LINEAR CONTROL DESIGN FOR A PATH PLANNING OF AUV-CORMORAN

Julián González, Andreína Benezra, Spartacus Gomáriz, Antoni Mànuel
SARTI Research Group. Electronics Dept.. Universitat Politècnica de Catalunya (UPC).
Rambla Exposició 24, 08800 Vilanova i la Geltrú, Spain. Phone: +(34) 938967200, Fax: +(34) 938967201

Abstract- This work shows a linearization for a AUV-Cormoran dynamic mathematical model with the aim of designing linear controllers for trajectory control. The model is developed under 3 degrees of freedom and the whole system has been simulated in Matlab Simulink environment. The linearization model is based on understanding the dynamics of the vehicle under different operating speeds, which present a different behavior, yet to be controlled by a single linear controller. For the linear control has raised the PD control that allows eliminate the position error, performing simulations of different trajectories and comparing its results in stability.

Introduction

The Cormoran is a low-cost vehicle for ocean observing, is a hybrid of the AUV (Autonomous Underwater Vehicles) and ASV (Autonomous Surface Vehicles) which was built in the Mediterranean Institute of Advanced Studies (IMEDEA), from Mallorca (Spain), for a group of Oceanography, in collaboration with the University of the Balearic Islands. Figure 1 shows a picture of the vehicle.

The vehicle was designed to sail just below the water surface along a predetermined path following way-points, in which it sinks vertically and obtains samples of the water column. Then it emerges also vertically and transmits by GSM messages with the most relevant data (temperature, salinity, depth and position, given by a GPS on board).

Afterwards, it moves to a new way-point repeating the process, and so on until a mission is completed [1].

Figure 1. AUV Cormoran

Vehicle Model in 3DOF

Due to the movements of the vehicle described above, the heave, roll and pitch can be neglected, so that the characterization of the vehicle can be achieved through a 3-DOF model for the advance ( ), lateral movement ( ) and yaw angle ( ) [2]. Vectors position, speed and strength can be expressed as shown in (2.1).

$$\eta = [x, y, \psi]$$
$$\nu = [u, v, r]$$
$$\tau = [X, Y, N] \qquad \textbf{(2,1)}$$

II-A. Vehicle Dynamics

Equation (2.2) is the nonlinear dynamic equation of an underwater vehicle,

$$M_{RB}\dot{\nu} + C_{RB}(\nu)\nu = \tau_{RB} \qquad \textbf{(2,2)}$$

where,
M_{RE} is the mass and inertia matrix.
C_{RE} is the centripetal and Coriolis matrix.
τ_{RE} is the hydrodynamic force and moment general vector (produced by movement of the hull in the water, forces due to the control surfaces, the forces generated by the propulsion system and the forces due to environmental perturbations).
ν is the velocity vector.

Taking into account the dynamic equation of the vehicle in (2.2), and making an assessment of forces and moments of terms, the equations can be expressed describing the nonlinear model of the vehicle as Cormoran shows in (2.3). In the same equation, combine the terms of the rigid body dynamics, the added mass, the damping terms, and the terms of the thrust (see Figure 2 for the block diagram of this dynamic).

$$m\dot{u} - mvr = X_{\dot{u}}\dot{u} - Y_{v}vr - Y_{r}r^{2} + X_{u|u|}u|u| + X_{prop} \qquad \textbf{(2,3)}$$

Linearization

To design a linear control system, first it is necessary obtain a linear model of the system to which these techniques will be applied. The model is linearized respect the forward speed u, neglecting the velocities v and r, because they are small compared with u; similar approaches were carried out work on the vehicle REMUS [3], as well as in the Infante AUV [4]. Consequently, the operating point on which we will work is (u,v,r) = (un 0,0).
Applying Taylor series approximations [5] to (2.3), produce the linear vehicle model expressed in matrix form, equation (3.1). For this model, the propulsion motor X_{nrnn} and the rudder angle δ are considered the system inputs.

$$
\begin{aligned}
m\dot{v} + mur &= Y_{\dot{v}}\dot{v} + Y_{\dot{r}}\dot{r} + X_{\dot{u}}ur + Y_{v|v|}v|v| + \\
&+ Y_{r|r|}r|r| + Y_{uvf}uv + Y_{urf}ur + \\
&+ Y_{uuf}u^2\delta_r \\
I_z\dot{r} &= N_{\dot{v}}\dot{v} + N_{\dot{r}}\dot{r} + Y_{\dot{r}}ur - (X_{\dot{u}} - Y_{\dot{v}})uv + \\
&+ N_{v|v|}v|v| + N_{r|r|}r|r| + N_{uvf}uv + \\
&+ N_{urf}ur + N_{uuf}u^2\delta_r
\end{aligned}
$$

