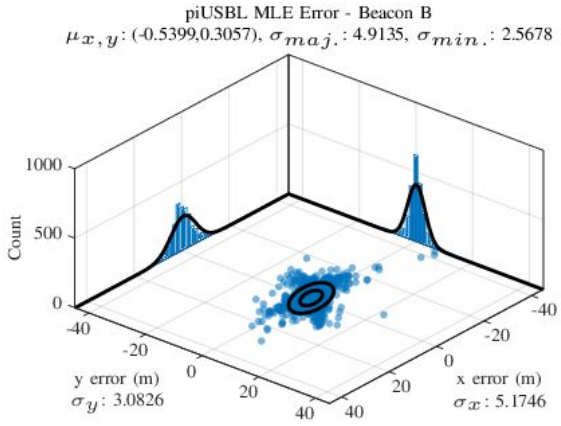

Acoustic Beacon (x2)
Garmin 18xLvC
GPS
Arduino Uno
w/ Wave Shield
Lubell
Speaker

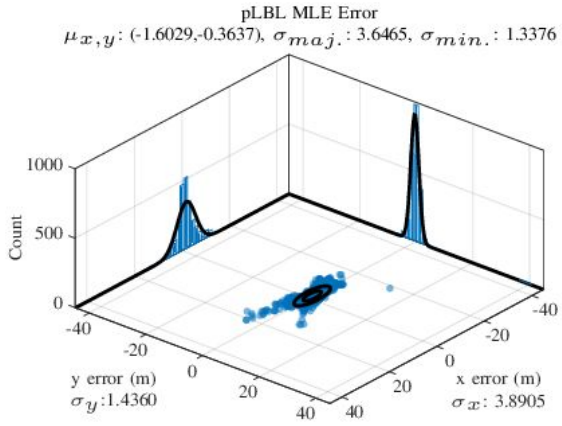

piUSBL Acoustic MLE Position - Beacon A
Start
End
Beacon A (40,0)
0
-50
-100
-150
-200
-250
-300
-350
y (m)
-150
-100
-50
0
50
100
150
x (m)


MLE Range (m)
350
300
250
200
150
100
50
0
500
1000
1500
2000
2500
Time (s)


CDF of Absolute Range Error (Beacon A and Beacon B)
Prop. of Meas.
0.95
0.68
0.34
0
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
|Range Error| (m)
CDF of Absolute Azim. Error (Beacon A and Beacon B)
Prop. of Meas.
0.95
0.68
0.34
0
0
1
2
3
4
5
6
7
8
9
10
|Azimuth Error| (°)


piUSBL MLE Error - Beacon A
$\mu_{x,y}$: (0.1014,-0.4346), $\sigma_{maj.}$: 7.6109, $\sigma_{min.}$: 2.9387
Count
1000
500
0
-40
-20
0
20
40
y error (m)
σ_y: 3.8362
x error (m)
σ_x: 8.3341

