CPS: Synergy: Tracking Fish Movement with a School of Gliding Robotic Fish

Xiaobo Tan (PI), Charles Krueger (Co-PI), and Guoliang Xing (Co-PI)

PROJECT OVERVIEW

The goal of this project is to create an integrative framework for the design of coupled biological and robotic systems that accommodates system uncertainties and competing objectives in a rigorous, holistic, and effective manner. The design principles are developed using a concrete, end-to-end application of tracking and modeling fish movement with a network of gliding robotic fish.

Acoustic tag surgically implanted into fish. (Credit: Great Lakes Fishery Commission)
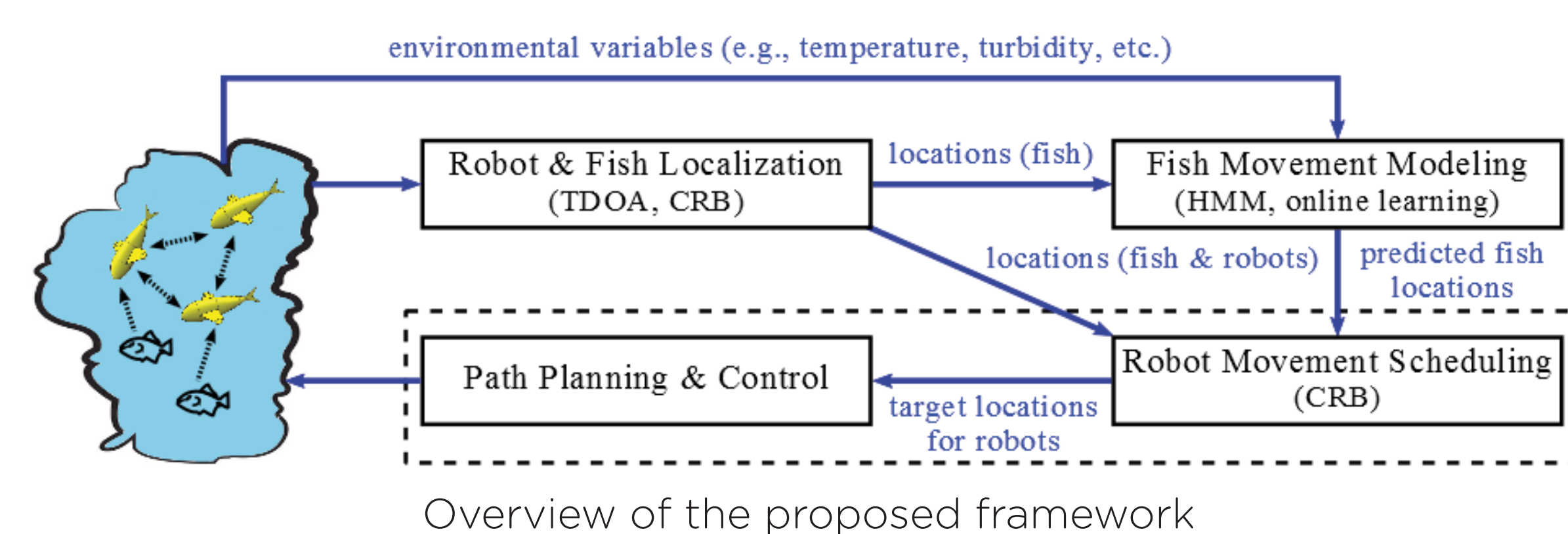

Locations of acoustic telemetry receivers deployed in the Great Lakes. (source: GLATOS)

CHALLENGES

- Uncertainties due to environmental disturbances, information transmission delays, and inherent stochasticity in fish movement.
- Competing objectives, such as accurate tracking and long system lifetime, with constraints on computing power, communication bandwidth, robot mobility, and battery capacity.

APPROACH

Overview of the proposed framework

- Robotic platform enhancement by incorporating Raspberry Pi, acoustic micro-modems, and telemetry receivers.
- Robust algorithms with analytical performance assurance for fish localization.
- Fish movement modeling using hidden Markov models and online model identification algorithms.
- Coordination and control of robotic network to track fish.
- Real-world experimental validation in Lake Huron, Thunder Bay.

