EgoNav: A Reliable, Interval-based Egocentric Navigation and Obstacle Avoidance Approach for Autonomous Marine Vehicles

Quentin Brateau[1], Loïck Degorre[1], Fabrice Le Bars[1], and Luc Jaulin[1]

[1] ENSTA Bretagne
LabSTICC - ROBEX, 2 rue François Verny, 29200 Brest
{first_name.last_name}@ensta.fr

Keywords: Robotics, Navigation, Obstacle Avoidance, Interval Methods

Introduction

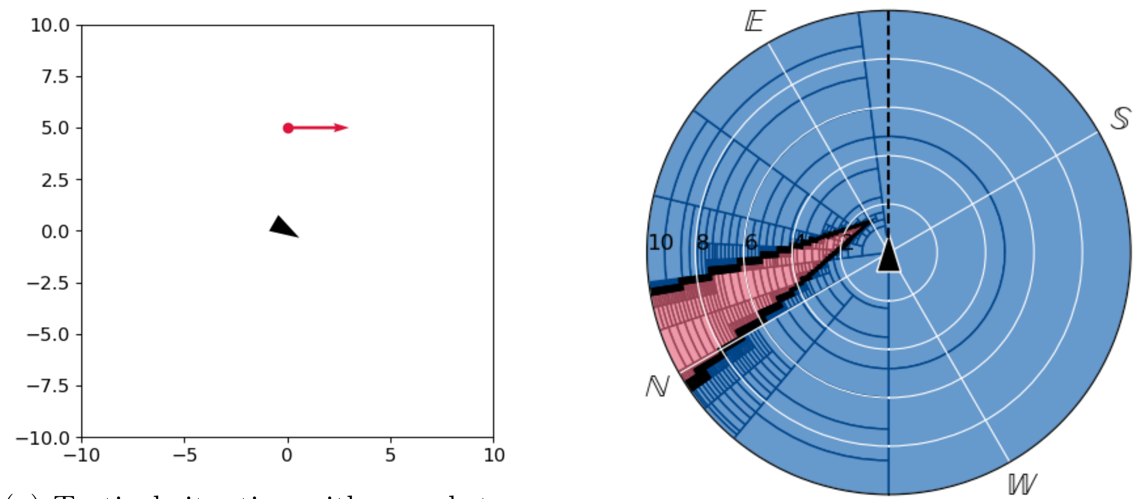
This presentation introduces Egocentric Navigation (EgoNav), a novel interval-based method for autonomous obstacle avoidance in maritime environments. EgoNav provides guaranteed safety bounds for Uncrewed Surface Vehicles (USVs) by computing feasible sets of navigation parameters—specifically heading and speed combinations—that ensure collision-free trajectories. While traditional obstacle avoidance methods such as potential fields [6] and velocity obstacles [2] have shown limitations in handling uncertainty and providing formal safety guarantees, our approach leverages interval analysis to address these shortcomings.

Comparison to traditional methods

Unlike probabilistic approaches that approximate collision risks [7], our interval analysis framework rigorously accounts for uncertainties in sensor measurements, environmental conditions, and vehicle dynamics to establish provable safety guarantees, building upon fundamental interval computation techniques [9, 5]. This work extends previous applications of interval methods in robotics to the maritime domain [10].

EgoNav approach

We demonstrate how EgoNav constructs interval-based representations of the navigable space around a USV, efficiently identifies unsafe regions through constraint propagation techniques [1], and determines the complete set of safe navigation options in real-time. The method's egocentric perspective simplifies the decision-making process by transforming the complex obstacle avoidance problem into a direct parameter selection task within validated safe sets, addressing limitations found in global path planning approaches [8]. Figure 1 illustrates the EgoNav framework on a simple example with one obstacle. The blue area represents the set of desired speed and heading for the boat to avoid collision with the obstacle, while the pink area represents the set of speed and heading that would lead to a collision.



