Recent Progress in the RAUVI Project

A Reconfigurable Autonomous Underwater Vehicle for Intervention

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Abstract— **Starting in January 2009, the RAUVI project is a three years coordinated research action funded by the Spanish Ministry of Research and Innovation. This paper shows the research evolution during the first half of RAUVI's live, bearing in mind that the long term objective is to design and develop an underwater autonomous robot able to perceive the environment and, by means of a specific hand-arm system, perform autonomously simple intervention tasks in shallow waters.**

Keywords-underwater robotics; autonomous intervention mission; AUV for intervention; robot architerctures; Human-Robot Interaction

I. THE AIM OF THE PROJECT

Nowadays a relevant number of field operations with unmanned underwater vehicles (UUVs) in applications like marine rescue, marine science and the offshore industries, to mention some but a few, need intervention capabilities in order to undertake the desired task. In the offshore industry, UUVs have to dock to an underwater panel to manipulate valves with their robotic arms. It is of interest, for marine scientists, to further develop the capability of accurately deploy and recover specialized instrumentation. In the context of the permanent observatories currently under design and development, it will be of vital importance the intervention capability for maintenance operations. Interventions in marine rescue, are needed for instance to tight ropes to wrecks for towing or recovery. Currently, most of the intervention operations are being undertaken by manned submersibles endowed with robotic arms or by Remotely Operated Vehicles (ROVs). Manned submersibles have the advantage of placing the operator in the field of operation with direct view to the object being manipulated. Their drawbacks are the reduced time for operation (e.g. few hours), the human presence in a dangerous and hostile environment, and a very high cost associated with the need of an expensive oceanographic vessel to be operated. Work class ROVs, are probably the more standard technology for deep intervention. They can be remotely operated for days without problems. Nevertheless, they still need an expensive oceanographic vessel with a heavy crane and automatic Tether Management System (TMS) and a Dynamic Position system (DP). It is also remarkable the cognitive fatigue of the operator who has to take care of the umbilical and the ROV while cooperating with the operator of the robotic arms. For all these reasons, very recently some researchers have started to think about the natural evolution of the intervention ROV, the Intervention AUV (I-AUV). Without the need for the TMS and the DP, light I-AUVs could theoretically be operated from cheap vessels of opportunity reducing considerably the cost. With the fast development of batteries technology, and being removed the operator from the control loop, we can even think about intervention operations lasting for several days, where the ship is only needed the first and the last day for launching and recovering operations.

But this fascinating scenario, where I-AUVs are launched to do the work autonomously before recovery, comes at the cost of endowing the robot with the intelligence needed to keep the operator out of the control loop. Although standard AUVs are also operated without human intervention, they are constrained to survey operations, commonly "flying" at a safe altitude with respect to the ocean bottom while logging data. I-AUVs must be operated in the close proximity of the seabed or artificial structures. Therefore, they have to be able to identify the objects of interest (i.e. for manipulation purpose) and the intervention tasks to be undertaken, while safely moving within a cluttered area of work. For this reason, while I-AUVs are the natural way of technological progress they represent at the moment an authentic research challenge for the Robotics community. Moreover, the I-AUVs developed until now, which have proven field capabilities, are heavy vehicles (e.g. 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 [1], 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 300 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. And in fact, this is the aim of the RAUVI project, here presented.

The rest of this paper is organized as follows. Section II presents the evolution about the I-AUV concept under development, introducing details of both the vehicle and the robot arm. Section III shows an overview of the global control architecture. Section IV describes the user interface. Section V introduces the main vision perception characteristics to implement. And finally, some discussion remarks are offered in Section VI.

Figure 1. GIRONA500 AUV in survey configuration.

II. THE I-AUV UNDER DEVELOPMENT

A. The Autonomous Underwater Vehicle

The GIRONA500 is a reconfigurable autonomous underwater vehicle (AUV) designed for a maximum operating depth of up to 500 m (see figure 1). The vehicle is composed of an aluminum frame which supports three torpedo-shaped hulls of 0.3 m in diameter and 1.5 m in length as well as other elements like the thrusters. This design offers a good hydrodynamic performance and a large space for housing the equipments while maintaining a compact size which allows operating the vehicle from small boats. The overall dimensions of the vehicle are 1 m in height, 1 m in width, 1.5 m in length and a weight of less than 200 Kg. The two upper hulls, which contain the flotation foam and the electronics housing, are positively buoyant, while the lower one contains the more heavy elements such as the batteries and the payload. This particular arrangement of the components makes the separation between the centre of gravity and the centre of buoyancy about 11 cm, which is significantly more than any typical torpedo shape design. This provides the vehicle with passive stability in pitch and roll, making it suitable for imaging surveys. The most remarkable characteristic of the Girona 500 is its capacity to reconfigure for different tasks. On its standard configuration, the vehicle is equipped with typical navigation sensors (DVL, AHRS, pressure gauge and USBL) and basic survey equipment (profiler sonar, side scan sonar, video camera and sound velocity sensor). In addition to these sensors, almost half the volume of the lower hull is reserved for mission-specific payload such as a stereo imaging system or an electric arm for manipulation tasks. The same philosophy has been applied to the propulsion system. The basic configuration has 4 thrusters, two vertical to actuate the heave and pitch and two horizontal for the yaw and surge. However, it is possible to reconfigure the vehicle to operate with only 3 thrusters (one vertical and two horizontal) and with up to 8 thrusters to control all the degrees of freedom.

