Novel Reference Trajectories for Improved Marine Surface Vehicle Path Following

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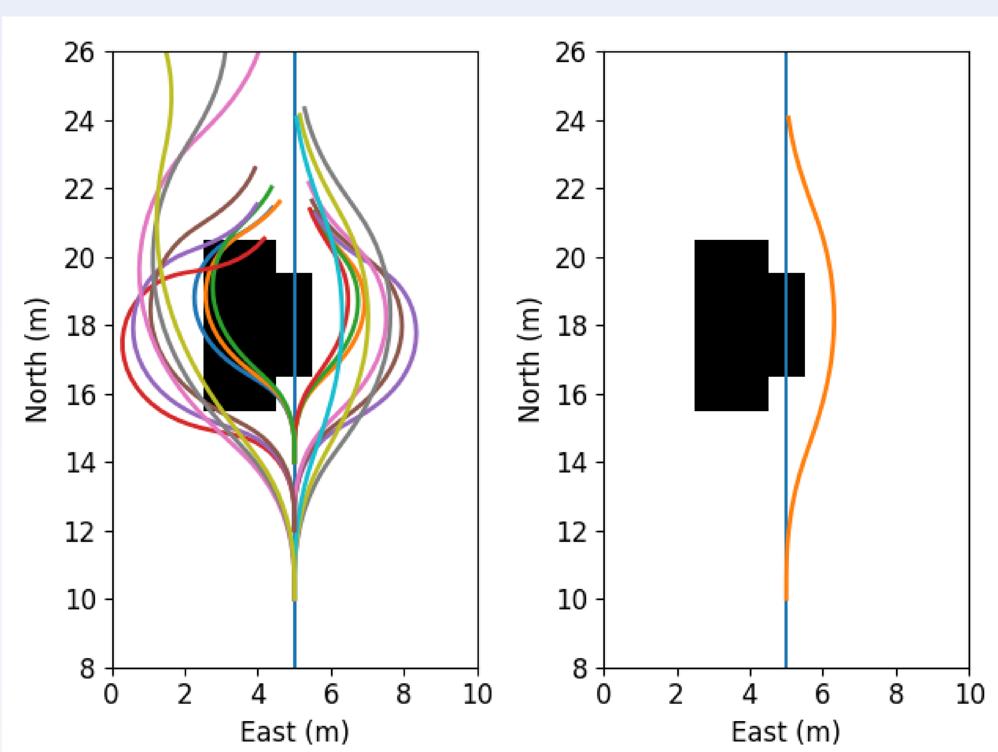
Background

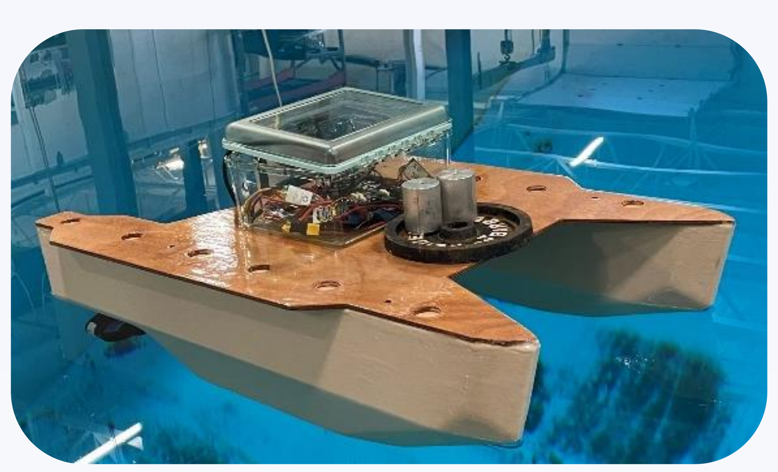
MPPlan is a model-based motion planner developed by at UNH [Custer & Thein, 2023] to plan contingency maneuvers. The system provides dynamically feasible paths that are fully characterized in terms of kinematics and planned actuations. The figure below gives an example of the contingency paths generated by MPPlan. It depicts an obstacle avoidance scenario. The 18 candidate paths modelled by the system are shown on the left; the selected path is shown on the right.

