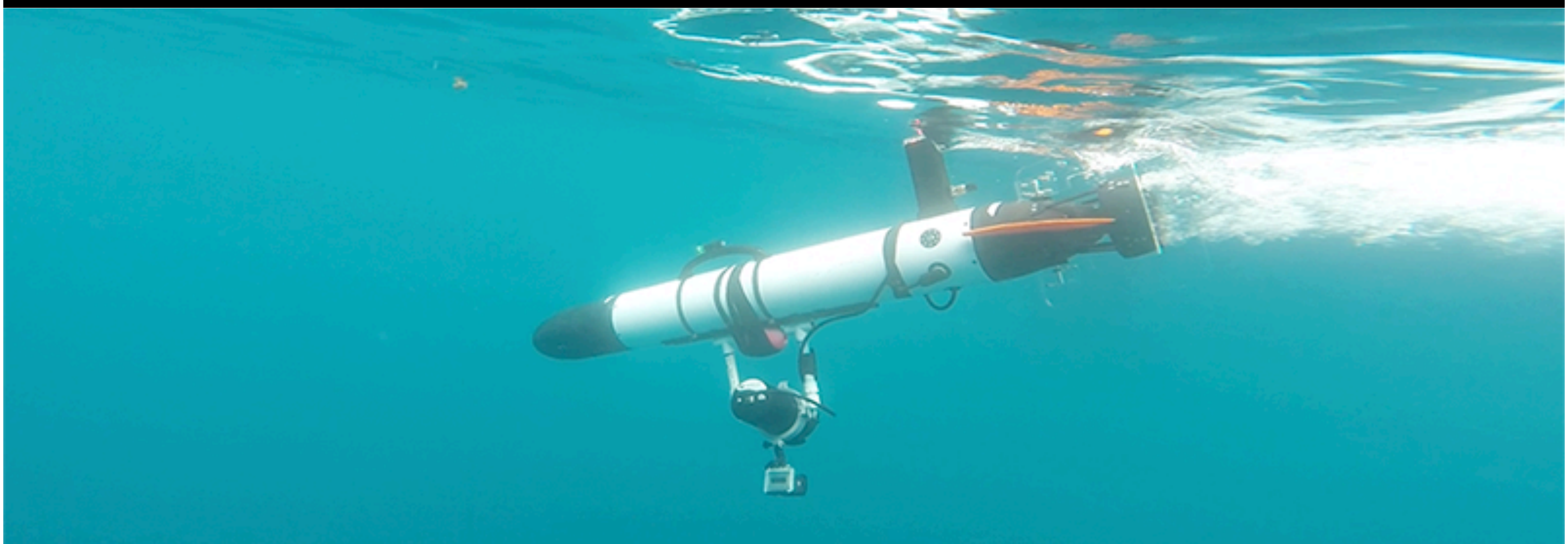
MRRSS

Marine Robotics Research Summer School

Research Topics in Underwater Robotics

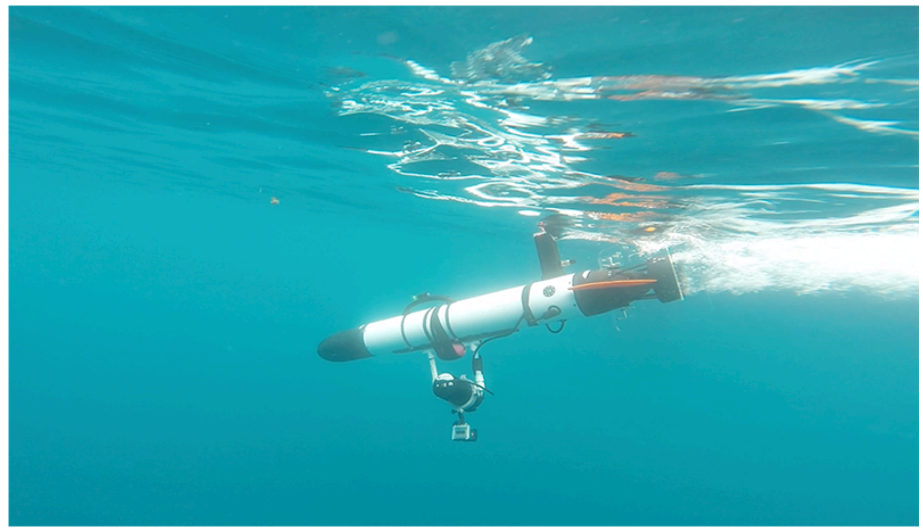


MRRSS - 2016

Christopher M. Clark

Welcome!

1. Overview
2. Example Project
3. Exercise B



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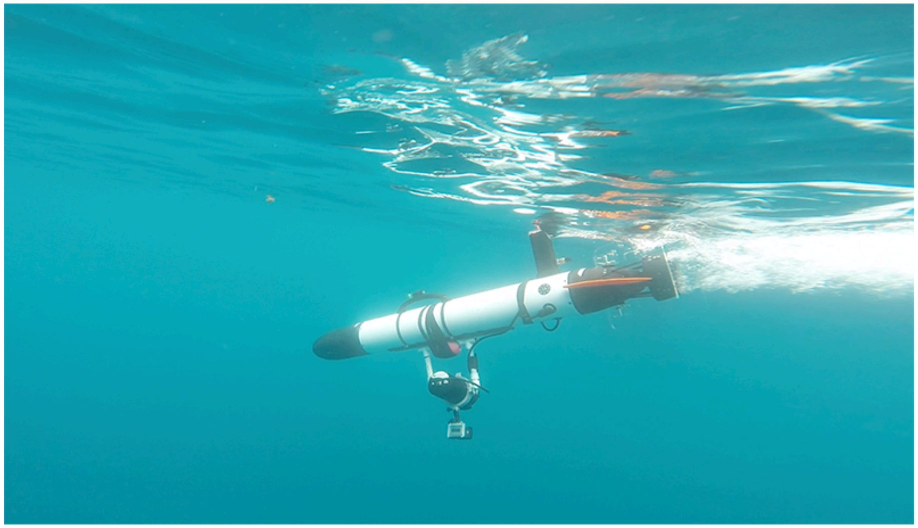
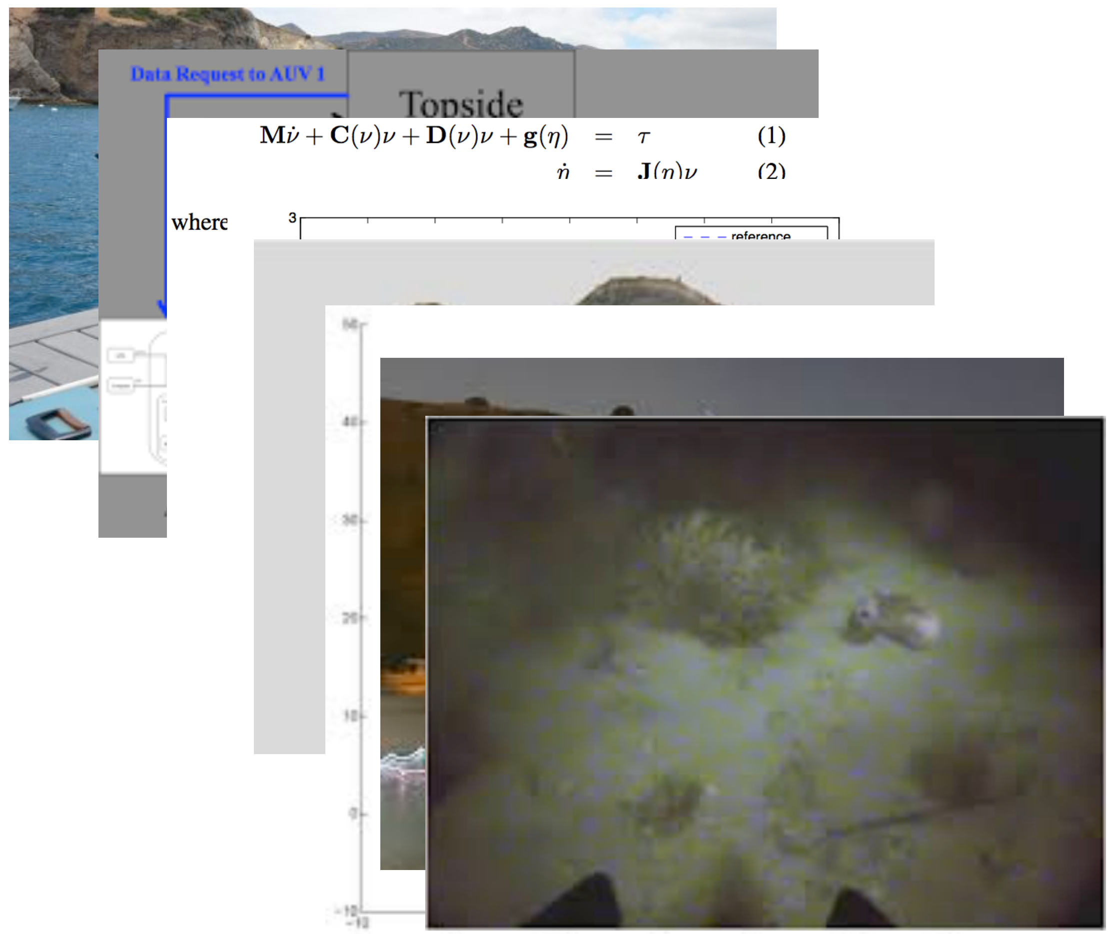


1. Overview

- Platform Hardware
- Software Architecture
- Vehicle Modeling
- Control Theory
- State Estimation
- Mapping
- Planning
- Multi-Robot Systems
- Driven by Applications



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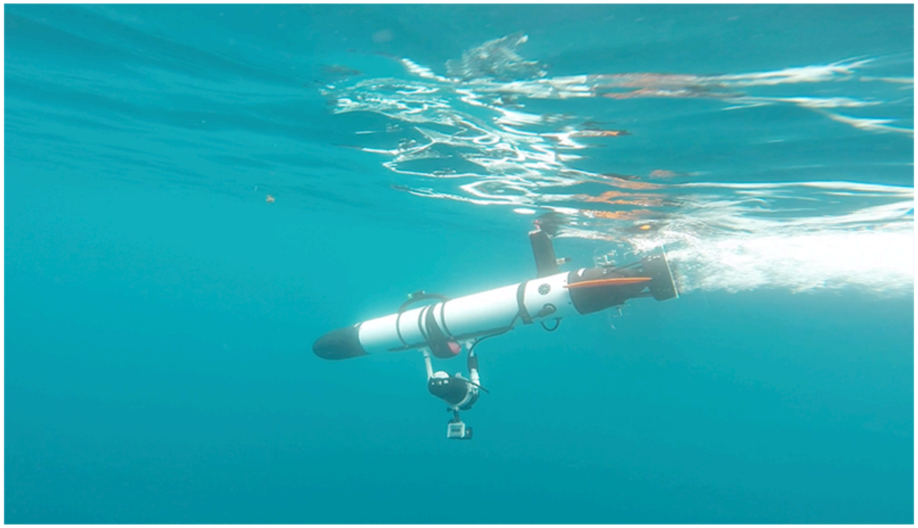

