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Editorial

Autonomous Marine Vehicle Operations

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1. Introduction

The world has witnessed the rapid development of autonomous marine vehicles, such as surface vehicles and underwater vehicles, which have created fruitful innovative approaches to previously unsolvable problems in marine and ocean engineering [1,2]. In practice applications, single-vehicle operations inevitably face many difficulties and challenges, such as non-linearity, strong coupling, multi-inputs/multi-outputs, uncertainties and multi-constraints. In addition, the information interaction-based swarm system has complicated dynamics, such as high state dimensions and complicated connection topology, thus leading to great challenges for autonomous operations. At present, the main subjects for autonomous marine vehicle operations can be divided into perception, decision making and control. In this context, this Special Issue "Autonomous Marine Vehicle Operations" has been launched, including 11 selected hot topics.

Perception is the essential precondition for autonomous and intelligent operations [3,4]. Environment information with high precision is difficult to obtain by a single sensor. In this context, multi-sensor fusion-based perception technology receives more attention. All kinds of sensors are used to realize multi-level and multi-spatial information complementation and optimal combination, thus generating the consistency explanation for the observation environment. With the challenges of complicated marine environments, such as ocean disturbances, uneven illumination and non-significant targets, the vehicles need to realize information fusion of the appointed target based on the typical attributes of each sensor. The system navigation unit and electronic chart are utilized to build a multi-dimensional tridimensional situation picture of the task environment, contributing to the tasks of target tracking, target detection, target recognition and cognition. For example, in [4], a space-scale attention-based context-aware detection network model is proposed to realize marine multi-scale target detection and recognition. In [5], considering the distributed multi-platform data fusion, by utilizing the Dempster–Shafer evidence theory to analyze multi-source information, the confidence conflict of different information sources during information fusion is addressed successfully.

Decision making is at the core of autonomous and intelligent operations [6,7]. Under complicated marine environments, obtaining effective information and generating feasible control commands face great challenges. According to the differences in control objectives and spatial constraints, the main results of single-vehicle decision making include target tracking, path following and trajectory tracking, where light-of-sight guidance, backstepping and artificial potential field are widely utilized [8,9]. The main results of swarm decision making include cooperative target tracking, cooperative path following and cooperative trajectory tracking, where leader following and graph theory are widely employed [10]. Considering operation environments and operation constraints, marine vehicles are allocated one or more tasks in order during decision making. And the objective is to optimize the system task efficiency in terms of task types, spatial constraints and system performance [11]. In this context, the allocation model and the allocation algorithm are available, where the former transforms the allocation problem to the multi-traveling

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salesman or mixed integer linear programming, and the latter is responsible for obtaining a solution based on the Hungarian algorithm, ant colony algorithm, game theory, Bayesian theory, auction algorithm, etc.

Control is utilized to stabilize and control the system attitude, forcing vehicles to accomplish the desired command generated by decision making [12]. According to the differences in solving disturbances, the main results include passive anti-disturbance control and active anti-disturbance control. The former depends on the inherent robustness, such as adaptive control, sliding mode control and model predictive control, etc. And the latter is also called disturbance observation-based control, where the unknown disturbance is approximated by the approximator/observer and then applied to the feedback controller as the feedforward compensation. The main types of observation-based control include neural network approximators, fuzzy logic systems and normal model-based observers. For example, in [13], the radial basis function neural network-based finite-time controller is designed. In [14], the fixed-time disturbance observation-based terminal synovial controller is proposed, reducing the time of disturbance estimation efficiently. In [15,16], based on the form of differential inclusion, a finite time observer is designed to compensate system unknowns and time-varying disturbances exactly. In [17], the active anti-disturbance controller is developed by combining a fuzzy logic system and speed error-based prediction, guaranteeing that the desired command can be tracked accurately despite the existence of unknown dynamics.

2. An Overview of Published Articles

This Special Issue focuses on autonomous marine vehicle operations under complex ocean environments and contains 12 published articles. The main contributions are as follows.

In contribution 1, considering the influence of situational static loads and varying hydrodynamic forces during high-speed movement, a novel S-plane controller is developed for an underwater vehicle by using a sliding mode variable structure. Prototype experiments including cruise control and path-following control are successfully carried out, thereby demonstrating the superiority of the S-plane controller and enriching our motion control technology for marine vehicles.

In contribution 2, to enhance the identification accuracy of underwater objectives under the complex environment, an accurate identification and detection method is employed using the sizeable convolutional-network-based You-Only-Look-Once (YOLO) algorithm. With the aid of the improved YOLO network, the problem of low image quality and dense objectives is well alleviated. The proposed network model can provide effective guidance for the intelligent aquaculture of fishes.

In contribution 3, two key problems including path planning and tracking control of USVs are considered. Within the planning module, a safe and optimal path can be generated using rapidly exploring randomized trees. Within the control module, an active anti-disturbance controller is designed for unmanned vehicles with unknown dynamics. In addition, considering the potential occurrence of thruster failures, different fault-tolerant schemes are developed based on the neural-network-based model predictive control. The proposed path planning and control methods can guide obstacle avoidance for marine vehicles in faulty conditions.

