A New Approach for a Reconfigurable Autonomous Underwater Vehicle for Intervention

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Abstract— **the present work shows an ongoing project named RAUVI (i.e. Reconfigurable AUV for Intervention). This project aims to design and develop an Underwater Autonomous Robot, able to perceive the environment by means of acoustic and optic sensors, and equipped with a robotic arm in order to autonomously perform simple intervention tasks. A complete simulation environment, including this new concept of robot, has been developed and it is presented as preliminary result.**

Keywords- underwater robotics; I-AUV; robot simulation

I. INTRODUCTION

Nowadays, many important applications of underwater robotics exist, in many different fields such as marine salvage, marine science, offshore industry, etc. which do not only need exploration capabilities, but also intervention skills. Traditionally, a dichotomy has been established in underwater robotics, between autonomous robots development for exploration tasks and teleoperated underwater robots endowed with manipulators for intervention tasks. However, very recently, the so-called I-AUV (i.e. Intervention AUV), an autonomous underwater vehicle endowed with one or more manipulators that allow to automatically perform manipulation tasks, have started to be developed by some researchers. The main advantage of I-AUVs robots is their low operational cost, since there is no need for large intervention ships with dynamic positioning capabilities.

II. ESTATE-OF-THE-ART

First works concerning I-AUVs were published in the former 90's addressing the coordinated control of the vehicle-manipulator system. Most of these pioneering works relied on numerical simulations of the coupled dynamics of both systems. First attempts to achieve an AUV endowed with a manipulator drove to the development of the ODIN AUV (University of Hawaii), the OTTER AUV (MBARI) and the VORTEX/PA10 robot within the UNION European project [1] (see Fig.2 and Table 1). While ODIN and OTTER are AUVs controlled in 6 DOF and endowed with a very simple 1 DOF arm, the VORTEX is a 5 DOF ROV operated as an AUV which carries a 7 DOF PA10 arm. Although these vehicles represented a step forward in I-AUV technology they were mainly used as research testbeds to prove concepts as the advanced hydrodynamics modeling of an underwater arm [2], the coupled AUV-manipulator simulation [3] and control [4][5], always working in water tank conditions. Since the coordinated control of the mobile platform and the manipulators is a very challenging problem from the control point of view, several control strategies were proposed and tested during the following years (see [6][1] and the references therein). During the mid 90s, AMADEUS EU project [7][8] supposed a step forward in the field of dexterous underwater manipulation, including within its objectives the realization of a set-up composed by 2 7-DOF ANSALDO Manipulators to be used in cooperative mode [9].

After this period, researchers proposed new concepts to avoid the complexity of the coupled motion of the vehicle-manipulator system in order to achieve true field operation in open sea conditions. In 2001, Cybernetix tested its hybrid AUV/ROV concept with the SWIMMER project [10]. In this case an autonomous shuttle (an AUV) carrying a ROV, is launched from a support vessel to autonomously navigate and dock into an underwater docking station in an offshore infrastructure. The docking station provides a connection to the AUV and from it to the ROV allowing carrying out a standard ROV operation without the need of a heavy umbilical. After SWIMMER, two more projects were launched, ALIVE (EU) [11] and SAUVIM (USA) [12]. ALIVE is a 4 DOF intervention AUV with a 7 DOF manipulator which has shown its capability of autonomous navigation towards a position nearby an underwater intervention panel, detect the panel using an imaging sonar and finally, approximating and docking to the panel with the help of a vision system and two hydraulic grabs. Once the AUV is grabbed to the panel, and assuming the panel is known, the manipulation is a simple task. ALIVE's project was complemented with the European Research and Training (RTN) network FREESUB devoted to the fundamental research on areas like the Navigation, Guidance, Control, Tele-Manipulation and Docking needed to further develop the I-AUVs [13][14]. Currently the FREESUBNET RTN, which followed the former FREESUB project, widens the fundamental research carried out in the previous project including new areas to explore like the operation of multiple vehicles or the mission planning and control. On the other hand, SAUVIM is an AUV carrying a 7 DOF electrical driven arm (ANSALDO), the same used in the AMADEUS EU project, which is intended to recover objects from the seafloor using dexterous manipulation. SAUVIM concept relies on keeping a strong difference of mass between the AUV and the manipulator, so the control of the vehicle-manipulator system can be considered as an uncoupled control problem.