This study investigates whether the a priori dynamic characterization provided by MPPlan can be used by the vehicle guidance and control system to improve path following performance during maneuver execution.

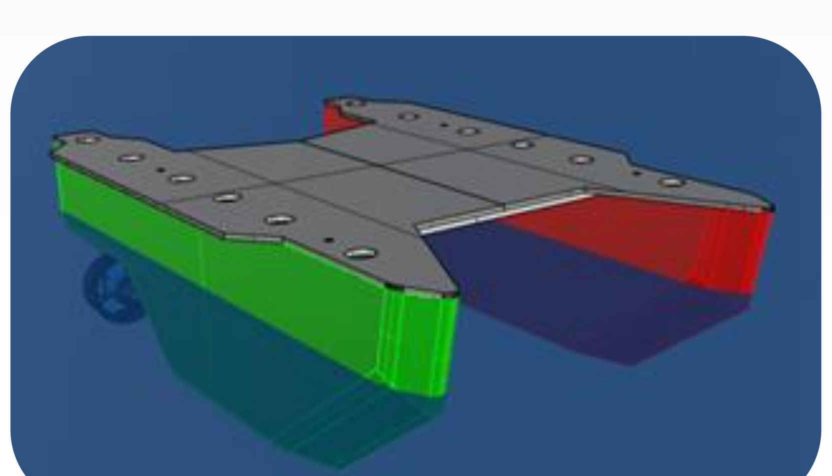


MPPlan example output for obstacle avoidance scenario. Left: Candidate paths, Right: Selected path