ROBOTIC PLATFORM

An energy-efficient underwater gliding robotic fish travels by changing its buoyancy and mass distribution (gliding) or by flapping tail fin (swimming). It carries a variety of environmental sensors and an acoustic receiver.
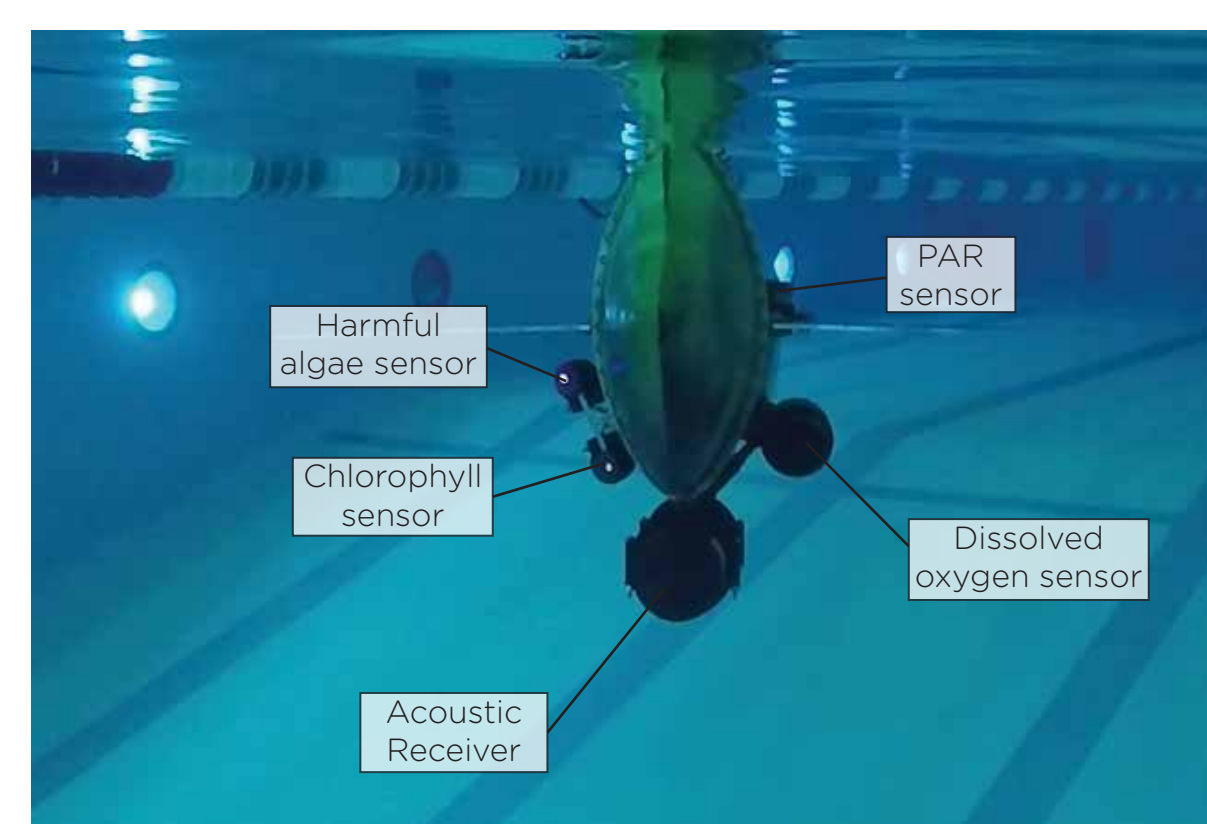

