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ON-LINE IDENTIFICATION OF HYDRODYNAMICS IN UNDERWATER VEHICLES

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Abstract: In this work an algorithm for on-line estimation of the nonlinear hydrodynamics in underwater vehicles is presented. The algorithm is able to estimate physical parameters from natural operation signals. Identifiability and convergence of the parameter trajectories are analyzed. The application of the algorithm to a spherical vehicle is described with numerical simulations. *Copyright © 2005 IFAC*

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1. INTRODUCTION

Remotely operated vehicles (ROVs) play an important role in the offshore industry. The use of conventional control systems for ROVs is limited in that the hydrodynamic coefficients of a particular vehicle are not usually known until after the vehicle has been completely design and test facilities, such as a wind tunnel or a wave tank, are employed for their determination. For dynamical positioning it is required the tracking and positioning of the vehicle to precisions ranging a few centimeters with short settling times.

Usually the model of the dynamics contains important structural uncertainties in the nonlinear characteristics of the frictional and pressure drag forces. These uncertainties makes difficult to achieve good behaviors and commonly the application of robust control can ensure stability at the cost of performance degradation (Caccia and Veruggio, 2000; Do *et al.*, 2004).

Due to the usual open frame architecture of ROVs, complex forms in the geometry ranging from a spherical, prismatic, prolate ellipsoid forms, the determination of hydrodynamics characteristics in the design phase and in posterior modifications is very complex.

The application of identification techniques with real signals of the kinematic and dynamics during ROV operation can provide a good method for uncertainty reduction. The on-line parameter identification has proven to be a general means to achieve adaptation to unknown modifications of physical parameters of the dynamics and its environment (Beltrán and Jordán, 2004). These strategies of parameter estimation provide a first link in the design of adaptive controllers and constitutes an alternative to expensive experimentation with scale models in test facilities.

In this work a method for adaptive on-line estimation is presented for the identification of pressure drag characteristics and added mass of a ROV. The algorithm is applicable for general geometric shapes of the ROV and can be used for self-

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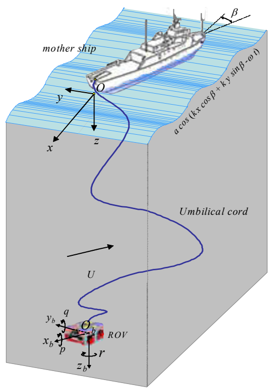

Fig. 1. Earth- and body-fixed frames for ROV motion characterization

tuning of model coefficients which are previously unknown. A case study for a sphere shaped ROV illustrates by means of numerical simulations the feature of the algorithm under simple motions.

2. ROV DYNAMICS

A mathematical nonlinear model for a ROV having three planes of symmetry and moving with 6 degrees of freedom can be described in a body-fixed frame as (see Fig. (1) and cf. Fossen, 1994, for conventions)

$$M\dot{\mathbf{v}} = -C(\mathbf{v})\mathbf{v} - D(\mathbf{v})\mathbf{v} + \tag{1}$$
$$+\mathbf{F}_b(\boldsymbol{\eta}) + \mathbf{F}_c + \mathbf{F}_e + \boldsymbol{\tau}$$
$$\dot{\boldsymbol{\eta}} = J(\boldsymbol{\eta})\mathbf{v}, \tag{2}$$

with the matrices

$$M = M_{rov} + M_a \tag{3}$$
$$C(\mathbf{v}) = C_{rov}(\mathbf{v}) + C_a(\mathbf{v}) \tag{4}$$
$$D(\mathbf{v}) = D_0 + D_1(\mathbf{v}), \tag{5}$$

where the generalized position in the earth-fixed frame is denoted by $\boldsymbol{\eta} = [x, y, z, \phi, \theta, \psi]^T$, the vector $\mathbf{v} = [u, v, w, p, q, r]^T$ indicates the generalized velocity vector of the ROV in its flight path in the body-fixed frame, J is a transformation matrix involving the Euler angles roll (ϕ), pitch (θ) and yaw (ψ), M is the inertia matrix composed by the ROV inertia matrix M_{rov} and the added mass matrix M_a, C is the centripetal and Coriolis matrix with a first component C_{rov} for the ROV and a second component for the hydrodynamics C_a, D is the damping matrix composed by a constant matrix D_0 and a velocity depending matrix D_1, $\mathbf{F}_b$ is the net buoyancy force, $\mathbf{F}_c$ the cable reaction force, $\mathbf{F}_e$ environmental forces like currents, and $\boldsymbol{\tau}$ the generalized impulse force of the thrusters.

3. ROV HYDRODYNAMICS

In general, the damping of an underwater vehicle moving in 6 degrees of freedom at high speed is highly nonlinear and strongly coupled. Usually, rough approximations are made based on the assumption that the vehicle moves slowly. The violation of this assumption, specially when high-gain controllers are applied, creates one of the major uncertainty in the dynamics. In this work we investigate the hydrodynamic damping in dependence on the geometric form and usual range of velocities of a ROV in the operation.

A body moving through a fluid experiences a drag force, which is of frictional and of pressure nature. Particularly, the last force is associated with the development of a wake behind a passing flow.

For usual ROV geometries, the pressure drag dominates over frictional drag since their shapes act as bluff bodies offering higher resistance to motion than streamlined bodies. The drag force experimented by body in relative motion with respect to the fluid depends on the Reynolds number defined as

$$\mathrm{Re} = \frac{\rho_{_{H_2O}} d}{\eta_{_{H_2O}}} |v_r| , \tag{6}$$

where v_r is the velocity of the body with respect to moving fluid particles, d the characteristic dimension of the body perpendicular to the direction of v_r, $\rho_{_{H_2O}}$ the salt water density ($\rho = 1026$ $[kg/m^3]$) and $\eta_{_{H_2O}}$ the dynamic viscosity of the sea water ($\eta_{_{H_2O}} = 10^{-3}$ [$\mathrm{Ns^2/m^2}$], at 20[^oC] and 1 [atm], $\eta_{_{H_2O}} = 1.52 \times 10^{-3}$ [$\mathrm{Ns^2/m^2}$], at 5[^oC] and 1 [atm], salinity 3,5%).

A common accepted expression for the drag force is given in (5) (Faltinsen, 1990), where $D(\mathbf{v})$ is a real, skew symmetrical and positive definite matrix with components D_0 being a constant matrix accounting for linear skin friction, and D_1 being a function matrix accounting for quadratic skin friction due to turbulent boundary layer and for damping due to vortex shedding. Thus

$$D_1(\mathbf{v}) = \begin{bmatrix} d_{uu}|u| & \cdots & d_{ur}|r| \\ \vdots & \ddots & \vdots \\ d_{ru}|u| & \cdots & d_{rr}|r| \end{bmatrix}, \tag{7}$$

with d_{ij} constant coefficients.

A more accurate approach of these dampings is given in the next. In Fig. (2) the drag coefficient for different shapes is shown. With exception of frontal flat plates, it is seen that C_D is not predictable over a large range in Reynolds number.

Large Reynolds numbers may be usual in the operation of ROVs. This is shown by a simple example. Let a spheric ROV with diameter $d = 1[m]$ have a frontal velocity u varying between 0 till $1[m/s]$, it results a range in Reynolds number from 0 till 10^6 (at 20 [^oC] and 1 [atm]). In this range the value of C_D varies significantly in magnitude, particularly about the value $\mathrm{Re} = 10^6$. At a Reynolds number between 10^5 and 10^6, the drag coefficient takes generally a sudden dip (Hideshi, 1989). In particular, near the shoulder, the pressure gradient changes from being nega-