Multipurpose Underwater Manipulation for Archaeological Intervention

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Abstract *- This paper presents a new research line recently started by our team (IRS-Lab, UJI) in the context of semi-autonomous underwater robotic intervention applied to the archaeological domain. This new research line is supported by the Spanish Ministry and represents an extension of previous developed work through different national and international projects. The robotic system under development will assist the archaeologist in the detailed work of monitoring, characterization, study, reconstruction and preservation of archaeological sites, always in accordance with the continuous supervision of the human expert.*

Keywords - I-AUV (Autonomous Underwater Vehicle for Intervention), manipulation, supervised control, archaeology.

I. INTRODUCTION

The sea hosts a big amount of invaluable archaeological sites that belong to the historical heritage of nations that allows fully exploring and understanding the legacy of previous generations. Although these archaeological sites can be found in an acceptable condition, they are in continuous risk of spoliation. Usually, the careful study of these archaeological scenarios is done manually by experimented divers. These experimented divers study and reconstruct the history, recovering key objects in order to classify and preserve them properly, facilitating their dissemination through museums and public institutions. This task is especially dangerous beyond 50 meters depth, where the archaeologist needs more sophisticated diving equipment and level of experience, due to the high risk of decompression situations that can arise.

II. OUR APPROACH

Bearing in mind the aforementioned context, our research group at UJI (Universitat Jaume I) has recently started to work in this domain. So, this paper presents work in progress to assist in those usual intervention activities that archaeologists demand. In particular, the long term objective is to progress in the semi-autonomous capabilities of underwater multipurpose robotic manipulation, extending our previous work on recent projects (i.e. RAUVI [1], TRITON [2], TRIDENT [3]). Thus, the robotic system to develop will assist the archaeologist in the specific work of monitoring, characterization, study, reconstruction and preservation of archaeological sites under the continuous supervision of a human expert (see the envisioned concept in Fig. 1).

It is worth mentioning that this new research is supported by the Spanish Ministry, under grant DPI2014-57746-C3 associated to the three years coordinated project MERBOTS (2015-17). So, the aim of this paper is to present some preliminary ideas in the context of the MERMANIP project, which is a subproject of MERBOTS. In fact, MERBOTS is coordinated by our research group at UJI, being responsible also of the MERMANIP subproject, and with UdG (Universitat de Girona) and UIB (Universitat de les Illes Balears) as partners in charge of other assumed issues like navigation [4], mapping, surveying [5] or multisensory perception to name but a few. MERBOTS aims at progressing in the underwater intervention systems development making extensive use of multirobot cooperation and multimodal perception systems. Particularly, the MERMANIP subproject is in charge of the multisensory based autonomous manipulation, the multimodal user interface, and the RF communication system for enabling compressed image transmissions between the robots and the human operator.

In the field of autonomous manipulation, underwater panel intervention was one of the objectives of the previous TRITON project [6]. In this case, a visually-guided algorithm to control a robotic arm in an autonomous way was developed. This algorithm, updates the values of the each joint of the robotic arm from the detection of a marker (a square that a vision algorithm can recognize and track), placed in a known part of the arm, using a camera. Using our experience, the proposed new archaeological scenarios will require updates and adaptations to the already developed 3D

