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Modified set-point controller for underwater vehicles

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Abstract

A modified PD (proportional-derivative) controller for autonomous underwater vehicles (AUVs) is presented in this paper. The controller is expressed in terms of first-order equations of motion with a unit inertia matrix. The main difference between the proposed controller and the classical one relies on that the dynamics of the system is taken into account. This property ensures fast error and force convergence to the end-value. The PD controller can be applied for fully actuated AUVs. It is worth noting that the regulator gain matrices are selected based on parameters of the tested vehicle. The stability of the presented control law is proved in the sense of Lyapunov. Moreover, some advantages and observations resulting from the use of the controller are given. The performance of the controller is shown via simulations on a 6-DOF underwater vehicle.

Keywords: Underwater vehicle; Dynamics; Quasi-velocities; First-order equations

1. Introduction

The number of autonomous underwater vehicles (AUVs) is rapidly increasing, mainly due to tasks arising from various commercial and scientific needs.

One of the crucial problems concerning an AUV is its control. Various strategies have been proposed in the literature for efficient control of underwater vehicles in dependence of the principal goal, e.g. in [1,2,4,5,7,12,13,16–18,20,21,23]. A survey of controllers used for AUVs can be found also in [6]. The point stabilization relies on steering of a vehicle to a final target point with a desired orientation. The set-point regulation plays a very significant role in autonomous underwater vehicles control. Recall that the proportional-derivative (PD) control plus gravity buoyancy compensation [6,22] is the simplest set-point control.

Investigation of the whole AUV, i.e. the system with six-degrees-of-freedom (6-DOFs) is also important because various effects can be better observable than for a reduced model. The approach seems more practical both for design and control of the underwater vehicle. A number of studies represent such strategy [2,5,13,21].

The problem of the position and orientation regulation for AUVs is addressed in this paper. The main result concerns an non-adaptive set-point controller which is expressed using the new quasi-velocities (NQ) instead of in terms of the position and angular velocities. The controller contains dynamic parameters of the underwater vehicle (the dynamics of the underwater vehicle is taking into account in the control law). Moreover, each quasi-velocity can be regulated

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separately because it includes coupling effects between the vehicle velocities. As a result of its use, the response of the system is quick, i.e. fast errors convergence and the kinetic energy reduction is observed. An additional advantage of the set-point controller concerns selection of the regulator gain coefficients. The regulator gain matrices arise from the decomposition of the inertia matrix and they strictly depend on the dynamics of the tested vehicle. It means that for different AUVs the gain coefficients values are also different. It is shown that the proposed approach is applicable to a 6-DOF underwater vehicle.

The paper is organized as follows. In Section 2 the equations of motion expressed in terms of quasi-velocities for UAV are presented. A set-point controller is considered in Section 3. Simulation results for a 6-DOF AUV are shown in Section 4. The last section gives conclusions.

2. UAV decoupled equations of motion

Consider the underwater vehicle shown in Fig. 1. The equations of an underwater vehicle can be written in the matrix form as follows [6]:

$$M\dot{\nu} + C(\nu)\nu + D(\nu)\nu + g(\eta) = \tau, \tag{1}$$

$$\dot{\eta} = J(\eta)\nu, \tag{2}$$

where $M \in R^{6\times 6}$ is the inertia matrix that includes a rigid body mass matrix and an added mass matrix, and satisfies $M = M^T > 0$, and $\dot{M} = 0$, $C(\nu) \in R^{6\times 6}$ is the Coriolis and centripetal matrix due to the rigid body and the added mass (that satisfies $C(\nu) = -C^T(\nu)$), $D(\nu) \in R^{6\times 6}$ is the friction and hydrodynamic damping matrix, $g(\eta) \in R^6$ is the resultant vector of gravitational and buoyancy forces, $\eta \in R^6$ is the the position and attitude vector expressed in the absolute frame, $\nu \in R^6$ is the vector of velocities in the vehicle coordinate frame, and $\tau \in R^6$ is the resultant vector of applied forces and moments influencing the vehicle.

The relationship between velocities in the vehicle and the absolute frame is expressed by (2) where $J(\eta)$ is the Jacobian matrix, $\eta = [\eta_1^T \ \ \eta_2^T]^T$, $\eta_1 = [x \ \ y \ \ z]^T$ represents the position, $\eta_2 = [\phi \ \ \theta \ \ \psi]^T$ is the vector of Euler angles representing the orientation.

The inertia matrix M is constant, symmetric, and in general, non-diagonal, i.e. it contains off diagonal elements. However, for a class of underwater vehicle models such approximation is allowed [6]. Obviously, in general, it can be found that components of the inertia matrix depend on geometry, fluid flow rates and other uncertainties. Moreover, the added mass coefficients are often estimated basing on experimental studies and empirical relations which are not quite accurate. Thus, it should be emphasized that if the matrix M cannot be approximated as a symmetric matrix (e.g. because of uncertainties or not exact known dynamics) then the proposed below approach is not valid.

In order to obtain transformed equations of motion with the identity inertia matrix assume that it is possible to decompose the inertia matrix into two matrices, i.e.

$$M = \Phi^T \Phi. \tag{3}$$

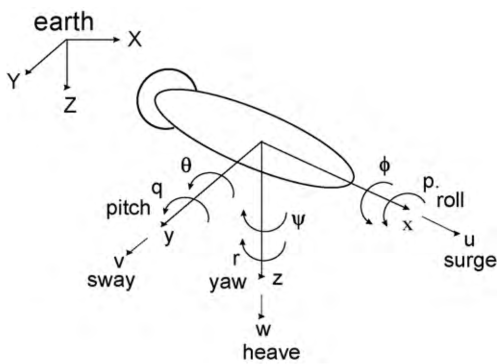

Fig. 1. The coordinate system for underwater vehicle.