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Controlling tracking trajectory of a robotic vehicle for inspection of underwater structures

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A B S T R A C T

This work presents nonlinear, multivariable control strategies, based on backstepping methodology and Control Lyapunov Function (CLF) for trajectory tracking problem of a Hybrid Remotely Operated Vehicle (HROV), which is under development at the Federal University of ABC (UFABC) since 2012. The main objective of the vehicle is to inspect underwater structures by measuring plates thickness. The design control for underactuated HROV presents some limitations in the vehicle trajectory. The control consists on the combination of two methodologies, which are the backstepping and the CLF. It also makes robustness study of controllers consider disturbance acting on the vehicle. The proposed control responded appropriately to the trajectories selected as reference and presents robustness for non-modeled external disturbances.

1. Introduction

There are applications of Remotely Operated Vehicles (ROV's) in a variety of areas, such as: biology, for marine habitat monitoring; archeology, for flooded site investigation and engineering, for submerged structures inspection and underwater mining.

The vehicle was named HROV (Hybrid Remotely Operated Vehicle) and the term hybrid installed due to its locomotion feature, which can use thrusters for a navigation on the water or a pair of motorized tracks for movement over the structure.

The Brazilian navy regulates that the release for operation of vessels has to be in national waters. This must be made through a complete dry deck inspection, in addition to a technical assessment of the thickness plates in the case of metallic vessels with more than fifteen years of operation (DPC, 2013).

Among the Naval applications, we can highlight a niche in the petroleum area that, in addition to using large ships in transportation, have Floating Production, Storing and Offloading (FPSO) structures for the production and storage in the offshore oil and oil products. These structures are designed to work in the same lease for up to 25 years and the withdrawal of a vessel in operation influences financial loss (Whitcomb, 2000). The inspection of the structure in place is necessary for this type of application.

In this scenario, in the Federal University of ABC (UFABC), we developed a project with the objective of developing a HROV (named Proteo) for inspection of underwater metallic structures in their normal operating environment, performing plate thickness measurements by ultrasonic sensor.

The project considers a control station, which is nearby the structure to be inspected or in a location, that allows the remote activation of the HROV with the umbilical communication. The vehicle is placed in the water and positioned by the operator using the thrusters. At the initial point of inspection, the HROV performs a rotation maneuver to keep the motorized tracks in contact with the structure and to do this is necessary that the vertical thrusters maintain a normal force to the inspection plane, causing the motorized tracks to have sufficient friction to maneuver the vehicle by performing the thickness measurements.

For the trajectory tracking problem, several control techniques are being used. In order to control an actuated ROV, in Srisamosorn et al. (2013)) was developed a robust adaptive control algorithm and used two Lyapunov candidate function to demonstrate the stability and to determine adaptive laws. The performance is verified with numerical simulation; in Encarnacao and Pascoal (2000) it was proposed a methodology utilizing a nonlinear dynamic inversion and applying backstepping techniques; in Zhu and Gu (2011a) it was proposed a combining of two controllers: an adaptive backstepping technique and a sliding control; in

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Patompak and Nilkhamhang (2012) it was developed an adaptive backstepping sliding-mode controller; in Fernandes et al. (2015) it was proposed a motion control system, which is an output feedback control composed of a MIMO PID controller, feedforward and high-gain observer.

For the control of an underactuated ROV, in Raygosa-Barahona et al. (2011) it was applied a combining of two controllers, a backstepping and a second order integral sliding modes controls; in Do (2010) it was proposed a control design based on several nonlinear coordinate changes, the transverse function approach the backstepping technique, the Lyapunov direct method and utilization of the ship dynamics; in Khadhraoui et al. (2014) it was developed the design control on the vertical plane with a backstepping methodology.

This article aims to give the next step of the project, which is the development of a navigation control for this HROV, which is underactuated, i.e., the direction sway, y, is not actuated, because of this it was necessary to combine two control techniques. The idea is to divide the vehicle model into two parts: the first part is considered fully actuated and is controlled with a backstepping control, this part of movement is provided by the four thrusters positioned in the vertical. The second part where the underactuated occurs, the movement is provided by two thrusters positioned in the horizontal.

In order to control the sub actuated part, it was used the ideas proposed in Fierro and Lewis (1995); Zidani et al. (2015), in which were developed a kinematic/torque control law for a wheeled mobile robot utilizing backstepping. The control Lyapunov function was used due to the need for a bottleneck, thus the underactuated model is very similar of a ship model (Liu et al., 2016; Jiang, 2002; Do, 2010).