Related Work

- [11] T. Grothues, J. Dobarro, and J. Eiler, "Collecting, interpreting, and merging fish telemetry data from an auv: Remote sensing from an already remote platform," in Autonomous Underwater Vehicles (AUV), 2010 IEEE/OES, Monterey, CA, 2010, pp. 1–9.
- [12] J. Rife and S. M. Rock, "Segmentation Methods for Visual Tracking of Deep-Ocean Jellyfish using a Conventional Camera," IEEE Journal of Oceanic Engineering, vol. 28, no. 4, pp. 595–608, 2003.
- [13] J. Zhou and C. M. Clark, "Autonomous fish tracking by ROV using monocular camera," Computer and Robot Vision, Canadian Conference, vol. 0, p. 68, 2006.
- [16] M. J. Oliver, M. W. Breece, D. A. Fox, D. E. Haulsee, J. T. Kohut, J. Manderson, and T. Savoy, "Shrinking the haystack: using and auv in an integrated ocean observatory to map Atlantic sturgeon in the coastal ocean," Fisheries, vol. 38, 2013.
- [17] Gwyneth E. Packard, Amy Kukulya, Tom Austin, Mark Dennett, Robin Littlefield, Gregory Packard, Mike Purcell, & Roger Stokey, Continuous Autonomous Tracking and Imaging of White Sharks and Basking Sharks Using a REMUS-100 AUV, Oceans, 2013

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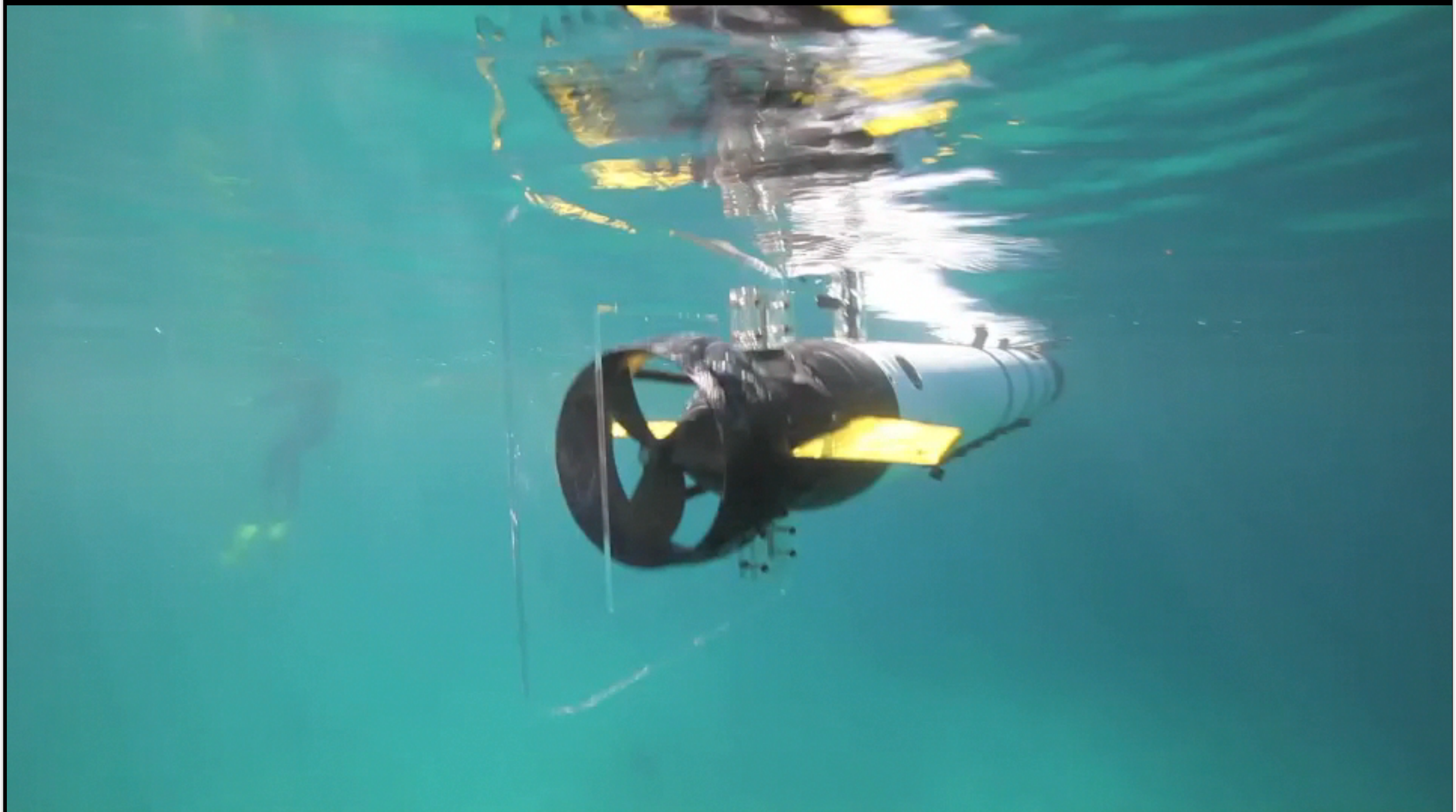
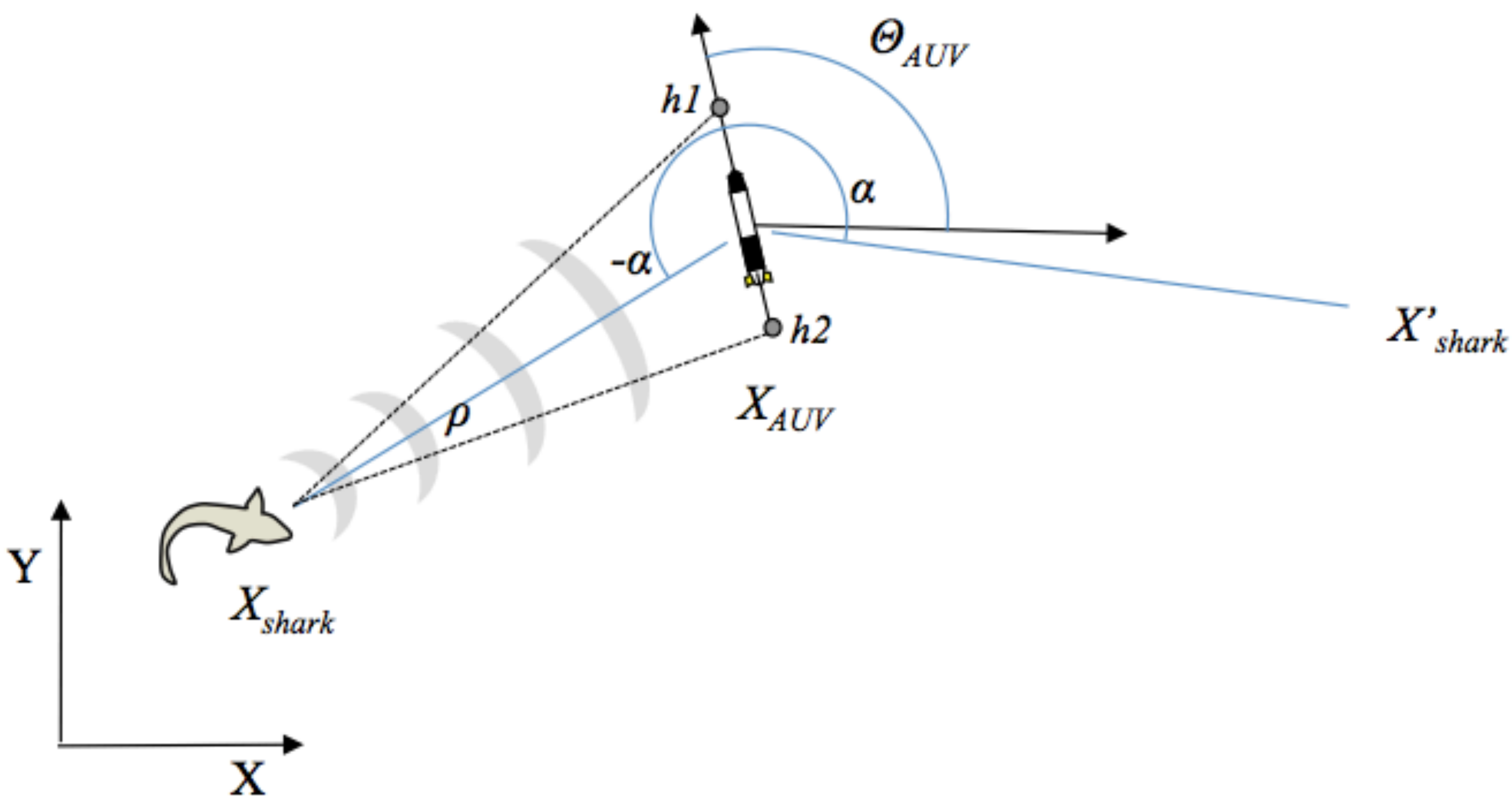