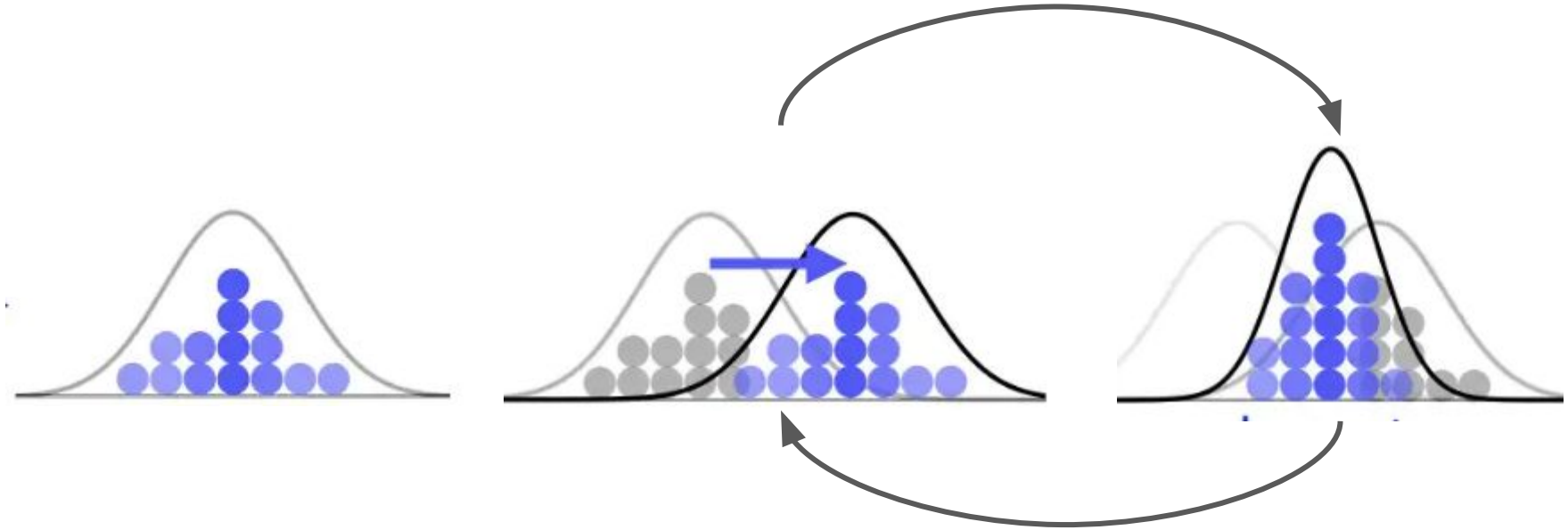

piUSBL MLE Error - Beacon B
$\mu_{x,y}$: (-0.5399,0.3057), $\sigma_{maj.}$: 4.9135, $\sigma_{min.}$: 2.5678
Count
1000
500
0
-40
-20
0
20
40
y error (m)
σ_y: 3.0826
x error (m)
σ_x: 5.1746


pLBL MLE Error
$\mu_{x,y}$: (-1.6029,-0.3637), $\sigma_{maj.}$: 3.6465, $\sigma_{min.}$: 1.3376
Count
1000
500
0
-40
-20
0
20
40
y error (m)
σ_y:1.4360
x error (m)
σ_x: 3.8905

Can we do better?

