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Tuning Marine Vehicles' Guidance Controllers through Self-Oscillation Experiments ⋆

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Abstract: This paper demonstrates the use of self-oscillation identification experiments for tuning heading and line following controllers for marine vehicles. The identification by use of self-oscillations (IS-O) has been developed for general LTI systems and for a class of nonlinear systems and it was used for tuning guidance controllers. The guidance controllers have been tuned using the results from IS-O experiments. Heading controller algorithm that gives smooth control output is presented. The line following controller generates reference heading as output. The described methodology is applied to autonomous catamaran Charlie and the experimental results are presented in the paper. It has been demonstrated that IS-O method gives good results in field conditions and that it is time conservative. All algorithms and results presented here are a result of joint work of researchers at the Consiglio Nazionale delle Ricerche, Genova and the University of Zagreb.

Keywords: Marine systems, Guidance systems, Line following, Self-oscillation

1. INTRODUCTION

Unmanned surface vehicles (USV) have recently become an ever-growing area of research around the world. Some examples of civil uses of USVs, which can be found in literature, are fishing trawler-like vehicle ARTEMIS, catamarans ACES and AutoCAT and kayak SCOUT (all developed at MIT), Measuring Dolphin, the catamaran Delfim, boat Caravela, autonomous catamarans Charlie and Springer, etc. Since the vehicles are unmanned, they all require different levels of control. The principle level of control is motion control and it usually implies the control of yaw and surge velocities. Mid control level, or guidance control, has the task to generate reference signals for the low level controllers. This level implies heading control and trajectory following (following a time-parametrized curve) and/or path following (following a planar path without temporal constraints). Finally, the upper level of control includes mission planning. This paper will address the problems of heading control and path following. These two controllers enable marine vehicles to either keep a desired heading or follow a desired line regardless of the external disturbances (sea currents which are always present).

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In order to tune control parameters in all three levels of control, process' parameters have to be identified. This can be a very time-consuming process. Usually, identification of marine vehicles' mathematical model is performed in open-loop where a great number of experiments have to be performed. Identification procedure for autonomous catamaran Charlie can be found in Caccia et al. (2006), while similar techniques used on underwater vehicles are reported in Ridao et al. (2004), Stipanov et al. (2007). All these experiments are based on finding the vehicle's drag (from steady-state experiments) and inertia (from zig-zag manoeuvres or open-loop transients). The biggest advantage of these identification techniques is that the model parameters can be determined as precisely as necessary, given enough experimental data. The disadvantages are the effects of the omnipresent external disturbances on the identified parameters, and the fact that the procedure itself is time-consuming.

The identification method which has been proposed here is based on self-oscillations, Vukic et al. (2003). The main advantage of this method is that it is performed in closed loop which means that the influence of external disturbances is minimized, Miskovic et al. (2009). In addition to that, the algorithm itself is very time conservative. On the other hand, in order to use this method, exact mathematical model of the identified process has to be known. Also, due to assumptions on the higher harmonics, the identified parameters can slightly differ from the real values. The main goal is to define and identify an approximated model of the system dynamics sufficient to allow the synthesis

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Fig. 1. Unmanned surface vehicle Charlie.

and tuning of guidance controllers and with a degree of precision compatible with the sensors on-board the vehicle.

The paper is organized as follows. Section 2 describes a method called identification by use of self-oscillations (IS-O) which can be used on linear and nonlinear systems. The application of IS-O on steering equations and closed-loop heading equations of marine vehicles is described in this section. Section 3 describes the heading and line following controller for Charlie ASV. Section 4 gives experimental results and the paper is concluded with Section 5.

