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Visually-guided manipulation techniques for robotic autonomous underwater panel interventions☆,☆☆

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ABSTRACT

The long term of this ongoing research has to do with increasing degree of autonomy for robots involved in underwater intervention missions. Bearing in mind that the specific mission to face has been the intervention on a panel, in this paper some results in different development stages are presented by using the real mechatronics and the panel mockup. Furthermore, some details are highlighted describing two methodologies implemented for the required visually-guided manipulation algorithms. These algorithms are used to correct problems caused by a bad initialization or miscalibration of the arm. They consist of detecting a marker placed in a known position of the arm and updating the value of each joint after any detection. A roadmap explaining the different testbeds used for experimental validation, in increasing complexity order, is also presented. It is worth mentioning that the aforementioned results would be impossible without previously generated know-how for both the complete developed mechatronics for the autonomous underwater vehicle for intervention, and the required 3D simulation tool. In summary, thanks to the implemented approach, the intervention system is able to control the way in which the gripper approximates and manipulates the two panel devices (i.e. a valve and a connector) in an autonomous manner. Results in different scenarios demonstrate the reliability and feasibility of this autonomous intervention system in water tank and pool conditions.

1. Introduction

Due to the high number of applications related to the underwater industry and, unfortunately, maritime disasters (e.g. shipwrecks or leaks on offshore platforms), the number of underwater robot interventions has increased considerably during the last two decades. The most common underwater applications can be summed up in the following list:

- Oil and gas industry: inspection and repairing of submerged infrastructures.
- Search and recovery: localization and grasping objects on the seafloor.
- Deep water archaeology: submerged sites documentation, using high resolution 2D/3D seafloor mapping techniques.
- Science: periodic maintenance of underwater permanent observatories, ocean survey and sampling of marine chemistry, geology and biology.

The most widely used technologies in these examples are Remote Operated Vehicles (ROVs) that are launched from support vessels, and remotely operated by expert pilots through an umbilical communication cable and complex control interfaces. Looking for higher autonomy levels in underwater intervention missions, a new underwater robot concept is being developed. This robot, called I-AUV (Intervention Autonomous Underwater Vehicle), lacks the umbilical communications cable and has attached a robotic arm to perform intervention tasks.

Endowing an I-AUV with the ability to manipulate an underwater panel in a permanent observatory is one of the challenges of the TRITON[1] marine robotics research project. This project is focused on the development of autonomous intervention technologies really close to the real needs of the final user and, as such, it can

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[1] TRITON: Underwater Marine Intervention by using Cooperative Robots and Multisensory Perception.

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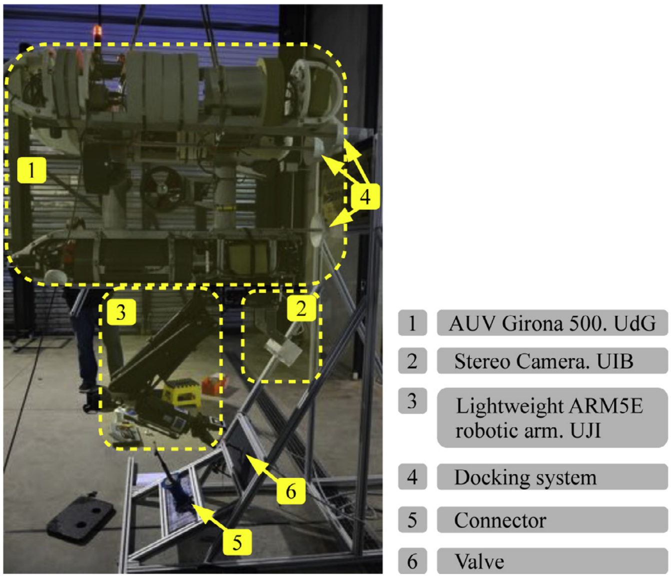

Fig. 1. TRITON hardware system with its components attached to an underwater panel mockup.

facilitate the potential technological transfer of its results. This project, entitled "Multisensory Based Underwater Intervention through Cooperative Marine Robots" and funded by the Spanish Ministry, is coordinated at the Universitat Jaume I (UJI) and includes three sub-projects: COMAROB ("Cooperative Robotics", under responsibility of the Universitat de Girona, UdG), GRASPER ("Autonomous Manipulation", under responsibility of the Universitat Jaume I, UJI) and VISUAL2 ("Multisensorial Perception", under responsibility of the Universitat de les Illes Balears, UIB). The project proposes two scenarios to demonstrate the developed capabilities: (1) the search and recovery of an object of interest (e.g. a "black-box mockup" of a crashed airplane), and (2) the intervention on an underwater panel in a permanent observatory. Related to the main goals to be achieved in the GRASPER sub-project and focused on the second scenario, this paper presents recent progress towards autonomous underwater manipulation and a new algorithm for visually-guiding the manipulation actions. In order to evaluate the new algorithm, a mockup of an underwater panel in a permanent observatory intervention has been used (see Fig. 1).