Robot equipped with environmental sensors and acoustic receiver.
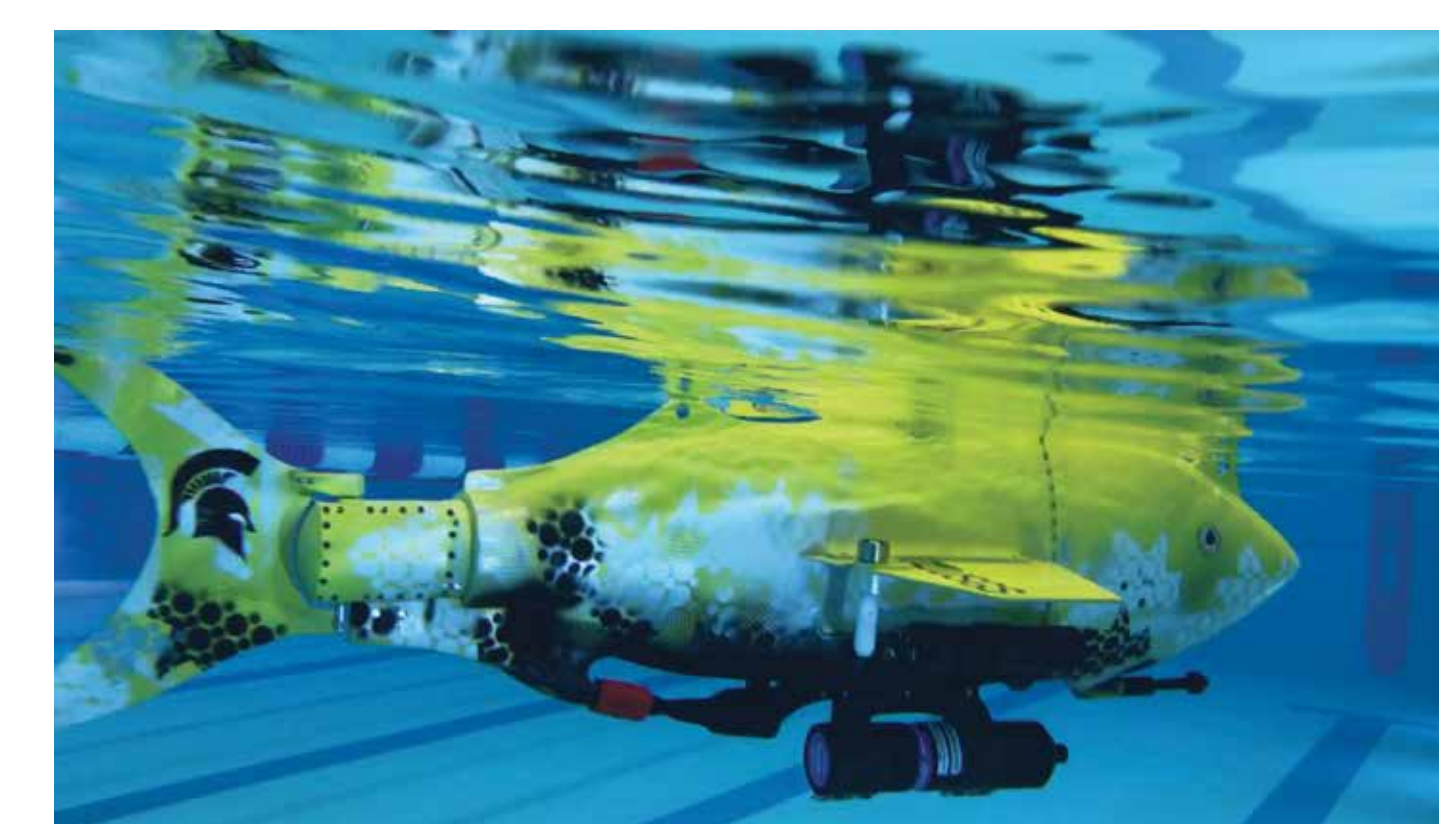
Improved prototype of gliding robotic fish.