The paper is organized as follows: Section 2, introduces the Proteo architecture; Section 3, shows the vehicle mathematical model; Section 4, presents the control design; Section 5, concerns the numerical simulation and Section 6, conclusions.

2. Proteo hardware architecture

The main function of the vehicle is the inspection of ship hulls by means of ultrasonic transducers to check the thickness of the plate and look for cracks.

It has two operating modes: free flight and crawling. In the first mode of operation, the vehicle uses six thrusters (4 vertical and 2 horizontal) for its displacement through the water and in the second mode, uses two motorized mats for its locomotion on the surface of the hull of the ship and 4 vertical thrusters to apply a normal force in the hull, avoiding the use of complex electromagnetic devices.

2.1. Mechanical designed

The structure of HROV consists in a polypropylene plates and its divided in 5 parts, two lateral and three horizontal plates. The top horizontal plate of the structure contains the float and four thrusters with their Vertically oriented axes; the middle plate contains a pressure vessel for the control of the electronics and the lower part of the structure contains two thrusters with their axes oriented horizontally as motorized tracks. In the initial design the float should be a block (Fig. 1), but due to the weight of the motorized tracks, tubes were used (Fig. 2).

An umbilical cable is used for an electrical signal and a signal transmission, which can be seen in Figs. 2 and 1.

It is noted that the general structure can be approximated being symmetrical in the longitudinal and transverse planes, which will influence the simplifications that will be made in the mathematical modeling, section 3.

2.2. Computer, sensors and actuators

Tiger board is a high performance computer manufactured by Versalogic Corporation that supports other PC/104 and PC/104-Plus expansion cards, and features an Intel Atom Z5xx processor. Tiger is compatible with Windows, Windows Embedded, Linux, VxWorks and QNX. In this work we used the Debian 6.0.0 operating system (Squeeze/Stable) (Versa Logic Corporation). The Fig. 3 shows schematically the architecture adopted for the project. It has a surface computer from which the vehicle is remotely controlled and an embedded, where the program that processes the data of the sensors, receives the desired trajectory and locally controls the actuators to keep the vehicle in the trajectory.

Sensors used in the HROV were chosen to provide information capable of giving orientation, position, speed and acceleration of the vehicle. The altimeter model PA500/6-PS (manufactured by Tritech International Limited) provides underwater distance measurements. In this design, the sensor is used to measure the distance between the vehicle and the inspected surface (Tritech International Ltd).

Velocity Log Doppler sensor (NavQuest 600 manufactured by LinkQuest Inc.) provides the speed of the vehicle in the surge, sway and pitch directions (LinkQuest Inc).

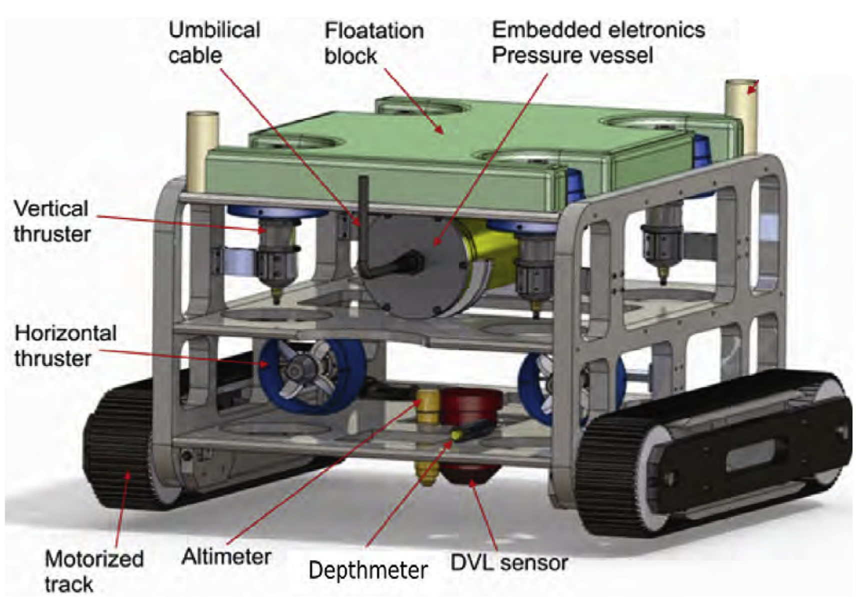

Fig. 1. The design of the HROV Proteo (Luque and Avila, 2013).