Indirect Adaptive Control for Autonomous Underwater Vehicle-Manipulator Systems

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ABSTRACT

An indirect adaptive control for an autonomous underwater vehicle-manipulator system (UVMS) based on an extended Kalman filter (EKF) is presented in this paper. This method overcomes the disadvantages of existing disturbance observers and direct adaptive control schemes, which are designed or analyzed by linear system techniques and regressor-based techniques. The proposed control scheme can be applied to UVMS for various purposes such as payload compensation, interaction effects compensation, underwater current or external disturbance compensation and independent system control. The performance of the proposed controller is demonstrated numerically by the payload compensation and disturbance (underwater current) compensation for an UVMS consisting of a six degrees of freedom (6-DOF) underwater vehicle and a 3-DOF underwater manipulator.

KEY WORDS: underwater vehicle-manipulator system; vehicle-manipulator interactions; indirect adaptive control; extended Kalman filter; feedback linearization; parameter estimation.

INTRODUCTION

The underwater manipulator plays a crucial role in underwater applications. Underwater Vehicle-Manipulator System (UVMS) is an underwater vehicle system carrying one or more manipulators to complete certain underwater task. With the increased interest in the fields of offshore oil, military, and ocean scientific investigation, many approaches have been presented to improve undersea intervention capability of UVMS (Antonelli, 2006; Cui and Sarkar, 2001; Yuh, 1995; Marani et al., 2009). Currently, the state of art of the underwater manipulator is represented by remotely operated vehicles with manipulators through master/slave schemes by human pilots (Cui and Sarkar, 2001). This human-piloted scheme causes several operational difficulties, inaccurate trajectory tracking and force control, time delay in the man-machine control loop, and fatigue and performance of the human operator (Cui and Sarkar, 2001). Some of the above mentioned difficulties can be overcome by the use of autonomous manipulation considering the nonlinear coupled dynamics between the underwater vehicle and manipulator systems. For developing a control scheme considering the nature of the system, a detailed mathematical model of the UVMS is required.

A summary of the recent developments and researches of modelling and control of an UVMS can be found in some literature (Antonelli, 2006; Cui and Sarkar, 2001; Yuh, 1995; Schjolberg and Fossen, 1994). A coordinated control scheme for the UVMS using a discrete-time approximation dynamic model was developed for compensating the tracking errors of the manipulator during vehicle motion (Schempf and Yoerger, 1992), and motion planning and coordination control of an UVMS (Sarkar and Podder, 2001; Mahesh et al., 1991; McAlpin et al., 1992; Han et al., 2011). Robust coordinated motion control of an UVMS was developed through minimizing restoring moments along with the H-infinity control (Han et al., 2011). Several control strategies based on perfect compensation of the UVMS dynamics have been proposed (Schjolberg and Fossen, 1994; De wit et al., 2000). A nonlinear model-based control scheme that controlled the vehicle and manipulator simultaneously was developed and investigated (De wit et al., 2000), and feedback linearization along with PID control was developed and investigated (Schjolberg and Fossen, 1994). However, these schemes require the exact knowledge of the UVMS dynamics whose hydrodynamic parameters generally have large uncertainties. Also, the manipulator total mass including its working payload can vary, which can lead to an additional uncertainty.

Considering these uncertainties, adaptive control schemes were proposed in some of the previous literature (Mahesh et al., 1991; McAlpin et al., 1992; Antonelli et al., 2004). In (Antonelli et al., 2004), an adaptive tracking controller was introduced with virtual decomposition along with regressor matrix with respect to the parameter vector. But this work requires a regressor matrix with respect to the parameter vector, as well as a proper update rule. Larger uncertainties are difficult to adapt in this scheme. The adaptive control based on the micro-macro manipulator concept has been proposed for the UVMS which can be applied only to non-redundant manipulators with full-rank Jacobian (Fossen, 1991). The application of an adaptive disturbance observer based on the non-regressor matrix control scheme was also proposed for the UVMS (Yuh et al., 2001). Sagara et al., 2006 suggested a discrete-time resolved acceleration control based on direct observer technique and this technique is further improved with the added compensation disturbance loop (Yatoh et al., 2008). Model-based adaptive approaches for UVMSs are generally based on the Lagrangian formulation which leads to computationally intensive control schemes. Hence in practice, simple control schemes (e.g., proportional-integral-derivative (PID) control) have commonly been adopted. They are computationally efficient; however often offer inadequate tracking performance of the control system.

In fact, the UVMS operations typically involve manipulation tasks in the presence of parameter uncertainties, sensor noises and external disturbances (e.g., underwater current). This requires the system