ID15 MODELLING AND IDENTIFICATION OF AN AUTONOMOUS SURFACE VEHICLE

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ABSTRACT

This work aims to provide technical information regarding the identification and modelling of the Yellowfish Autonomous Surface Vehicle (ASV) developed at Universidad Loyola Andalucía. The goal is to have a simple model of the vehicle that can be later exploited for estimation and control, either as an individual vessel, or as part of a coordinated fleet.

Keywords – Autonomous surface vehicles, identification, marine robotics, modelling.

INTRODUCTION

Identifying a system, such as an autonomous surface vehicle, is of paramount importance as it allows us to understand its characteristics, capabilities, and limitations. System identification also provides critical information about its behaviour and optimisation of different situations, which is essential for safe and efficient operation [1].

In the specific case of an autonomous surface vehicle, system identification is crucial to ensure its proper functioning in different environmental conditions and avoid potential risks and accidents [2]. Furthermore, system identification is also necessary for optimising and maintaining the vehicle, improving its performance, and extending its lifespan.

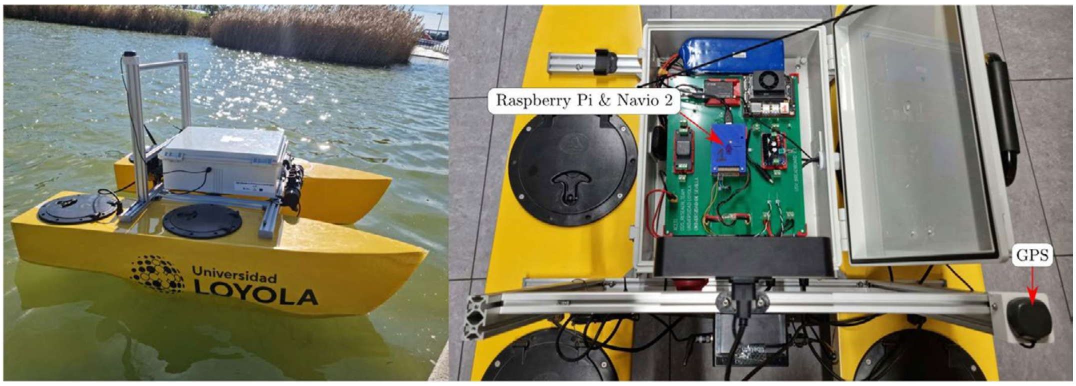

Fig 1. The Yellowfish ASV and the on-board sensors

THE YELLOWFISH ASV: TECHNICAL DESCRIPTION AND ON-BOARD ELECTRONICS

The Yellowfish ASV is shown in Fig. 1. This catamaran-like vessel is used for different purposes, such as monitoring water masses. This abstract focuses only on the elements with a role in the motion and control, independently from the application. The ASV is equipped with two propellers, thus giving the three-degree-of-freedom ASV two control actions, making it underactuated.

A Raspberry Pi 4 model B and Navio2 handle commands and drive actuators (see Fig. 1). The Raspberry supports system telemetry, communicates drone data, and enables settings changes. Navio2 has enough sensors (GPS, IMUs, UART, Radio, and PWM) to operate this low-cost ASV remotely and autonomously. However, the Yellowfish incorporates a GNSS RTK with a ground station for more reliable position measurements. The gyrocompass in Navio2 board measures the orientation of the vehicle. Finally, the control software that is implemented in Navio2 is called Ardupilot. All the telemetry data can be remotely accessed, so the ASV can be tracked in a software called Mission Planner.