Estimation



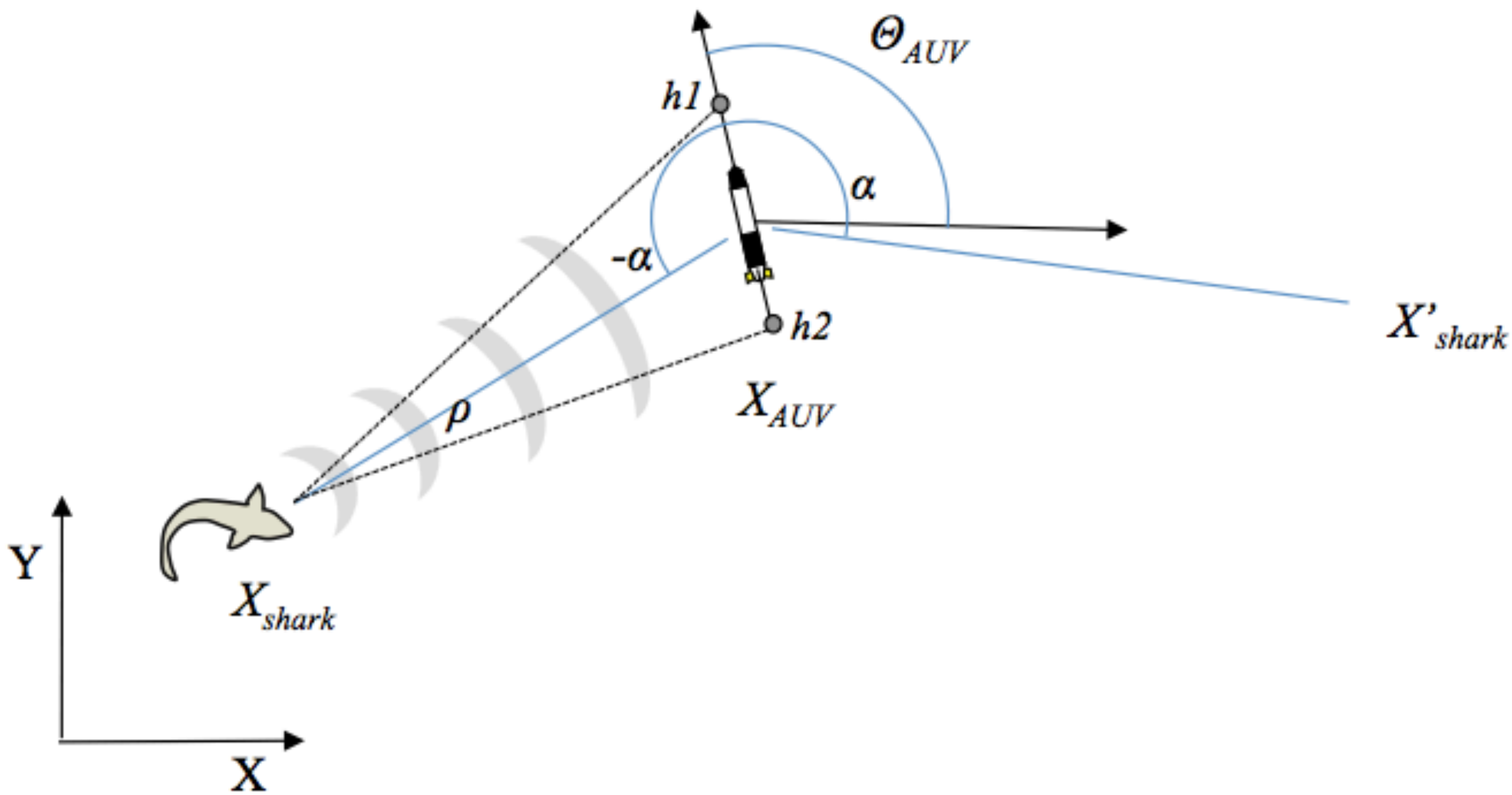
Estimation

- What is a Particle this time?
  - A particle is an individual state estimate.
  - In our shark Tracking, a particle i has two components

$$\{ \underbrace{X_{shark}}_{\text{State}}{}^{i} \ \underbrace{w}_{\text{Weight}}{}^{i} \}$$

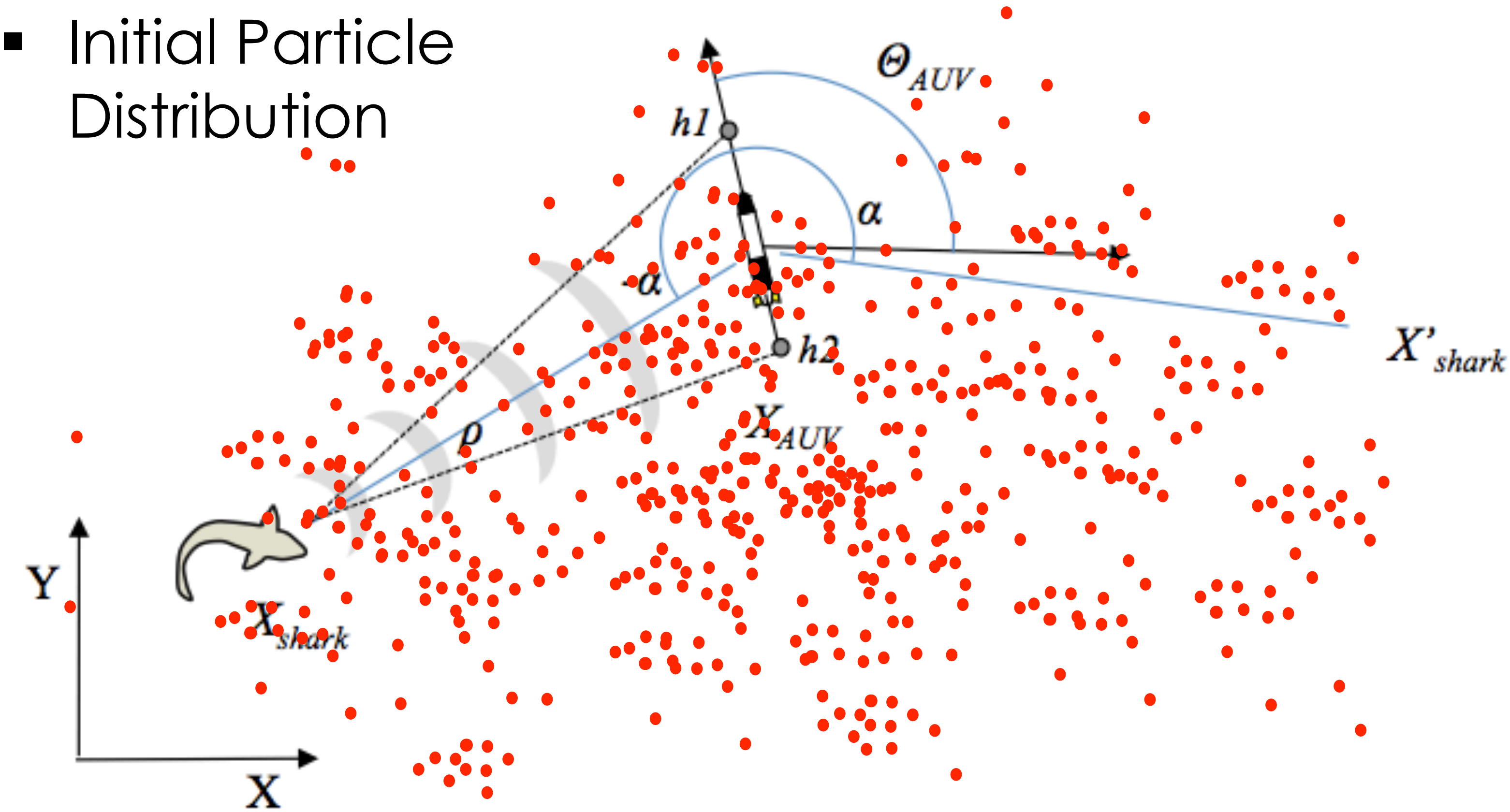
1. The state is $X_{shark} = [x \ \ y \ \ \theta \ \ v \ w]$
2. The weight w that indicates it's likelihood of being the correct state.

