Robust Diving and Composite Path Tracking Control of an Autonomous Underwater Vehicle

Spandan Roy, Sambhunath Nandy, Ranjit Ray, Siva Ram Krishna Vadali and Sankar Nath Shome
Robotics & Automation Lab, CSIR-Central Mechanical Engineering Research Institute
Durgapur, West Bengal, India

Autonomous Underwater Vehicles (AUVs) are becoming indispensable for the maritime industry and defense applications. The nonlinear, time-varying, and highly coupled dynamics of AUVs, along with the parametric uncertainties and unmodeled dynamics, make the design of efficient controllers a hard task. This article explores a robust control strategy that aims at providing better tracking accuracy by reducing the switching gain in order to reduce chattering and the control error bandwidth. The performance of the proposed controller is demonstrated through rigorous simulation on an experimentally validated AUV, and superior path tracking performance is noted against sliding mode and time delay control methodologies under various uncertain conditions.

INTRODUCTION

Autonomous Underwater Vehicles (AUVs) have received great attention in the last two decades from the maritime industry and defense applications due to the enormous need for these automated electromechanical systems. AUVs are very convenient to use during a voyage in the depths of the sea where situations are difficult for human deployment. As a result, a great deal of research is commonly focused on designing control methodologies that allow these systems to execute the assigned tasks often in unstructured and unpredictable environments. Needless to say, the difficulty in controlling AUVs not only resides in the highly nonlinear and coupled dynamics but also gets greatly enhanced due to model uncertainty and unknown disturbances. To illustrate the scenario, the modeling of the hydrodynamic parameters of an AUV is an extremely challenging task. Also, the deviation of the center of mass (COM) for the addition of payloads for different applications and environmental hazards, such as uncertain ocean currents, renders control of such mobile robotic systems highly tedious.

Well-known linear control techniques are inadequate to tackle the highly nonlinear, coupled, and time-varying dynamics of the AUVs and thereby to provide acceptable tracking performance. In a real-life scenario, the physical presence of uncertain parameters is inevitable, and the modeling of all such parameters is not always feasible. This makes the realization of the conventional nonlinear feedback linearization control law (i.e., the computed torque techniques) difficult as it requires precise knowledge of the hardware parameters of the system such as the mass and inertia parameters, COM, and hydrodynamic parameters. The global research community has adopted various nonlinear control techniques to accurately drive the AUVs, which are subjected to uncertainties and disturbances, along a defined path. Adaptive control and robust control strategies are the most commonly used techniques.

Cristi and Healey (1989) reported a model-based adaptive controller linearizing the vehicle dynamics within the limited operating range. A recursive least square method for parameter estimation and a pole placement technique for controller development were used. Adaptive control with online estimation of uncertain parameters was explored by Fossen and Sagatun (1991). Goheen and Jefferys (1990) proposed multivariable self-tuning controllers leading to autopilots for overcoming modeling uncertainty. Yuh (1996) and Choi and Yuh (1996) developed and implemented a multi-input multi-output (MIMO) adaptive controller with bounded estimation capability. Antonelli et al. (2003) proposed an adaptive control law considering the effect of hydrodynamic parameters on the vehicle trajectory tracking performance. Although the adaptive control methodology does not require a prior bound estimation of uncertainties and adjusts the parameters of the controller on the fly according to the pertaining uncertainties, the online calculation of the unknown system parameters and controller gains for complex systems such as an AUV becomes computationally intensive.

In view of the aforesaid limitations of the adaptive control methods, global research was shifted towards devising robust control techniques, whereby the need for larger computational requirements is avoided to a greater extent. Sliding Mode Control (SMC) is regarded as one of the most powerful robust control techniques that many researchers have adopted in the recent past. Yoerger and Slotine (1985) designed an SMC neglecting the cross-coupling terms to provide robustness against the uncertainties caused by hydrodynamic coefficients. Healey and Lienard (1993) proposed an SMC method in which the sliding surfaces are constructed as a function of state variable errors rather than output errors. They designed separate autopilots for separate subsystems, considering the subsystems to be noninteracting or lightly interacting. Cristi et al. (1990) and Papoulias et al. (1989) proposed an adaptive sliding mode control law on the basis of the linearized dynamics of an AUV around the operating paradigm. They considered the derived linearized model to be a good approximation of nonlinear dynamics for constant speed maneuvers. Dougherty and Woolweaver (1990) used classical SMC for designing the flight control system of an AUV. A discrete-time quasi-SMC that enhanced the controller performance over the growing sampling time was discussed by Lee et al. (1999). Innocenti and Campa (1999) compared the performance of the sliding mode and linear matrix inequality (LMI) techniques while linearizing the system around a suitable operating point. Higher bound estimation in SMC increases the possibility of activating substantially high switching gain and requires significantly high control inputs. This higher switching gain also invites unwanted chattering that in turn may activate high