Fig.1: The Borel buoy was moored North of the lava lake. © Ifremer MoMARSAT2010

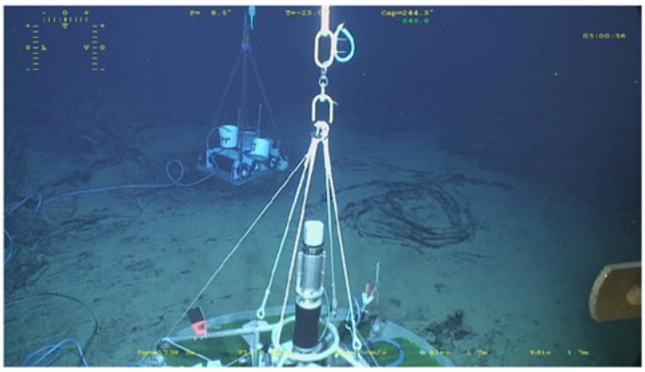

Fig. 2 Seamon East was deployed on the lava lake, © Ifremer MoMARSAT2010

HYDRODYNAMIC MODEL, SIMULATION AND LINEAR CONTROL FOR CORMORAN-AUV

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Abstract—this work shows the mathematic calculation for obtention of a Cormoran-AUV hydrodynamic model, it also shows a linar control design for a path tracking. The model has been simplified to three degrees of freedom of movement and the whole system has been simulated using Matlab Simulink Software. The system has been linearizated for different velocities to design a linear control for each one of them. However, all resulting systems can be controlled by a unique linear control due characteristics of the vehicle. The designed control is a PD controller, which avoids the position error since the pole of the vehicle model is at the origin. Different paths have been simulated using this control and their results have been comparated in both rising time as establish time.

Keywords—Hydrodynamic model, linear control, autonomous underwater vehicle.

Fig. 1. Cormoran-AUV.

I. INTRODUCTION

Cormoran (see figure 1) is a low cost oceanic observation vehicle, hybrid between AUV (Autonomous Underwater Vehicles) and ASV (Autonomous Surface Vehicles), which has been built in Mediterranean Institute of Advanced Studies (IMEDEA) of Mallorca (Spain) by the oceanographic group, in colaboration with the University of the Balearic Islands.

The principle of movement is based on the navigation over the marine surface where the vehicle follows a predetermined path in the mission. The path is defined by a series of waypoints, in which the vehicle stops and dives vertically to obtain a profile of a water column. Subsequently, the vehicle rises to the surface and transmits the most relevant data (temperature, salinity, depth and global position using GPS) through GSM messages. After sending this data, the vehicle continues to the next waypoint defined by the mission [1].

II. 3 DOF HYDRODINAMIC MODEL OF THE VEHICLE

Due to the movement described before, heave, roll and pitch are not taken into consideration. Therefore the characterization of the vehicle can be achieved through a three degrees of freedom that include the advance (x), the lateral displacement (y) and yaw angle (ψ) [2].

A. Vehicle dynamics

Once the general model of marine vehicles is simplified, we obtain 3 equations shown in (1), (2) and (3), which are functions of speed, mass, vehicles' propulsion and a set of hydrodynamic coefficients.

$$m\dot{u} - mvr = X_{\dot{u}}\dot{u} - Y_{\dot{v}}vr - Y_{\dot{r}}r^2 + X_{u|u|}u|u| + X_{prop} \quad (1)$$

$$m\dot{v} + mur = Y_{\dot{v}}\dot{v} + Y_{\dot{r}}\dot{r} + X_{\dot{u}}ur + Y_{v|v|}v|v| + Y_{r|r|}r|r| + Y_{uvf}uv + Y_{urf}ur + Y_{uuf}u^2\delta_r \quad (2)$$

$$I_z\dot{r} = N_{\dot{v}}\dot{v} + N_{\dot{r}}\dot{r} + Y_{\dot{r}}ur - (X_{\dot{u}} - Y_{\dot{v}})uv + N_{v|v|}v|v| + N_{r|r|}r|r| + N_{uvf}uv + N_{urf}ur + N_{uuf}u^2\delta_r \quad (3)$$

To simulate these equations in Simulink software of matlab is necessary taken to consideration that no algebraic loops are present. This requires re-express equations (1), (2) and (3) in order for them to be solved for the velocity vector ν. Figure 2 shows the final expression in Simulink environment.

