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Unmanned Sailboat

Incorporating MOOS-IvP Backseat Sailing Behavior

MOOS-DAWG 22

10 August 2022

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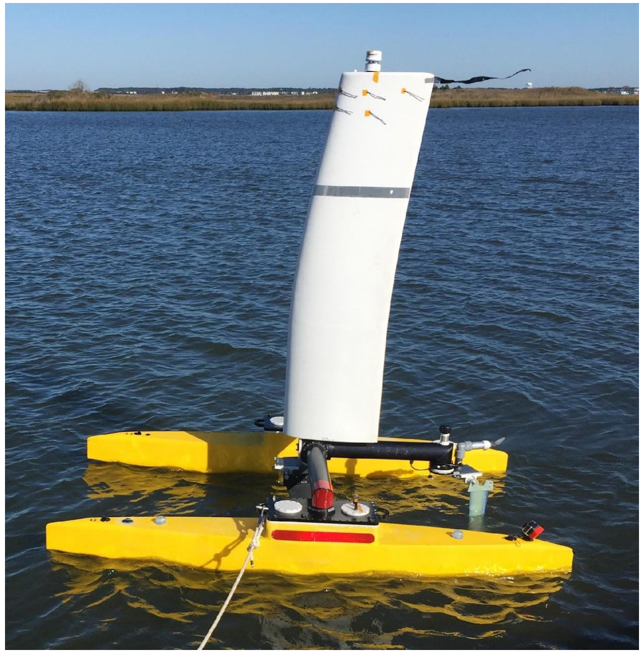
About Us

Mission
Develop cost-effective marine observation platforms for ecosystem restoration

Product
Autonomous sailing catamarans

Company
Founded in 2013
Seasoned team of engineers, scientists and students
Privately funded

Near term
Oyster reef restoration in Chesapeake Bay
Surface weather for space based weather spacecraft
Implement back seat control



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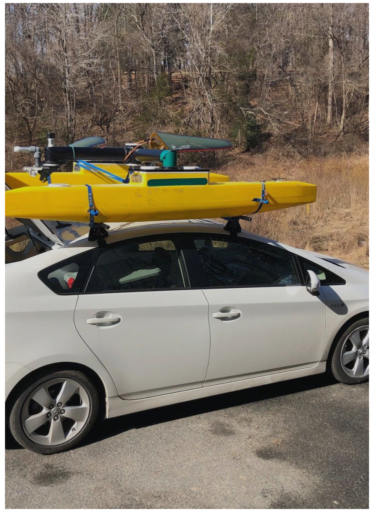
The Boats

Features

- Wind propelled
- Light, easy to handle
- Fast for its size
- Designed to evolve
- Collision tolerant
- Electric propulsion above waterline
- Able to navigate shallow and debris-laden water



Specifications

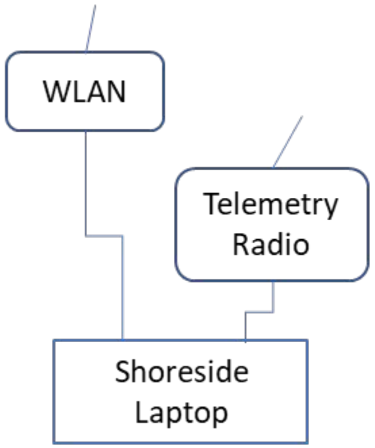
Speed:	4.5 Km/hr
Length:	2.5m
Beam:	1.5m
Draft:	0.3m
Height:	2.3m (above waterline)
Weight:	60 kg
Endurance:	3 months