Estimation



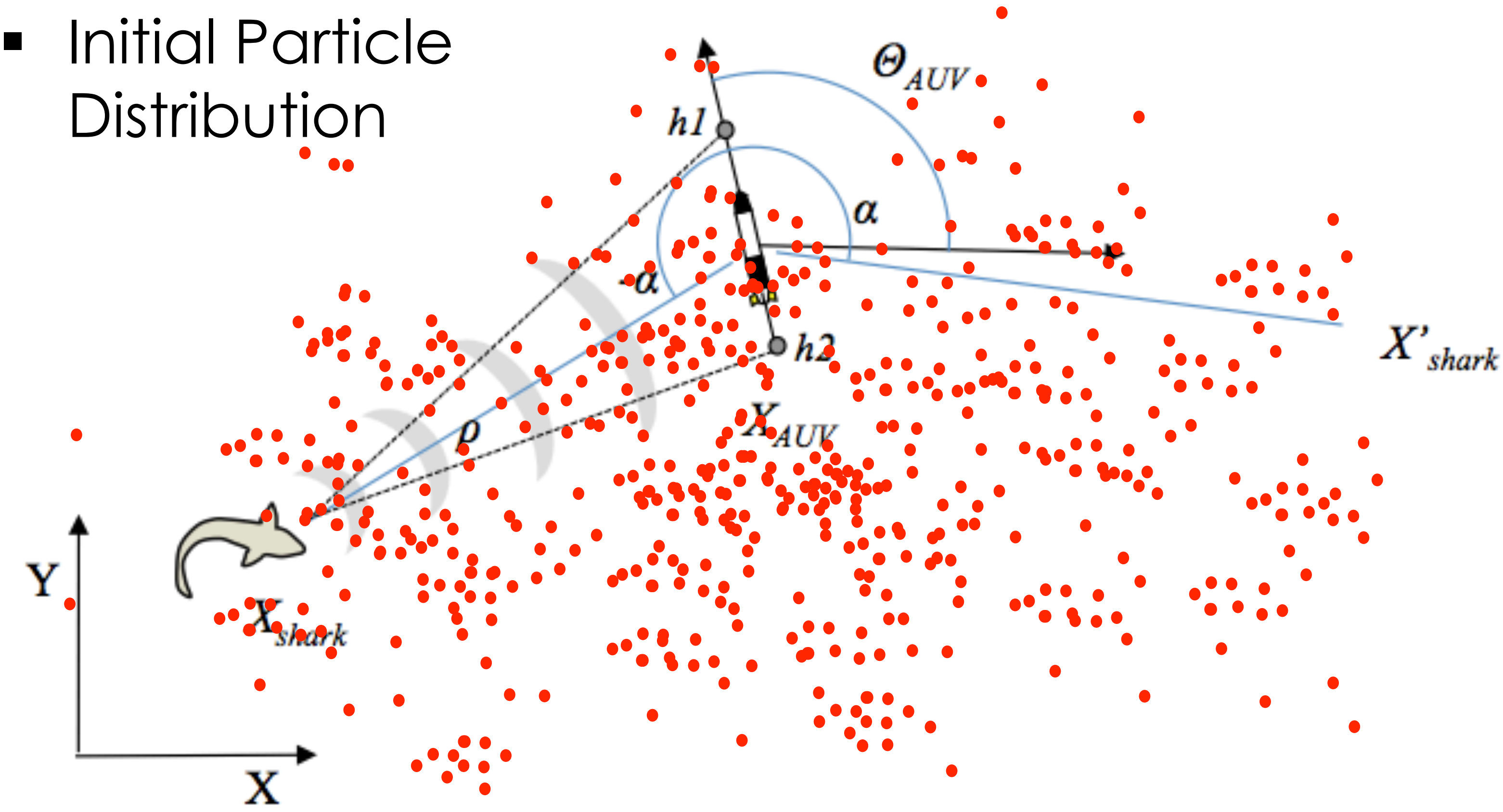
Estimation

- Initial Particle Distribution



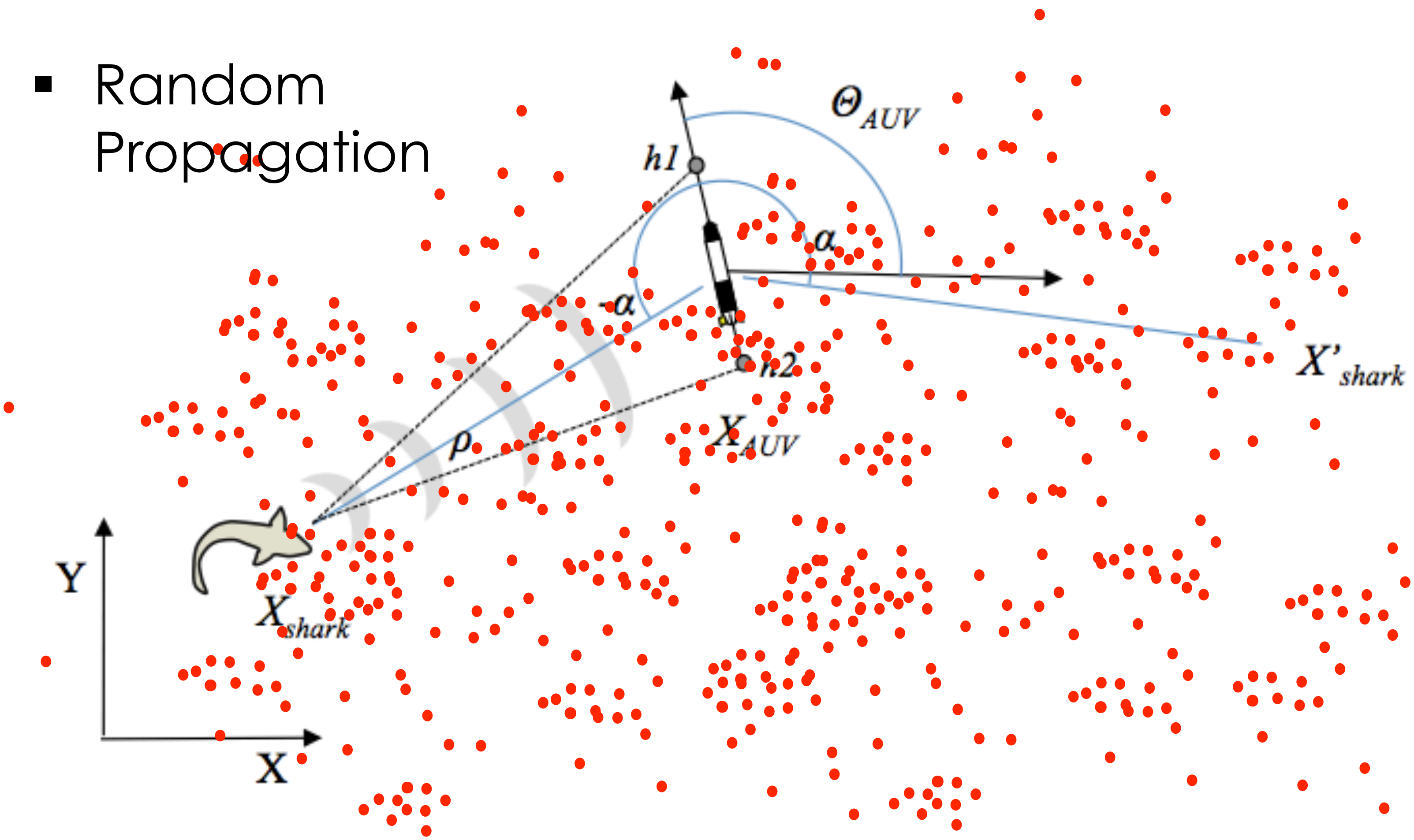
Estimation

- Initial Particle Distribution



Estimation

- Random Propagation



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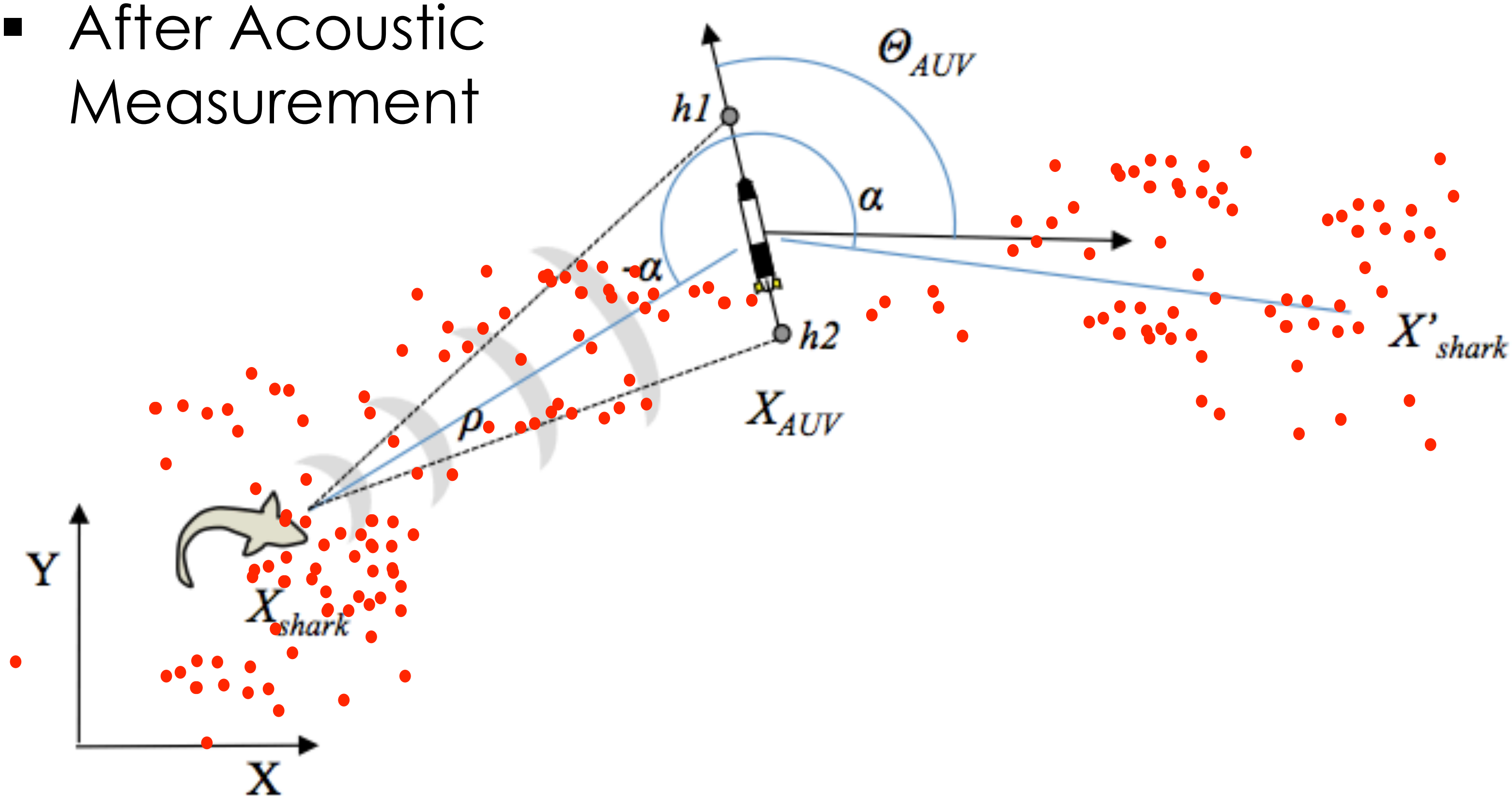
Estimation

- After Acoustic Measurement



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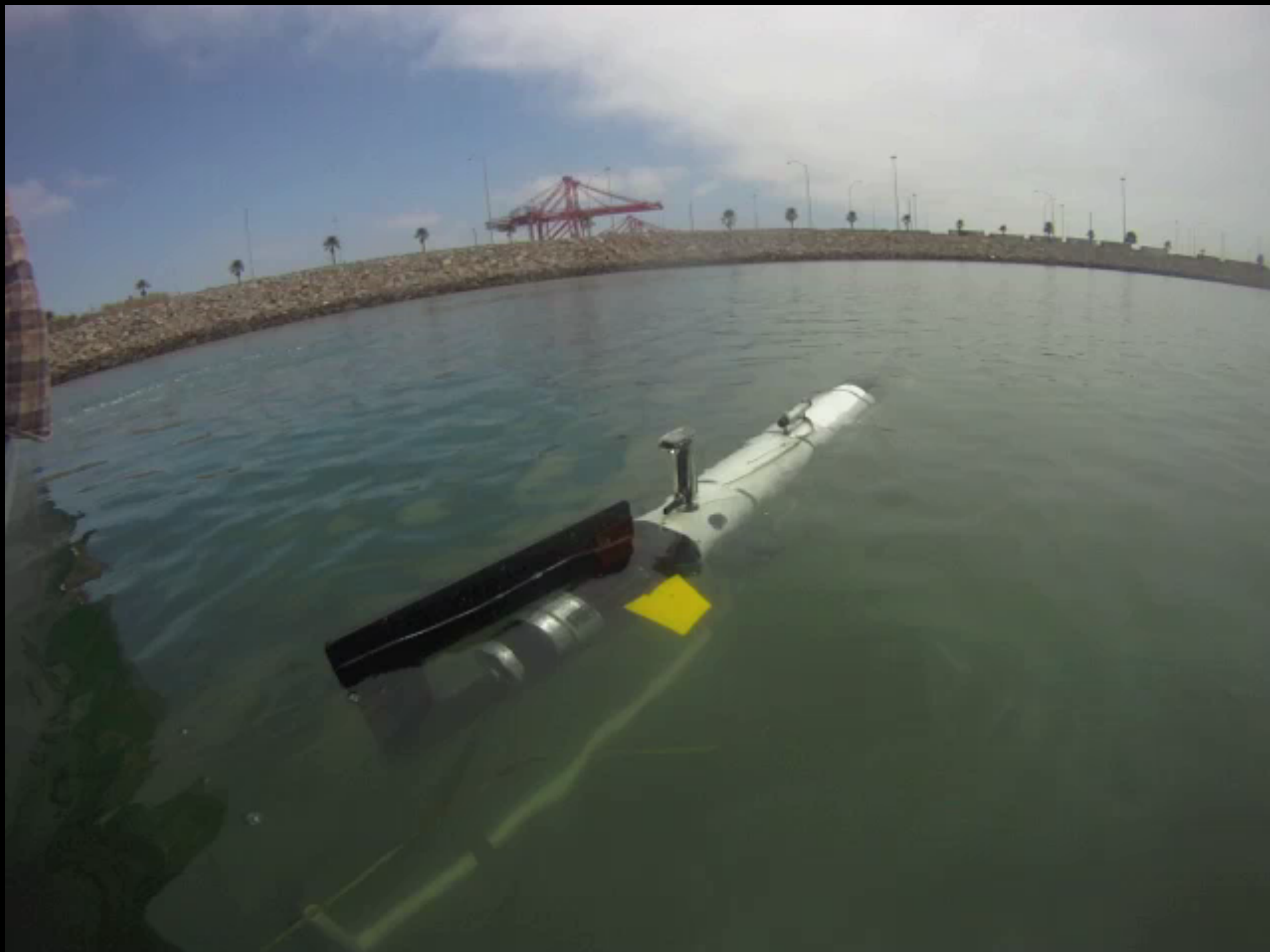