B. The electric arm

The "CSIP Arm 5E" is a robotic manipulator actuated by 24V brushless DC motors. It is composed of four revolute joints, and can reach distances up to 1 meter. An actuated robot gripper allows for grasping small objects, and its T-shaped grooves also permit handling special tools. The arm is made of aluminium alloy partially covered with foam material for guaranteeing suitable buoyancy. The total weight in the air is about 25 kg, whereas in fresh water it decreases to 9 kg approximately. The arm is capable of lifting 12 Kg at full reach, and can descend up to 300 m in water.

An eye-in-hand camera is mounted on the last link of the robot. It is a "Bowtech DIVECAM-550C-AL" high-resolution colour CCD camera, valid up to 100 m underwater. The current configuration of the arm, gripper and camera is shown in figure 2, together with a planar projection of the manipulator workspace.

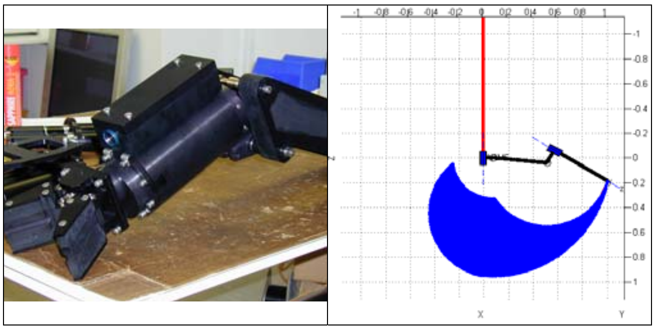

Figure 2. Current robot arm under development (left) and expected workspace (right).

C. The Integrated I-AUV

As can be observed in figure 3, the final prototype of the RAUVI project will be the mechatronics integration of both systems: the GIRONA500 underwater vehicle and the adapted "CSIP arm 5E".

The arm will be assembled in the part of the vehicle reserved for the payload, i.e. the lower hull, as shown in Figure 2. We establish a three-step roadmap towards the final arm-vehicle integration:

1. Software integration, where all the subsystems will be integrated at the software level. The software functionality will be validated with the hardware elements completely decoupled, i.e. the vehicle in UdG, the arm at UJI, and vision server at UIB. Communication between the different modules will be performed through the Internet.

2. Mechanics integration, where the vehicle and the arm will be mechanically assembled at UdG, although the electronics and PCs will be kept outside the vehicle.

3. Mechatronics integration, where all the subsystems, including electronics and PCs will be embedded in the vehicle.

Figure 3. GIRONA500 AUV in intervention configuration.

III. THE CONTROL ARCHITECTURE

The I-AUV control architecture is built of two initially independent architectures: the underwater vehicle and the manipulation architectures. Both of them have been combined into a new schema that allows for reactive and deliberative behaviours on both subsystems. Reactive actions are performed through a low-level control layer in communication with the robot hardware via an abstraction interface. On the other hand, the intervention mission is supervised at a high-level by a Mission Control System (MCS), implemented using the Petri net formalism. Both, the arm and vehicle perception and control modules communicate with the MCS by means of *actions* and *events*. They also share a centralized database where some sensor data is stored. The proposed architecture allows for the supervised execution of intervention missions requiring a tight coordination between the vehicle and the manipulator. For further details, please refer to [2].

IV. THE USER INTERFACE

Remotely Operated Vehicles (ROVs) are normally controlled by expert users -called ROV pilots- by means of a special Graphical User Interface (GUI) with specific interaction devices like a joystick, etc. The main drawback in this kind of systems, apart from the necessary expertise degree of pilots, concerns the cognitive fatigue inherent to master-slave control architectures [3].

The RAUVI project is progressing towards novel multimodal interfaces that allow an intuitive use by non-expert users. RAUVI follows a two stages strategy [4]: in a first stage, the I-AUV is programmed at the surface and receives a plan for surveying a given Region of Interest (RoI). During the survey it collects data under the control of their own internal computer system. After ending this first stage, the I-AUV returns to the surface (or to an underwater docking station) where its data can be retrieved. A 3D image mosaic of the seabed is reconstructed, and by using a specific GUI, including virtual and augmented reality, a non-expert user is able to identify the Target of Interest (ToI) and to select the suitable intervention task to carry out. Then, during the second stage, the I-AUV navigates again to the RoI and executes the target localization and the intervention mission in an autonomous manner.

At this moment, the mission specification system is composed of three modules: a GUI for object identification and task specification, a grasp simulation and specification environment, and the I-AUV Simulator used to allow for the software development while the mechatronics system is not yet available. Low level details can be found elsewhere [5].