Applications

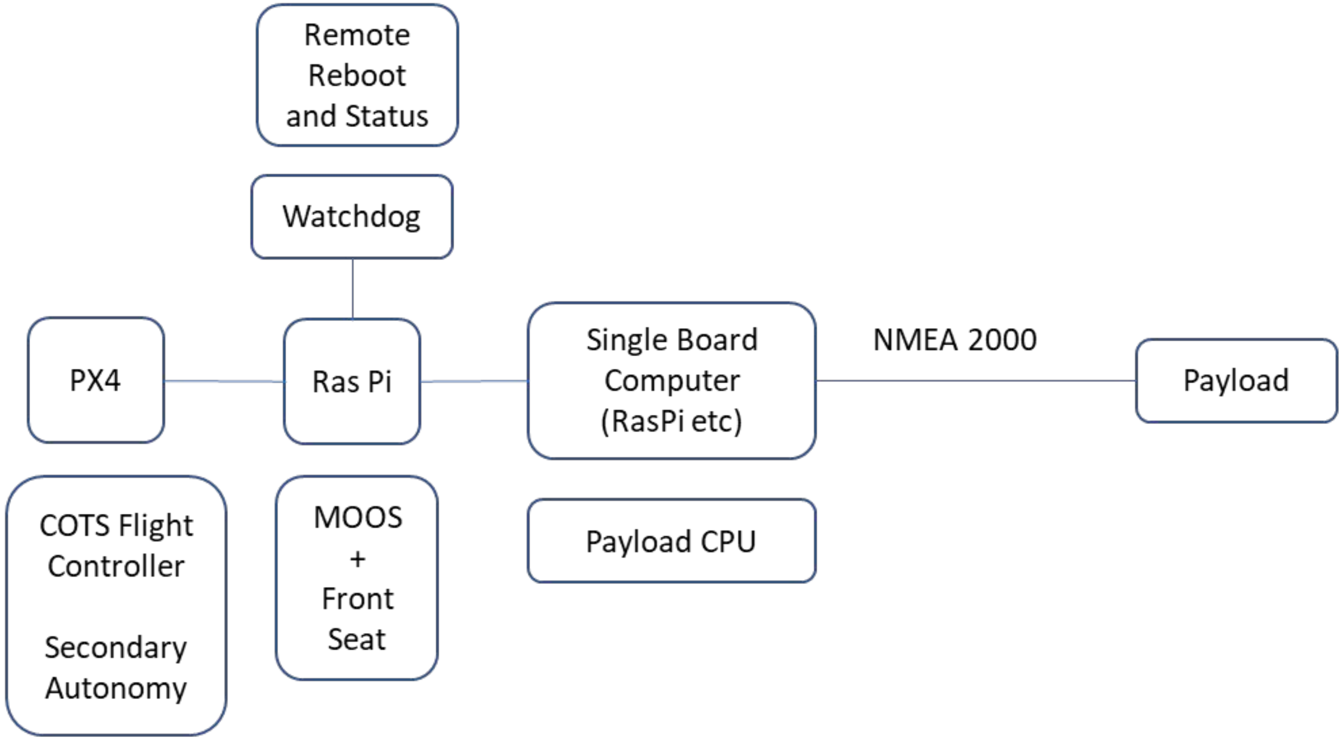
- Hydrographic surveys
- Mobile gateway Services (UUV, USV, UAV, Satellite)
- Oyster reef restoration
- Pollution monitoring
- Pelagic fishery tracking
- Benthic monitoring

New System Architecture

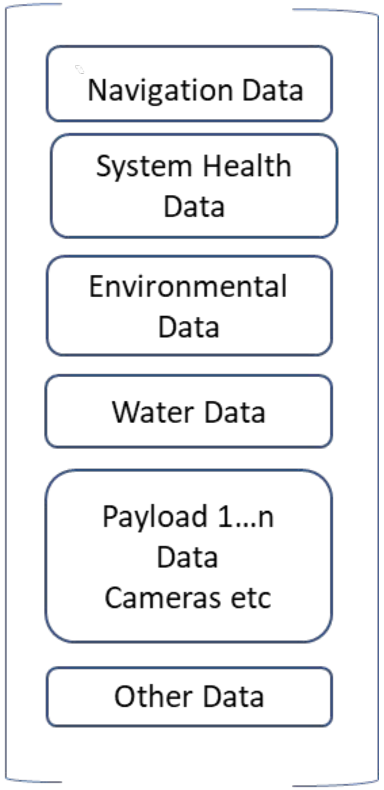
Shoreside
- Vessel Health data
- FPV Video Feed
- Waypoint data



Vehicle Systems - Px4 with Ras Pi MVC / Payload



Payload N2K and Data Acquisition



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ArduPilot (using PixHawk 4) Flight Controller with MOOS-IvP

- **Benefits**
  - Two Open Source products with existing user communities
  - New ideas, New applications, New approaches
  - Existing Support

- **Existing Behaviors**

ArduPilot (ardupilot.org)

- User Friendly GUI
- Station Keeping / Loitering
- Waypoint Following
- Survey Routes
- Dynamic pin drops
- Nested Behaviors