III. TOWARDS A NEW AUTONOMOUS UNERWATER VEHICLE

After the literature survey, it is clear that further research in I-AUV technology is needed to achieve full autonomous underwater intervention capabilities. Moreover, the I-AUVs developed until now, which have proven field capabilities, are heavy vehicles (SAUVIM and ALIVE are 6 and 3.5 ton vehicles respectively) for very deep water interventions. As stated by some of the researchers of the SAUVIM project [15], it is of interest for the science and the industry the design and development of a very-light I-AUV (<300 kg) constrained to shallow water interventions (up to 500 m). Thus, the construction of a new I-AUV able to perform intervention activities that will be experimentally validated through a real scenario by using a real prototype, in a complete autonomous way would be a crucial technological contribution. A preliminary I-AUV model designed within the RAUVI project can be appreciated in Fig. 1.

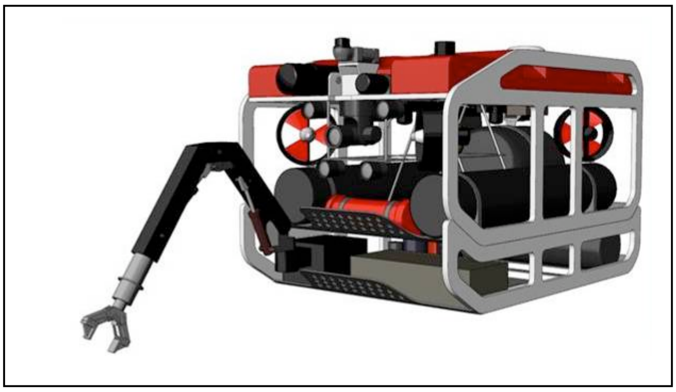

Figure 1. The envisioned I-AUV system to develop in the ongoing project RAUVI

Thus, the main goal of the RAUVI (i.e. Reconfigurable AUV for Intervention) project, here addressed, is to develop and improve the necessary technologies for autonomously performing an intervention mission in underwater environments. The approach can be summarized in two different steps: (1) survey and (2) intervention. Firstly, the I-AUV explores the region of interest, taking visual and acoustic data, synchronized with robot navigation. Then, the robot surfaces, and the information is downloaded to the base station, where a computer reconstruction of the explored region is built. By means of a specific human-robot interface to be developed, an operator identifies the object of interest and describes the task to perform. Next, the I-AUV robot navigates again to the region of interest, identifies the target object and performs the intervention task.

Some details describing the strategy to follow for this new RAUVI concept are stated in the following:

A. *Methodology for a Generic Intervention Mission*

The definition of a new methodology to face generic underwater intervention tasks, as well as the research and further development of the key technologies will be necessary to progress in the desired direction. In particular, it has been thought necessary to design and develop an AUV endowed with a 5 DOF hydraulic manipulator and a visual navigation system. A HMI module will play an important role enabling a friendly system's integration. In this context, a generic intervention mission will be carried out, by means of the HMI, in two stages involving several phases. A pictured recreation for the survey stage can be appreciated in Fig. 2, and also for the intervention stage in Fig. 3.