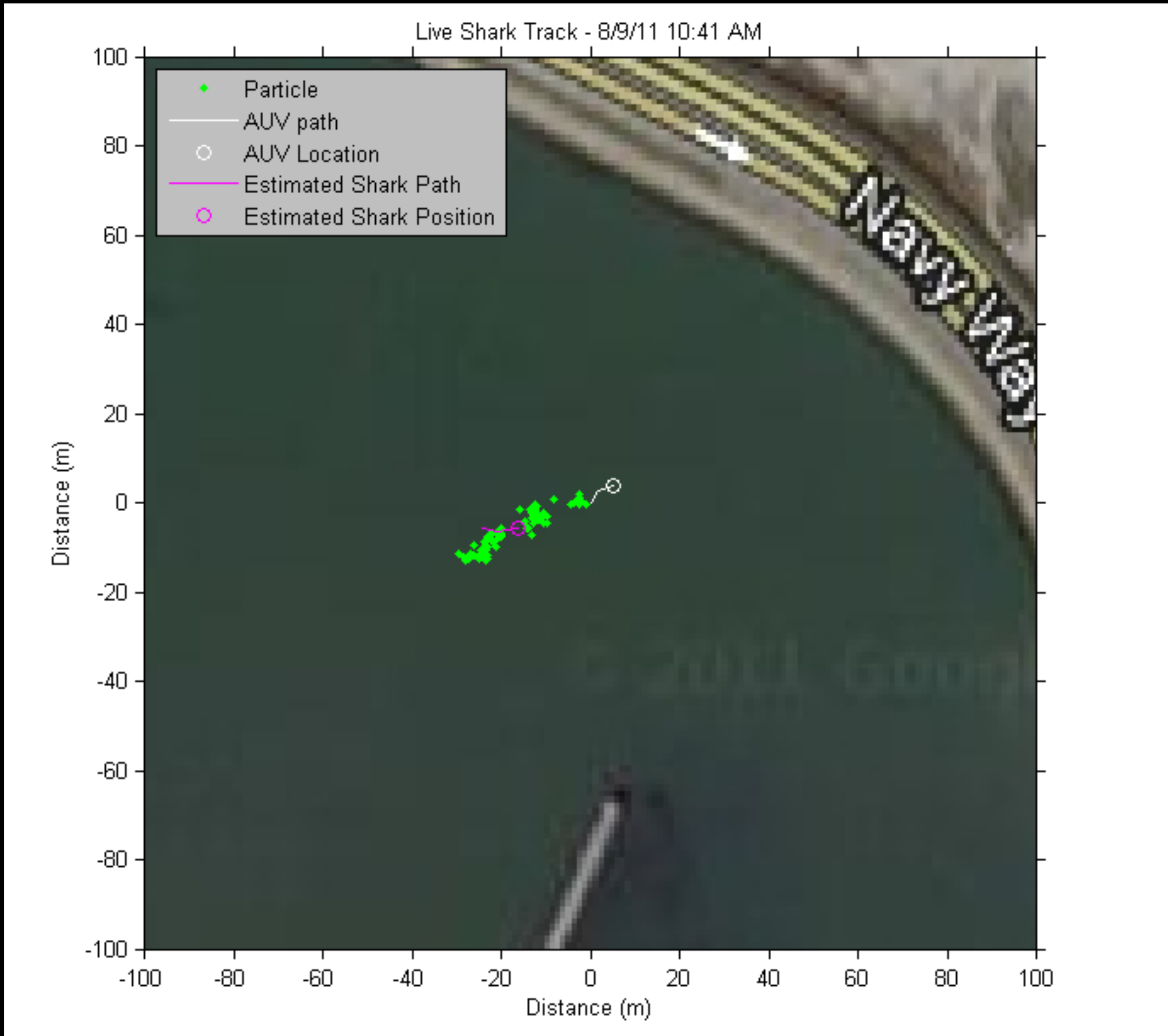

Live Shark Track - 8/9/11 10:41 AM
Particle
AUV path
AUV Location
Estimated Shark Path
Estimated Shark Position
Navy Way
Distance (m)
Distance (m)
100
80
60
40
20
0
-20
-40
-60
-80
-100
-100
-80
-60
-40
-20
0
20
40
60
80
100

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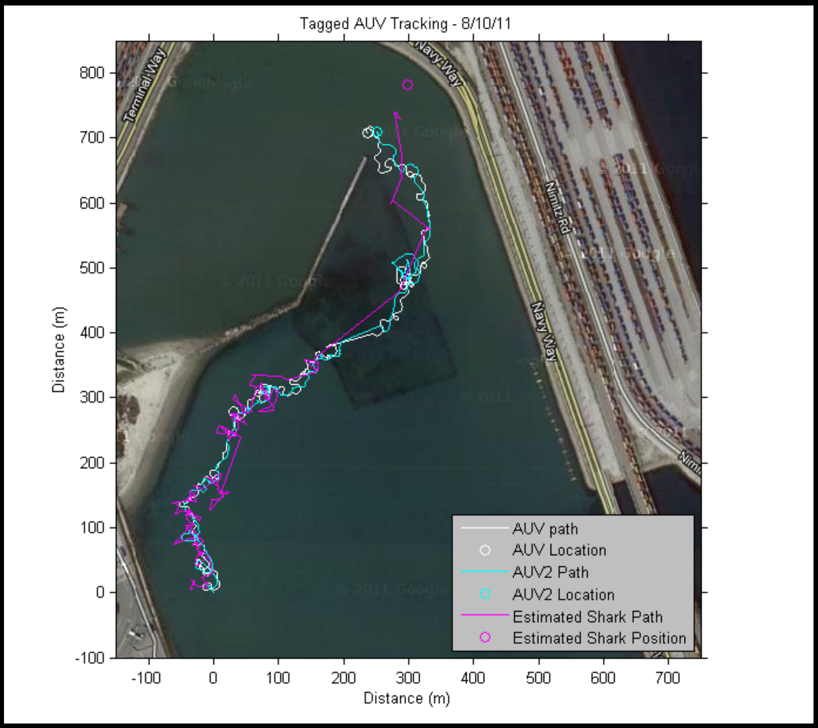
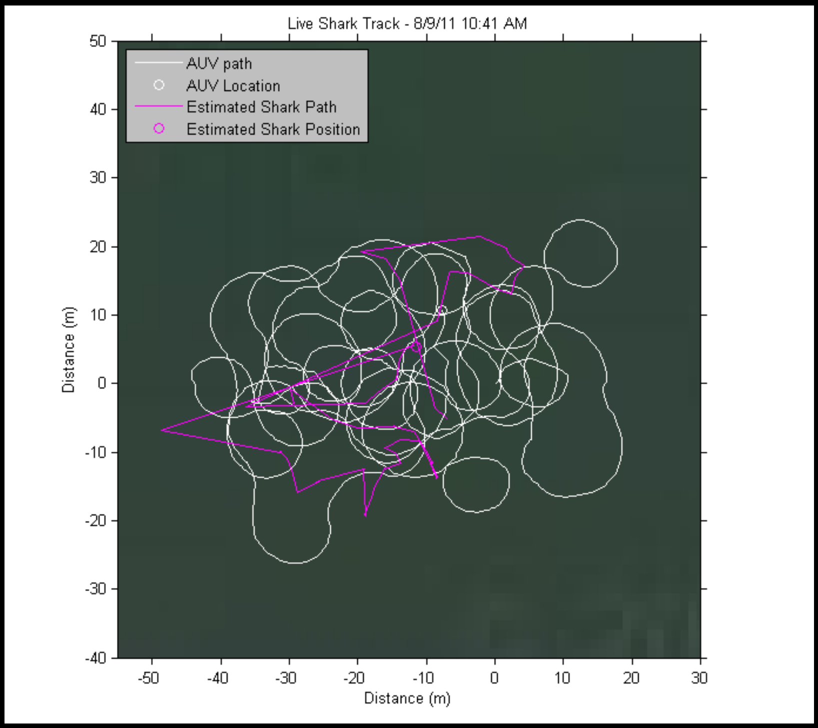
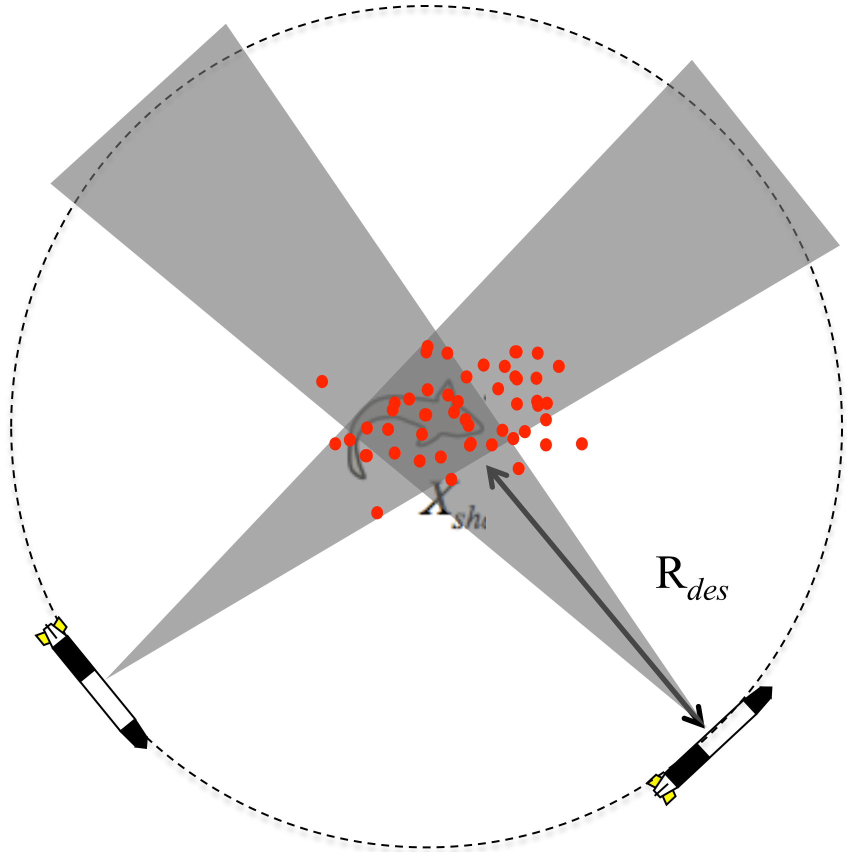




Multi-Robot Controller

- Problem Definition
  - The Robots should not affect the shark's **behavior**
  - The Robots should position themselves to optimize **information gain**



Problem Definition

- Robot state

$$\mathbf{X}_{i,t}^{robot} = [x_{i,t} \; y_{i,t} \; \theta_{i,t}]^T$$

- Robot kinematics

$$x_{i,t+1} = x_{i,t} + v_{i,t}\cos(\theta_{i,t})\Delta t$$
$$y_{i,t+1} = y_{i,t} + v_{i,t}\sin(\theta_{i,t})\Delta t$$
$$\theta_{i,t+1} = \theta_{i,t} + \omega_{i,t}\Delta t$$

