Development of 3D multibody models of Intervention-Autonomous Underwater Vehicle (I-AUV)

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Abstract

Currently, a considerable number of operations in sea-rescue, research and maintenance of oil rig appliances exploit Unmanned Underwater Vehicles (UUVs) with manipulation capacity to be concluded successfully [1], [2]. In such scenario, most of the intervention missions at high depths are faced up by Remotely Operated Vehicles (i.e. ROV) equipped with one or more robotic arms (Intervention-ROVs), representing until today the standard technology in that field [2] (Figure 1(a)). The ROVs for assistance, which can be tele-operated for long periods, are usually controlled with a master-slave approach. This kind of strategy has some limitations: the operator must be skilled with special type of training, a delay in the control loop can be present and the overall costs of the missions are for from being negligible.

The technical evolution of such tele-operated vehicles are Autonomous Underwater Vehicles (AUVs), where the vehicle performs a pre-planned tasks (e.g. survey and exploration) without any operator support. However, in the AUVs field, there are many open problems: the introduction of manipulation tasks of a single vehicle (with relevant vehicle velocity), the dynamic performances and the control of the vehicle and the cooperation among vehicles. Despite free floating base autonomous underwater manipulation is far from reaching an industrial product, especially when relevant vehicle velocities are required (i.e. dynamic manipulation, in contrast with hovering manipulation), many research activities on Intervention-AUVs (usually called I-AUVs) modelling and control architecture have been carried out. In this paper, the authors developed a complete 3D multibody model of an I-AUV (Figure 1(b)) and analysed an innovative control architecture based on optical cameras, specifically thought for the underwater mobile manipulation. In fact, as concerns I-AUV control strategies, the problem is still open. Vehicle-manipulator

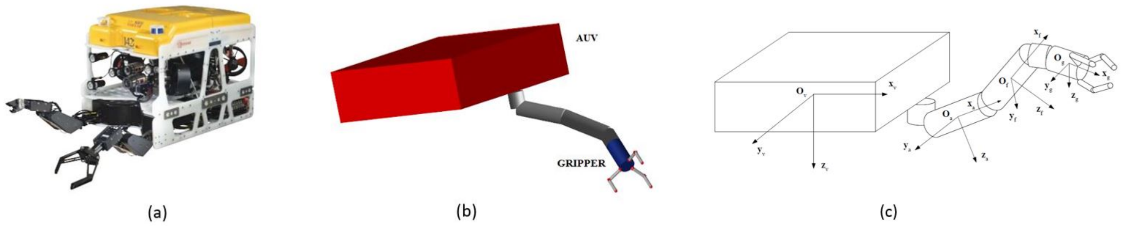
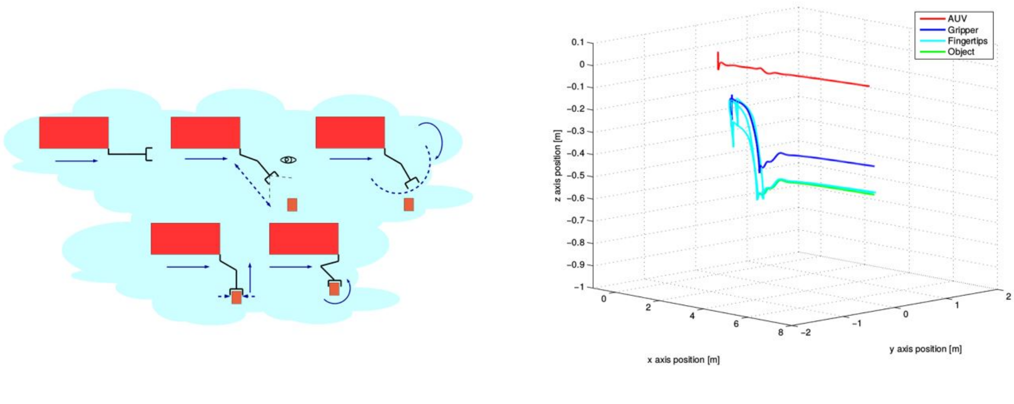


Figure 1: (a) Example of an I-ROV - (b) 3D multibody model of the I-AUV - (c) Structure of the I-AUV, equipped with a robotic arm and a gripper

decoupled control strategies have been mostly studied until now, which independently control the AUV and the robotic arm [3]; these strategies offer simpler hardware and software implementation and require less knowledge of the system parameters compared to arm-vehicle coupled control techniques [1], [3].

In this paper, a dynamic manipulation strategy for an I-AUV is proposed; the considered system (Figure 1(c)) is composed of an AUV equipped with a 7 Degree Of Freedoms (DOFs) robotic arm and a three-fingered gripper (6 DOFs in total). Mathematical and simulation models for the system are derived, including interaction with the fluid [4]. CFD analysis have been used to estimate the hydrodynamic coefficients, and the coupling between the multibody model and fluid equations has been efficiently simulated through the software Matlab®. A suitable hard finger contact model is employed to model the interaction between the gripper fingers and the object to be manipulated. A decoupled control strategy is proposed for the vehicle and the arm; in addition, exploiting the hand kinematics, the control of the arm has been

further decoupled from the gripper one, to improve the performances of the I-AUV while maintaining higher vehicle velocities. Finally, a grasp planning technique is presented, composed of a visual pose estimation algorithm and a contact point individuation strategy.
The control architecture has been validated simulating a suitable test case using the software Matlab®: the logical scheme of the manipulation tasks is presented in Figure 2(a). The task consists of grasping a



(a) (b)

Figure 2: (a) Dynamic manipulation task scheme - (b) 3D trajectory of the I-AUV

cylindrical object lying on the sea floor, and it is composed of the following steps:

- the I-AUV, starting from rest, accelerates for 5 seconds until steady-state speed is reached;
- as soon as the cylinder enters the field of view of a camera mounted on the palm of the gripper (eye-in-hand configuration), the reference trajectory is changed so as to align the camera focal axis with the line connecting the palm of the gripper to the position of the center of mass of the object (estimated by the POSIT algorithm). This way, the cylinder is kept inside the field of view of the camera all the time;
- when a threshold distance between the gripper and the object is reached, the arm is lowered and the gripper grasps the cylinder;
- the cylinder is lifted and carried as the arm reaches a final “rest” configuration (i.e. the cylinder carried vertically under the bow of the vehicle).

In Figure 2(b), the complete 3D trajectory of the I-AUV is shown. It is worth to note that the AUV never stops during the execution of the task, which is a fundamental requirement for real dynamic manipulation tasks. The proposed techniques, after further tests, will be used in opportune hardware tests in the framework of existing projects, such as the Italian research project SUONO (*Safe Underwater Operations iN Oceans*) and the European research project ARROWS, coordinated by the MDM Lab of the University of Florence, to obtain the initial experimental results.

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