FIELD EXPERIMENTS

The gliding robotic fish was tested in Higgins Lake, MI. In those tests, we were interested in comparing the detection performance of the acoustic receiver on the robot to that of stationary receivers at varying distances from the acoustic tags. Detection performance was tested under both navigation modes (gliding and swimming) to examine the effect of acoustic noise from the actuators on detection performance.
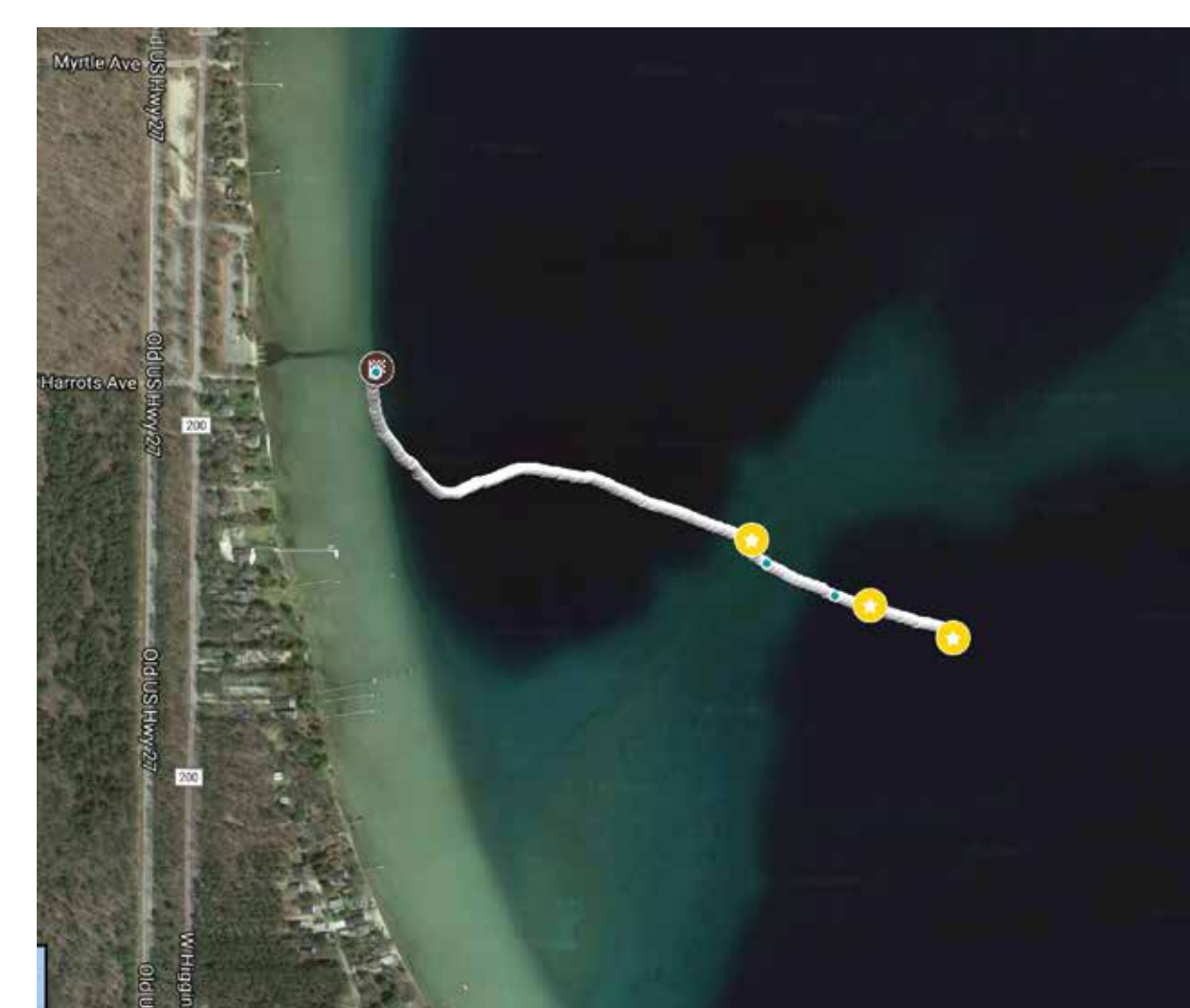
Path taken by robotic fish during swimming navigation test.
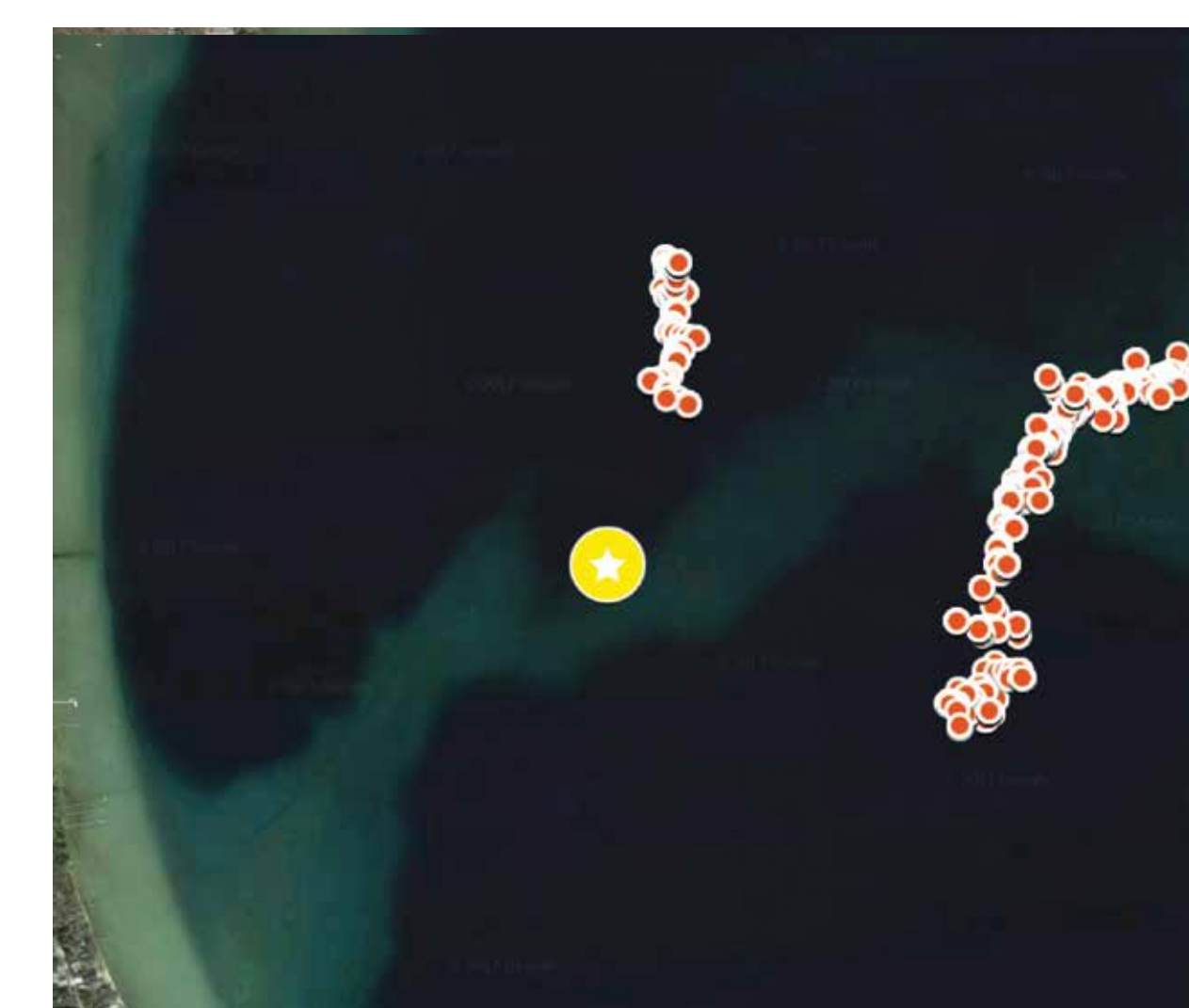
Path taken by robotic fish during gliding navigation test.