Yes! With a cheap IMU

Particle filter

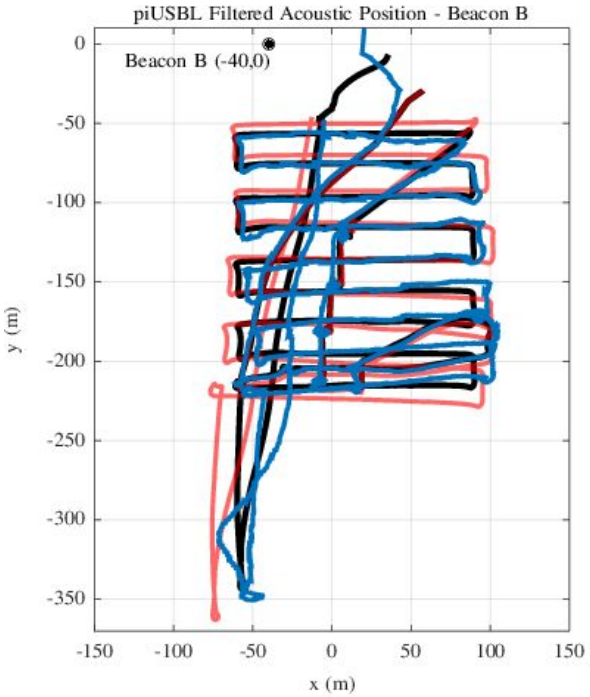


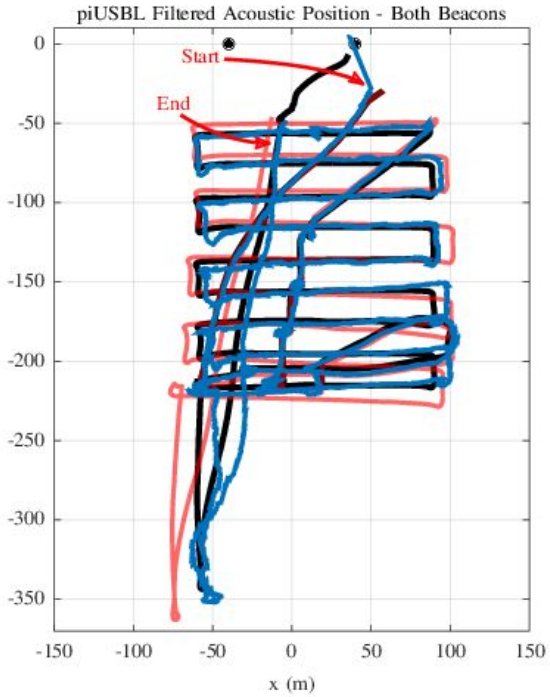
Last GPS Reading

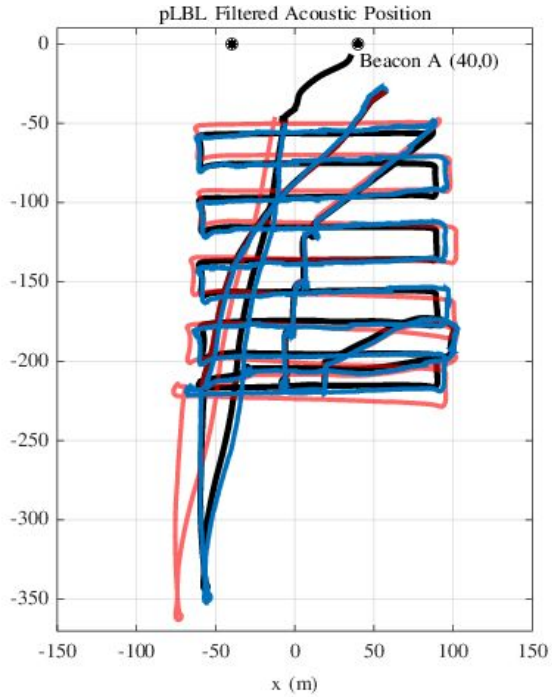
IMU Readings

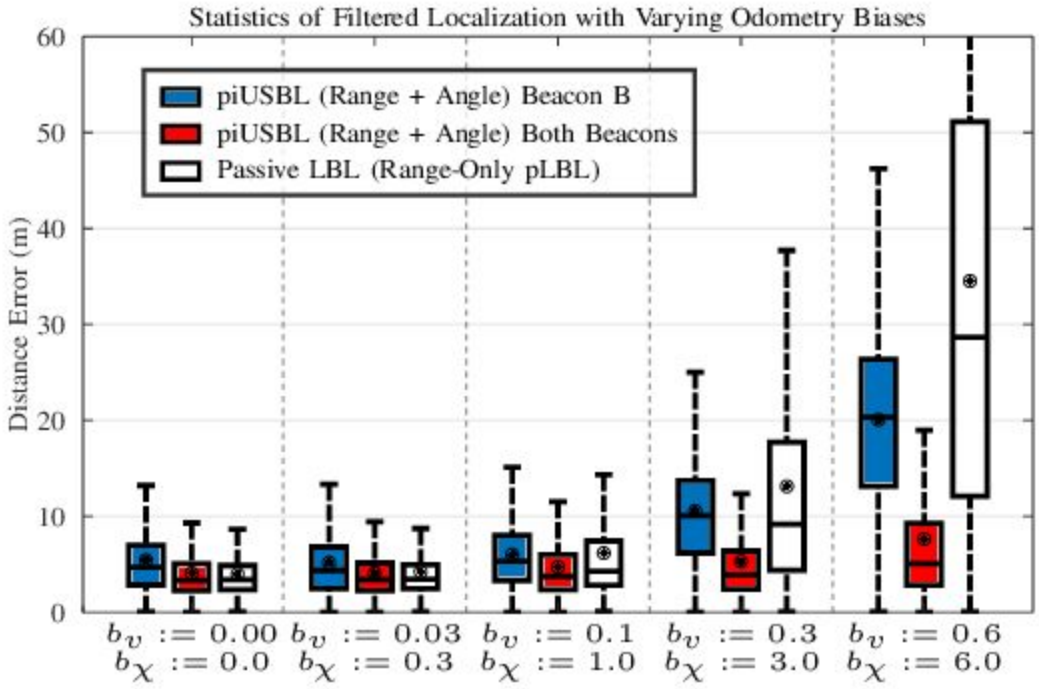
Range & Angle

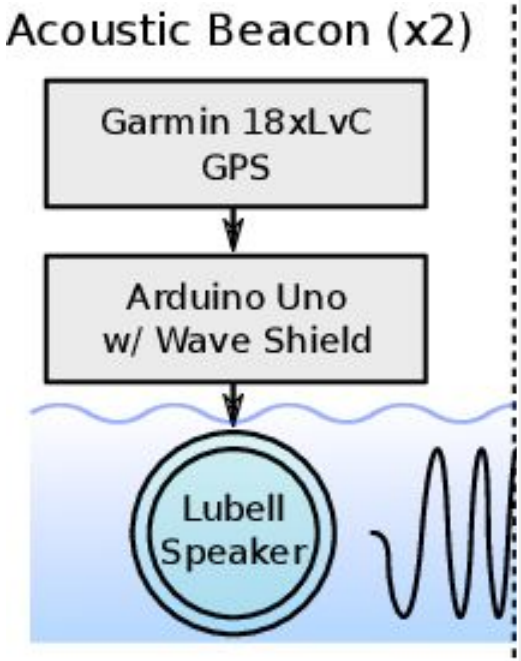
Source: https://www.slideshare.net/kohta/particle-filter-tracking-in-python