Research Vehicle

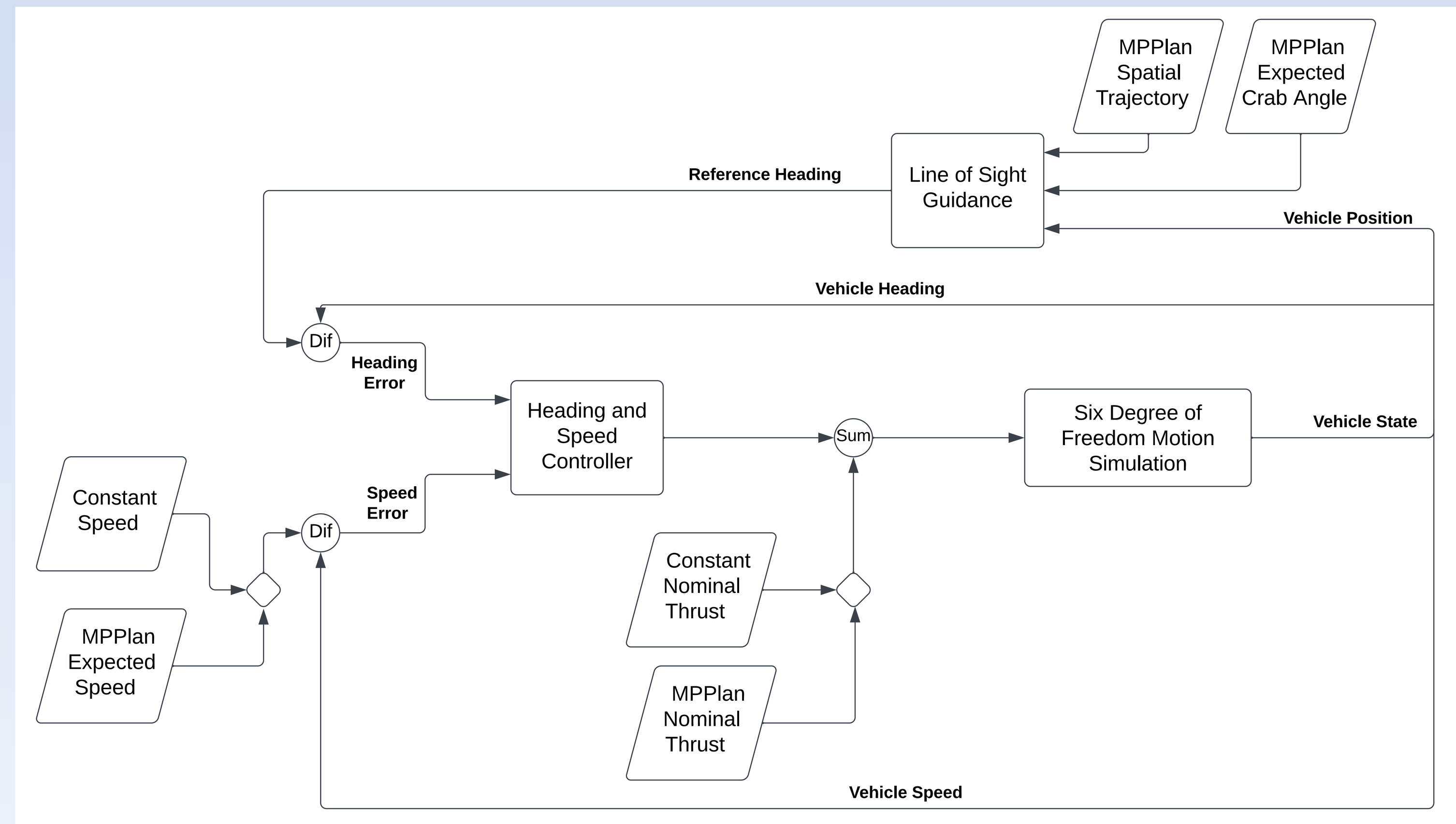


- Hulls and Deck CNC Milled from CAD Model
- Hull Material: Model Foam
- Deck Material: Plywood
- Epoxy Encapsulated
- Dual Thrusters
- Differential Thrust Steering



Principal Dimensions	
Length Overall	100 cm
Beam	50 cm
Displacement	10 kg
Top Speed	2 m/s

Path Following Guidance and Control



Levels of Input:

Level 1:
- Waypoint-defined Path

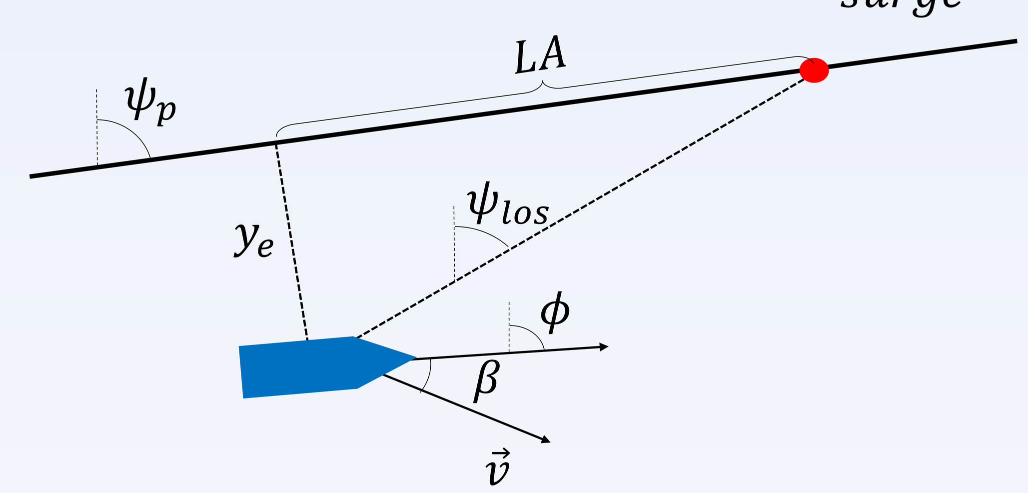
Level 2:
- Level 1 Features
- Expected Crab Angle
- Expected Speed

