別紙様式第１３

学位論文の内容の要旨

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学位論文題目	Study on the Multi-sensor Information Fusion and Control Strategy for Spherical Underwater Robots
学位論文の内容の要旨	（日本語1,000～2,000字、又は英語400～800語） Spherical Underwater Robot (SUR) is a kind of special structural underwater robot with low-noise and high compression characteristics. Due to its overall symmetry, there are no coupling terms in the fluid dynamics calculation. Therefore, it is widely used in underwater missions. There are many researchers in the world who are committed to developing spherical robots. In the previous research in our laboratory, the open water efficiency, mutual interference and availability for SUR with hybrid thrusters are not efficient enough. Moreover, the attitude regulation and multi-mode switching strategies considering the robot model, uncertainties, and anti-disturbance for SURs are inadequate. More importantly, the rich multi-source information from different types of sensor nodes for SURs has not yet formed a relatively specific theory and method. To address these issues, the multi-sensor information fusion and control strategy for the SUR with hybrid thrusters is proposed. The thesis consists of 8 chapters as follows: **Chapter 1:** Introduction In this chapter, the need for maneuverability, stability and effectiveness of the SUR is introduced in order to perform tasks safely and efficiently. **Chapter 2:** Mechanical design and modeling of the SUR The novel SUR with hybrid propulsion devices is proposed, including the hybrid thruster unit, the sensor unit, the decision unit and the power unit. Considering the strong nonlinearities, external disturbances and obstacles, the kinematic and dynamic model of the SUR is described. **Chapter 3:** Hydrodynamic and open-water performance of the SUR with hybrid propulsion devices (Journal #1) To improve the accuracy and efficiency of the SUR, the hydrodynamic characteristics of hybrid propulsion devices are analyzed. The open-water performance and flow field of individual water-jet and propeller thrusters are analyzed using ANSYS WORKBENCH. The thrust measurement and basic motion experiments for SUR using hybrid propulsion devices are carried out. **Chapter 4:** Development of the multi-mode switching control of the SUR (Journal #2) A multi-mode adaptive switching strategy for the SUR combining the advantages of each thruster is proposed, which provides the possibility for the SUR to choose the

	optimal control mode according to the unpredictable operating environment. A series of multi-mode switching experiments are conducted using the water-jet mode, propeller mode and hybrid mode. By adding external disturbances and other comparative experiments, the effectiveness and accuracy are further verified. **Chapter 5:** Performance evaluation of an attitude controller of the SUR (Journal #3) A suitable self-balancing mechanism and an attitude controller for the SUR are proposed. The center of gravity adjustment structure is designed. The attitude controller for the SUR is developed by dividing the attitude control problem into roll angle control and pitch angle control. Two nonlinear disturbance observers are constructed to handle errors in the uncertainties and linearization process in the dynamic model. The back-stepping sliding mode control method is implemented for SUR to improve the robustness and feasibility of the attitude controller. A series of experiments are conducted to verify the performance of the developed method. **Chapter 6:** Improved obstacle avoidance strategy based on the ultrasonic sensor array (Journal #4, #5) In this chapter, the waypoints-based trajectory tracking with obstacles and uncertainties is proposed to ensure its safety and stability. An obstacle avoidance control strategy for the SUR is developed based on the ultrasonic sensor array. The stability and robustness of the control system are verified using the Lyapunov theory. A series of simulations and experiments in the real environment is conducted to evaluate the performance of the control strategy for detecting unknown environments. **Chapter 7:** Performance evaluation of the multi-sensor information fusion of the SUR (Journal #6) Multi-source information fusion is an important guarantee for improving the quality of data analysis and processing. Considering the key issues such as attitude estimation, positioning and obstacle avoidance involved in performing tasks, a fusion model for SUR is proposed by constructing the optimized prediction models. The correlation and fusion scheme between multiple sensors is developed. A series of locomotion and obstacle avoidance experiments are performed by integrating the fusion model into the SUR to comprehensively evaluate the performance metrics. **Chapter 8:** Conclusion To expand the comprehensive capability of SUR to the underwater environment and realize long-term monitoring and exploration tasks, this thesis focuses on using multi-sensor technology to improve the perception and obstacle avoidance capabilities of SUR in complex environments. The summary of the conclusion is as follows: 1) The SUR with hybrid thruster is designed and the open-water performance of the hybrid thruster is evaluated using a numerical calculation to improve the execution efficiency, multimodality and maneuverability. 2) Control strategies for the SUR, including attitude regulation and multi-mode adaptive switching, are proposed based on the kinematic and dynamic models. 3) The multi-sensor information fusion model for SURs is proposed by constructing the optimized prediction models, such as the attitude estimation model, velocity estimation model, obstacle avoidance model, and so on.