Challenges and Real-world Validation of Autonomous Surface Vehicle Decision-making System

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Abstract : *Autonomous decision-making is key to safe and efficient marine autonomy, as global marine industry comprises over 90 percent of the world's cargo transportation. Challenges of the real-world validation in the aquatic domain limits the wide-spread of ASVs despite their promising societal impacts. We propose and demonstrate the real-world validation platform and comprehensive algorithm steps. Such a framework will serve as a more explainable and reliable decision-making system of ASVs as well as autonomous vehicles in other domains.*

Key words : *marine autonomy, decision-making, autonomous surface vehicle, autonomous navigation*

1. Introduction

The goal of this paper is to identify challenges of maritime autonomous decision-making in the aquatic domain and develop a framework for real-world validation of autonomous surface vehicles (ASVs)—see Fig. 1. The proposed comprehensive approach—sense, decide, and act—will overcomse a typical limitation of the development of autonomous systems, that is, just focusing on modules separately (e.g., perception, motion planning only).

2. System Development

As a fundamental step of real-world validation, we have built robot hardware platforms for testing the proposed algorithms as well as conducting an ultimate task, e.g., environmental monitoring (see Fig. 2). The key advantage is to design and build a custom robotic boat fit for our research. For instance, off-the-shelf robotic boats do not meet our requirements−motion stability and durability−to achieve sensing reliability, sea worthiness, and long-term operation. We tested the proposed platform based on Computational Fluid Dynamics (CFD) and on-field testing.

3. Algorithmic Development

3.1 Perception

ASVs are mainly deployed in unknown local environments [1]. Such a perception algorithm needs to

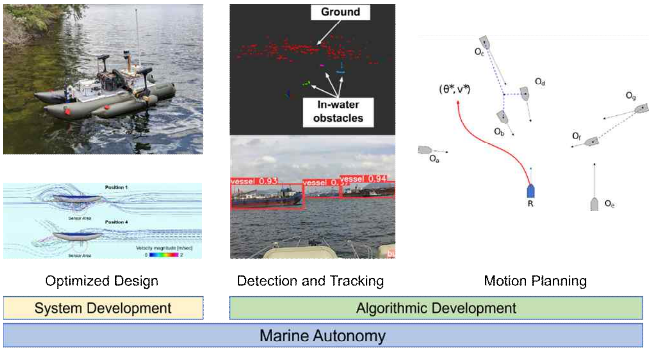

Figure 1. Comprehensive pipeline for autonomous surface vehicle decision-making including system and algorithm development.

address more challenges compared to large ocean going vessels relying on charted maps or self-driving cars as shown in Fig. 3. We have proposed an efficient and adaptive point clouds clustering method based on a spherical image projection [2]. Also, we propose a Deep Learning-based sensor fusion framework for in-water obstacle detection and segmentation (see Fig. 4).

Figure 2. custom built ASV *Catabots* by Dartmouth Reality and Robotics Lab are in action.

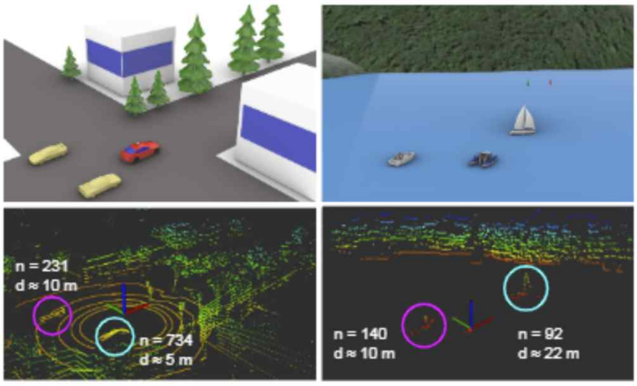

Figure 3. Comparison of typical navigation scenarios and actual 3D LiDAR point clouds between urban environments and aquatic ones.

Figure 4. LiDAR-camera sensor fusion result based on the neural network model.

3.2 Collision Avoidance

In-water navigation is typically more challenging due to the following reasons: (1) unstructured waterway conditions; (2) vehicle dynamics; and (3) not explicit traffic regulations. Our study proposes a novel real-time non-myopic obstacle avoidance strategy that enables ASVs to have a holistic view of surroundings, navigate in demanding high-traffic conditions, and decide the optimum course of action based on Pareto optimality [3]. We tested the proposed algorithm not only on the realistic 3D simulator but also on real robots as shown in Fig. 5.

4. Discussion and Future Steps

Despite the unique characteristics of the marine domain, the foundation of our approach to the full-pipeline validation of autonomy and decision-making

Figure 5. On-field validation of the proposed collision avoidance algorithm in a head-on encounter.

can also be applied to autonomous vehicles in other domains such as ground vehicles, aerial drones. Furthermore, enhancing the autonomy of ASVs can enable several high-impact social applications, such as shipping and environmental monitoring.

We will collect more operation data with our fleet under different challenging environments such as fog and rain. We will also integrate a tracking algorithm for the reliable state estimation of multiple obstacles and mutiple obstacle avoidance in actual coatal, ocean areas. As a long-term goal, we plan to release open-sourced modules and dataset to contribute to the marine robotics and shipping community.

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