1.1 Charlie USV

The Charlie USV (see Fig. 1) is a small catamaran-like shape prototype vehicle originally developed by the CNR-ISSIA for the sampling of the sea surface microlayer and immediate subsurface for the study of the sea-air interaction Caccia et al. (2005). Charlie is 2.40 m long, 1.70 m wide and weighs about 300 kg in air. The propulsion system of the vehicle is composed by a couple of DC motors (300 W @ 48 V). The vehicle is equipped with a rudder-based steering system, where two rigidly connected rudders, positioned behind the thrusters, are actuated by a brushless DC motor. The navigation instrumentation set is constituted of a GPS Ashtech GG24C integrated with compass KVH Azimuth Gyrotrac able to compute the True North. Electrical power supply is provided by four 12 V @ 40 Ah lead batteries integrated with four 32 W triple junction flexible solar panels. The on-board real-time control system, developed in C++, is based on GNU/Linux and run on a Single Board Computer (SBC), which supports serial and Ethernet communications and PC-104 modules for digital and analog I/O.

Steering Equation Steering equation is often described in literature with (1) where r is yaw rate, ψ is heading, τ_N commanded yaw torque, and parameters to be identified are yaw inertia, I_r, and drag $k_{r|r|}$.

$$\begin{aligned} I_r\dot{r} &= -\tilde{k}_{r|r|}r|r| + \tau_N \\ \dot{\psi} &= r \end{aligned} \tag{1}$$

For Charlie ASV, the yaw torque control is achieved by controlling the rudder angle δ while propeller revolution rate n is kept constant, i.e. $\tau_N = n^2\delta$. The dynamic parameters in (1) have been identified in Caccia et al. (2006). The identification experiments have also shown that the sway speed can be neglected.

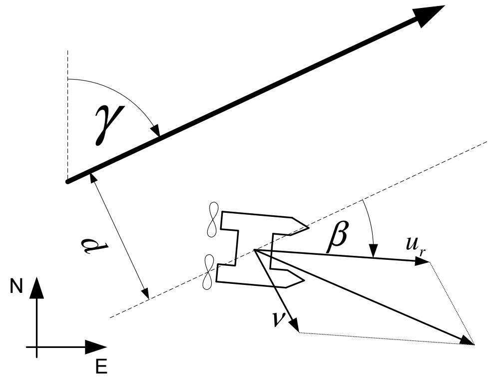

Fig. 2. Line following.

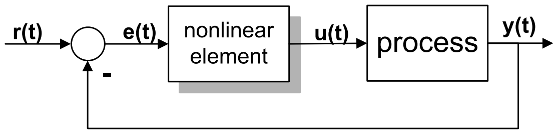

Fig. 3. Scheme for causing self-oscillations

Line Following Equations The line following approach is shown in Fig. 2. The aim is to steer the vehicle moving at surge speed u_r in such a way that its path converges to the desired line. If γ is orientation of the line that should be followed, a new parameter $\beta = \psi - \gamma$ (vehicle's orientation relative to the line) is defined. Having this in mind, the line following equations (2) - (5) can be written, where ν is drift due to sea current.

$$\dot{r} = -\frac{k_r|r|}{I_r}r|r| + \frac{1}{I_r}\tau_N \tag{2}$$

$$\dot{\psi} = r \tag{3}$$

$$\dot{\beta} = r \tag{4}$$

$$\dot{d} = u_r \sin\beta + \nu \tag{5}$$

The nonlinearities of the line-following model appear in (2) and (5). The first one can be eliminated by introducing a low level yaw rate or heading feedback. The second nonlinear equation can be linearized if angle β is assumed to be small. In this case (5) can be rewritten as $\dot{d} = u_r\beta + \nu$.

2. IDENTIFICATION BY USE OF SELF-OSCILLATIONS (IS-O)

The idea of using-self-oscillations to determine system parameters was introduced in Åstrom and Hagglund (1984) under the name "autotuning variation" method. Since then, relay-feedback systems proved to be a great tool for controller tuning in processes and for process identification, especially in pharmaceutical industry. Recent works on application of this methodology to marine vehicles (surface and underwater) can be found in Miskovic et al. (2007b), Miskovic et al. (2008) and Bibuli et al. (2008).

The self-oscillation experiment is performed in closed loop which consists of the process itself and a nonlinear element (see 3). The method is based upon forcing the system into