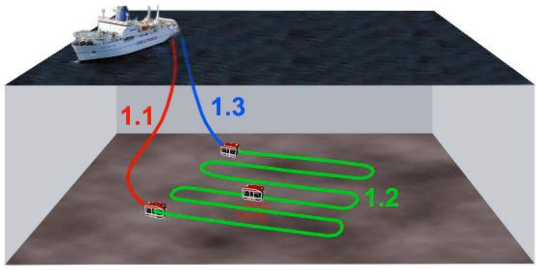

Figure 2. Survey Stage. Phase I: Launching (1.1); Phase II: Survey (1.2); Phase III: Recovery (1.3)

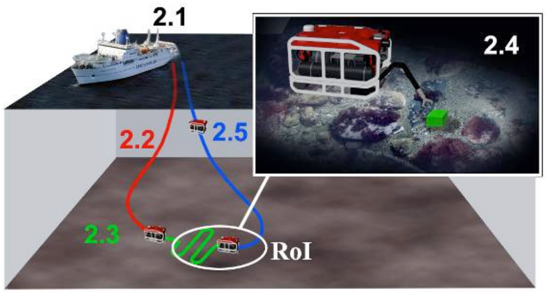

Figure 3. Intervention Stage. Phase IV: Intervention Specification (2.1); Phase V: Launching (2.2); Phase VI: Approaching (2.3); Phase VII: Intervention (2.4); Phase VIII: Recovery (2.5).

To carry out a generic intervention, RAUVI project assumes that someone else has carry out a previous survey, probably with multibeam or side-scan data, to identify a reduced area where the target is localized. With this input, RAUVI project starts the survey using the HMI to define the area where a visual survey will be executed, which is automatically translated into a mission program to be downloaded to the I-AUV. After launching the vehicle (Phase I), the robot follows the programmed survey pattern while recording images synchronized with the navigation data (Phase II). Once the whole searching area has been covered, the robot is recovered (Phase III) and the HMI is used to provide the user with a visual map (image mosaic) of the surveyed area. Over this map, the user selects and characterizes the target based on visual features before specifying an intervention task from the library. Again, the HMI will automatically generate an intervention mission program to be downloaded into the I-AUV (Phase IV) before its launching (Phase V). In this second stage, since the target position is known, the robot will approach the Region of Interest (RoI) using its navigation system (Phase VI). Then, with the help of the visual-based navigation the target will be search. At this moment, the I-AUV switches to intervention mode (holonomic thruster's configuration) and the vehicle executes a station keeping task while the manipulator undertakes the intervention. Finally, the vehicle is recovered.

IV. The Simulation Environment: Implementation Details

In order to facilitate the definition of the vision and control algorithms for the robotic device, an ad hoc simulation environment has been developed. The environment, see Fig. 4, allows emulating the dynamic behaviour of the underwater platform and of the robotic arm in realistic conditions, as well to simulate the vision system and its performances.

Figure 4. UWSim user interface.

The "realistic" conditions that it is possible to simulate include the effect of water streams, the presence of obstacles, noisy conditions for the vision systems, submarine life forms, different environments (pools, submarine, lake, rivers,...) varying conditions (in terms of lights, moving objects, and so on). Within this environment, it is therefore possible to emulate the expected working conditions of the underwater system, and then to develop proper vision and control algorithms that can be tested in realistic conditions, see Fig. 5, 6, and 7.

In order to test vision algorithms, there are six different virtual cameras that can be placed on the robot. Moreover, an external camera can be freely positioned around it to check the task execution. The virtual cameras behave as real devices, and simulate some common effects like image noise, reflexes and so on. It is also possible to set their working parameters (resolution and frame rate). Thus, all the information necessary for task planning and execution are available, as well as data for the real-time control of the intervention device.

Figure 5. Obstacle on seafloor, from the onboard camera point of view.

Figure 6. Fishes and particles can generate problems in vision tasks.

The external camera is self guided by an algorithm that allows the user to observe the robot from a correct point of view, without having to execute positioning tasks. The environment in which the underwater system operates can be chosen within a list of available environments, among which environments that can be reconstructed on the basis of real 3D data and videos.

The simulated robot can be guided manually, by means of a joystick, or autonomously, running a controller library. In this latter case, images from the simulated video cameras are used to compute proper control actions in order to move the platform and/or the arm. At the moment, the simulated robot platform has 8 actuators, while the robot arm presents 4 degrees of freedom and a gripper. Obviously, also these parameters can be easily changed if other design solutions for the mechanical system are developed in the project.