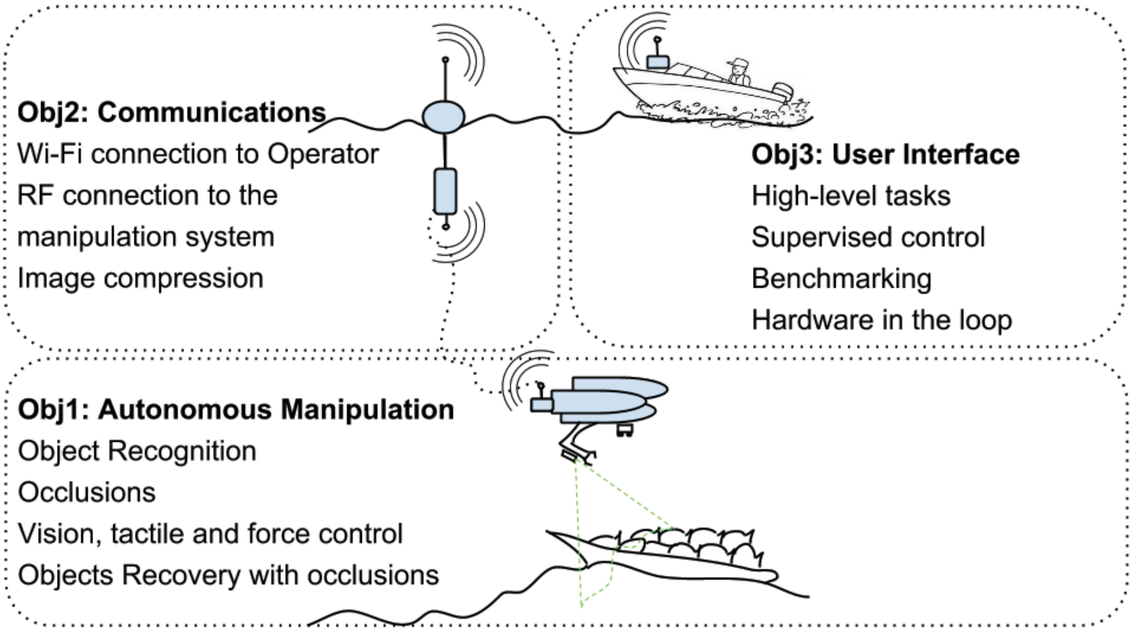

Fig. 1: Envisioned Concept and main assumed goals to be achieved.

reconstruction methods and algorithms to visually control the robotic arm.

A master piece to progress toward the achievement of the aforementioned goal will be to get a better reliability, feasibility and robustness and also dexterity in the manipulation, by guiding the hand-arm system actions with different sensors. For this purpose, we will start from the acquired know-how, previously developed in the aforementioned projects.

On the one hand, it is worth mentioning that the manipulation actions have been successfully carried out by using 3D vision, mainly in contexts such as search and retrieval of objects (e.g. a flight recorder mockup), or underwater panels manipulation (e.g. opening and closing a valve, or inserting and removing a connector). In this project, new possibilities will be explored, combining different sensors (i.e. force/torque, vision and tactile) in a suitable manner, to provide better fault tolerance in the positioning of the manipulator with respect to the target object. This robustness will be crucial because of the inherent uncertainty environments such as those discussed here, where poor visibility or currents are always present.

On the other hand, with the aim to successfully achieve the particular MERMANIP objectives and the overall MERBOTS ones, the consortium will follow an increasing complexity experimental methodology developed and successfully carried out in the previous cited projects. Within this methodology, simulation is the first step, and it is devoted to test and integrate the software developed from the different partners. In the second step, each partner can test its own algorithms and hardware in their respective water tank facilities using a hardware-in-the-loop (HIL) approach. In the third step, the first general hardware-software integration is made, and it is also tested in controlled water tank conditions. In the fourth and last step, and after successfully passing the previous steps, field experiments are carried out.

In summary, the main objective of the project is to foster the available know-how to achieve the cutting edge of technology assisting underwater archaeological intervention. Thus, the first research motivation will be the semi-autonomous manipulation in real scenarios with object occlusions and the second one in the improvement of wireless communication and image compression systems to achieve, if needed, the mobility of the intervention vehicle without umbilical cable. Moreover, the supervised control by a remote human operator will be explored, taking into account the network constraints of these scenarios.

It is worth mentioning that all those aspects concerning the underwater vehicle to use are out of the scope of this paper. However, it is noticeable that all developments of this project

Fig. 2: Corresponding path generated (yellow line) from the 3D point cloud using projection and concave hull methods.

will be finally integrated into a hybrid intervention system (HROV), following our successful experience demonstrated in previous projects (RAUVI, TRIDENT, TRITON).