MOOS-IvP

- Open Publish - Subscribe Architecture
- Station Keeping / Loitering
- Waypoint Following
- Survey Routes
- Dynamic pin drops
- Nested Behaviors
- Swarm Autonomy
- Collision Avoidance

- **CONOPS with multiple “Modes” of operation**
  - Radio Control for local maneuvering
  - Fully Remote Operation via shoreside or over Internet (both MOOS and Mission Planner)

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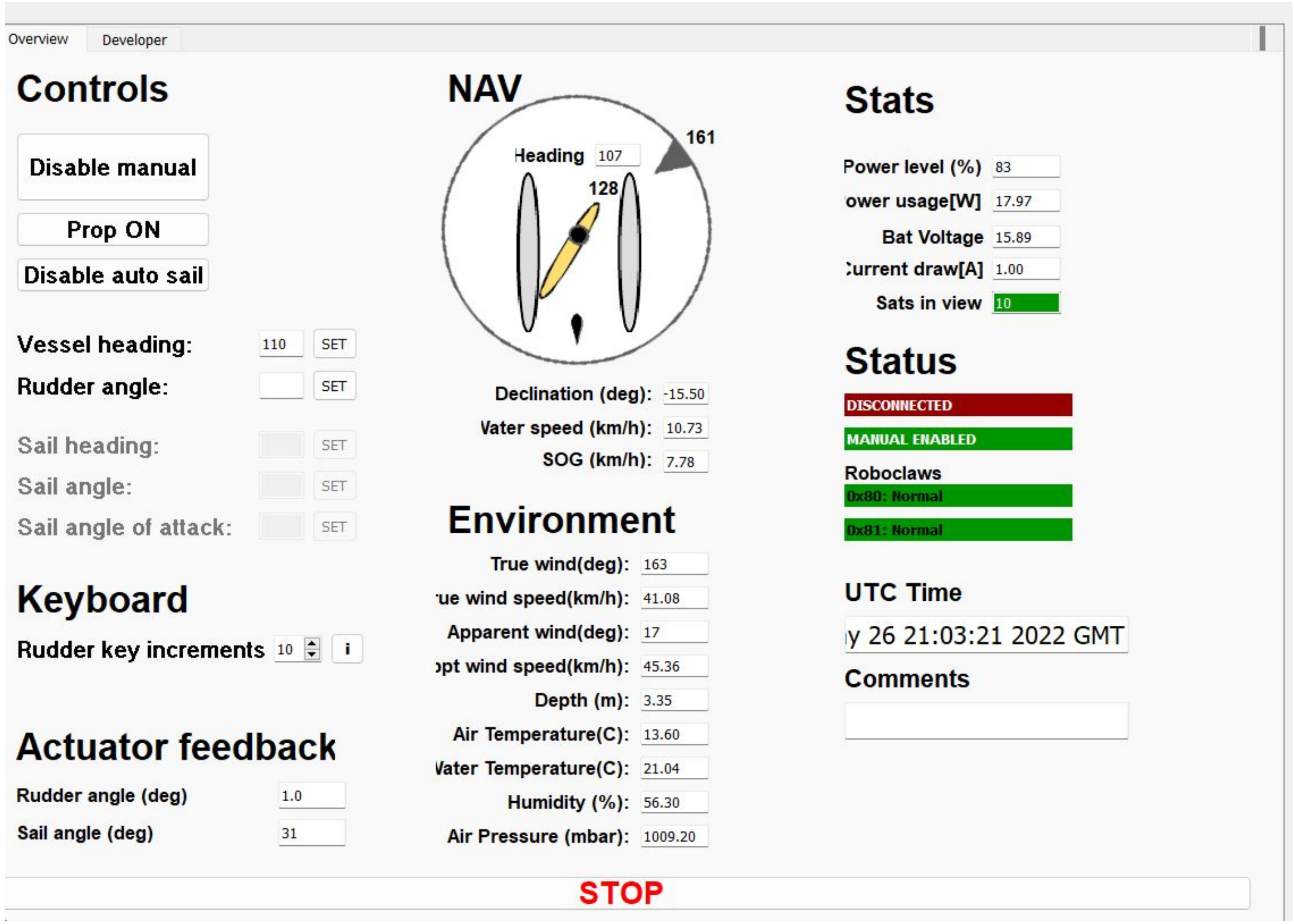
Control Architecture