1. *A GUI for target identification and task specification*. The user first looks for the ToI in the seabed mosaic and loads the image that contains this ToI in the GUI. After selecting the ToI, the intervention task is selected by choosing between different pre-programmed actions such as recovery, hooking a cable, etc. After that, the GUI requests the vision server for object identification solutions to characterize the robot grasping. So, the planned grasp will be later used in the grasping simulator and finally, in the real system.
2. *Grasp simulation*. Recent work is focused on a easy-to-use grasp simulation and supervision system that allows the user to visually check and validate the candidate grasps or to intuitively refine them in case they are not suitable for the planned intervention task.
3. *The I-AUV Simulator*. This is in charge of simulating the whole mission, including vehicle navigation and the intervention task through the robot arm. The work in this line is now focused on Hardware in the Loop (HIL) simulator that receives control commands from the architecture via TCP/IP sockets and sends back simulated sensor signals.

V. VISUAL PERCEPTION ASPECTS

When propagating in water, light suffers from different phenomena that affect the image formation [6]. Absorption and scattering dramatically reduce the effective distance of vision and the contrast of the image. Moreover, flora and fauna present in the scene produce variable and irregular shapes that often can hide the original appearance of objects layered on the seabed. Thus, a suitable underwater vision system has to take into account the media it works in, the nature of the images it deals with, as well as the application it is designed for.

The vision equipment under development in this project includes a high-resolution camera and a stereo-pair video system and takes into account some techniques specifically designed to improve the underwater image quality. More specifically, geometric configuration of the camera-lighting system and the use of polarized light as efficient solutions to reduce backscattering effect and thus to extend the working area are under study [7].

A. Vision System Tasks

Visual information can be useful in many different tasks of an AUV mission. As it has been described in [4], the RAUVI project splits a mission into two stages: survey and intervention. A relation of vision tasks to be executed during these stages follows.

During the survey stage and whenever the seabed is visible, the position estimation of the vehicle can be improved fusing visual feature tracking information with data provided by other onboard navigation sensors. To that end, a visual odometer is under development. The first version available is a monocular 2D system although two methods to manage 3D information are under development based on structure from motion and binocular vision, respectively. Thanks to this process, images will also be tagged with their estimated localization, thus, contributing to improve and accelerate the mosaic building process.

Once the survey stage finishes, the vehicle goes back to the surface and downloads all the information gathered with which the intervention stage is planned. In this intermediate stage a human operator selects the Target of Interest (ToI) on which the intervention has to be done, as described in section IV. At this moment, the vision module is responsible for characterizing both the scene and the ToI. Although these two tasks can be considered as the same problem but focusing on different scale, particular strategies are being used to solve them. The scene characterization will be done with invariant image descriptors [8, 9]. To characterize the target, a constellation of invariant features is the selected option [10].

When the AUV goes for the intervention stage, it will use all the navigation data associated to the images formerly obtained to guide the vehicle when approaching to the target. Thus, a navigation strategy will be performed until the scene descriptor matches the current view. At this moment, a finer vehicle maneuvering and a local feature detection and analysis will start in order to find a matching between the target description and the visible objects.

While the intervention is being executed, vision will be used to help keeping the position of the vehicle. A feature-tracking algorithm, close to that used by the visual odometer will feed the dynamic positioning system to provide this service. Finally, both at the end of the survey and the intervention stages, the submarine will dock the surface vehicle. This process will also be partially guided by the vision module thanks to the tracking of special marks placed at the docking module.

B. The Vision Module Architecture

The vision module must provide the rest of the system with higher-level processing capabilities as described in the previous paragraphs. To that end, this module is conceived as a server whose mission is to attend one-shot or cyclic service requests coming from other modules of the whole system (see figure 4).

VI. DISCUSSION

This paper shows work in progress after one year and a half of research in the Spanish Coordinated RAUVI Project. Besides further development of the main software components (i.e. the control architecture, the user interface, the visual perception system and so on), the pending master piece under development is, without doubt, the mechatronics integration of the proposed I-AUV, which is planned to be done before December 2011.

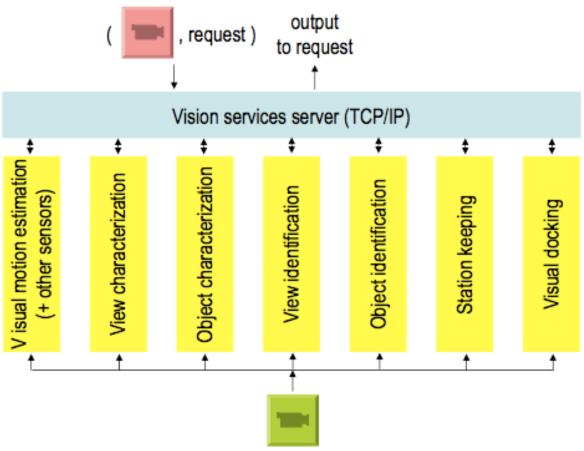

Figure 4. Vision module architecture as a service server

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