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Model-based Sliding Mode Control of Underwater Robot Manipulators

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In this paper, a model-based sliding mode control method is proposed for trajectory tracking of underwater robot manipulators. The proposed sliding mode controller is designed based on the dynamics of underwater manipulators. The controller in this paper has the advantages of precision and robustness, and it is easy to implement. In order to demonstrate the effectiveness of the controller, several experiments using a 3 degrees-of-freedom underwater manipulator are conducted in a test tank. The results show that the proposed controller provides high performance of trajectory tracking in the presence of uncertainties about the dynamics.

INTRODUCTION

A majority of underwater robots currently in operation are of the remotely operated vehicle (ROV) type. ROV have the advantages of ease of use, reliability due to human teleoperation, and large range and depth of operation due to use of the umbilical cord. However, the major disadvantages of ROV lie in their need for skilled teleoperation by humans and high operational costs. Additional drawbacks to the ROV technology include operator fatigue, low operational efficiency, and possible loss of the vehicle due to umbilical cord damage.

In view of the above limitations, in recent years underwater robotics researchers have turned their attention to research and development of autonomous underwater vehicles (AUV). AUV incorporate intelligent navigation and control capabilities, and their energy source is carried on board. As a result, AUV are ideally suited for low-cost, unmanned exploration and monitoring of the vast underwater environments of the oceans and other marine ecosystems.

However, the majority of AUV in use today are limited to underwater reconnaissance tasks as they are not fitted with the on-board manipulators necessary for underwater intervention tasks, such as handling and manipulation of payloads and interaction with the environment. Examples of such tasks include placing or removing objects like sensors and mines, as well as underwater maintenance and repair. The precise and robust operation of such AUV manipulator systems (UVMS) remains a challenging task, mainly due to the highly nonlinear, time-varying, uncertain coupled dynamics of vehicle-manipulator systems and the strong influence of hydrodynamic forces and disturbances such as tidal currents and waves, particularly in shallow and very shallow water environments.

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In the case of ROV, it is often considered that the problem of UVMS control is comparatively easier because of human teleoperation and the large size and weight of the vehicle compared to the on-board manipulator(s). However, even with ROV there are complex tasks such as performing hot stabs on a subsea manifold or collecting sample organisms under ice, where accurate UVMS control requires more than one operator, can cause extreme operator fatigue, or even result in damage to the vehicle and/or arm. There is then is increasing interest in sensor-based automatic control of ROV and their on-board manipulators (e.g., Stanley, 2005).

In view of the above issues, robust high-performance control of UVMS has become a major research topic in underwater robotics. It has been rightly pointed out (U.S. Department of Defense, 2002) that, “Manipulator use on AUV is embryonic, and much R&D is needed before AUV are able to perform more than simple tasks.” Thus research on effective methods for automated, and indeed autonomous, control of AUV and their on-board manipulators will significantly contribute to the development of the next generation of autonomous underwater robots that can be used not just for simple monitoring tasks, but also for more complex underwater manipulation and intervention.

The authors have recently proposed a robust sliding mode and fuzzy sliding mode control of autonomous UVMS (Xu et al., 2005a and b), with their effectiveness demonstrated through simulation studies. In this paper, a decentralized sliding mode control method is presented for simple, precise and robust control of underwater manipulators. The control law is theoretically shown to result in bounded stability of tracking errors. The practical effectiveness of the method is illustrated using results of experimental implementation on a 3 degrees-of-freedom underwater manipulator.

The nonlinearities and uncertainties of the dynamics are mainly caused by hydrodynamic forces. The elemental nature of the hydrodynamic forces acting on the underwater manipulators is considered (McLain et al., 1996; Leabourne et al., 1998). These authors theoretically and experimentally have investigated the hydrodynamic forces acting on an underwater manipulator for the