Level 3:
- Level 2 Features
- Planned Actuations

Guidance: Proportional Line-of-Sight

$$\psi_{los} = \psi_p - \arctan\left(\frac{y_e}{LA}\right) - \beta$$

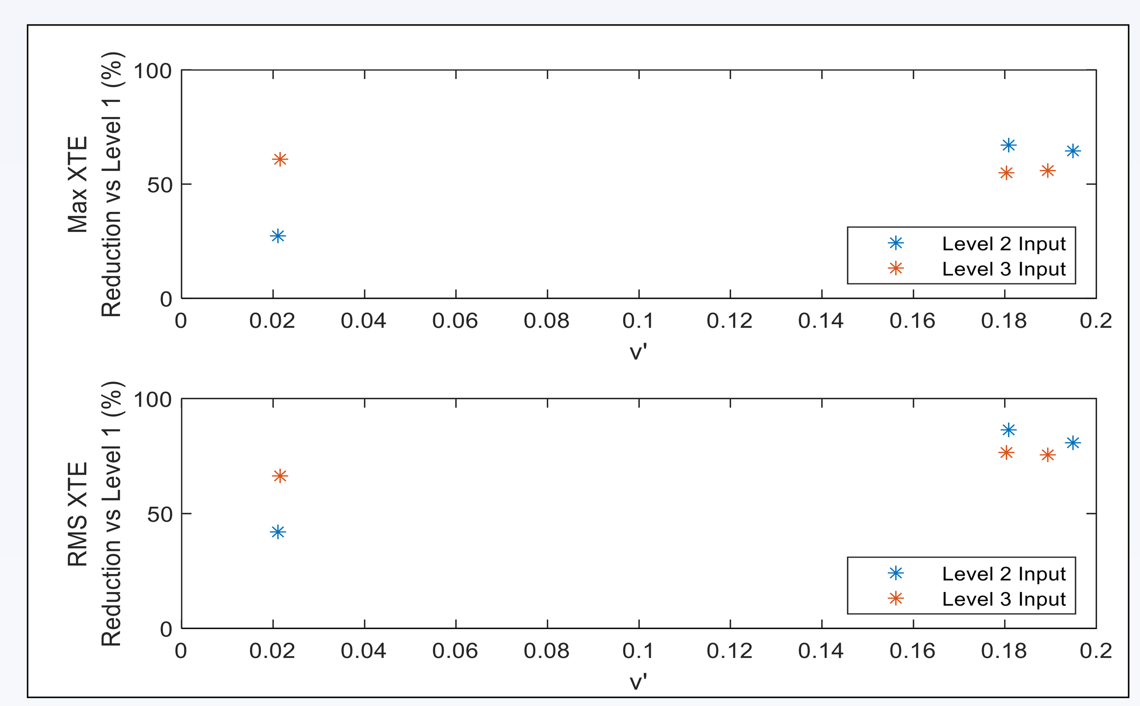
$$\beta = \arctan(v') \qquad v' = \frac{sway}{surge}$$



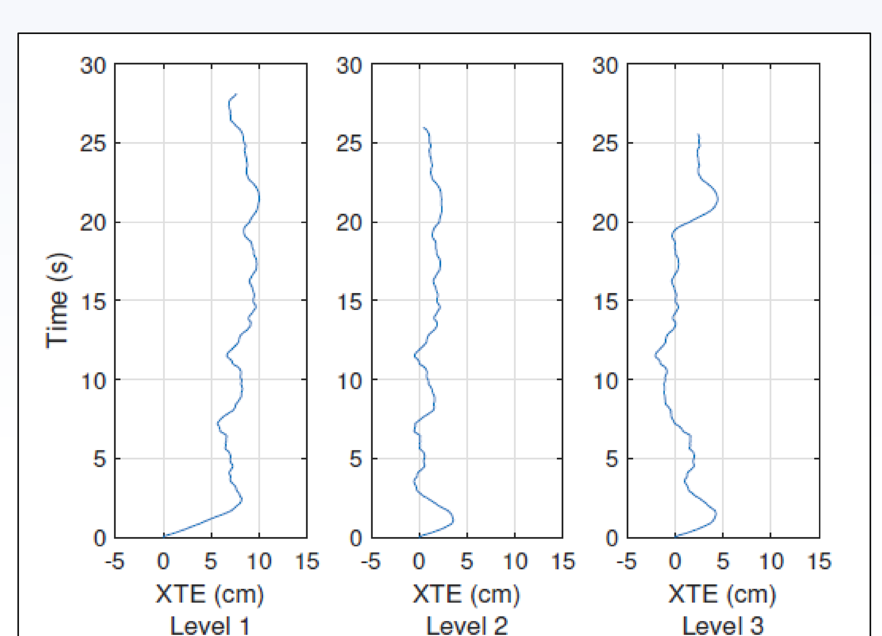
Controller: Multi-input Multi-output Heading and Speed
- H-infinity optimized
- Perturbation controller
- Output in Newtons relative to linearization point nominal thrust
- Linearized Speed Equation [Fossen, 1999]:
  $$(m - X_{\dot u})\Delta\dot u = X_u\Delta u + (1 - t)(\Delta T_P + \Delta T_S)$$
- Steering Model of Davidson and Schiff [1946]:
  $$m(\dot v + u_o r + x_G\dot r) = Y_{\dot v}\dot v + Y_{\dot r}\dot r + Y_v v + Y_r r$$
  $$I_z\dot r + m x_G(\dot v + u_o r) = N_{\dot v}\dot v + N_{\dot r}\dot r + N_v v + N_r r + y_{prop}(\Delta T_P - \Delta T_S)$$

