A Novel Terminal Sliding Mode Control for the Navigation of An Under-actuated UUV

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ABSTRACT

In this paper, we present a self-developed under-actuated Unmanned Underwater Vehicle (Hereinafter abbreviated as UUV). After analyzing the motion and actuating characteristics of the UUV, the maneuvering motion models are established in the horizontal plane and vertical plane separately. Considering the model parameter uncertainties and unknown environmental disturbances, the course and depth automatic operating controllers of UUV are designed respectively on the basis of the sliding mode variable structure control algorithm to overcome these problems. The stability of the presented control laws is proved in the sense of the Lyapunov stability theory. Simulations performed on the under-actuated UUV demonstrate the effectiveness of the proposed method.

KEY WORDS: UUV; under-actuated vehicle; fast terminal sliding mode control; course keeping; depth control.

INTRODUCTION

In recent years, people pay more and more attention to the UUVs due to their important applications value in the fields of marine environment surveying and mapping, objective searching and other ocean scientific research. In order to realize the satisfactory and steady characteristics of navigation when the UUV is carrying out the sailing tasks in the complex ocean environment, the automatic motion control system must be robust and insensitive against the influence of system uncertainty. In addition, owing to the nonlinear characteristics of the UUV motion system, traditional linear control algorithms can not meet the performance requirements in the practical experiments. Therefore, it is meaningful to design an adaptive and robust control system for the under-actuated UUV to reduce the impact of hydrodynamic parameters uncertainties and unknown environmental disturbances.

With the development of nonlinear control theory, the nonlinear control methods for unmanned underwater vehicles have also been extensively studied in a large number of published literatures. In Gianluca et al (2001) and Yeow et al (2009), two kind of adaptive control laws are proposed for autonomous underwater vehicle (AUV), which have the advantages of simplicity and ease of implementation. On the basis of the neural networks (NNs) control approach, some research results were presented for tracking control of under-actuated autonomous underwater vehicles with model uncertainties; see for example (Pepijn, 2005 and Bong, 2014). However, there are no generic analytical methods to prove convergence of online learning for NNs. Besides, Ma and Cui (2006) designed a robust path-following control method for a nonlinear and under-actuated AUV based upon a fuzzy hybrid control strategy. In summary, a good application perspective of the nonlinear control theory for the underwater vehicle has been certified through all of the above researches.

In this article, aiming at the driving characteristics of an under-actuated unmanned underwater vehicle and according to the designing decoupling approach, the course and depth automatic operating controllers of the UUV are designed respectively on the basis of the sliding mode variable structure control algorithm. Numerous simulation results indicate that the course and depth control systems based on the fast terminal sliding mode variable structure principle are provided with the excellent control performance in the case of system uncertainty and external disturbance.

This paper is organized as follows: The movement characteristics and the 6-DOF (degree of freedom) motion model of the under-actuated UUV is introduced in Section 2; Then, Section 3 describes the definition of sliding mode variable structure control, as well as the design means of fast terminal sliding mode controller; In Section 4, according to the horizontal plane mathematical motion equations of the UUV, the heading controller taking advantage of fast terminal sliding mode method is developed. What we can see in Section 5 is that the depth controller using fast terminal sliding mode method is obtained in accordance with the vertical planar mathematical motion function. Next, in Section 6, the robustness and effectiveness of the presented control laws are confirmed by Matlab simulations. The satisfactory dynamic quality of the control system is evidenced by comparing the simulations in the disturbance and interference-free environment. Finally, a brief conclusion is included in the Section 7 of this paper.