In the following sections, the methodology followed to perform interventions with the manipulator arm mounted on the AUV is presented. First of all, in Section 2, an extensive review of related works and state of the art is provided. In Section 3, a visually-guided algorithm to control the robotic arm is explained and developed. The aim of this algorithm is to increase the robustness of the robotic arm, preventing calibration joint errors. Section 4 describes the methodology for manipulating a valve and a connector (hot-stab). Section 5 presents a roadmap for experimental validation developed from the experience of previous projects (RAUVI, TRIDENT) and describes successful results of valve turning and plugging/unplugging a connector in water tank and pool conditions. Finally, Section 6 provides some conclusions, work in progress and future improvements to the system.

2. State of the art

Grasp planning in a regular environment is a well-known problem, because of the large number of possibilities of hand configurations, grasp types and object properties. Although the most common approach has been the model-based paradigm (using physical laws to model the object shape, contacts and forces), some researchers have focused on grasp analysis (the study of the physical properties of a given grasp) and grasp synthesis (the computation of grasps that meet certain desirable properties) (Shimoga, 1996). Unfortunately, these two last approaches fail to deliver practical implementations in complex and uncertain environments (i.e. underwater environments), because they rely on assumptions that are difficult to satisfy: the scene is not static, relative object positions vary dynamically as the intervention vehicle is affected by underwater dynamics; target objects can move due to underwater currents; illumination is not stable and varies continuously due to water waves and different sunlight intensity depending on the time of the day, producing flickering light on the captured images; floating particles appear in the scene causing disturbances in the vision algorithms, etc.

The current trend is to incorporate sensor information for grasp planning and synthesis, such as vision (Cipolla & Hollinghurst, 1997; Coelho, Piater, & Grupen, 2001; Hauck, Ruttinger, Sorg, & Farber, 1999; Morales, Recatalá, Sanz, & del Pobil, 2001; Sanz, Requena, Inesta, & Del Pobil, 2005b) or range sensors (Rusu, Holzbach, Diankov, Bradski, & Beetz, 2009). In this line, several approaches have also adopted machine learning techniques to determine the relevant features that indicate a successful grasp (Coelho et al., 2001; Kamon, Flash, & Edelman, 1998; Morales, Chinellato, Fagg, & del Pobil, 2004; Sanz, Marín, & Sánchez, 2005a). Others make use of human demonstrations for learning grasp tasks (Ekvall & Kragic, 2004). Most of these approaches commonly consider grasps as a fixed number of contact locations with no regard to hand geometry (Bicchi & Kumar, 2000; Shimoga, 1996). Some recent work includes kinematics constraints of the hand in order to prune the search space (Borst, Fischer, & Hirzinger, 2003; Miller, Knoop, Christensen, & Allen, 2003; Morales, Asfour, Azad, Knoop, & Dillmann, 2006). Alternatively, the so-called knowledge-based approach tries to simplify the grasp planning problem by reasoning on a more symbolic level. Objects are often described using shape primitives (Liu, Iberall, & Bekey, 1989; Stansfield, 1991), grasp prototypes are defined in terms of purposeful hand preshapes (Prats, del Pobil, & Sanz, 2007), and the planning and selection of grasps is made according to programmed decision rules (Bekey, Liu, Tomovic, & Karplus, 1993). 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 (Prats, del Pobil, & Sanz, 2013).

Regarding autonomous manipulation in underwater environments, after the pioneering works in the 90s (OTTER, Wang, Rock, and Lee (1995), ODIN, Choi, Takashige, and Yuh (1994)), significant advances in this direction arrived over the last ten years, especially when the first simple autonomous operations at sea were demonstrated. Most of the advances were obtained in multi-partner research projects like the ones listed hereafter:

- UNION 1996–1999 (Rigaud et al., 1998): The project focused mainly on the development of coordinated control and sensing strategies for combined manipulator and vehicle systems. UNION represents the first mechatronic assembly of a complete vehicle-manipulator system for automated manipulation.
- AMADEUS 1993–1999 (Lane et al., 1997): Amadeus had two phases: develop a dexterous gripper suitable for underwater applications and coordinated control of two underwater electro-mechanical arms. The project demonstrated the coordinated motion of the two fixed based manipulators while manipulating a rigid object inside a water tank.
- SWIMMER 1999–2001 (Evans, Keller, Smith, Marty, & Rigaud, 2001): It was a hybrid AUV/ROV intervention system, where an AUV shuttle transports an intervention ROV to the subsea. SWIMMER was able to autonomously transit to the seafloor and dock to a subsea cradle based docking station. Once the