Stranding Risk for Underactuated Vessels in Complex Ocean Currents: Analysis and Controllers

Andreas Doering\textsuperscript{1,2,*}, Marius Wiggert\textsuperscript{1,*}, Hanna Krasowski\textsuperscript{2}, Manan Doshi\textsuperscript{3}

Pierre F.J. Lermusiaux\textsuperscript{2} and Claire J. Tomlin\textsuperscript{1}

Abstract—Low-propulsion vessels can take advantage of powerful ocean currents to navigate towards a destination. Recent results demonstrated that vessels can reach their destination with high probability despite forecast errors. However, these results do not consider the critical aspect of safety of such vessels: because of their low propulsion which is much smaller than the magnitude of currents, they might end up in currents that inevitably push them into unsafe areas such as shallow areas, garbage patches, and shipping lanes. In this work, we first investigate the risk of stranding for free-floating vessels in the Northeast Pacific. We find that at least 5.04% would strand within 90 days. Next, we encode the unsafe sets as hard constraints into Hamilton-Jacobi Multi-Time Reachability (HJ-MTR) to synthesize a feedback policy that is equivalent to re-planning at each time step at low computational cost. While applying this policy closed-loop guarantees safe operation when the currents are known, in realistic situations only imperfect forecasts are available. We demonstrate the safety of our approach in such realistic situations empirically with large-scale simulations of a vessel navigating in high-risk regions in the Northeast Pacific. We find that applying our policy closed-loop with daily re-planning on new forecasts can ensure safety with high probability even under forecast errors that exceed the maximal propulsion. Our method significantly improves safety over the baselines and still achieves a timely arrival of the vessel at the destination.

I. INTRODUCTION

Autonomous systems are increasingly deployed for long-term tasks and need to operate energy-efficient. For systems operating in the oceans or in the air, this leads to a growing interest in utilizing the dynamics of the surrounding flows as a means of propulsion. Stratospheric balloons and airships utilize wind fields [1], [2], while ocean gliders and active drifters exploit ocean currents [3]–[6].

Our recent work [7] has demonstrated that a vessel with just 0.1 m s\textsuperscript{-1} propulsion can navigate reliably to a target region by hitchhiking on ocean currents of up to 2.0 m s\textsuperscript{-1}. This work has further been extended to the application of floating farms which maximize the growth of seaweed over

* A.D. and M.W. have contributed equally to this work.
\textsuperscript{1} A.D., M.W. and C.J.T. are with the Department of Electrical Engineering and Computer Sciences, University of California, Berkeley, USA. For inquiries contact: mariuswiggert@berkeley.edu
\textsuperscript{2} A.D. and H.K. are with the School of Computation, Information and Technology of the Technical University of Munich, Germany
\textsuperscript{3} M.D. and P.F.J.L. are with the Department of Mechanical Engineering at the Massachusetts Institute of Technology, USA.

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