In contribution 4, an automatic alignment approach of an underwater charging system is employed with the aid of monocular vision recognition, where the vehicle number can be identified, guiding the charging pile to accurately insert into the charging port of the vehicle. To enhance the accuracy and robustness of decoding, this research proposes a redundant information-based encoding and ArUco code reconstruction approach. In addition, the target position can be determined, thereby overcoming the difficulty of an underwater two-dimensional location and meeting the accuracy requirements for alignment.

In contribution 5, considering the complexities of the maritime environment and the non-holonomic characteristic of the operation system, a novel path planning method for surface vehicles is creatively established, consisting of an optimization model, a meta-heuristic solver, and a Clothoid-based path connector. By virtue of the proposed path planner, a path with both optimally safe and quick convergence can be generated, enhancing its adaptability to time-varying environments. Compared with the existing results, this study guarantees the continuity of paths and the consistency of planners and controllers, solving the non-holonomic limitations.

In contribution 6, an underwater object detection model is developed for underwater unmanned vehicles by using a mobile vision transformer and YOLOX, providing a good balance between accuracy and memory. In addition, the double coordinate attention strategy with fewer parameters is built to strengthen the ability of extracting data from difficult objectives. This study is beneficial for underwater vehicles to identify small and difficult targets in water.

In contribution 7, to enhance the hydrodynamic performance of the underwater vehicle, the steady-stream (SS) active flow control (AFC) method is employed via numerical calculation. The mechanism of the SS-AFC influencing the lift-to-drag performance is revealed in terms of the flow field, contributing to operations of underwater vehicles with large angles of attack. This proposed method improves the hydrodynamic performance of the vehicle, thus guaranteeing vehicle stability, maneuverability and safety.

In contribution 8, a swarm key node identification method is developed using network structure entropy to address the critical identification of underwater vehicles. The network structure of multiple vehicles is built using the motion similarity model and the information entropy of swarm nodes is solved by the aid of the weighted network structure entropy method. Simulation and lake experiments are carried out, where the time-varying trajectory of the swarm and the importance ranking of the swarm nodes can be successfully calculated. This research provides a valuable reference for underwater cluster countermeasures.

In contribution 9, a dynamic data-driven operation system is employed, effectively overcoming the difficulties of high-resolution and accurate flow field forecast in ocean environments. The neural network structure is developed using information extracted from historic flow data, thereby enhancing the flow forecast performance. In addition, the Kalman filter is applied to assimilate spatially correlated flow-sensing data from vehicles, thereby enabling efficient learning and accurate flow forecasts. This study offers a feasible solution to high-resolution and accurate flow field forecasts in practice engineering.

In contribution 10, an accurate path-following controller including kinematics and dynamics is developed for an unmanned surface vehicle suffering from system uncertainties and wind, wave and current disturbances. At the kinematics level, the desired guidance signals can be generated by the proposed surge-heading joint guidance method. At the dynamics level, the deep-reinforcement-learning-based surge and heading control laws are designed using the error feedback between the actual and desired signals. In addition, actor networks and critic networks are established by utilizing the long-short time memory network, helping the vehicle to take advantage of historical data. This study provides an optional plan for path-following operations of surface vehicles.

In contribution 11, the hydrodynamic interaction between the underwater vehicle and the submarine is studied using computational fluid dynamics, where the two systems are defined as relatively static states. Simulation tests show that, in the recovery phase, the submarine appreciably affects the velocities and relative attitudes of underwater vehicles. This research offers a valuable reference for submarine recovery operations involving underwater vehicles in terms of stability, safety and efficiency.

In contribution 12, aiming at small target detection on water surfaces using cameras in complex environments, a novel millimeter-wave radar-based visual detection technology is developed, achieving robust coordination of radar data and images in the presence of inaccurate extrinsic parameters. Note that the developed technology has lower computational complexity and has been successfully applied in practical engineering. And the results show that the proposed target detection technology has obvious advantages compared with the existing work.

3. Conclusions

This Special Issue delves into the forefront of autonomous marine vehicle operations in terms of perception, decision making and control. Within the perception community of surface and underwater vehicles, an improved YOLO mode for identification and a mobile vision transformer-based object detection model are developed under the complex environment, alleviating the situation of low-quality underwater images and dense objectives. Within the decision-making community of vehicles, with the aid of geometric optimization, several path planning methods have been successfully developed, guaranteeing path continuity and reliable coordination. Within the control community, improved S-plane and reinforcement-learning-based dynamic control is proposed for underactuated systems suffering from model uncertainties and environment disturbances, achieving accurate path following and motion control. Additionally, this Special Issue explores the hydrodynamic interaction of the submarine and the underwater vehicle by using computational fluid dynamics, providing a valuable reference for submarine recovery operations. The current studies presented in this Special Issue should not only be considered as the results of an investigation accomplished by the respective scholars, but as a starting point, encouraging readers to continue with new studies.

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List of Contributions:

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