III. LINEARIZATION OF THE SYSTEM

First of all, It is necessary to obtain a system linearization in order to design a linear control system [3]. The model is linearized around the speed, assuming that the forward speed *u* is constant and *v* and *r* speeds are smaller compared to the forward speed, several velocities were used to linearize the system. Similar approaches are made in works on the Remus vehicle [4], as well as the AUV- Infante [5]. Applying Taylor series approximations [6], linear vehicle model is achieved, expressed in matrix form (4). In this model, the propulsion engine X_{prop} and rudder angle δ are considered inputs to the system.

$$\begin{bmatrix} -2X_{u|u|} & 0 & 0 \\ 0 & -Y_{uvf} & m - X_{\dot{u}} - Y_{urf} \\ 0 & X_{\dot{u}} - Y_{\dot{v}} - N_{uvf} & -Y_{\dot{r}} - N_{urf} \end{bmatrix} \begin{bmatrix} \Delta u \\ \Delta v \\ \Delta r \end{bmatrix} u_0 + \begin{bmatrix} m - X_{\dot{u}} & 0 & 0 \\ 0 & m - Y_{\dot{v}} & -Y_{\dot{r}} \\ 0 & -N_{\dot{v}} & I_z - N_{\dot{r}} \end{bmatrix} \begin{bmatrix} \Delta \dot{u} \\ \Delta \dot{v} \\ \Delta \dot{r} \end{bmatrix} = \begin{bmatrix} X_{prop} \\ Y_{uuf} u_0^2 \Delta\delta_r \\ N_{uuf} u_0^2 \Delta\delta_r \end{bmatrix} \quad (4)$$

IV. CONTROL DESIGN

A controller must be developed to track a predefined path. The controller must lead the nonlinear system to a desired dynamic. This dynamic is defined in (5), which specifies the maximum overshoot and settling time desired.

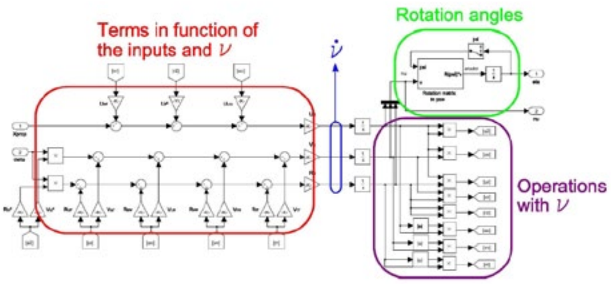

Fig. 2. Simulink implementation

$$\xi \leq 0.707$$
$$t_{ss} \leq 0.8 seg$$

A. PD controller

Since the linearized model with yaw as output has a pole in the origin, PD controller is enough to eliminate the position error and achieve the desired dynamic area. For example, the equation (6) shows the design of the PD controller for constant velocity of 0.3m/s.

$$G_C(s) = 22.25(s + 5.44) \quad (6)$$

Eventhough PD controllers were calculated for different velocities, only one is needed to move the poles of all systems to the target zone, speccifically, the control designed for the smallest velocity, 0.3 m/s.

RESULTS

A unique linear controller has been applied to the vehicle as it is described above. Figure 3 shows the S-plane representation of the system's poles in closed loop for linearizations for different velocities ranging between 0.3m/s and 0.6m/s. When increasing speed, the poles become more stables and with less imaginary part. Poles at smallest velocity are the poles on the boundary of the target zone.