- ROS frontseat, soon ROS 2
- Honor existing frontseat-backseat paradigm
- MOOS uses wind for heading decision
- Frontseat adjusts sail + rudder



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Field Tests Forest Lake Maine May 2022
Front Seat Verification - Trackline Data

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Field Tests Forest Lake Maine May 2022
Tacking and Jibing

https://youtu.be/rYBTMpFbgl4

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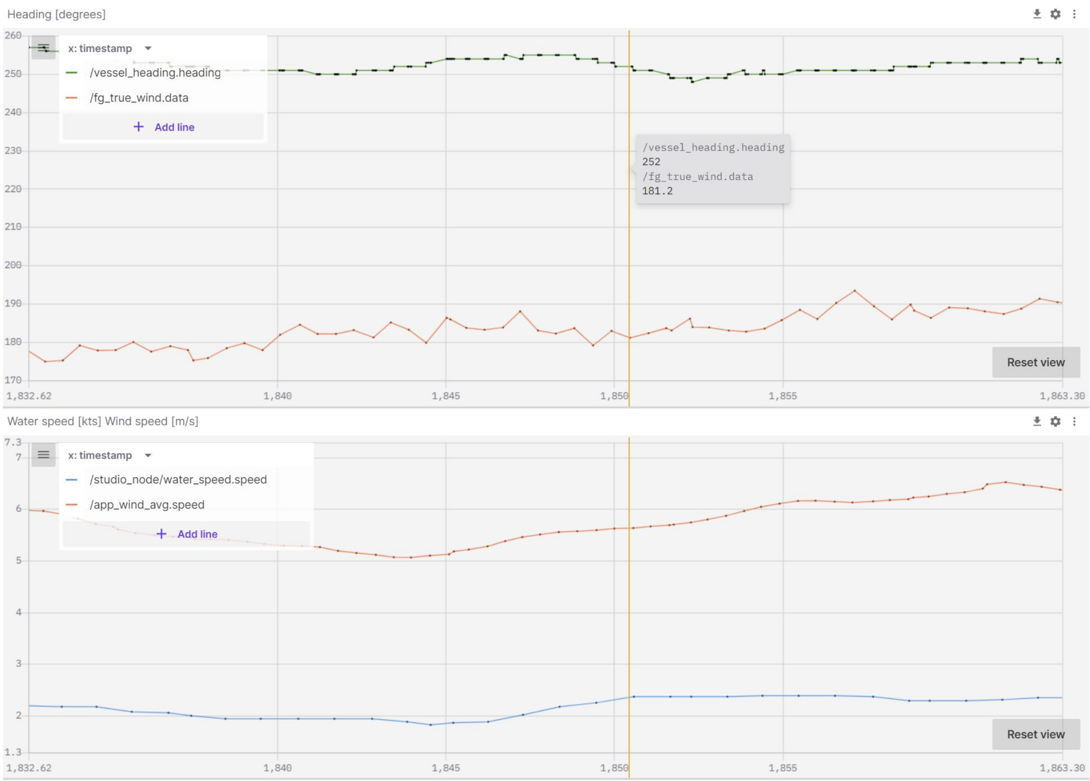
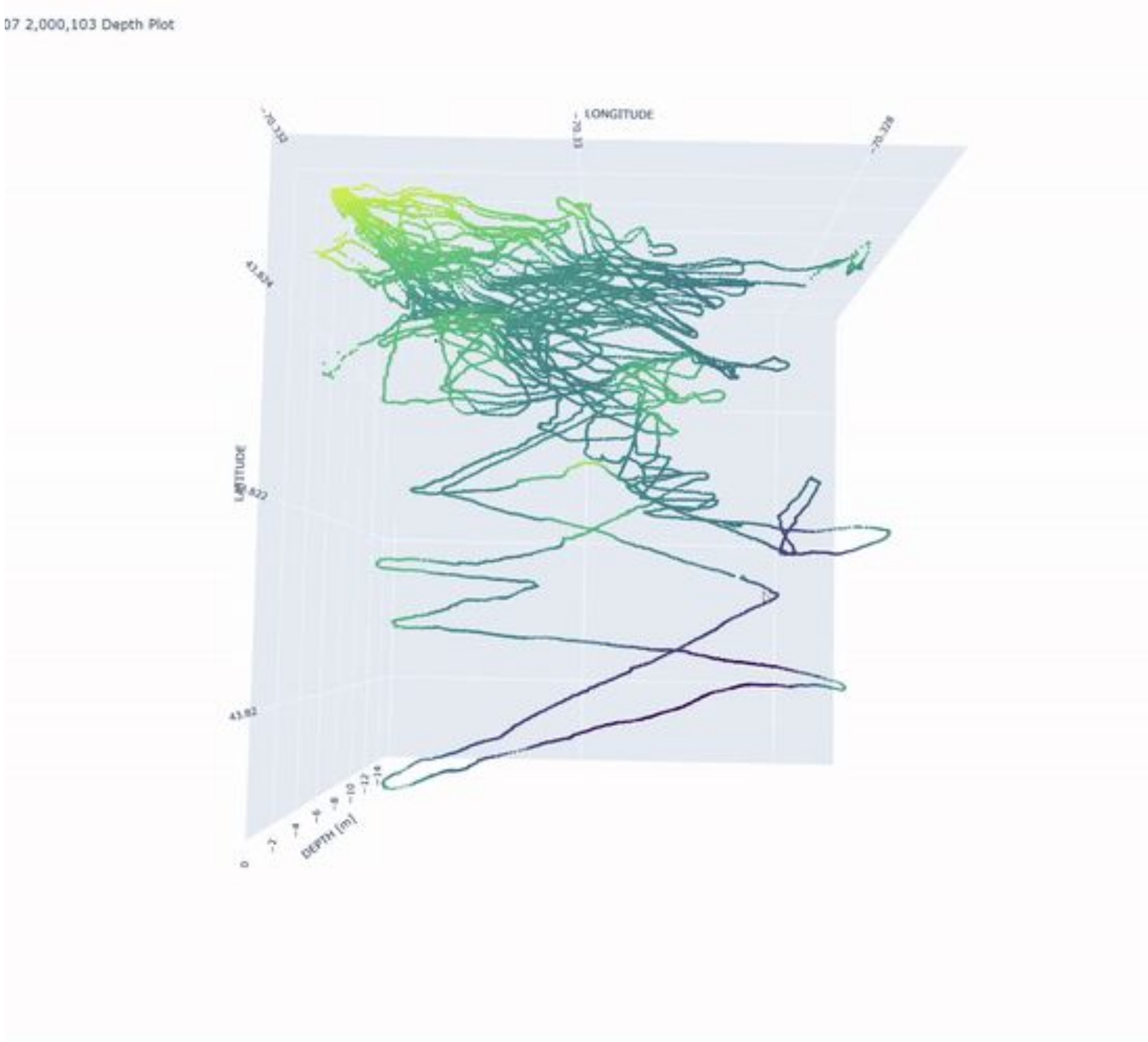
Sample Data





