New Approach for a Reconfigurable Autonomous Underwater Vehicle for Intervention

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ABSTRACT

This shows an on-going 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 is presented as a preliminary result.

INTRODUCTION

Nowadays, many important applications of underwater robotics exist, in many different fields such as marine salvage, marine science, offshore industry, etc., which 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 tele-operated 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 us to automatically perform manipulation tasks, have begun to be developed by 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.

STATE-OF-THE-ART

The first works concerning I-AUVs were published in the late 1990s addressing the coordinated control of vehicle-manipulator systems. Most of these pioneering works relied on the numerical simulations of the coupled dynamics of both systems. The first attempts to achieve an AUV endowed with a manipulator drove the development of the ODIN AUV (University of Hawaii), the OTTER AUV (MBARI), and the VORTEX/PA10 robot within the UNION European project [1] (Figure 2). 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-1990s, 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

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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 in an underwater docking station in an offshore infrastructure. The docking station provides a connection to the AUV and from it to the ROV allowing 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 toward a position near an underwater intervention panel, detecting 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 electrically-driven arm (ANSALDO), the same used in the AMADEUS EU project, which is intended to recover objects from the sea-floor using dexterous manipulation. The 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 an uncoupled control problem.

TOWARD A NEW AUTONOMOUS UNDERWATER 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 up to the present, 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 SAUVIM project researchers [15], it is of interest to the science and industry 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 completely autonomous way would be a crucial technological contribution. A preliminary I-AUV model designed within the RAUVI project can be appreciated in Figure 1.

Thus, the main goal of the RAUVI (i.e. Reconfigurable AUV for Intervention) project, herein 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:

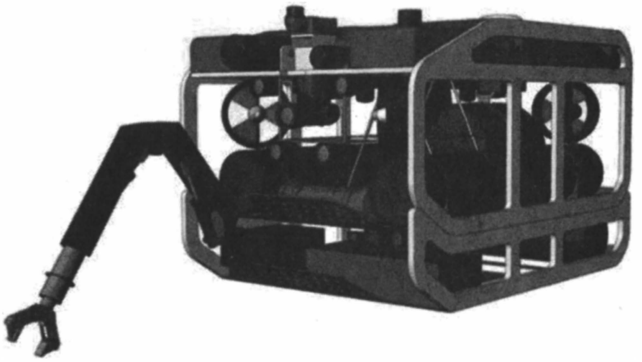

Fig. 1. The envisioned I-AUV system to develop in the ongoing project RAUVI

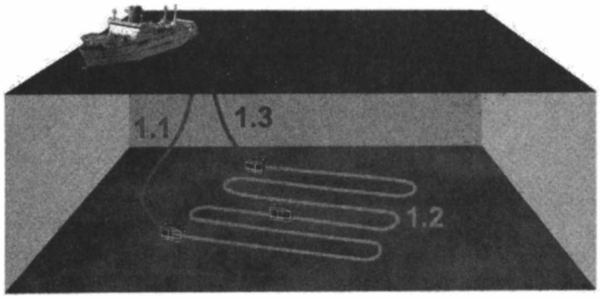

**Fig. 2. Survey Stage.
Phase I: Launching (1.1);
Phase II: Survey (1.2); and
Phase III: Recovery (1.3)**

1) **Survey,** and

2) **Intervention.**

First, 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.

Details describing the strategy to follow for this new RAUVI concept are stated following:

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 Figure 2, and also for the intervention stage in Figure 3.

To carry out a generic intervention, RAUVI project assumes that someone else has carried out a previous survey, probably with multi-beam 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 search 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 the 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 searched. 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.

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 Figure 4, allows emulating the dynamic behaviour of the underwater platform and of the robotic arm in realistic conditions, as well as to simulate the vision system and its performances.

The *"realistic"* conditions make it 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 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 Figures 5, 6, and 7.

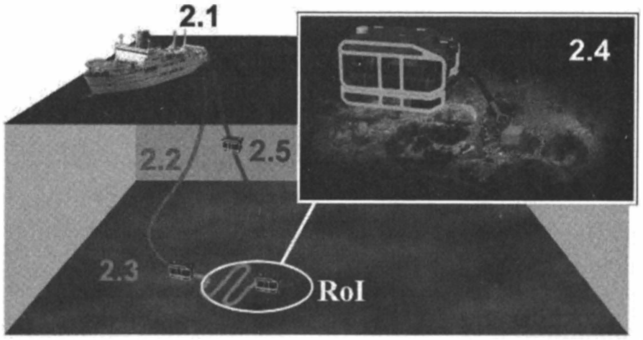

**Fig. 3. Intervention Stage.
Phase IV: Intervention Specification (2.1);
Phase V: Launching (2.2);
Phase VI: Approaching (2.3);
Phase VII: Intervention (2.4); and
Phase VIII: Recovery (2.5)**

