On the Frontiers of Mobile Manipulation: the Challenge of Autonomous Underwater Intervention

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***Abstract*— Autonomous manipulation of unknown objects by a robot is a highly challenging skill that is receiving increasing attention in the last years. This problem becomes still more challenging (and less explored) in underwater environments, with highly unstructured scenarios, limited availability of sensors and, in general, adverse conditions that affect in different degree the robot perception and control systems. The FP7 TRIDENT project proposes a new methodology for multipurpose underwater intervention tasks with diverse potential applications like underwater archaeology, oceanography and offshore industries, and goes beyond present-day methods typically based on manned and / or purpose-built systems. In this paper an overview concerning the main research ongoing under this project will be presented and discussed, focusing on the underwater manipulation issues.**

I. INTRODUCTION

A few years ago, the first pioneering projects concerning underwater intervention were launched. In particular, during the mid-90s, the AMADEUS EU project achieved a step forward in the field of dexterous underwater manipulation, including within its objectives the setup of a system composed by two 7-DOF, ANSALDO manipulators to be used in cooperative mode [1]. The ALIVE project [2] demonstrated the capability to autonomously navigate, dock and operate on an underwater panel. The SAUVIM project [5] demonstrated the autonomous recovery of seafloor objects with a 7 DOF arm, whereas the CManipulator project [4] obtained interesting results on autonomous object grasping and connector plugging.

Progressing in this context, TRIDENT, described in [3], is a research project funded by the European Commission, that started on March 2010, and will end three years later. The consortium is made up of eight partners: Universities Jaume-I (UJI), Girona (UdG), Balearic Islands (UIB), Bologna (UNIBO), Genova (UNIGE), Heriot-Watt (HWU) and Lisbon (IST); and the company Graal Tech (GT). The long term objective of the project is the design and implementation of a new methodology enabling multipurpose underwater intervention missions with a very high autonomy level. Under this project, a new Autonomous Underwater Vehicle for Intervention (I-AUV) has been developed. This I-AUV has two main parts: the vehicle, named Girona-500, and the attached hand-arm system, made up by a redundant 7-DOF manipulator and a three-fingered dexterous hand, currently manufactured and pending of final integration. The concept of the project is shown in Fig. 1: an I-AUV first maps the area of interest and after that, a user identifies a target and specifies the intervention so that the I-AUV descends again and performs the recovery action.

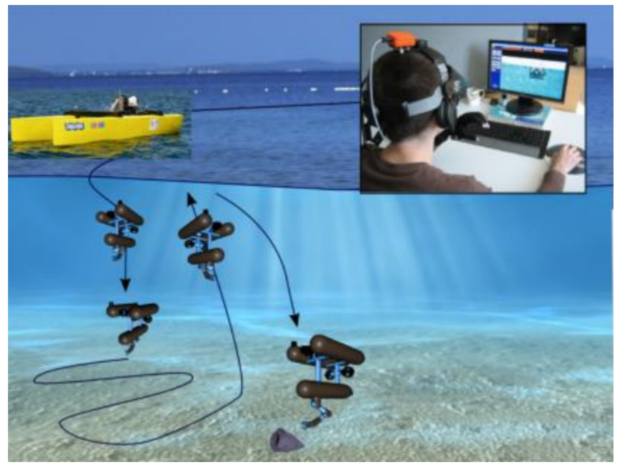

Fig. 1. The concept of TRIDENT.

This paper overviews the manipulation issues associated with this ambitious project, and more concretely, the main challenges and the adopted approaches.

II. CHALLENGES

Autonomous underwater manipulation can be seen as a specific case of the mobile manipulation problem, but with the following challenges when compared to classical approaches in the surface:

High number of DOF. Some underwater vehicles can be controlled in the six cartesian DOF. Together with the arms, a high number of DOF need to be controlled, which are normally highly dynamically coupled.

Limited use of sensors. Due to the physical properties of water, the use of sensors is very limited. For instance, there is no kinect-like sensor, due to the fact that infrared is highly attenuated in the water. Similar sensors using ultrasound are extremely expensive and provide much worse accuracy. High pressure, which in addition varies with the depth, affects significantly any pressure-sensitive sensor like touch and force sensors.

Mobile platform. Unlike grasping in the surface, it cannot be generally assumed that the robotic platform stays fixed while doing manipulation. Adverse sea conditions like waves, underwater currents, or simply the fact that the robot is a floating platform creates the necessity of doing grasping while in motion. Therefore, reactive controllers that adapt in real time according to the relative vehicle-object pose are needed.