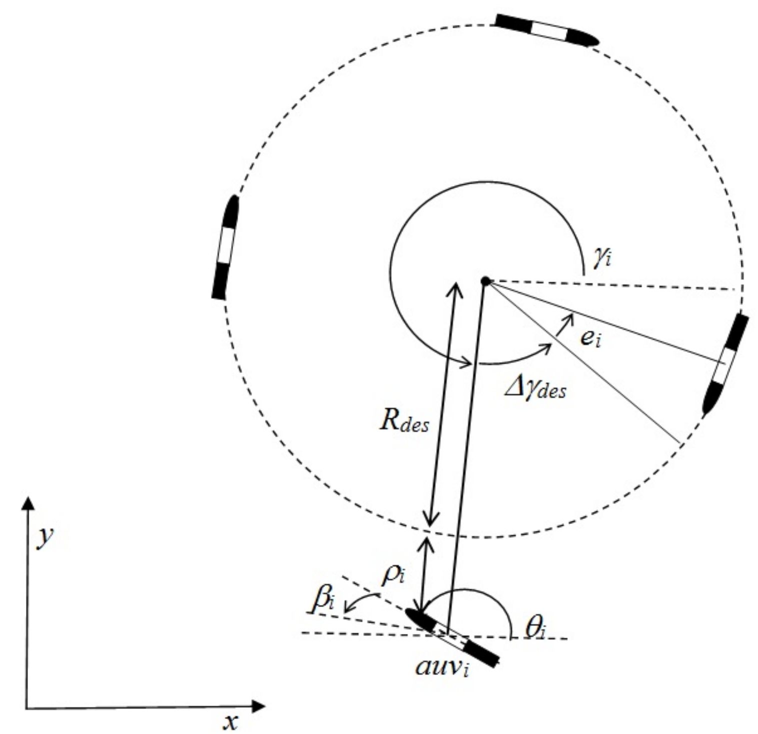
Problem Definition

- Robot relative to target

$$r_{i,t} = \sqrt{(x_{i,t} - x_{target,t})^2 + (y_{i,t} - y_{target,t})^2}$$

$$\gamma_{i,t} = \tan^{-1}\left((y_{i,t} - y_{target,t})/(x_{i,t} - x_{target,t})\right)$$

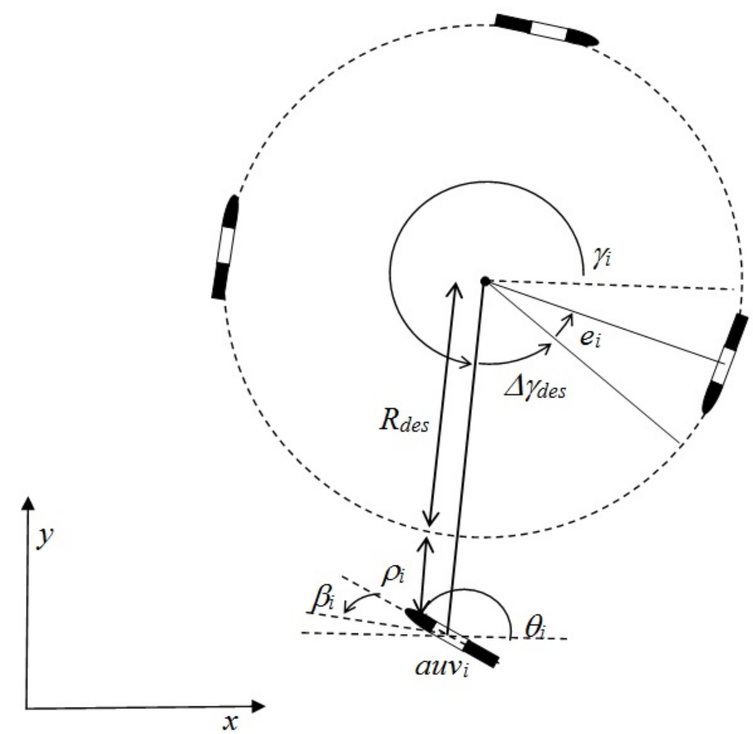
$$\theta_{des_i,t} = \gamma_{i,t} - \frac{\pi}{2}$$



Problem Definition

- Error variables

$$\rho_{i,t} = \mathrm{R}_{des} - r_{i,t}$$
$$\beta_{i,t} = \theta_{des_i,t} - \theta_{i,t}$$
$$e_{i,t} = \Delta\gamma_{des} - (\gamma_{i,t} - \gamma_{i-1,t})$$



Problem Definition

- Error states

$$\chi_{i,t} = [\rho_{i,t}\ \beta_{i,t}\ e_{i,t}]^T$$

- Control vector

$$\mathbf{U_{i,t}} = [v_{i,t}\ \omega_{i,t}]^T$$

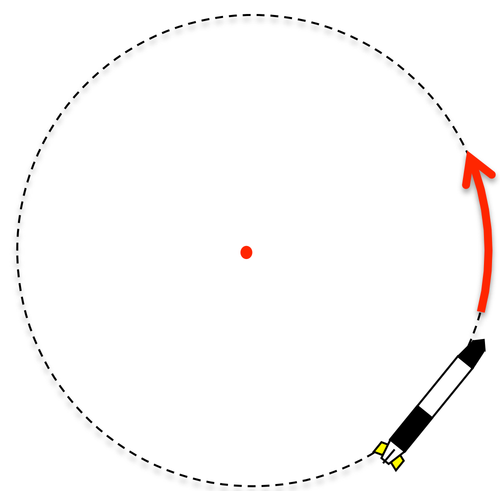
1. Single Robot, Single Target

- Control law

$$\omega_{i,t} = -\frac{v_{i,t}\cos(\beta_{i,t})}{R_{des} - \rho_{i,t}} + \frac{K_\beta}{\Delta t}\beta_{i,t} + \frac{K_\rho}{\Delta t}\rho_{i,t}$$

- Stability bounds

$$K_\rho > 0$$
$$0 < K_\beta < 4$$
$$\frac{2(K_\beta - 2)}{K_\rho \Delta t} < v_{i,t} \leq \frac{K_\beta^2}{4K_\rho \Delta t}$$



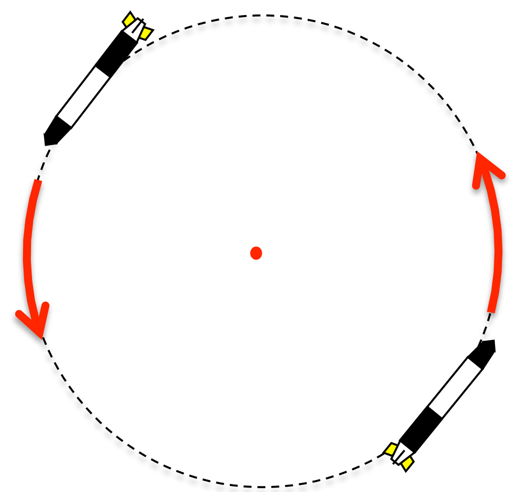
2. Multi-Robot, Single Target

- Control law

$$v_{i,t} = \frac{R_{des} - \rho_{i,t}}{\mathrm{R}_{des}\cos(\beta_{i,t})}\left(v_{nom} + \frac{R_{des}K_{\gamma}}{\Delta t}(e_{i+1,t} - e_{i,t})\right)$$

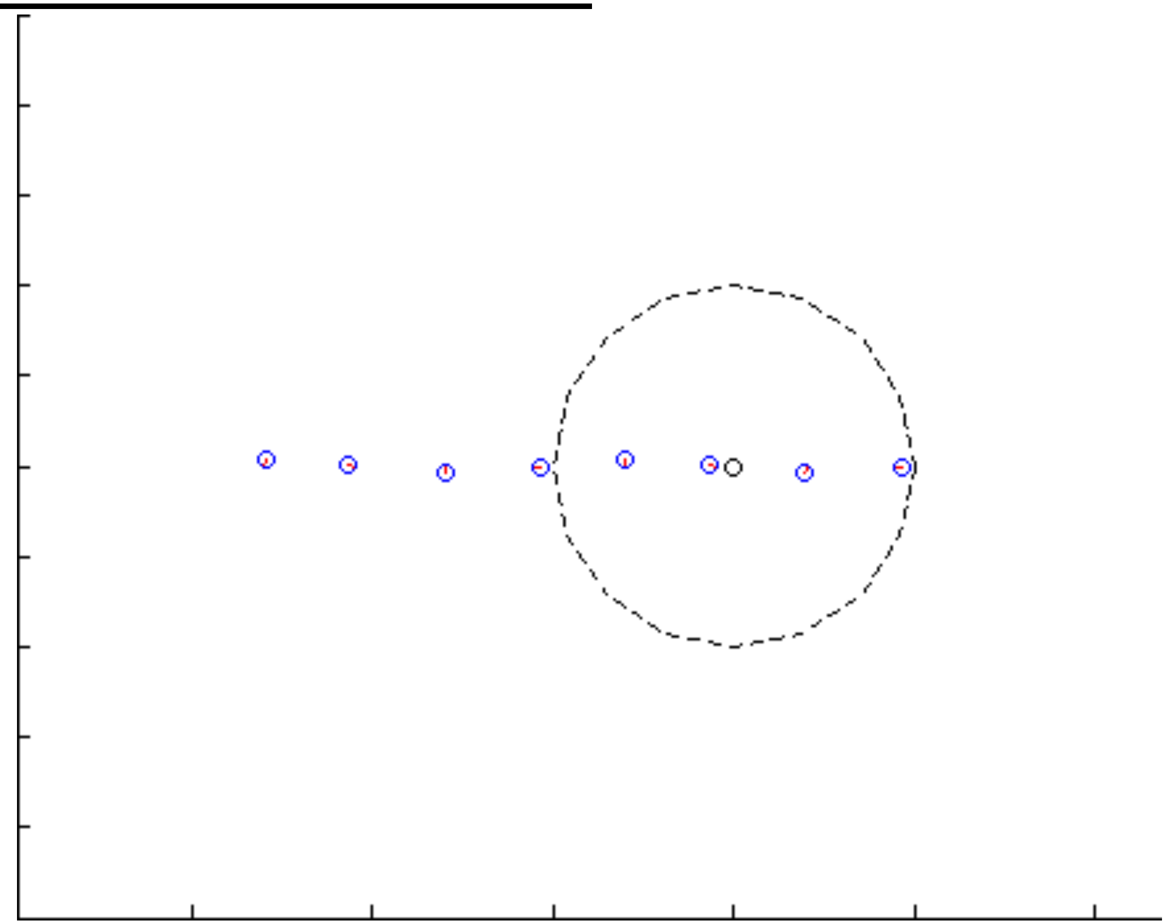
- Stability example (3 robots)

