Semi-autonomous grasping approach of unknown objects in underwater environments combining structured light and a virtual simulation environment

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Abstract *– Many scientific and industrial works that take place underwater are increasingly demanding for technology to allow their autonomous execution. Autonomous grasping of unknown objects by a robotic arm is a task that is being highly studied by researchers in the last years. This is a really difficult task in itself, but the problem is bigger if the grasp is done in underwater environments, where the sensors that can be installed in the arm, decrease their performance drastically. This paper describes an approach for semi-autonomous grasping of underwater unknown objects using a robotic arm. To achieve this purpose, a scan of the scene is performed using a structured laser beam attached to the forearm of the manipulator. At the same time, a digital video camera is used to capture the scene. The laser stripes are triangulated to obtain a 3D point cloud. The entire process is shown inside an underwater simulator, acting in this case as a virtual representation of the real environment. This virtual representation allows the user to specify the grasp, to see how the grasp will be executed, and to monitor the final process in real time. To validate the good performance of the proposed approach, several grasping experiments with two different objects have been performed in water tank conditions with a real I-AUV system.*

Keywords *– Intervention AUV, 3D reconstruction, semiautonomous grasping, underwater recovery*

I. INTRODUCTION

This paper proposes a combination of structured light and a virtual simulation environment that allows a user to specify the grasping points of a real unknown object in a 3D reconstructed scenario. This approach allows semi-autonomous grasping of underwater unknown objects using a robotic arm mounted in a fixed underwater platform.

II. STATE OF THE ART

In the area of underwater intervention, ALIVE [1] (FP5 EU project, AUV with manipulation capabilities), and SAUVIM [2] (University of Hawaii, Semi-Autonomous Underwater Vehicle for Intervention Missions) have become milestone projects. The result of both projects have led to significant reductions in cost thanks to its autonomous operation, which avoids the need for extremely expensive intervention ships.

Planning a grasp is generally known to be a difficult problem due to the large search space resulting from all possible hand configurations, grasp types and object properties that occur in regular environments. The dominant approach to this problem has been the model-based paradigm, in which the object shape, contacts, and forces are modelled according to physical laws. So, the research has been focused on grasp analysis (the study of the physical properties of a given grasp) and grasps synthesis (the computation of grasps that meet certain desirable properties) [3]. Unfortunately, these approaches have failed to deliver practical implementations, mainly because they rely on assumptions that are difficult to satisfy in complex and uncertain environments.

The current trend is to incorporate sensor information for grasp planning and synthesis, such as vision [4] or range sensors [5]. Recently, the knowledge-based approach has been combined with vision-force-tactile feedback and task-related features that improve the robot performance in real scenarios [6], [7].

Regarding autonomous manipulation in underwater environments, so far very limited research has been carried out. Only the very recent TRIDENT project [8] has demonstrated quasi-autonomous manipulation capabilities without any requirement for the objects to be analyzed, and a bit earlier, SAUVIM project demonstrated also semi-autonomous grasping skills, although making use of predefined object models with specific markers for easy recognition. In the author's previous project RAUVI [9], a novel user interface with integrated autonomous grasp planning capabilities was developed [10], and real grasping and hooking experiments were also successfully carried out.

In summary, there remains a huge amount of research to be done in the grasping and manipulation field, and this is even truer for underwater scenarios. In the shallow water context, new complexities arise, increasing the difficulty of controlling grasping and manipulation actions with agility capabilities. Under these very hostile conditions, only a few robot systems are endowed with semi-autonomous manipulation capabilities, mainly focused on specialized operations requiring a reasonably structured environment, like those devoted to the offshore industries.

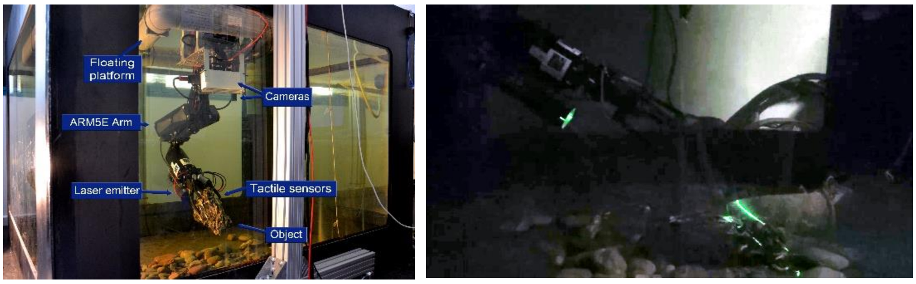

Fig. 1 The vehicle is equipped with a light-weight robot arm and a 4-finger gripper, an underwater looking down camera and the 3D laser stripe emitter (left). The laser stripe emitter attached to the arm, scanning the floor (right).

This paper is organized as follow: in Section III, the scenario and the system used in the experiments are described. The strategy to reconstruct the scene and to specify the grasp is detailed in the Section IV. Then, section V details the strategy for grasping. Finally, results and conclusions are detailed in Sections VI and VII respectively.

III. SCENARIO AND SYSTEM DESCRIPTION

The scenario includes a 2m x 2m x 1.5m water tank, whose floor recreates a real seafloor (see Fig. 1 left). The I-AUV consists of a fixed 4 D.O.F. robotic arm (CSIP Light-weight ARM5E with four metal fingers in its end-effector [11]) that is attached to an underwater vehicle floating inside the tank. The vehicle is equipped with an underwater camera (Bowtech 550C-AL) that is placed near the base of the arm and is looking downwards. The 3D reconstruction is done with a laser stripe emitter (Tritech SeaStrip) attached on the forearm of the manipulator. The user interface is provided by the Underwater Simulator UWSim [12].