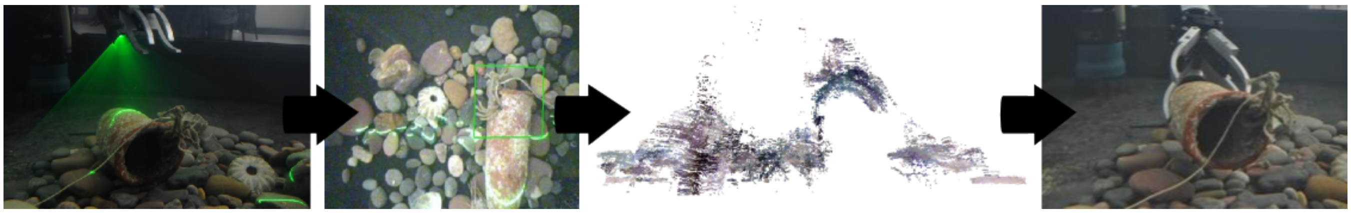

Fig. 2. The process of scanning, 3D reconstruction and grasping of an amphora.

Poor visibility. Floating particles like sand and silt, occlusions, color attenuation, darkness, etc. make visual processing of underwater objects a very challenging problem.

Unknown objects. In many situations, the objects to be recovered from the seafloor are either completely unknown (e.g. indicated in the place by the operator), or known but in an undeterminate state (e.g. the blackbox of an airplane crash, an amphora, etc.). Object 3D models are not generally available a priori, with the exception of very specific interventions, for instance, in underwater panels.

III. OUR APPROACH

Our approach to underwater manipulation starts with a combinination of a laser emitter with a vision system in order to scan and recover the 3D structure of unknown objects lying on the seafloor. The reconstructed 3D point cloud is then used for planning a grasp that is executed autonomously by the robot, after a simple user indication.

The seafloor is scanned by moving the elbow joint of the manipulator (where the laser emitter is attached) at a constant velocity. At the same time, two visual processing algorithms run in parallel: the laser peak detector, in charge of segmenting the laser stripe from the rest of the image and computing the 3D points, and a template tracking algorithm that tracks a patch of the floor and estimates the motion of the floating platform from the patch motion (visual odometry).

After the 3D reconstruction, a supervisory grasping strategy is adopted: the approach is to let a human indicate – via a user interface– the most suitable part for grasping, and then automatically plan a grasp on that part. In fact, in some underwater robotic applications such as archeology, the selection of the part where to grab an object is crucial in order to avoid any damages of the item. Therefore, in our approach it is a human who indicates the most suitable region for grasping, and the grasp is finally planned around that area.

Specifically-adapted resistive touch sensors are installed in the jaws and help detecting if the grasp has been performed successfully. A sealed force sensor is also installed at the wrist and enables a reactive force control of the manipulator. To the best of the author's knowledge, this is the first time that laser, vision, force and touch sensors are put together for underwater manipulation.

IV. RESULTS

Different recovery tasks have been already demonstrated in water tank conditions and in a harbour. Figure 2 shows the complete process for recovering an amphora, whereas Figure 3 shows the Girona-500 I-AUV hooking a black box in an experiment at the harbour. Further experiments in the sea are planned for October 2012.

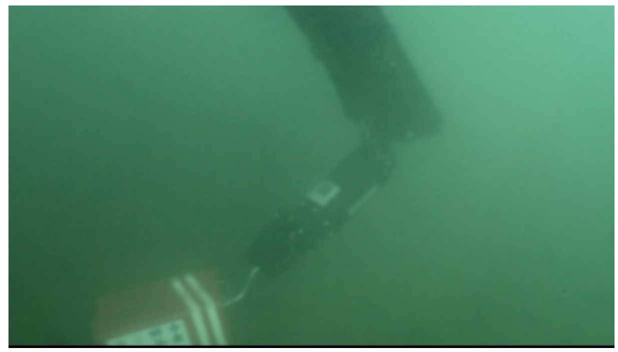

Fig. 3. Autonomous recovery of a black box in a harbour.

V. CONCLUSION

Robot manipulation has been rarely explored in underwater scenarios. However, the underwater environment introduces additional challenges, and its research can contribute to identify new directions, and to the evolution of more general-purpose grasping methods that can be later applied to ground, aerial and space robotics. Following this direction, the TRIDENT project is expanding the frontiers of mobile manipulation and grasping to the underwater world.

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