Planning and Control of Autonomous Underwater Vehicle's Trajectory for its Recovery from a Mobile Submarine Platform.

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Abstract

The technology of autonomous underwater vehicles (AUV) has seen very strong growth over the last decade. Small hydrodynamic forces and associated resistance acting on these vehicles require a low power propulsion unit which, together with the high performance of their navigation systems and information acquisition devices, enables them to develop long-range invaluable missions. Due to their high performance AUV's applications grows constantly in many different sectors: commercial, performing risky and expensive maritime maintenance tasks as in oil platforms; institutional, with maritime investigation and oceanography tasks for a better protection and use of natural resources; and national defense, in security operations relative to surveillance, intelligence and inspection.

Despite the AUV's broad field of applications and the benefits generated in economic and security scopes, launch and recovery systems of these vehicles have not seen a parallel development; often, handwork is required in their recovery, exposing both staff and the vehicle itself. The risks associated with the underwater recovery of AUVs are even greater. For these reasons there is great interest in the scientific community in the development and implementation of effective methods and algorithms to assist in this complex maneuver.

In this paper an algorithm that plans and controls the trajectory of an AUV for the underwater recovery in a mobile platform is presented. This algorithm consists of two main modules: I) Plan the AUV's trajectory and velocity to reach the mobile target in the specified conditions, and II) Controls AUV's government to follow the path with the least possible error in position, orientation and velocity.

The planning module defines the AUV's path and speed in three sections (Figure 1): (Homing) from an arbitrary starting position for the AUV to an specific transition point at a defined distance, aft of the target and with the same course, (Approach) directs the AUV to a preset position in the same plane as the target, (Docking) allows the AUV reach the mobile platform. The Docking phase ends when some specific device or mechanical system (not considered in this work) ensures the AUV's fixation to the mobile platform. During the Docking phase, the AUV's trajectory must avoid certain restricted navigation areas whose position is known and fixed with respect to a reference system attached to the target.

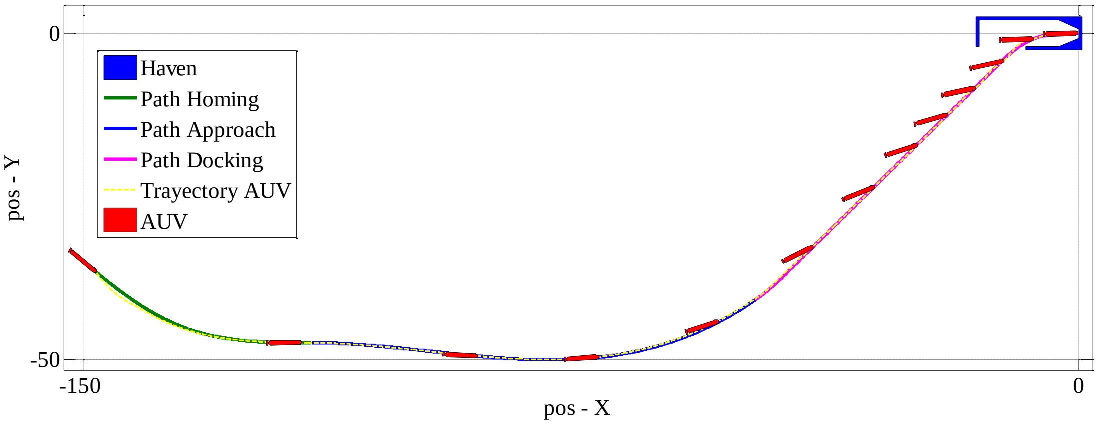


Figure 1. XY view of the 3D trajectory planning and control for the underwater recovery of AUV in a mobile platform with restricted navigation areas.

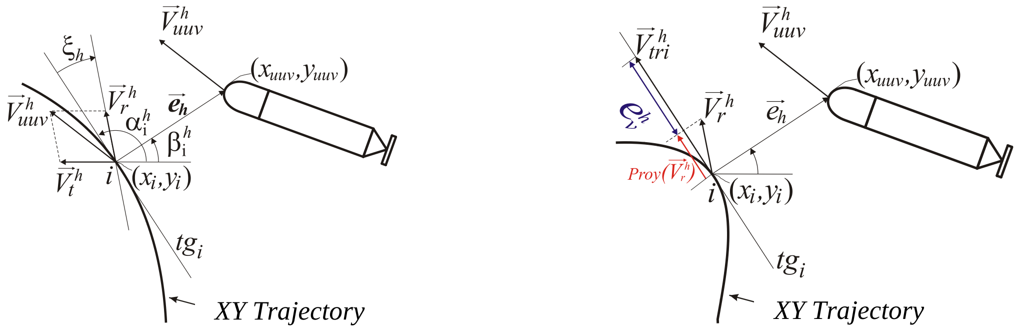
The control module is composed of three controllers. The Yaw and Pitch angles use PD controllers to govern the AUV keeping its bow $(x_{uuv}, y_{uuv}, z_{uuv})$ on the calculated trajectory (x_i, y_i, z_i) and its

orientation such that the AUV's velocity $(\overrightarrow{V_r})$, relative to the moving target, is parallel to a vector tg_itangent to the trajectory (Figure 2). Position and orientation errors, both in horizontal plane (h) and vertical axis (z) are calculated at each integration point as shown in Equations (1) and (2) respectively.

$$\overrightarrow{e_h}(t) = [x_{uuv} - x_i, y_{uuv}, -y_i] \; ; \; \overrightarrow{e_z}(t) = [0, z_{uuv}, -z_i] \tag{1}$$

$$\xi_h(t) = arg\left(\overrightarrow{V_t^h}\right) - \alpha_i^h; \xi_z(t) = arg\left(\overrightarrow{V_t^z}\right) - \alpha_i^z \tag{2}$$

The AUV's velocity error is calculated as the difference between its planned relative velocity at each point of the trajectory $\overrightarrow{V_{tri}}$ and the projection of its relative velocity on the vector tg_i tangent to the trajectory at that point. This control is achieved by using a PID controller. It is considered that the AUV can update, at some refresh rate, information enabling it to estimate its actual position and orientation with respect to the recovery point. For that purpose, both Inertial Measurement Unit (IMU) and Ultra Short Base Line (USBL) commercial devices, together with their corresponding measurement errors have been considered in the control algorithm.



a) b)

Figure 2. Vector and variables needed to calculate position and orientation errors (a) and velocity error (b). Only the horizontal plane is shown.

The effectiveness of the algorithm has been tested using dynamic simulations of models based on AUVs REMUS100 and NPS Aries, although it is fully applicable to any other type AUV. Tests have been performed considering variations in the following variables: initial position and orientation of the AUV to the mobile platform, velocity of the platform, uncertainty and refresh rate in USBL and IMU measurements. The errors in the AUV's position, orientation and velocity at each point of the trajectory, including the docking point, have been calculated.

From the results it can be inferred that the developed algorithms for planning and control of AUV trajectory for underwater recovery in a mobile platform are capable to control the vehicle from its initial position to the target point with an error under 0.5m in position and 10º in orientation during the whole trajectory. At the point of capture, the AUV's error does not exceed in any case 0.2m in position or 5 º in orientation. It is found that the vehicle, during its approach to the target, does not encroach the restricted areas on any of the simulated cases.

References

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