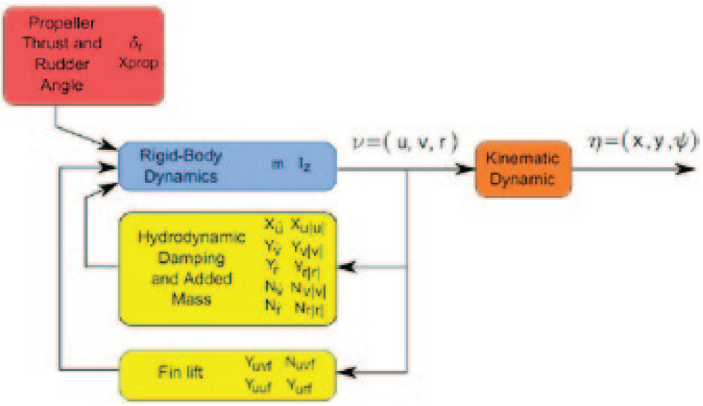

Figure 2. Block diagram of vehicle dynamics

$$
\begin{bmatrix} -2X_{u|u|} & 0 & 0 \\ 0 & -Y_{uvf} & m - X_{\dot{u}} - Y_{urf} \\ 0 & X_{\dot{u}} - Y_{\dot{v}} - N_{uvf} & -Y_{\dot{r}} - N_{urf} \end{bmatrix} \begin{bmatrix} \Delta u \\ \Delta v \\ \Delta r \end{bmatrix} u_0 +
$$
$$
+ \begin{bmatrix} m - X_{\dot{u}} & 0 & 0 \\ 0 & m - Y_{\dot{v}} & -Y_{\dot{r}} \\ 0 & -N_{\dot{v}} & I_z - N_{\dot{r}} \end{bmatrix} \begin{bmatrix} \Delta\dot{u} \\ \Delta\dot{v} \\ \Delta\dot{r} \end{bmatrix} = \begin{bmatrix} X_{prop} \\ Y_{uuf}u_0^{\,2}\Delta\delta_r \\ N_{uuf}u_0^{\,2}\Delta\delta_r \end{bmatrix}
$$

(3,1)

III-A. Analysis of poles and zeros

Following the linearization of (3.1) are calculated the transfer function of yaw with respect to the rudder angle, for different speeds advance from to . These transfer functions have a pole and a zero that are very close between them, so it was decided to cancel them to simplify the transfer function.

Figure 3 shows these poles in closed loop with negative gain (due of the opposite relationship between the yaw angle and rudder angle) so that the system is stable. It is important to know that while increases the speed, the system response becoming faster, and at the same time maintains the overshoot.

Control Design

The tracking of requirements focus on designing a controller that takes the whole nonlinear system to a desired dynamic area. This dynamic area will be defined as desired specifications are achieved, such the time in (4.1).

In Figure 4, the dynamic target zone is delimited for the vehicle showed in (4.1)

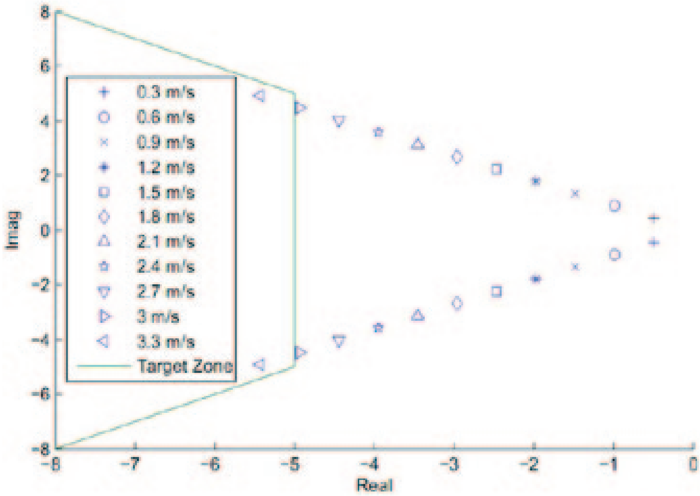

Figure 3. Closed loop Poles in yaw with gain k=-1 for differents u

IV-A. PD Control

For the controller design, it is sufficient to implement a PD control in the system linearization to eliminate the position error and reach the target zone stated in (4.1).

When the system is at a rate of 3.3m/s, the desired dynamic is already accomplished by simply applying a proportional control with gain k = -1, as shown in Figure 3; for other linearization it is

$$
\xi \leq 0.707
$$
$$
t_{ss} \leq 0.8seg \qquad \textbf{(4,1)}
$$

necessary to move the poles with a PD control.

A zero to the plant has been added applying linear control techniques, so to move the system poles at a speed of 0.3m/s to the target dynamic area, matching the system poles for the speed 3.3m/s in closed loop with gain k = -1. The result was a zero at s = -5.44, with a gain k = -22.25.

Similarly, it was the same PD control design for the linearized system at the other speeds, resulting in different PD controls, each of them to bringing the poles to the desired dynamic area. However, making a comparison between different PD controls design, it was concluded that it was only necessary to create one PD control to move the system poles for the different linealizations to the target zone.

$$
G_C(s) = -22.25(s + 5.44)
$$

(4,2)

Results

Following the study shown above, the same linear PD control was applied throughout the plant. In this case, the control that was used is the designed for the first speed (4.2). The outcome was represented in the S-plane, showing all the modified poles for the different speeds, Figure 4 shows these poles for different linearizations between 0.3m/s and 0.6m /s, which show that as speed increases, the conditions significantly improve the design.

V-A. Position Error

This PD control has been applied to the nonlinear model operating at different speeds. Figure 5 shows their responses to a step input. It is evident that as the speed increases the settling time decreases, as well as the maximum on impulse (and that going