Robot performing various tasks during tests in Higgins Lake, MI.

Crew on USGS boat during field test in Lake Higgins, MI.

FIELD RESUTS

Estimated detection efficiency for the receiver attached to GRACE was similar (0.78 for stationary receivers; 0.76 for mobile receiver) to stationary receivers at 300 m, but decreased faster than stationary receivers as the distance increased farther. Estimated efficiency was 0.44 for stationary receivers and 0.03 for the mobile receiver at 1000 m. Further efforts will attempt to identify and resolve such differences, but the observed detection ranges are well within the useful range for fish telemetry.
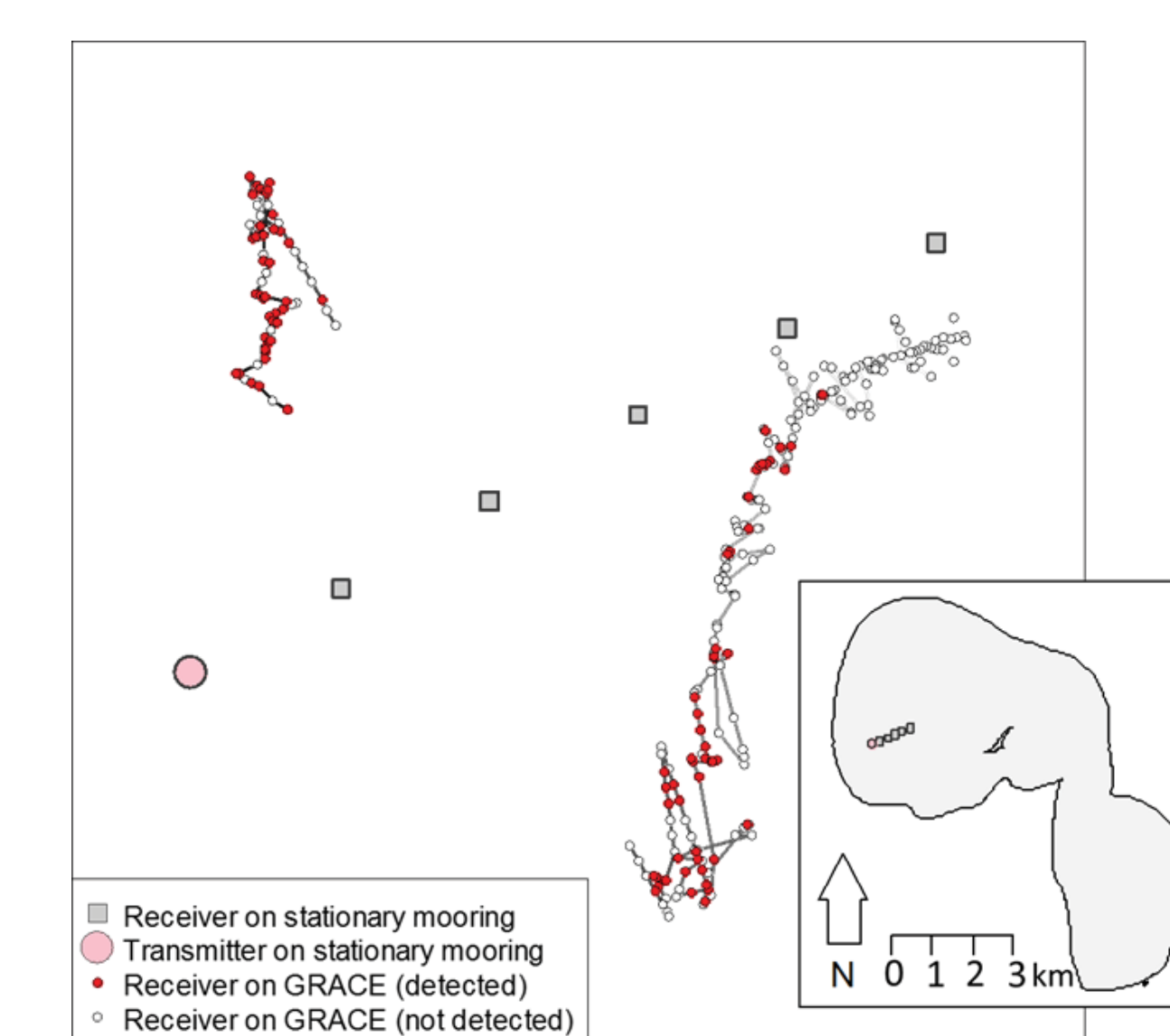