Figure 4 shows the step response with the yaw as output for two forward velocities: 0.3m/s and 3.3m/s. It also shows a better performance at high velocities, where the overshoot and settling time are lower than in low velocity. In both velocities, the position error has been eliminated. Figure 5 shows the misfit of the vehicle in the XY plane because an implicit control of the yaw angle over time is used.

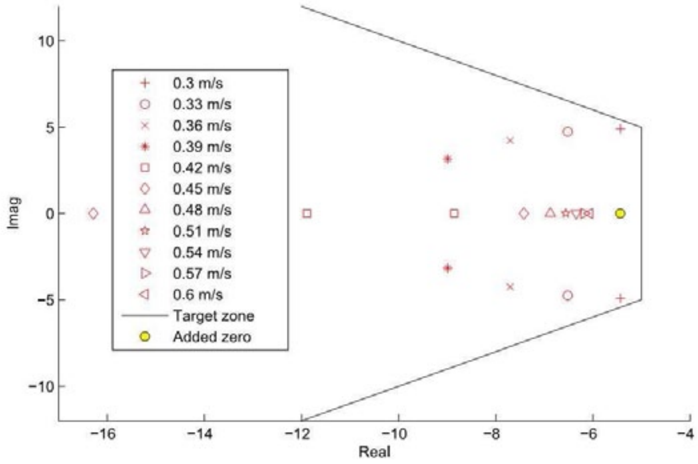

Figure 3. closed loop poles applying PD controller

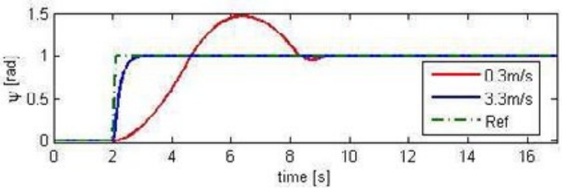

Figure 4. Step response using PD controller in the non-linear model

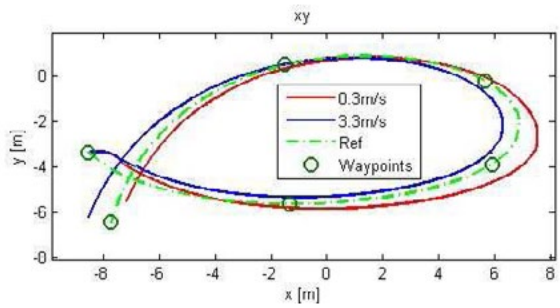

Figure 5. Path tracking using waypoints.

CONCLUSIONS

This paper presented a nonlinear model of the Cormoran vehicle using three degrees of freedom. The model has been linearized at different velocities to analyse their behavior. In order to develop a path tracking, a PD controller has been designed to control all the system. It showed that is possible to define a desired dynamic area in the S-plane for the systems' poles, where the position error is eliminated. Also, the results showed that as speed increases better performance in the desired dinamic is achieved. For this reason a unique PD controller is enough to control the vehicle.

REFERENCES

[1] D. Roig Broman, M. Martínez Ledesma, B. Garau Pujol, A. Alvarez Díaz, J. Tintoré Subirana. "A Low-Cost Autonomous Vehicles For Coastal Sea Monitoring". Mediterranean Institute of Advanced Studies (CSIC – UIB). Autumn 2005.

[2] Thor I. Fossen. "Marine Control Systems".

[3] Xin-quian Bian Jia-jia Zhou Xiang-quin Cheng, Zhe-ping Yan. "Application of linearization via state feedback to heading control for autonomous underwater vehicle". IEEE International Conference on Mechatronics and Automation, 2008.

[4] Timothy Prestero. "Verification of a six degree of freedom simulation model for the REMUS autonomous underwater vehicle. Master's thesis, September 2001.

[5] A. Pascoal, C. Silvestre. "Depth control for the infante auv using gainscheduled reduced order output feedback". Science Direct, pages 883- 895, 2007.

[6] K. Ogata. "Ingeniería de control moderna". 3º edition.