IV. 3D RECONSTRUCTION OF THE SCENE & GRASP SPECIFICATION

To reconstruct the geometry of the unknown object by using the laser strip, the floor is scanned by moving the elbow joint of the manipulator at a constant velocity (see Fig. 1 right). During the scan, a visual processing algorithm runs in parallel, the laser peak detector, which is in charge of segmenting the laser stripe from the rest of the image and computing the 3D points [13]. With these points, a 3D point cloud of the scene is built.

Once the scene has been reconstructed, the virtual environment, the 3D point cloud, and a snapshot of the scene (taken by the camera before the laser scan) can be observed in the simulator (see Fig 2).

The user then specifies the grasp by selecting two antipodal grasp points on the snapshot image. The projection of those 2D points specified by the user defines two 3D lines that are used to define a 3D volume (with a fixed width). This volume is intersected with the point cloud, and thus, only those points lying inside are kept. The next step is to remove outliers and to build a downsampled cloud. These operations significantly reduce the size of the point cloud, making it possible to perform all posterior computations faster.

A CAD model of the end-effector of the manipulator is also represented on the scene, thus improving the virtual representation of the real grasp.

V. AUTONOMOUS GRASP DETERMINATION & EXECUTION

Using the prior sensors information and the arm constraints, the best grasp position and orientation is autonomously calculated. The CAD model of the end-effector is properly positioned and orientated over the point cloud in the simulator. The user can see how the grasp is going to be performed and can decide to choose different grasp points before launching the grasp. Once the grasp is launched, the end-effector autonomously reaches the position and orientation selected in the previous step. Then the hand of the manipulator is closed until the current of the hand motor reaches a threshold. At this moment the arm with the recovered object moves back to the home position.

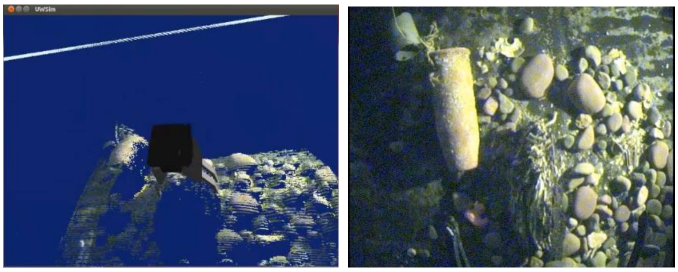

Fig. 2 Reconstructed scenario in the UWSim underwater simulator: 3D point cloud and CAD model of the end-effector (left). Real scenario captured by the camera with the two experimental objects (right).

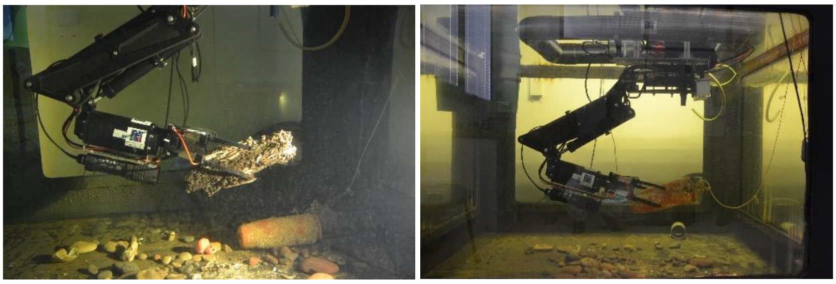

Fig. 3. The I-AUV grasping a wooden trunk (left) and an anphora (right) inside the water tank

VI. LAST REMARKS

The proposed approach has been tested thoroughly with two different objects: a wooden trunk and an amphora (see Fig. 3). The first one produces a good 3D reconstruction and good grasps despite its nonuniform shape (http://youtu.be/VOLNBWfeoLs). In the second case, the shape is more uniform but due to some white spots on it, which reflect the laser light, the reconstructions are not so good and therefore, the grasp is no always satisfactory (http://youtu.be/c62FTTycxsQ).

The proposed approach based on 3D structured light provides a good alternative to the use of other sensors that could not perform well in underwater environments (low visibility, bad propagation of signals, humidity, etc.) The use of a simulation environment provides 3D visual feedback and a preview of the specified grasps.

VII. CONCLUSION

In this paper, recent progress towards autonomous underwater manipulation has been presented. The proposed approach allows the semi-autonomous grasping of underwater unknown objects by using a robotic arm mounted in a fixed underwater platform. It is based on a combination of structured light and a virtual simulation environment that allows a user to specify the grasping points of a real unknown object in a 3D reconstructed scenario. This approach provides a good alternative to the use of other sensors that are not able to perform well in underwater environments (low visibility, bad propagation of signals, humidity, etc.). The use of a simulation environment provides 3D visual feedback and a preview of the specified grasps.

ACKNOWLEDGMENT

This research was partly supported by Spanish Ministry of Research and Innovation DPI2011-27977-C03 (TRITON project), by the European Commission's Seventh Framework Programme FP7/2007-2013 under Grant agreement 248497 (TRIDENT Project), by Foundation Caixa Castelló- Bancaixa PI.1B2011-17, and by Generalitat Valenciana under grants ACOMP/2012/252.

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