Locations of stationary acoustic telemetry receivers with tracks of gliding robotic fish GRACE showing locations where acoustic transmitter signals were detected or not.
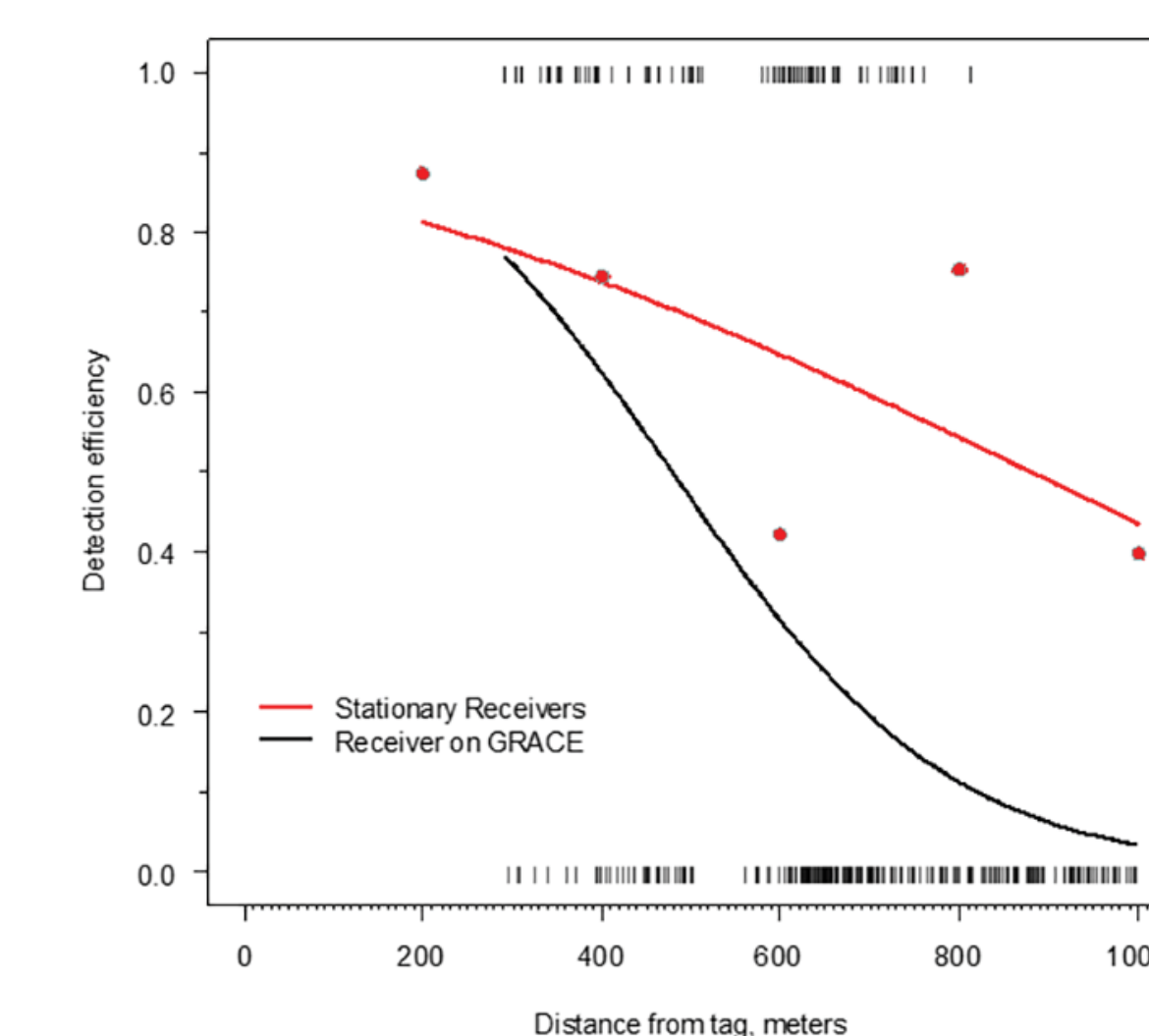
Estimated detection efficiencies of an acoustic transmitter on acoustic receivers affixed to stationary moorings (red) and gliding robotic fish GRACE (black).