The assumed final HROV system is composed of an autonomous underwater vehicle, the Girona 500 [7], endowed with optical sensors, being able to observe and reconstruct the intervention scene. Moreover, the vehicle is equipped with an ECA-CSIP Light-weight ARM5E manipulator [8] and a multi-sensory parallel jaw gripper [9].

III. IN THE CUTTING EDGE OF TECHNOLOGY

The functionalities developed under MERMANIP project (i.e. perception and action) will assist underwater archaeologists with its daily work. In those archaeological sites where divers (i.e. archaeologists) have to expend a lot of time performing cleaning operations, identification and handling of different kind of objects, this robotic system will facilitate these operations thanks to its multipurpose manipulation capabilities guided by sensors, and the new perceptual possibilities such as the 3D reconstruction of the intervention area. Grasping objects generally requires at least some partial 3D information, which will be gathered using stereo vision and laser reconstruction [10]. The obtained point will be then used for planning a grasp, which will be executed autonomously by the robot.

Thanks to communications improvements, the system will be able to operate with or without umbilical cable in a robust way. A preliminary wireless communication system based on radio-frequency (RF) has already been tested in water tank conditions [11], and will allow compressed image transmissions between the robots and the human operator. This duality will enable the exploration of new possibilities of the HROV, where this system can work in standalone or teleoperated mode, as appropriate.

IV. PRELIMINARY RESULTS

The MERMANIP project has just started. Following the experimental methodology presented above, in this paper we present preliminary ongoing work implemented in simulation, which is the first step in this methodology. Concretely, we address the problem to autonomously assist the user during the dredging intervention phase following a supervised control approach. In this first attempt, the dredging intervention phase is divided into two steps.

In the first one, the path to follow by the end-effector of the HROV where the dredged pump is placed is generated. To do that, we suppose that previously to this dredging intervention phase, a survey phase has been carried out over a specific area of interest following the instructions of the end user, the archaeologist in this case. Furthermore, we assume that the archaeologist also selects the target of interest (ToI) and that a georeferenced 3D point cloud of this ToI is available from the data gathered from the survey phase. The previously gathered 3D point cloud is the starting input to generate the path to follow by the end-effector where is located the entry of the dredge pump. We use RANSAC based shape detection methods [12] over this point cloud to segment the scene. The points that represent the object are then extracted to calculate its projection to the seafloor (see Fig. 2). The concave hull of these points is then calculated to obtain the georeferenced path that the end-effector of the I-AUV has to follow in a suitable manner (without colliding with the ToI or the seafloor, etc).

In the second step, an automatic control follows the path generated in the previous step dredging the ToI. In this first approach to this problem, we have selected a cascade control architecture with a kinematic controller in the outer loop and a dynamic controller in the inner loop. The kinematic controller is devoted to set the velocity references for each DOF (Degrees Of Freedom) of the HROV. In this case, the ECA-CSIP Light-weight ARM5E manipulator has 4 DOF and we consider the full configuration of the vehicle with its 6 DOF, making the overall HROV system redundant. The kinematic controller implemented is based on the *Singularity-Robust Task Priority Redundancy Resolution* algorithm [13], which can manage the redundancy of the system in an optimal manner by means of task priorities. In this first approach, we have chosen the end-effector position as a primary task, the vehicle null roll-pitch as a secondary task and the end-effector field of view as the last task. On the other hand, the dynamic controller tries to follow the kinematic velocity references applying forces and torques on the HROV with the actuators. In this case, simple PI controllers have been implemented for each DOF of the HROV. The dredging effect around the amphora is a new contribution to the UWSim simulator [14] achieved by means of dynamic heightfield terrain which reacts in the presence of a dredging tool. More details about the simulation results and dredging effects could be found in [15].

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