Simulation Results

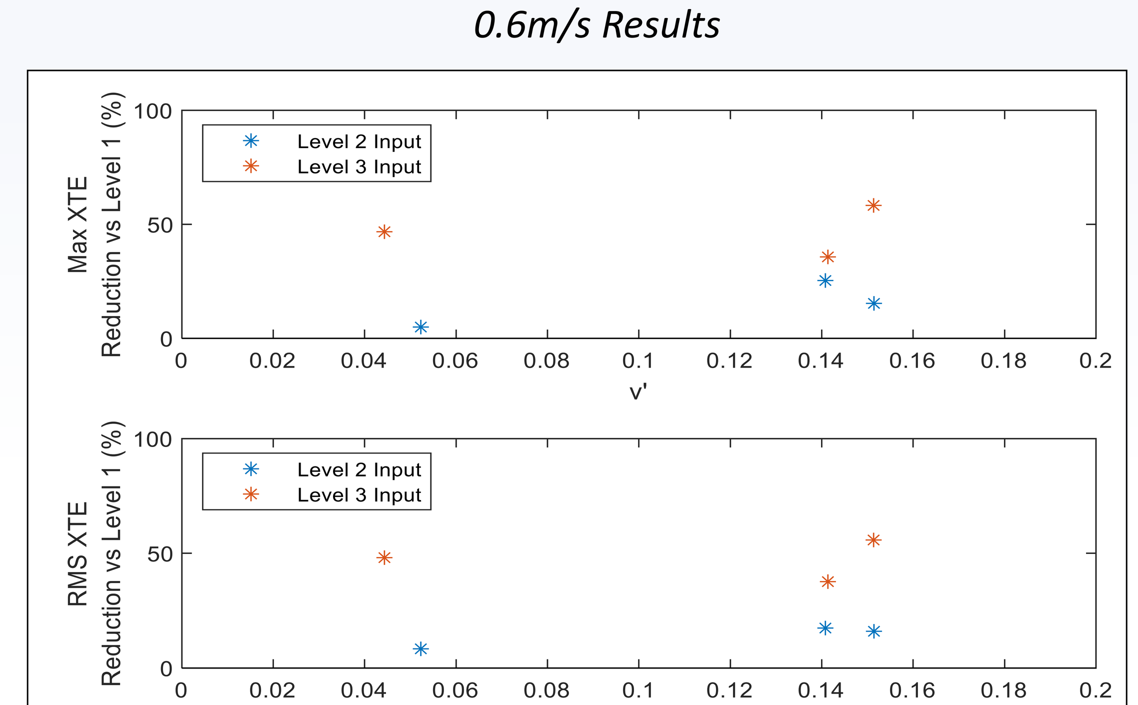
- Higher levels of input using knowledge provided by MPPlan do improve path following performance.
- Performance vs. v'
  - Level 2: Performance improves with higher v'
  - Level 3: No trend with respect to v'
- Performance vs. Speed
  - Lower performance increase at higher speeds; XTE reduction of 5 – 58% at 0.9m/s vs. 27 – 65% at 0.6m/s
  - Level 3 outperforms Level 2 for all trials at 0.9m/s, but only for low v' trials at 0.6m/s