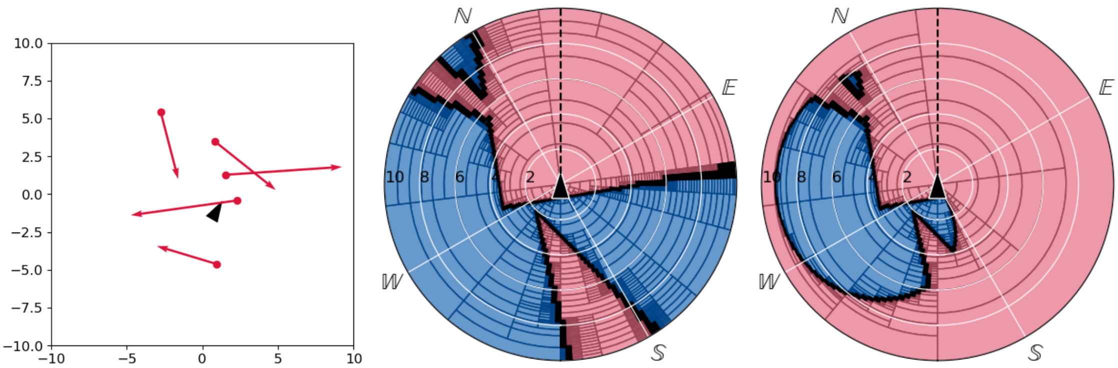
(a) Tactical situation with one obstacle

(b) EgoMap with one obstacle

Figure 1: EgoNav's interval-based approach to obstacle avoidance.

Results

Experimental results from both simulated scenarios and real-world maritime tests highlight EgoNav's robustness in dynamic environments with multiple moving obstacles. Performance metrics show that our interval-based approach maintains safety margins while achieving navigation objectives, even under challenging conditions where traditional methods might fail to provide reliability guarantees [4]. Figure 2 illustrates the EgoNav framework in a more complex scenario with multiple obstacles. Moreover, some other constraints are easily integrated in this framework such as the ability of a sailboat to navigate with respect to the wind.



(a) Tactical situation (b) EgoMap (c) With the wind polar

Figure 2: EgoNav example with five obstacles

This work contributes to the growing body of interval methods applications in marine autonomous systems [3], particularly emphasizing how set-based techniques can enhance safety-critical navigation decisions in maritime autonomy.

Acknowledgement

This work is supported by the French Ministry of Defense (AID-2022850).

References

[1] Gilles Chabert and Luc Jaulin. Contractor programming. *Artificial Intelligence*, 173(11):1079–1100, 2009.

[2] Paolo Fiorini and Zvi Shiller. Motion planning in dynamic environments using velocity obstacles. *The international journal of robotics research*, 17(7):760–772, 1998.

[3] Thor I Fossen. *Handbook of marine craft hydrodynamics and motion control*. John Wiley & Sons, 2011.

[4] W.H. Huang. Optimal line-sweep-based decompositions for coverage algorithms. In *Proceedings 2001 ICRA. IEEE International Conference on Robotics and Automation (Cat. No.01CH37164)*, volume 1, pages 27–32 vol.1, 2001.

[5] Luc Jaulin, Michel Kieffer, Olivier Didrit, Eric Walter, Luc Jaulin, Michel Kieffer, Olivier Didrit, and Éric Walter. *Interval analysis*. Springer, 2001.

[6] O. Khatib. Real-time obstacle avoidance for manipulators and mobile robots. In *Proceedings. 1985 IEEE International Conference on Robotics and Automation*, volume 2, pages 500–505, 1985.

[7] Yoshiaki Kuwata, Michael T Wolf, Dimitri Zarzhitsky, and Terrance L Huntsberger. Safe maritime autonomous navigation with colregs, using velocity obstacles. *IEEE Journal of Oceanic Engineering*, 39(1):110–119, 2013.

[8] Fuqiang Liu, Zuxing Ma, Bingxian Mu, Chaoqun Duan, Rui Chen, Yi Qin, Huayan Pu, and Jun Luo. Review on fault-tolerant control of unmanned underwater vehicles. *Ocean Engineering*, 285:115471, 2023.

[9] Ramon E Moore. *Methods and applications of interval analysis*. SIAM, 1979.

[10] Simon Rohou, Luc Jaulin, Lyudmila Mihaylova, Fabrice Le Bars, and Sandor M Veres. Guaranteed computation of robot trajectories. *Robotics and Autonomous Systems*, 93:76–84, 2017.