$$0 < K_{\gamma} < \frac{2}{3}$$



Multi-Robot Controller

- Simulation Results
  - 8 Robots
  - 1 Particle



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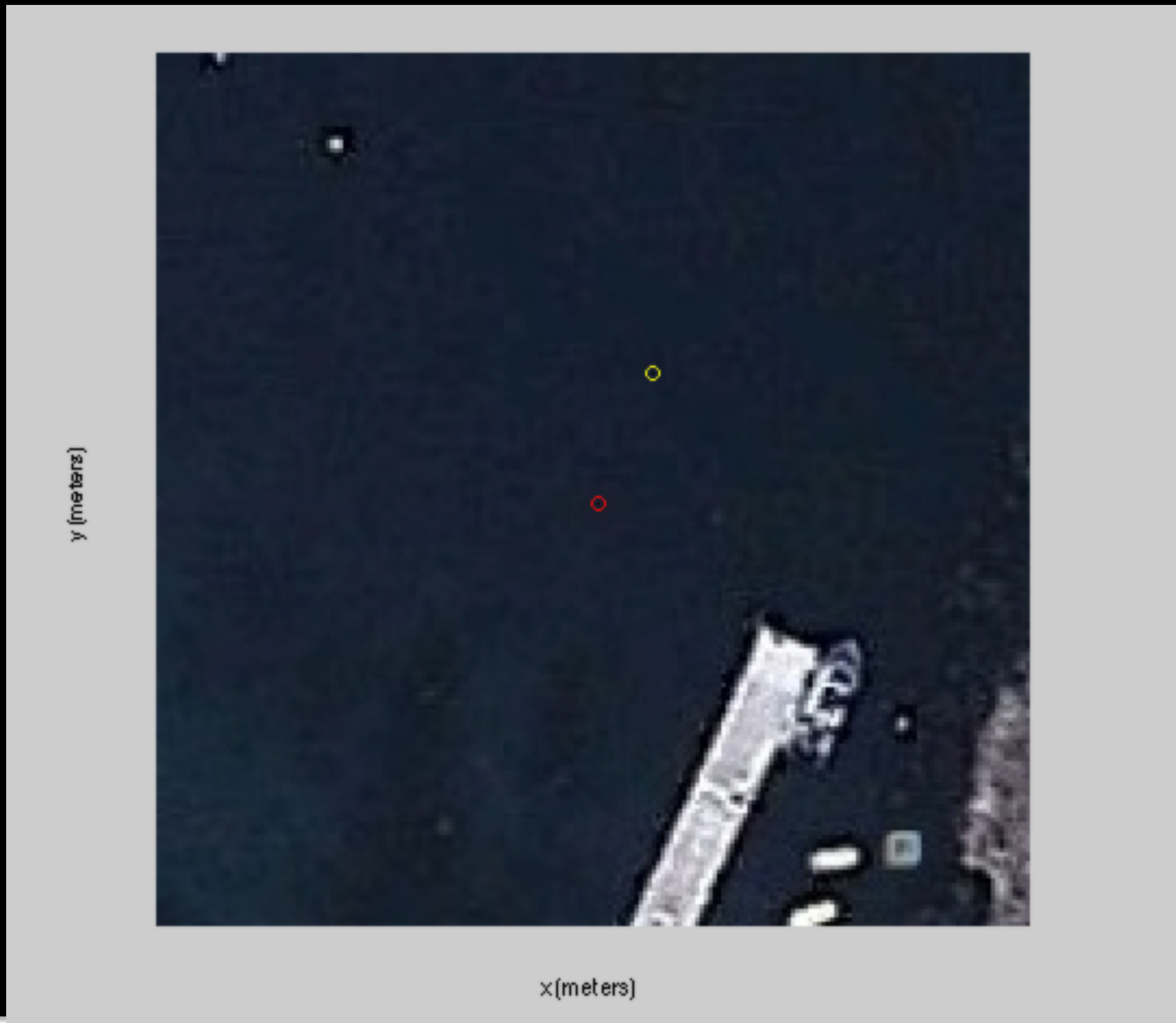
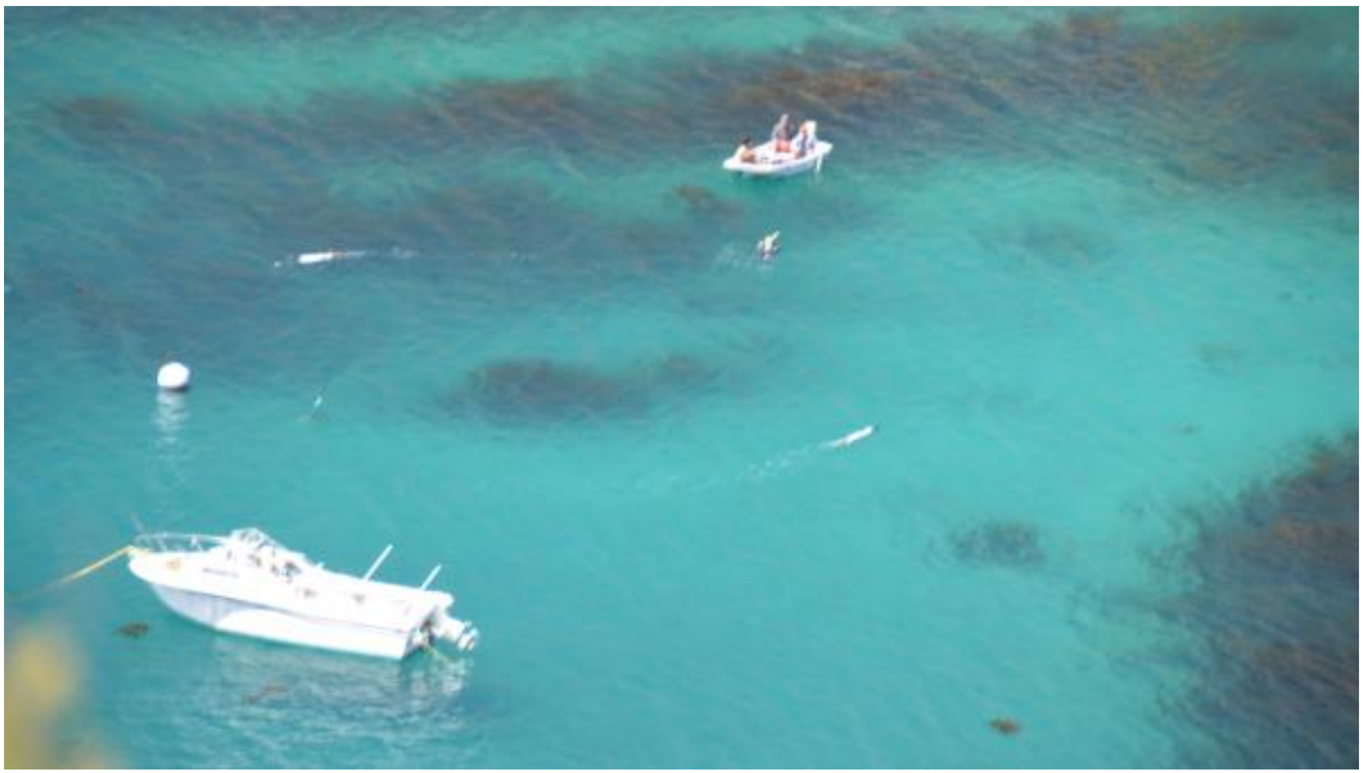


Shark Trials



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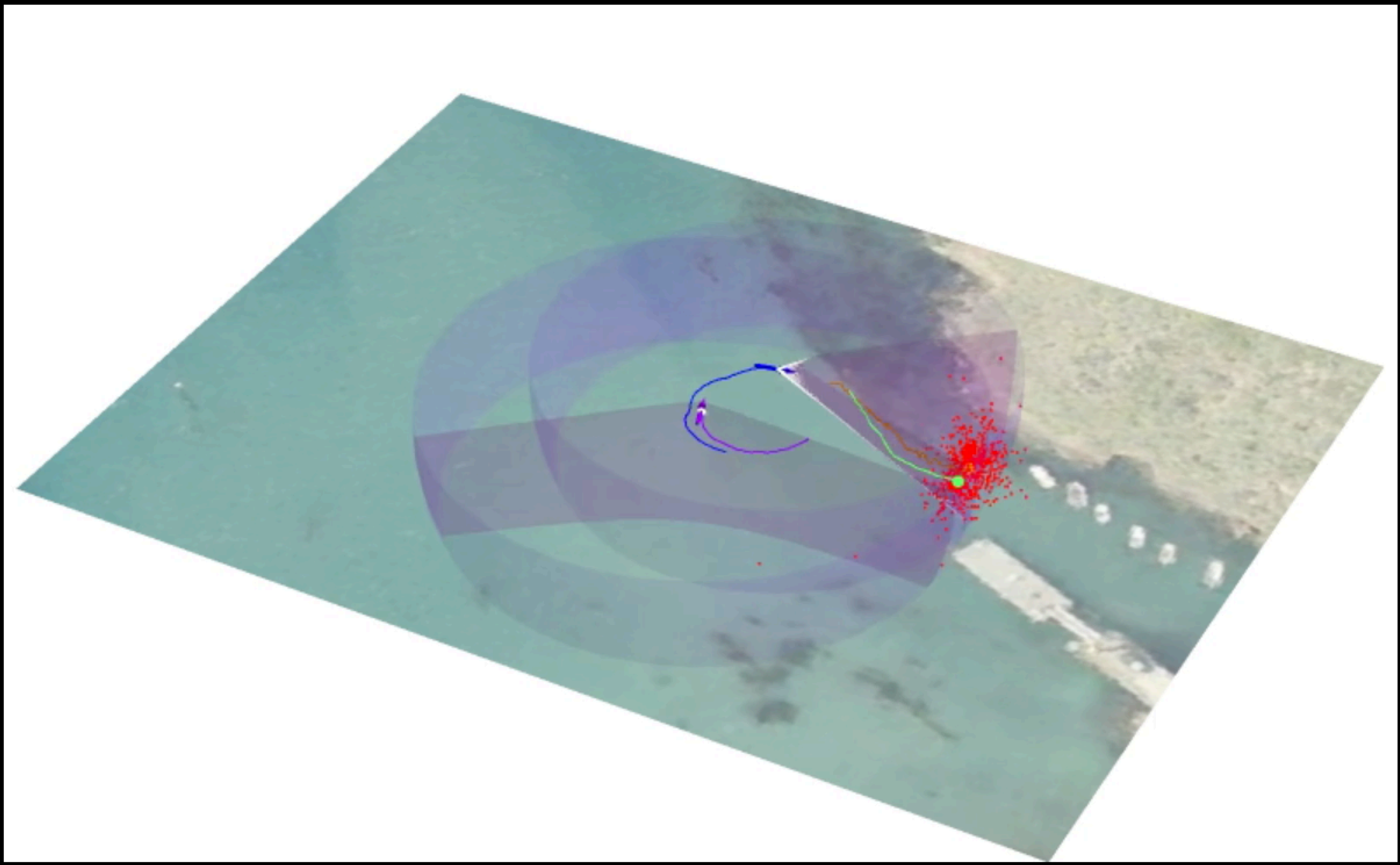

Boat Trial Results

STATE ESTIMATION ERRORS OF STATIC AND BOAT TRIALS.

