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A real-time control for path following of an USV

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Abstract: Control design for marine autonomous vehicles is a subject of great interest in the control systems. These vehicles are strongly non linear and show complex hydrodynamics effects that make difficult the control design. Besides, the use of underactuated vehicles is very important for different reasons like simplicity, cost, efficiency, etc, so these vehicles and their use for collaborative tasks are main topics of investigation. A non linear control for path following for USVs is presented in this work with an infrastructure capable of performing multiple AUV and ROV in collaborative tasks. So this control law and this infrastructure will be used in future projects for formation control of USVs.

1. INTRODUCTION

The problems of control of autonomous vehicles, that are dealt in a wide range (Aguiar 2003, 2007, Fossen 2000), can be classified in three fundamental groups: point stabilization, trajectory tracking and path following.

Path planning problems are related to the design of control laws that force a vehicle to reach and follow a reference. The main difference with respect to the trajectory tracking is that there are no time references in path following. The degree of difficulty to solve this problem depends on the vehicle's configuration and it is of very interest when the vehicle is underactuated (Pettersen et al, 2006).

It is important to emphasize that the drift velocity in the underactuated marine vehicles is often linearly independent respect to the forces that actuate over them, so that it is not possible to convert the model into another model without drift.

Furthermore, the fully actuated systems are expensive and, in many situations, it is not convenient to equip the ship with more actuators due to weight problems, complexity, efficiency and other considerations. For this reason, the control of underactuated vehicles is a very active investigation topic.

The path following systems are widely studied in (Encarnação 2001), (Ghabcheloo, 2007), (Pettersen, 2006) and more.

In this control problem the vehicle's forward velocity does not have to be controlled with high precision, so that an adequate orientation control to drive the vehicle along the desired path is enough. Nevertheless, the forward speed can be controlled to fulfill some soft time references.

Usually, this kind of control reaches a convergence with the path smoother than the trajectory tracking control, and moreover, the control signals obtained do not have too much tendency to saturation. In this line, this work deals with the path following of an unmanned surface vessel (USV).

On the other hand, the other main objective of our project is to construct an infrastructure capable of performing multiple AUV and ROV in collaborative tasks. In order to achieve this objective, a standard inter-vehicle communication protocol must be developed. In this work a WiFi approach is presented.

Wireless Networks Technologies available nowadays can be subdivided into the following categories: Satellite Networks, Mobile Cellular Networks, Broadband Wireless Access, Wireless Local Networks (WLAN) and Wireless Personal Networks (WPAN).

The most widespread type of WLAN at present is the IEEE 802.11 [ref 1] (WiFi) based on CSMA/CA (Carrier Sense Multiple Access/Collision Avoidance) mechanism known as DCF (Distributed Control Function). Due to this statistical nature there is some probability of collisions and communication loss. This is an important point that must be considered during the communication protocol design.

Due to robustness considerations, the communication protocol is a server-client approach based on TCP sockets. The vehicles act as autonomous servers; they receive high level orders or low level commands (in the AUVs or the ROVs respectively) from a client that acts as a global coordinator. They also send feedback information about their states to the station. This gives the vehicles the capability of make decisions in case of loss of communication. This scheme is flexible, allowing direct interconnections between

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vehicles for collision avoidance and coordination purposes without the global coordinator.

2. CONTROL LOGIC

The control logic consists in a simple algorithm that calculates the necessary rudder rate to reach the desired path in a smooth way.

An anticipatory control element is used for the control which overcomes the inherit limitation of feedback control to follow curved paths. This anticipatory control element and guidance logic is described deeply in (Park, S., Deyst, J., & How, J. P. 2006) for its use in unmanned air vehicles (UAVs). Here lies one of the new approaches of this work: the use of a simple and new aeronautic control for marine vehicles.

The basic idea is to do path following by using an imaginary point moving along the desired path as a pseudo target, as in the common LOS control algorithm. It can be considered as an element of anticipation for the upcoming desired path.

In the forthcoming approach, we consider two reference frames, one inertial frame in which the variables referred to it will be expressed without sub index, and a body fixed frame, which will move with the vehicle fixed at its mass centre. This second frame has its x-axis aligned with the vehicle's forward velocity vector (figure 1).

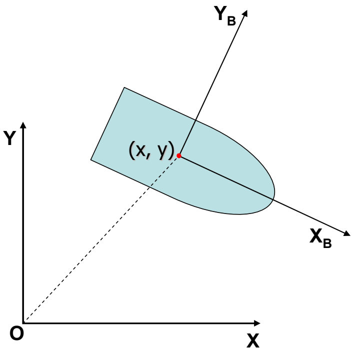

Fig. 1. Reference frames

A line of sight (LOS) of 1000m is used to compute the error between the desired and the real path followed by the vehicle. In figure 1 the variables used to calculate the error between the desired and the real path are shown, so the distance *d* between them can be controlled.

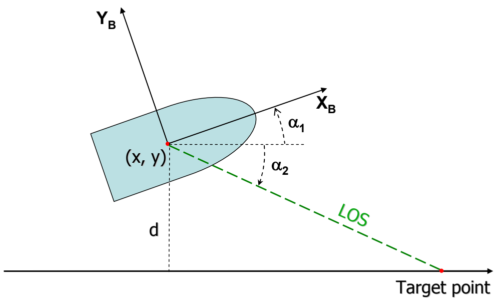

Fig. 2. Control variables

The algorithm consists firstly in finding the point in the desired trajectory that is at the distance of LOS. Then, the angles α_1 and α_2 are calculated, the first one as the inverse tangent of the ship's velocity coordinates, and the second one, as an inverse tangent as well, but in this case of the vector that joins the vessel to the point in the path at the distance of LOS.

$$\begin{aligned} \alpha_1 &= \arctan(v_y, v_x) \\ \alpha_2 &= -\arctan(yLOS - y, xLOS - x) \end{aligned} \tag{1}$$

The sum of these two angles is used to calculate the rudder rate, which will feed the low level control of the craft.

$$\begin{aligned} \alpha &= \alpha_1 + \alpha_2 \\ w &= -2 \cdot \frac{U}{L} \cdot \sin(\alpha) \end{aligned} \tag{2}$$

Where w is the yaw rate, U is the advance speed and L is the distance of LOS. The yaw rate is integrated to obtain the yaw angle as a control input of the ship.

From this equation we can observe two properties. The first one is that the direction of the acceleration depends on the sign of the angle between the line of sight segment and the vehicle velocity vector, so the vehicle will tend to align its velocity direction with the direction of the Line of Sight segment. The second one is that at each point a circular path can be defined by the position of the reference point, the vehicle position and tangential to the vehicle velocity vector. The acceleration command generated is equal to the centripetal acceleration required to follow this instantaneous circular segment.

Hence the guidance logic will produce a lateral acceleration that is appropriate to follow a circle of any radius R.

About the length Line Of Sight some considerations can be made:

-The direction of LOS makes a large angle with the desired path, when the vehicle is far away from the desired one.

-The direction of LOS makes a small angle when the vehicle is near to the desired path.

Therefore, if the vehicle is far from the desired path, then the control law rotates the craft so that its velocity direction approaches the desired path at a large angle. If the vehicle is close to the path, it is rotated so its velocity direction approaches the desired path at a small angle (Park, Deyst & How, 2006).

3. EXPERIMENTAL SETUP

3.1 Experimental Assembly

The USV used for experimental tests is a scale model of a cargo ship of 1 meter and a half long. This USV is overactuated, nevertheless, the two stern nozzles are synchronized. With this, the ship is experimentally