The simulation software has been developed in Visual C++ using a powerful 3D engine based on OpenGL APIs, optimized for real-time applications. Vision and control algorithms are developed independently from the simulation and are encapsulated in an external DLL library in order to subdivide the high complexity of the VR environment simulation from the control algorithms. As a matter of fact, they can be written in any language (C, Java …) and exchange data with the simulation environment through a small set of I/O APIs.

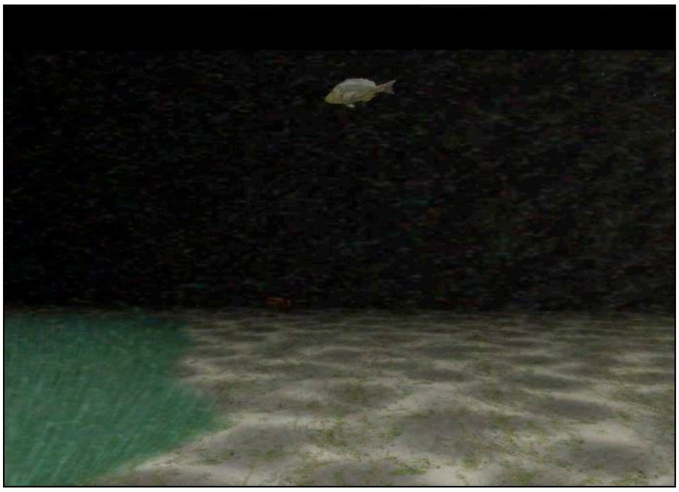

Figure 7. Simulation of a dark environment.

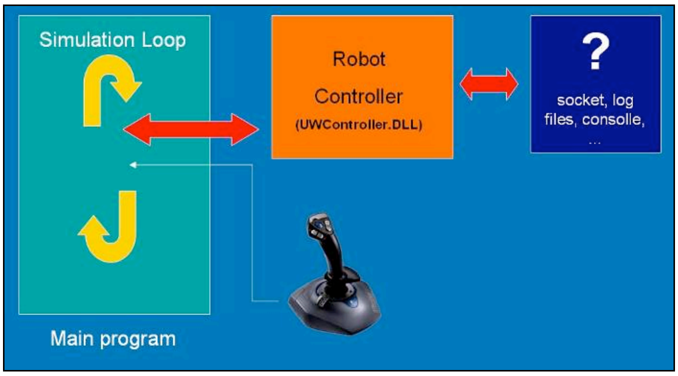

Figure 8. The system architecture.

In this manner, it is possible to develop code and procedures without the need to reconvert them at the need for the real system. It is possible to use the controller library as an external interface for the simulator using it to connect with different external environments (for example, with a controller developed in Matlab). The system architecture (see Fig. 8) is open and allows the user to interact with the virtual environment in many ways. The steps to develop a new control library are few and easy, considering that there are just 2 APIs used for data/commands exchange. Each time the controller runs, it can read data from the virtual robot (camera images, sensors data …), and generate commands for the robot actuators. The controller DLL can be used also to extend the user interface with other windows in order to show all control data and settings.

V. Conclusions and Future Lines

Robot-environment interaction is evidently very important in order to obtain behaviour similar to the real situation; for example, when the robot touches the seafloor, this event is not a simple collision, but it triggers other events that influence the state of the environment (losing of visibility caused by the powder). The last example, suggests that the collision detection and response are just a subset of information needed in a realistic simulation that involves vision, for this reason an accurate scene synthesis is not only an aesthetic feature, but represents an important aspect. In the natural world there are a large variety of environments and conditions that needs to be simulated and that can provide a powerful tool to minimize time and costs for the development of this kind of application. Finally, it is noticeable that the work here presented shows only the first step in the progress direction towards the long term objective, described in the introduction section.

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