An Adaptive Control Scheme for 6-DOF Control of an AUV Using Saturation Functions

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***Abstract*—** In this paper, the trajectory tracking control of autonomous underwater vehicles (AUVs) in six-degrees-of-freedom (6-DOFs) is analyzed. It is assumed that the system parameters are unknown and vehicle is underactuated. The desired trajectory can be any sufficiently smooth bounded curve parameterized by time even consist of straight line. To guarantee robustness against parameter uncertainty, an adaptive controller based on the Lyapunov's direct method and the back-stepping technique, is proposed while Control signals are bounded using saturation functions. The nonlinear adaptive control scheme yields asymptotic convergence of the vehicle to the reference trajectory. The stability of the presented control law is proved in the sense of Lyapunov theory and Barbalat's lemma. Numerical simulations are presented to illustrate the controller' behavior.

***Keywords*—** Adaptive control, Autonomous underwater vehicle, Back-stepping technique, Lyapunov theory, Saturaion function.

I. Introduction

THE ocean covers about 70% of the earth surface and has great effect on the future existence of all human beings, beside the land and aerospace. Underwater robotics is no doubt an important scientific area due to its great applications that vary from scientific research of ocean, inspection of undersea facilities to military operations.

Over the last few years, there has been considerable interest in the development of powerful methods for trajectory tracking control of underwater vehicles. Because of the highly nonlinear dynamics and the unpredictable operating environments of AUVs, conventional control schemes such as the PID controller may not be able to provide satisfactory outcomes in relation to the control problems experienced by underwater vehicles. Besides this, it is essential to deal with parametric uncertainties acting on the underwater vehicles in order to obtain a robust autopilot In the past, variety of design techniques based on optimal control, Lyapunov stability theory, feedback linearization, adaptive control, and sliding mode control have been attempted [1], [2], [3], [4], [5], [6].

For the control of nonlinear deterministic and uncertain MIMO systems, often a back-stepping design technique [7] is used. This is a sequential design process applicable to systems with matched as well as unmatched uncertainties. It provides flexibility in the choice of Lyapunov functions and stabilizing virtual control signals at each step of the design process for shaping the closed- loop responses.

The trajectory planning and tracking control of AUVs in the horizontal plane without parameter uncertainties using back-stepping procedure has been attempted [8]. An adaptive back-stepping control law has been developed for dive plane control using a single control surface (stern plane) [5]. In [9] a back-stepping nonlinear controller with certain parameters without any disturbances was proposed. However, there has been very few works in the literature considering 6 DOF trajectory tracking control of AUVs.

In this paper, we consider six DOF model to design a controller for an AUV [9]. In addition, we have assumed that the system parameters are unknown. The desired trajectory does not need to be of a particular type; it can be any kind of sufficiently smooth bounded curve parameterized by time. Infact, in this paper, an adaptive back-stepping controller is proposed using saturation function and parameter estimation done by projection algorithm. Then, suggesting a novel Lyapunov function, stability analysis will be carried out using Lyapunov theory and Barbalat's lemma. The results verify our control design robustness in the presence of parameter uncertainty while tracking remains satisfactory a high extent.

II. Vehicles Model And Control Problem

We adopt the standard notation for the motion equations of an AUV, see [6], [9]. Linear velocity $v = [u\ v\ w]^T$ consists of surge, sway and heave, angular velocity $\omega=[p\ q\ r]^T$ consists of roll, pitch and yaw rate, and attitude $\eta = [\varphi\ \theta\ \psi]^T$ consists of roll, pitch and heading angle. Furthermore, we assume that the center of gravity and the center of buoyancy are located vertically on the O_bZ_b-axis, in that there are no couplings (off-diagonal terms) in the matrices M, D, and $D_n(v)$.

The mathematical model of an AUV in 6 DOF can be described as:

$$\dot{\eta}_1 = J_1(\eta_2)v_1,\ \dot{\eta}_2 = J_2(\eta_2)v_2$$
$$M\dot{v} = -C(v)v - D(v)v - g(\eta) - \tau \tag{1}$$

$\eta = [\eta_1\ \eta_2]^T$ is the position and orientation vector in the earth-fixed frame, where $\eta_1 = [x\ y\ z]^T$ and $\eta_2 = [\varphi\ \theta\ \psi]^T$. $v = [v_1\ v_2]^T$ is the velocity and angular rate vector in the body-

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