foxglove

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Current Efforts and Path Forward

- Next Generation Vehicle Electronics
- Next Generation Mechanical Systems
- Additional Communication Protocols
- Optional Secondary Flight Controller (ArduPilot)
- Frontseat enhancements
- GUI
- Back Seat Open Source Sailing Behaviors at MIT
- Demo on River tomorrow

MIT Marine Autonomy Lab

- Overview of sailing considerations
  - Sailing fundamentals
  - Catamaran vs. Monohull vehicles
- Sailing in MOOS-IvP
  - Sailing behavior in the IvP framework
  - Current sailing behavior methodology
- Preliminary results and observations

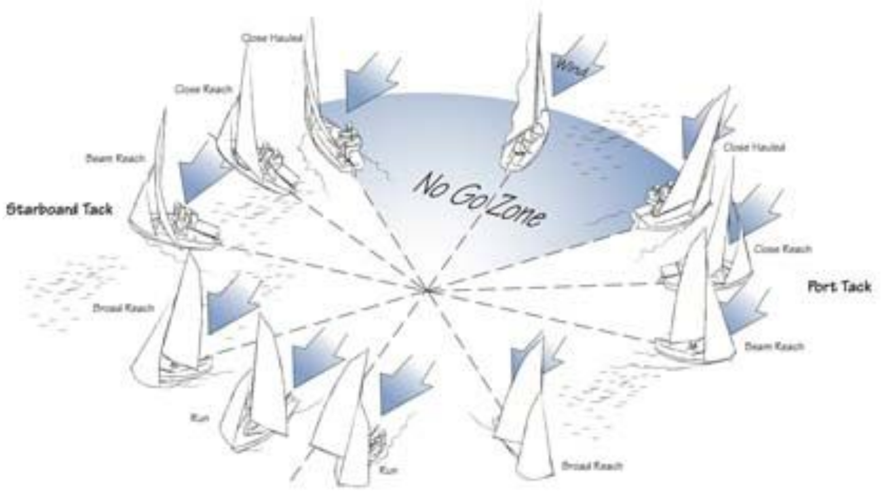

Fig 2.1: Points of sail [2.1]

Presented by: Raymond Turrisi & Michael Sacarny

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Sailing Fundamentals

- Sailing fundamentals - polar plot
- Tacking and gybing
- Catamaran vs monohull
- Polar plot as foundation of autonomy
- Backseat vs frontseat
- Differences from powered vessels
    - Difficulty holding correct speed and course to waypoint
    - Who decides tack vs gybe?
    - What is stationkeeping behavior?
    - What is All Stop?

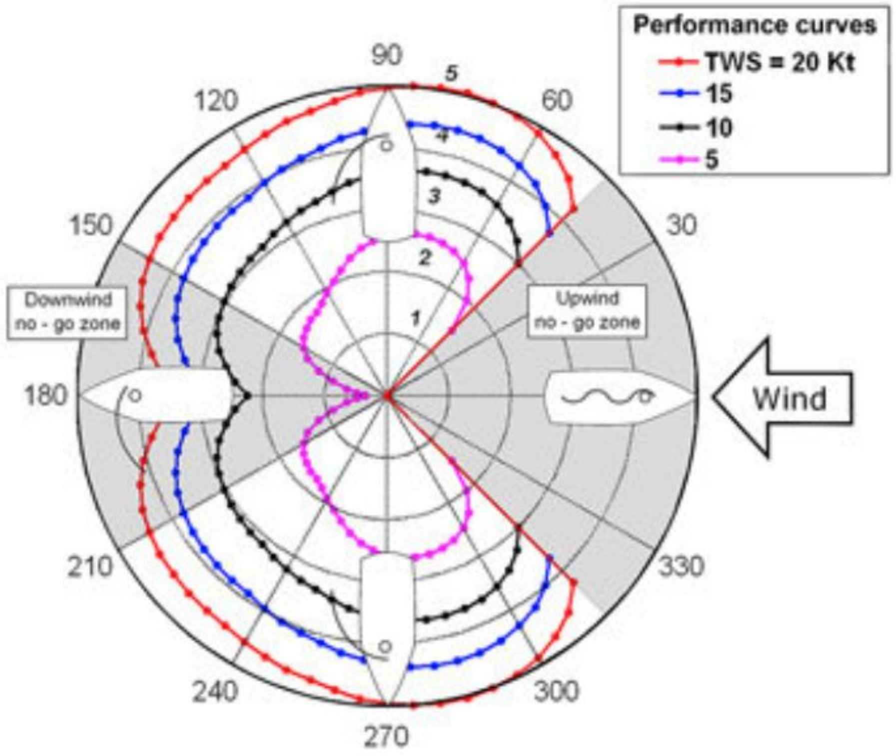

Fig 2.2: Example polar plot for monohull sailboat [2.2]

- Prototype behavior (Dr. Michael Benjamin)
  - Developed to work with existing waypoint behavior
  - Uses a simplified 2D version of polar plots
  - Implicitly provides upwind tacking and downwind gybing based on instantaneous conditions

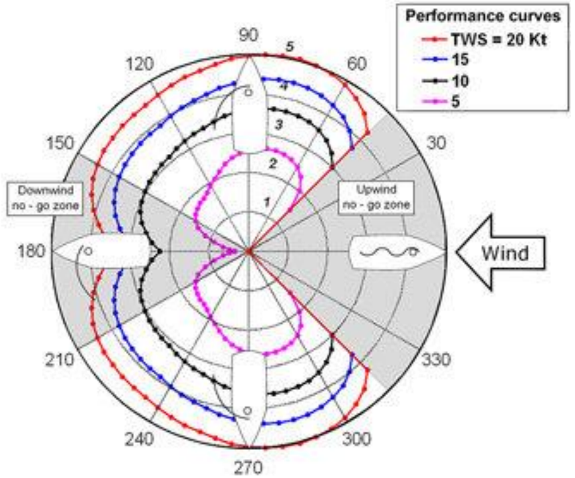

Fig 2.2: Example polar plot for monohull sailboat [2.2]