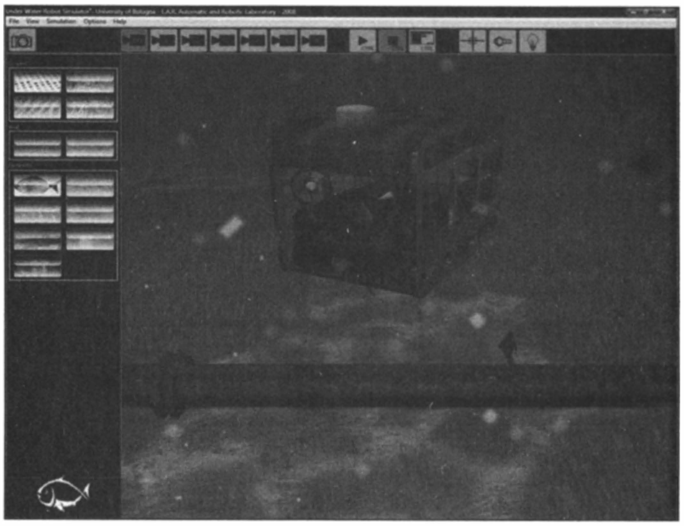

Fig. 4. UWSim user interface

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.

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 3-D data and videos.

The simulated robot can be guided manually, by means of a joystick; or autonomously, running a controller library. In

Fig. 5. Obstacle on sea-floor, from the on-board camera point of view

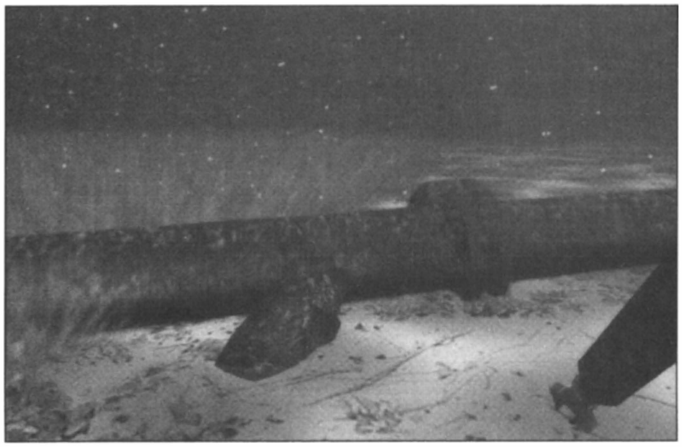

Fig. 6. Fish and particles can generate problems in vision tasks

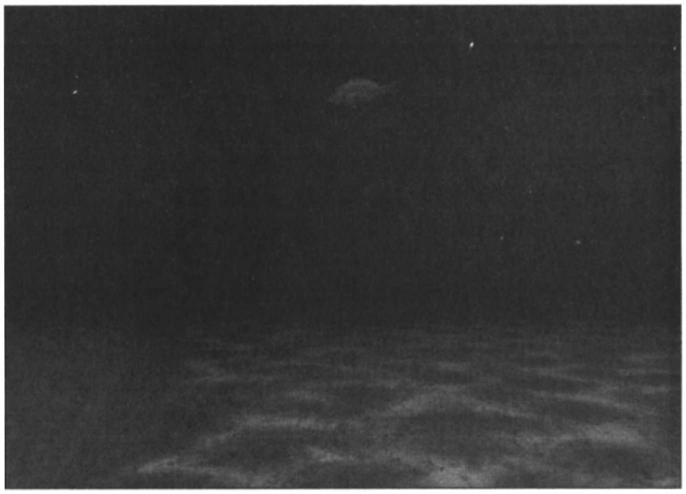

Fig. 7. Simulation of a dark environment

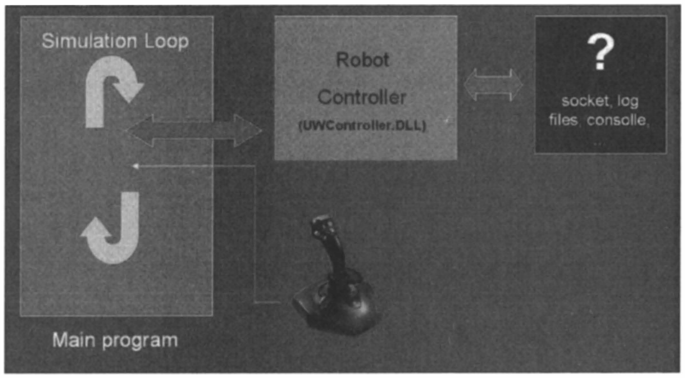

Fig. 8. System architecture

the 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, 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 3-D 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 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, etc.) and exchange data with the simulation environment through a small set of I/O APIs.

In this manner, it is possible to develop code and procedures without the need to reconvert at the need for a 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 Figure 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, etc.), and generate commands for robot actuators. The controller DLL can be used to extend the user interface with other windows in order to show all control data and settings.

CONCLUSIONS AND FUTURE LINES

Robot-environment interaction is evidently very important to obtain behaviour similar to the real situation; for example, when the robot touches the sea-floor, 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 sub-set 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 need to be simulated and can provide a powerful tool to minimize time and costs for the development of this application. Finally, we note that the work presented herein shows only the first steps in the progress toward the long term objective described in our *Introduction.*

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