ANALYTICAL WORK

- Time-difference-of-arrival (TDOA) measurements at multiple locations are used to estimate the location of a moving target (e.g. fish) in a distributed manner, where each receiver only has access its neighbors' information.
- Necessary and sufficient conditions for 3D distributed localization has been investigated[*].
- Development of energy-efficient control strategies for tracking target in 2D[**].
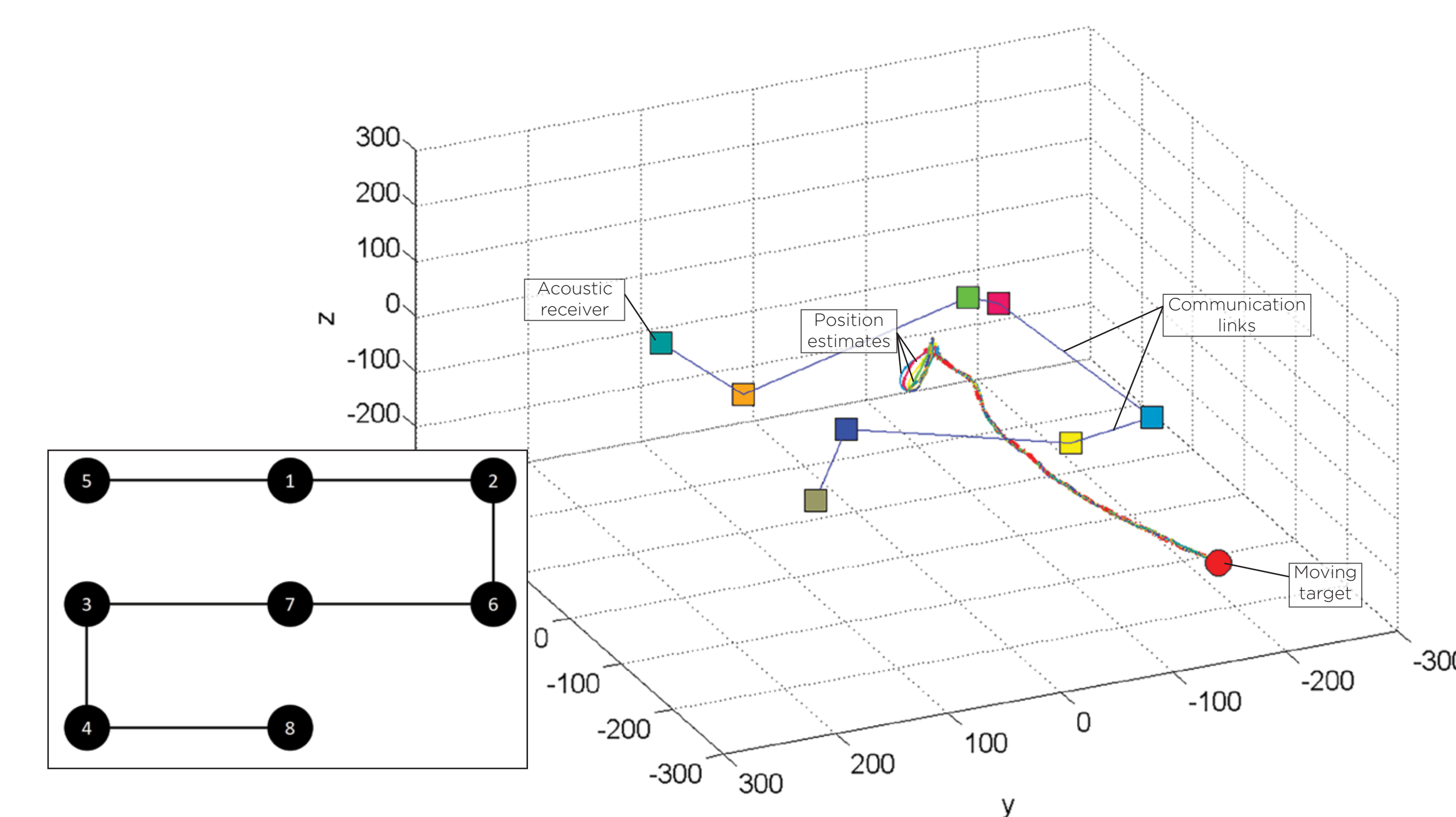
Simulation of distributed target localization algorithm.[*]

[*]O. Ennasr and X. Tan, "Distributed Localization of a Moving Target: Structural Observability-based Convergence Analysis," submitted to IEEE American Control Conference, 2018.
[**]O. Ennasr and X. Tan, "Distributed Estimation and Tracking Using Time-Difference-Of-Arrival (TDOA) Measurements," in ASME Dynamics Systems and Control Conference, Tysons, VA, 2017.