Fig 2.3: Polar plot and wind conditions as observed in pMarineViewer

Sailing in MOOS-IvP - Behavior (2)

- Waypoint behavior: 80%
- Sailing behavior: 100%
- Conditions:
  - Simulated sailboat sailing **upwind**
- Observe:
  - Composition of behavior functions **prevents the vehicle from trying to sail directly upwind**
  - Instead encourages the vehicle to tack slightly off course

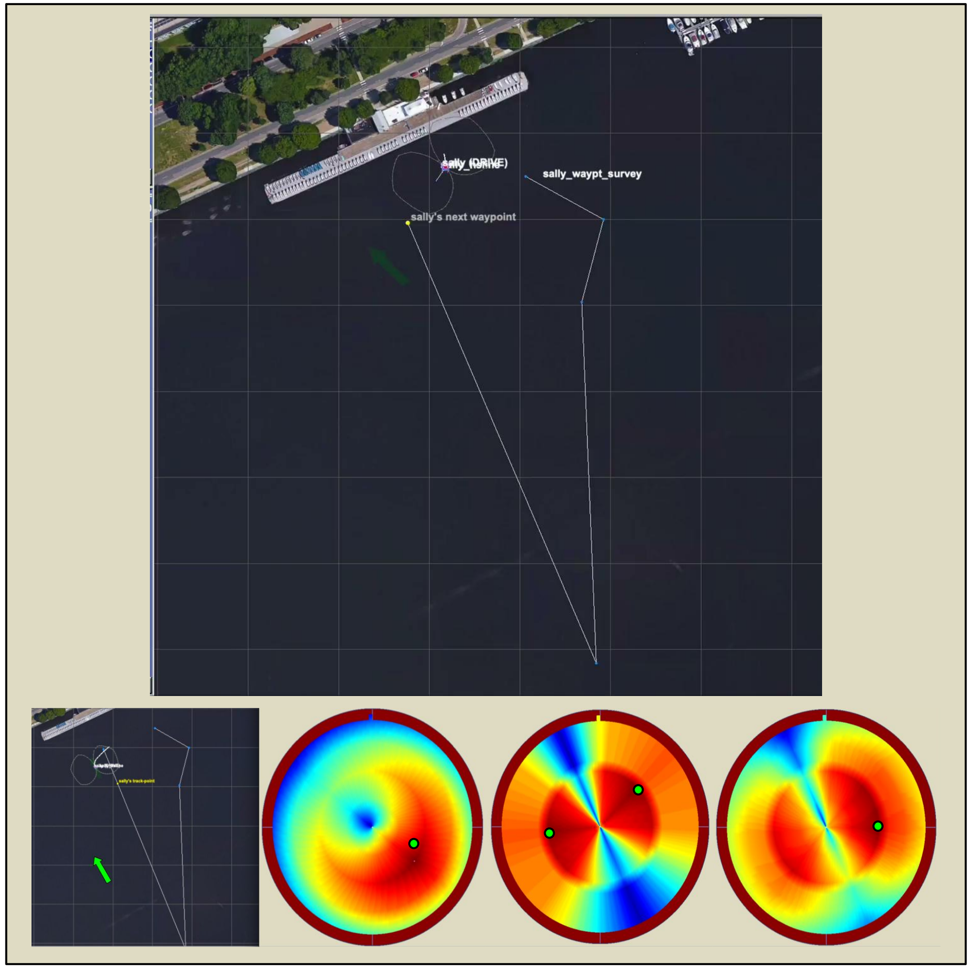

Fig 2.4: (Bottom, left to right) [a] scene, [b] waypoint behavior function, [c] polar plot behavior function, [d] combined decision surface. **From a different time step and slightly different conditions than the video above.**

Sailing in MOOS-IvP - Behavior (3)

- Waypoint behavior: 80%
- Sailing behavior: 100%
- Conditions:
  - Simulated sailboat sailing **crosswind**
- Observe:
  - Composition of behavior functions **complements the vehicle's optimal expected track**
  - Vehicle is allowed to run towards the target waypoint