Trial	Mean Err. (m)		Median Err. (m)		SD Err. (m)	
	Static	Boat	Static	Boat	Static	Boat
1	8.1	8.0	7.2	5.0	4.3	10.5
2	4.8	6.8	4.6	5.3	1.6	4.8
3	3.7	13.7	3.6	8.4	1.1	13.2
4	2.8	8.8	2.0	6.5	3.4	8.4

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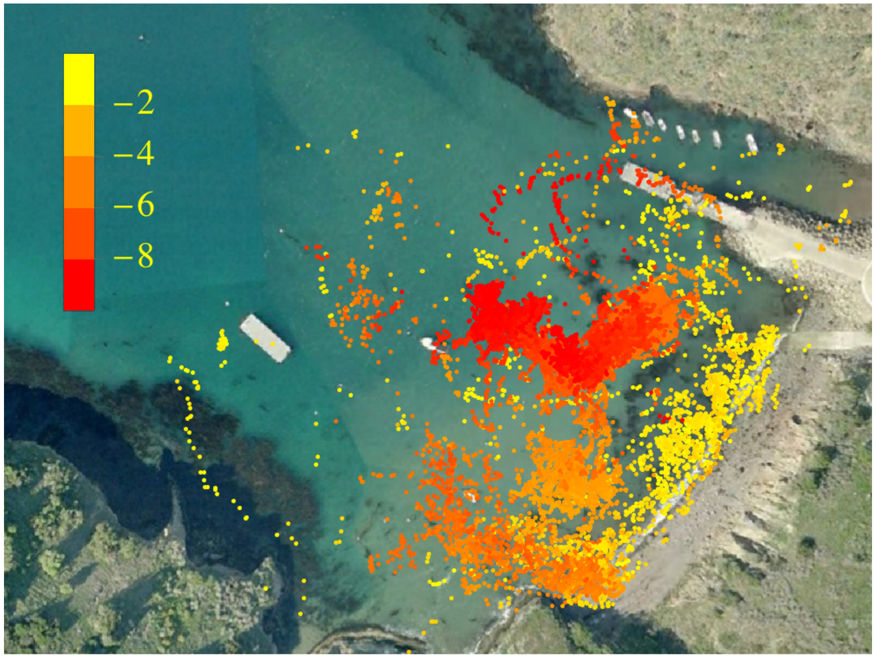
Shark Trial Results



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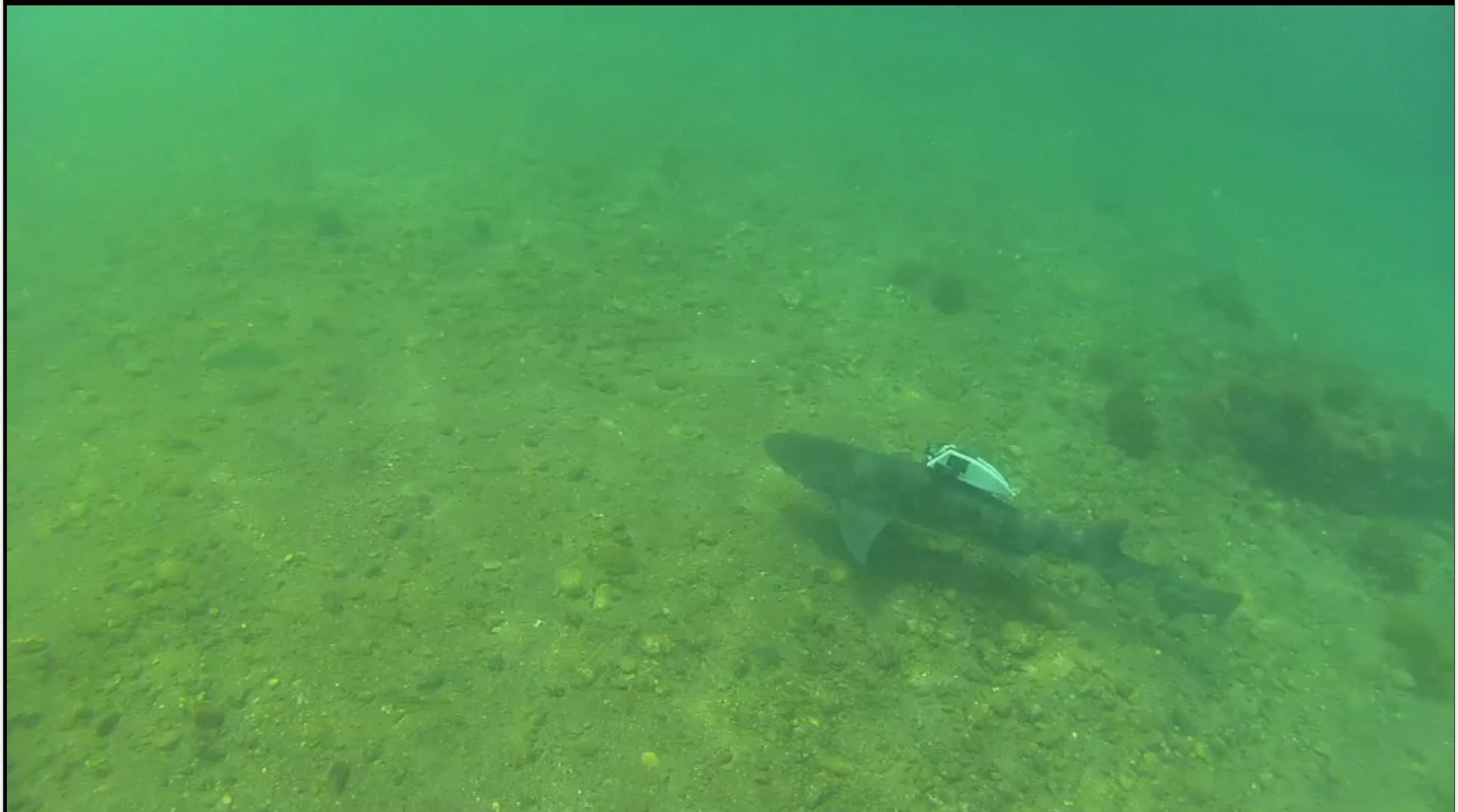

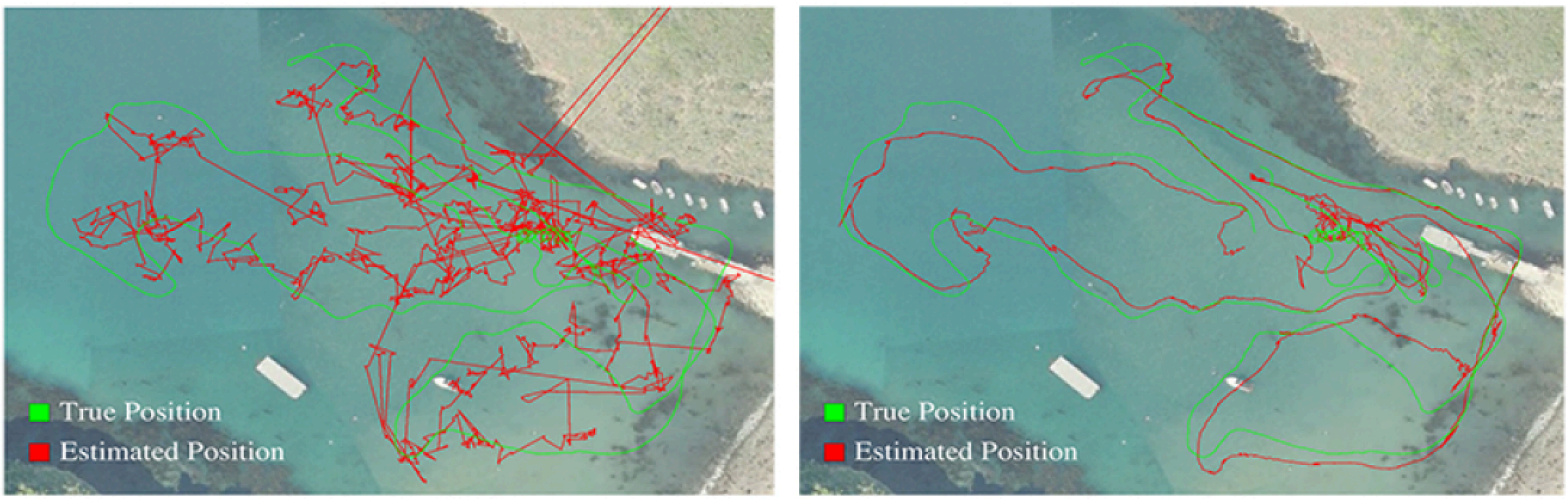

Figure 7: Left) Tracking without IMU data Right) Tracking with IMU data.

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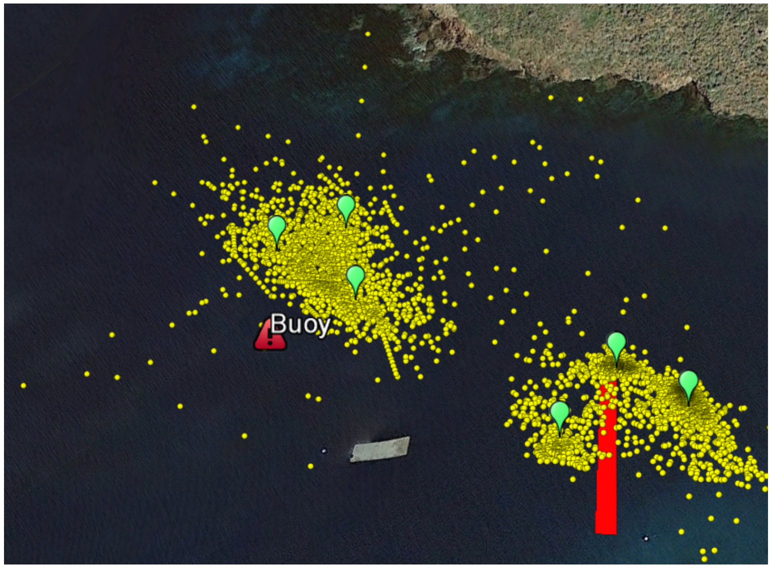
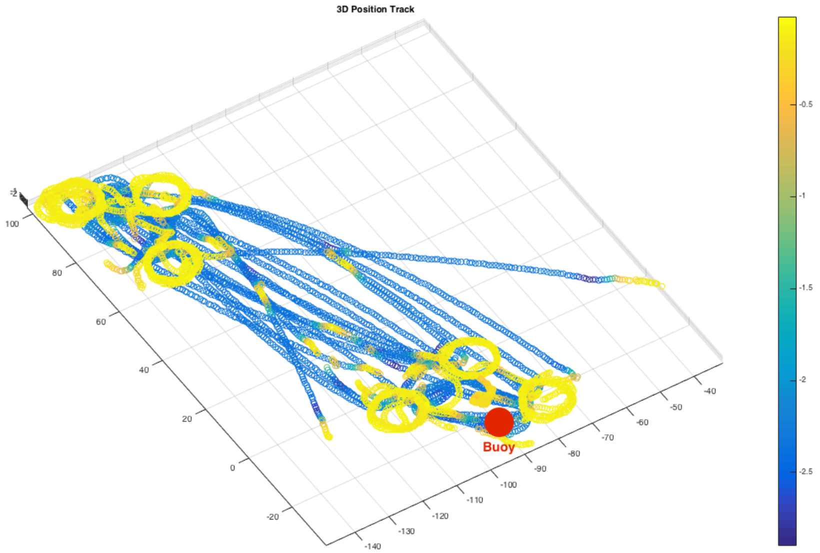
Tracking >1 Target

- Stochastic Control





3. Exercise B

- Find a partner
- Find one underwater robot research publication. Select based on novelty or research interest as desired.
  - Journal Field Robotics
  - IROS, ICRA
  - OCEANS
  - MTS Journal
- Present a summary of the platform in 1-3 slides.

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