piUSBL Filtered Acoustic Position - Beacon B
Beacon B (-40,0)
y (m)
x (m)
0
-50
-100
-150
-200
-250
-300
-350
-150
-100
-50
0
50
100
150


piUSBL Filtered Acoustic Position - Both Beacons
Start
End
x (m)
0
-50
-100
-150
-200
-250
-300
-350
-150
-100
-50
0
50
100
150


pLBL Filtered Acoustic Position
Beacon A (40,0)
x (m)
0
-50
-100
-150
-200
-250
-300
-350
-150
-100
-50
0
50
100
150


Statistics of Filtered Localization with Varying Odometry Biases
piUSBL (Range + Angle) Beacon B
piUSBL (Range + Angle) Both Beacons
Passive LBL (Range-Only pLBL)
Distance Error (m)
0
10
20
30
40
50
60
$b_v := 0.00$ $b_\chi := 0.0$
$b_v := 0.03$ $b_\chi := 0.3$
$b_v := 0.1$ $b_\chi := 1.0$
$b_v := 0.3$ $b_\chi := 3.0$
$b_v := 0.6$ $b_\chi := 6.0$


Acoustic Beacon (x2)
Garmin 18xLvC
GPS
Arduino Uno
w/ Wave Shield
Lubell
Speaker

Passive Inverted Ultra-Short Baseline(piUSBL)

Scalable to multiple robots

Low cost

Easier to deploy

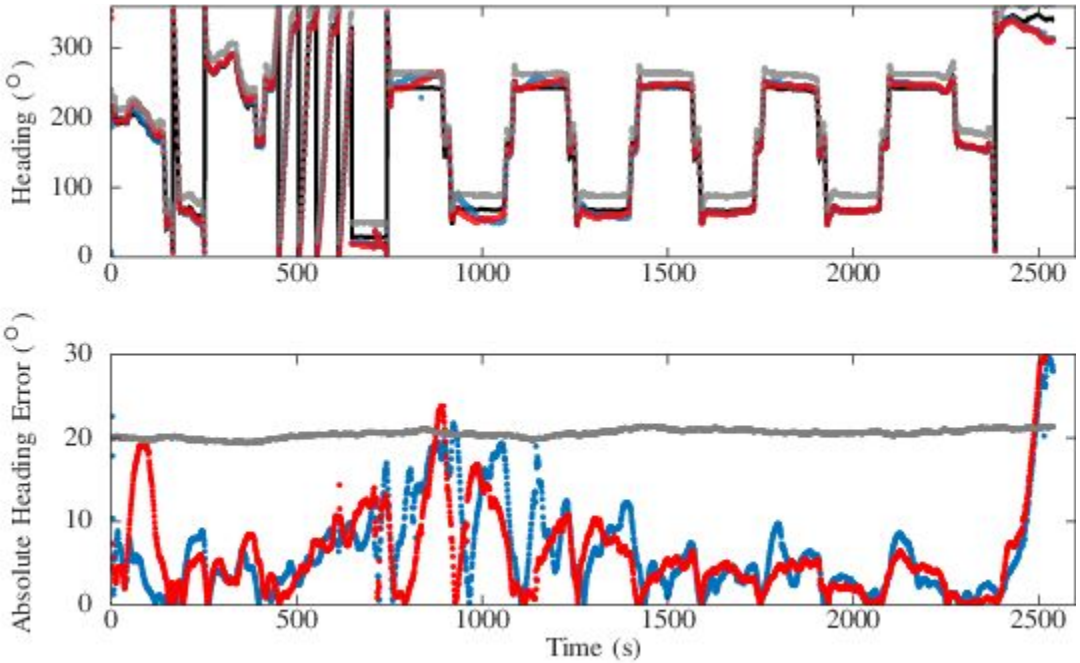
Outstanding Questions

1. How well will the system perform with various
    a. Depth
    b. Pitch
    c. Roll

2. How well will the system perform when not using GPS for synchronization?

3. Will the performance match when using a real IMU?

Thanks for listening!


Heading (°)
300
200
100
0
0
500
1000
1500
2000
2500
Absolute Heading Error (°)
30
20
10
0
0
500
1000
1500
2000
2500
Time (s)