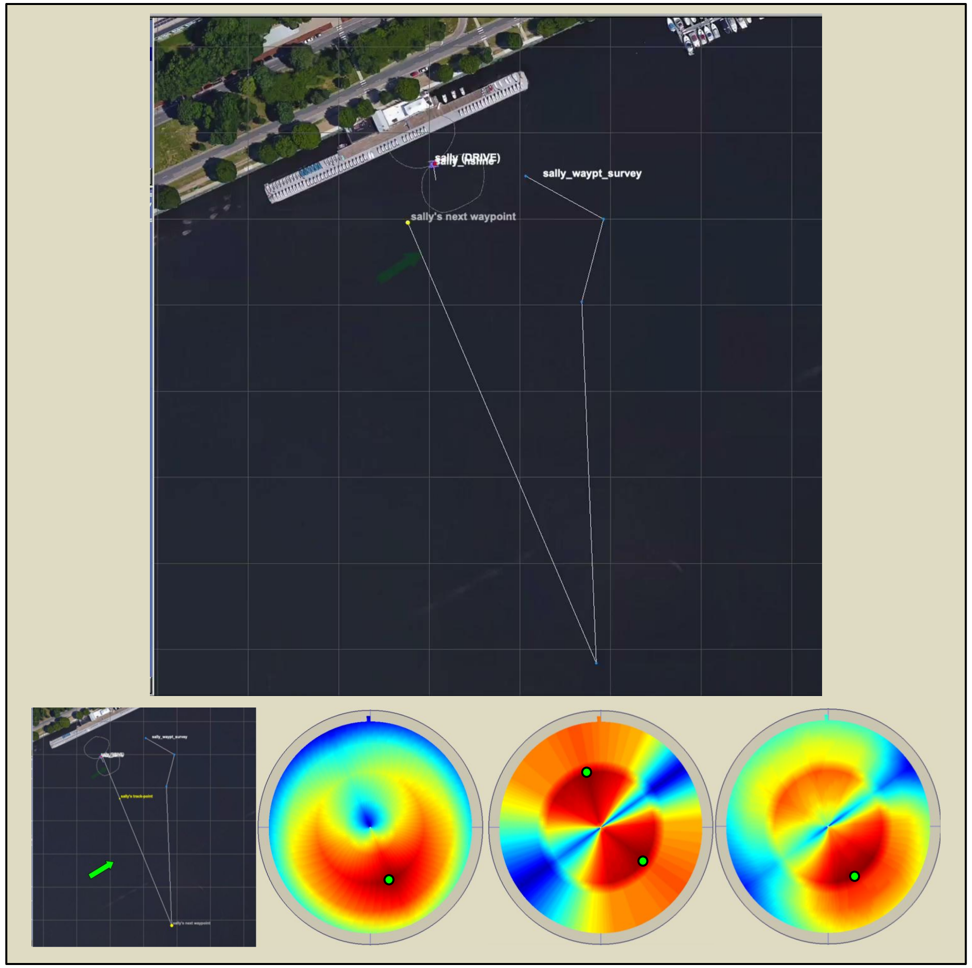

Fig 2.5: (Bottom, left to right) [a] scene, [b] waypoint behavior function, [c] polar plot behavior function, [d] combined decision surface. **From a different time step and slightly different conditions than the video above.**

Observations & Future Work for MIT

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- Derive new polar plot for vehicle
- Improve prototype sailing behavior
    - Improve the use of the polar plot
    - Incorporate deliberate tacking or gybing depending on environmental conditions
    - Plan sailing routes, read high level waypoints, and publish intermediate waypoints along course to optimize sail power to current waypoint behavior
    - Control how strongly we want to minimize prop use
        - i.e. If returning/leaving region is a high priority due to weather conditions, deprioritize prop minimization
    - Minimize number of tacks and gybes to prevent losing ground

References

2. MIT
   2.1. https://www.discoverboating.com/resources/points-of-sail-and-directions-of-sail-trim
   2.2. Plumet, Frederic & Petres, Clement & Romero-Ramirez, Miguel-Angel & Gas, Bruno & Ieng, Sio-Hoi. (2015). Toward an Autonomous Sailing Boat. IEEE Journal of Oceanic Engineering. 40. 397-407. 10.1109/JOE.2014.2321714.

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Thank You

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