0.6m/s Results



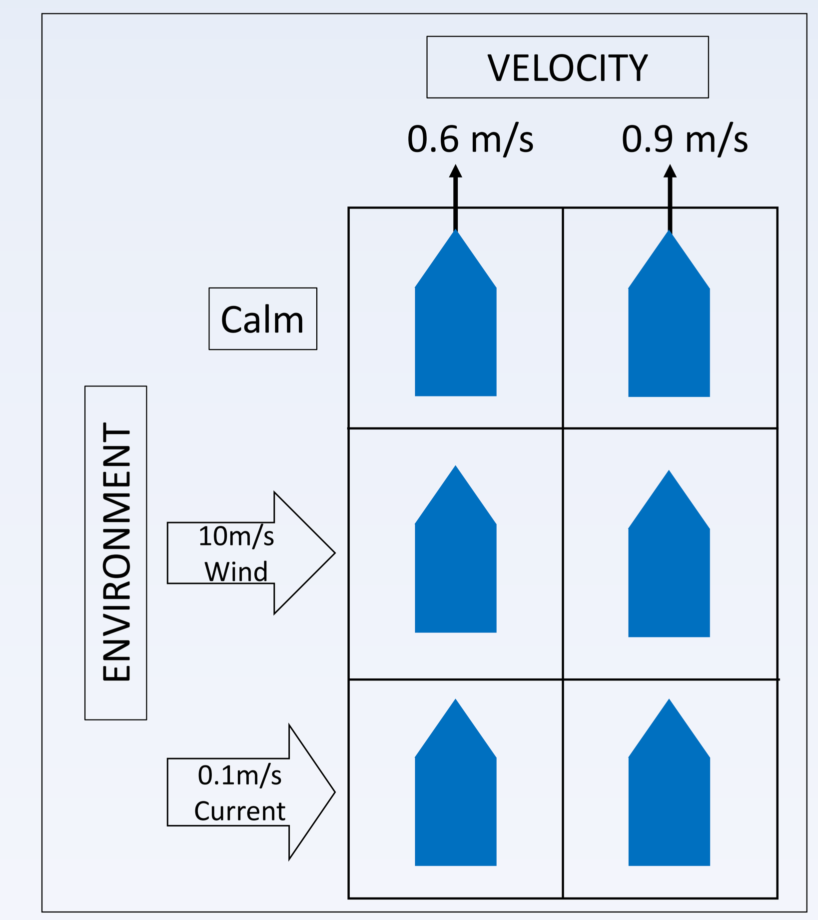
Example XTE result for scenario with environmental forcing



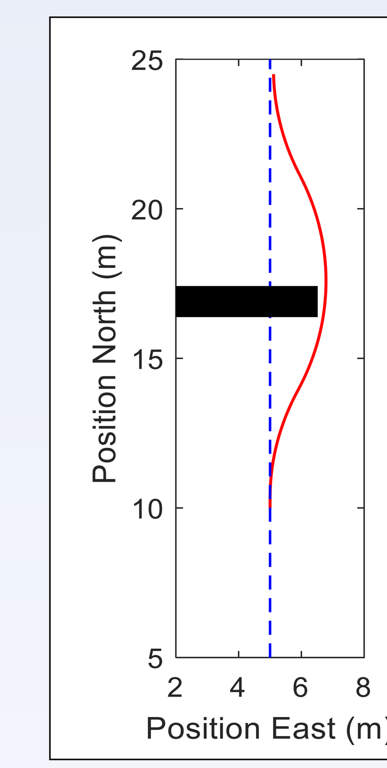
0.9m/s Results

Simulation Scenarios

- Six scenarios tested with variation of crab angle via:
  - Vehicle speed to vary inertia-induced sway velocity in turns
  - Transverse wind and current to induce sway velocity from external forcing
- Each scenario tested with three levels of input for a total of 18 trials.
- Environmental forcing
  - Wind: 10m/s at 90° to base course
  - Current: 0.1m/s at 90° to base course



Scenario test matrix



Example avoidance path

Acknowledgements

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