MODELLING AND IDENTIFICATION OF THE YELLOWFISH ASV

The rigid-body kinematics and kinetics of an ASV moving in the horizontal plane under the maneuvering theory can be expressed in vectorial form according to:

$$\begin{cases} \dot{\boldsymbol{\eta}} = \boldsymbol{R}(\psi)\boldsymbol{\nu}, \\ \dot{\boldsymbol{\nu}} = \boldsymbol{M}^{-1}\boldsymbol{\tau} + \boldsymbol{\sigma}, \end{cases} \qquad \text{with } \boldsymbol{M} = \begin{bmatrix} m - X_{\dot{u}} & 0 & 0 \\ 0 & m - Y_{\dot{v}} & m x_g - Y_{\dot{r}} \\ 0 & m x_g - N_{\dot{v}} & I_z - N_{\dot{r}} \end{bmatrix}, \quad \text{and } \boldsymbol{R}(\psi) = \begin{bmatrix} \cos(\psi) & -\sin(\psi) & 0 \\ \sin(\psi) & \cos(\psi) & 0 \\ 0 & 0 & 1 \end{bmatrix},$$

where $\eta = [x,y,\psi]^T$ denotes the position and orientation vector expressed in the earth-fixed frame $\{n\}$, $\boldsymbol{v} = [u,v,r]^T$ denotes the linear and angular velocity vector expressed in the body-fixed frame $\{b\}$, and $\tau = [F_u, 0, T_r]^T$ describes the force and torque acting on the vehicle in the body-fixed frame $\{b\}$. Matrix $\mathbf{R}(\psi)$ represents the rotation matrix between the body-fixed frame $\{b\}$ and the earth-fixed inertial frame $\{n\}$[3]. This formulation groups most nonlinear terms (Coriollis, buoyancy, and damping) into the lumped generalized disturbances σ, so only the inertia matrix $\boldsymbol{M}$, consisting of the rigid-body inertia and the added mass, is required. For matrix $\boldsymbol{M}$, m is the total mass of the vessel, X_g is the vector from the centre of origin of $\{b\}$ to the centre of gravity [3], I_z is the moment of inertia about the Z_b axis, and $X_{(\cdot)}$, $Y_{(\cdot)}$, and $N_{(\cdot)}$ are the added mass hydrodynamic parameters according to standard notation [4].

Table 1 lists all identified values within a range for the inertia matrix and control system of the Yellowfish ASV. Each main component of the ASV is weighted to determine its mass. Steiner's Theorem was used to calculate the centre of gravity and moment of inertia, considering both the hulls and the electronics box to have uniformly distributed mass. The added mass is estimated with the heuristic method in [5], considering the hull as an ellipsoid submerged in a fluid.

Due to the particular geometry of the vessel, control forces are given by $F_u = T_R + T_L, \tau_r = \frac{a}{2}(T_L - T_R)$, where d is the distance between propellers, and T_L , T_R are the thrusts of left and right propeller, respectively. The thrusts depend on the

PWM signals. However, due to their highly non-linear internal dynamics, the propeller thrust is tough to calculate [5]. The Yellowfish ASV considers a second-order static model with identified dead-zone:

$$T_i(N) = \begin{cases} 15.7454\tilde{\delta}_i^2 + 15.8080\tilde{\delta}_i - 1.3197, & \tilde{\delta}_i \geq \tilde{\delta}_f \\ 0, & \tilde{\delta}_r < \tilde{\delta}_i < \tilde{\delta}_f \\ -12.3884\tilde{\delta}_i^2 + 12.4403\tilde{\delta}_i + 1.2567, & \tilde{\delta}_i \leq \tilde{\delta}_r \end{cases}$$

where $i \mathrm{E} L, R$. The PWM input signal δ_i is scaled to the range [−1,1]. Lastly, δ_f and δ_r are the experimentally obtained dead-zone values for forward and reverse movement of the propellers, being $\delta_f = 0.0775$ and $\delta_r = -0.0925$.

Parameter	*Minimum*	*Nominal*	*Maximum*	*Units*
m	23.73	24.39	25.73	kg
x_g	−18.7	−19.6	−20.5	mm
I_z	1.07	1.81	2.81	kg m^2
$X_{\dot{u}}$	−2.15	−1.00	−0.27	kg
Y_v	−22.59	−10.92	−3.59	kg
N_r	−4.35	−3.95	−3.74	kg m^2
Y_r	–	0	–	kg m
N_v	–	0	–	kg m

Table 1. Parameters of the Yellowfish ASV

CONCLUSIONS

This report gathers different sorts of information required to automatically control the Yellowfish ASV, a surface vessel designed by Universidad Loyola Andalucía. It covers transversal topics, such as vessel equipment, modelling, and identification.

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