Motion control of Work-class ROVs based on discrete double-loop sliding mode controller with a new adaptive reaching law: Theory and experiment

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ABSTRACT

Work-class ROVs are always subject to external disturbances and system uncertainties. The sliding mode control is an effective method to overcome the disturbances, but its chattering phenomenon restricts its practical application on ROVs. In this paper, we propose a model-free discrete double-loop sliding mode controller, the feasibility and robustness of the controller are illustrated by quasi sliding mode theory. To further reduce chattering, an adaptive reaching law is proposed while ensuring robustness to conquer the poor steady-state error. The experiment results show that the proposed method has better robustness than PID, and the adaptive reaching law can lightly reduce chattering.

KEY WORDS: sliding mode control, reaching law, discrete control.

INTRODUCTION

Remotely operated vehicles (ROVs) have been extensively applied in deep-sea exploration, submarine pipeline maintenance, deep-sea mining and underwater search and rescue, becoming an indispensable tool for exploration, development and protection of the oceans. The ROVs for deep sea applications are generally manually operated, with the accompanying drawback of inefficiency and high costs. To exploit the potential benefits provided by ROVs, automatic control capability improvement has become a crucial issue (Zereik et al., 2018). Therefore, how to realize control algorithm upgrade of ROVs is urgent to be solved.

The precision control of underwater vehicle is never an easy task, especially for the ROVs. The complex underwater environment and strong nonlinearity make it a challenge to deriving controller, let alone the influence of cable and model uncertainty. To address the above problems, especially to achieve the accurate trajectory tracking, a kind of double-loop control strategy is commonly utilized to design the motion controller. The principle of this strategy is to divide the control system of the carrier into two subsystems, kinematics and dynamics, and to design separate feedback controllers for the two systems. The inner loop is the dynamics system, which mainly considers the handling of external disturbances and emphasizes the robustness of the controller. The outer loop is the kinematic system, which achieves accurate tracking of the given trajectory, requiring accuracy and avoiding overshoot as much as possible. The advantage of this control strategy is that multiple control methods can be integrated into the controller design of the inner and outer loops to obtain better control performance.

Kong et al. (2020) designed the outer-loop controller as a model predictive governor, which utilize kinematic tracking error model to produce reference velocities. Besides, an ESO is designed to estimate the lumped disturbances and unmeasured velocity states. Based on the ESO, a kinetic controller is offered to accomplish the precise velocity tracking only in virtue of the position and orientation information. Gan et al. (2018), a model predictive control method based on quantum-behaved particle swarm optimization (QPSO) is proposed in the kinematic controller to obtain the velocity signal. QPSO is utilized to handle the speed jump problem. Then sliding mode control based dynamic controller is adopted to achieve good robustness. Huang and Yang (2019) proposed a double-loop sliding mode controller to drive the trajectory tracking problem of work-lss ROVs. A novel inverse tangent substitution function is proposed to overcome the chattering problem of sliding mode control. To further improve the robustness while reducing chattering, Huang and Yang (2022) proposed a double-loop sliding mode approach, using super twisting sliding method in the inner loop to achieve both fast and good steady-state performance. A disturbance observer is also introduced in the inner loop to compensate the total disturbance term. The above literature has a common problem that the controller design is not based on a discrete approach. Even though the MPC method (Kong et al., 2020; Gan et al.,2018), which is itself discrete, is used in the outer-loop control, the controller of the inner loop is designed based on continuous type. In practical applications, the control program must be discretized before it can be easily translated into computer language. Subject to the sampling frequency of the hardware system, the controller designed based on the continuous-time method may lead to instability of the controlled system, and its direct discrete use will lead to its performance degradation (Ma, Wu, & Xiong, 2016). Therefore, the development of controllers based on the discrete method is more practical.

However, the above mentioned controllers have another common disadvantage, i.e. the model parameters need to be known, which is inappropriate for practical application, especially for the work-class ROVs. They have open frame structure with complicated surface structure and often have to change operating tools or place load frames on the bottom, so it is difficult to obtain its hydrodynamic coefficient.