Control Engineering Practice 74 (2018) 153–167

Contents lists available at ScienceDirect

Control Engineering Practice

journal homepage: www.elsevier.com/locate/conengprac

Fully automatic visual servoing control for work-class marine intervention ROVs

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ARTICLE INFO

Keywords:
Underwater manipulation
Manipulator control
Visual servoing
Robot arm
Underwater inspection and intervention
Marine robotics
ROV

ABSTRACT

ROVs with hydraulic manipulators are extensively used for subsea intervention. With camera feedback from the scene, manipulators are teleoperated and slaved to pilot held master arms. While standard for offshore oil and gas, for challenging applications in waves or currents a new approach is required. We present development of robot arm visual servo control approaches used in manufacturing and the transfer and adaption of these to underwater hydraulic manipulators. This is the first time a visual servoing algorithm for automated manipulation has been developed and verified, through subsea trials, on a commercial work-class ROV with industry standard hydraulic manipulators.

1. Introduction

This paper presents the research and development of semi-autonomous Remotely Operated Vehicle (ROV) manipulator control systems using vision based servo control which are suitable for deployment on the global fleet of work class ROVs. These systems are designed to replace the teleoperation role of pilots with auto-assist functions enabling ROVs to address challenging conditions encountered in emerging sectors such as Marine Renewable Energy (MRE) (offshore wind, floating wind, wave energy conversion and tidal energy conversion).

Work-class submarine ROVs equipped with robot manipulators have been the workhorse of subsea operations for many years in marine sectors such as marine civil engineering, marine science, military and chiefly in the offshore oil and gas industry. A wide range of subsea tasks undertaken by ROVs is done using underwater manipulators, including pipe inspection (Christ & Wernli, 2014), salvage of sunken objects (Chang, Chang, & Cheng, 2004), mine disposal (Djapic et al., 2013; Fletcher, 2000), surface cleaning (Davey, Forli, Raine, & Whillock, 1999), valve operating, drilling, rope cutting (Christ & Wernli, 2014), cable laying and repair, clearing debris and fishing nets, biological (Jones, 2009) and geological sampling (Noé, Beck, Foubert, & Grehan, 2006), archaeological work (Coleman, Ballard, & Gregory, 2003), etc. Work-class ROVs are generally equipped with one advanced seven function manipulator (six degrees-of-freedom plus the jaw/gripper) and one less advanced five function supporting grabber arm. The latter is used to anchor the ROV onto the hydro engineering structure on which the intervention is to take place while the former performs the actual intervention operation. Automatic capabilities of subsea robot manipulator systems are generally significantly lower compared to their industrial robot counterparts. The majority of automated industrial robotic arms used in factories are electrically driven and utilize servo control. Motion of these robots is usually pre-programmed at a high level using dedicated PC software suites. These control/programming environments include full kinematic engines (implementing forward and inverse kinematics) and enable programming servo controlled robots to automatically follow detailed motion control programmes including interaction with target(s). Additionally, advanced robot systems often integrate advanced sensors such as vision systems and visual servoing techniques in order to deal with non-static target objects of various shape, colour, etc., while addressing these target objects in automatic programme operation (Corke, 2011). Another important feature of industrial robotics is that the environment can be controlled and specifically designed and built to ease the robotic automation task, i.e. known fixtures, lighting, etc. Marine field robots by contrast work in real world subsea environments which are significantly more variable and challenging. The majority of commercial underwater manipulators are not servo controlled and none are supported with kinematic engine control approaches. They are predominantly hydraulically driven, and utilize traditional teleoperation approaches with an open loop control system, completely reliant on human operator skill and experience. The pilot who is located on the support vessel acquires visual feedback of the

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https://doi.org/10.1016/j.conengprac.2018.03.005
Received 2 August 2017; Received in revised form 25 January 2018; Accepted 2 March 2018
Available online 23 March 2018

scene through camera and/or forward looking sonar systems and often simultaneously performs multiple tasks: manipulates the robot arm(s), flies the vehicle, or performs underwater inspection (Yuh, 2000). The pilot must handle or interact with an enormous quantity of information dispersed across different screens, constantly looking from camera to gauge distances or check different angles, while also adjusting camera fields of view and lighting. As a result, the operator is often under high cognitive load which can prevent important information from being correctly perceived and result in failed or prolonged missions due to pilot fatigue. Sometimes ROV pilots face dangerous and stressful situations, e.g. British Petroleum ROV fleet working to shut off the well and stop the oil spill in the Deepwater Horizon disaster (Cavnar, 2010). ROV operations are generally not performed in the top 20 m–40 m splash zone but rather in the relatively quiescent conditions below on or near the seabed. By contrast, MRE energy farm plant is located in the splash zone in challenging environments, so the device may even be in motion. As motion disturbances affecting the underwater vehicle and the manipulator become significant, the task execution with a human pilot in the loop becomes difficult and eventually impossible. A human operator can react only after the change has already happened, and therefore even an experienced operator is likely to fail at performing IRM operations in such challenging conditions. With current state-of-the-art commercial ROV control systems, simple tasks from an industrial robotics perspective can become difficult even for a very skilled pilot/operator due to difficulties such as poor visibility, poor 3D perception based on 2D image presented on screen, and pilot fatigue. This makes subsea operations time consuming and therefore very expensive, i.e. the cost of mobilizing a support vessel with ROV systems can cost €18,000 per day for research vessels and well in excess of €50,000 per day for oil and gas touch down operations support.

Despite their significant utility to date in deep water operations, commercial intervention ROV technologies as used in other sectors are not sufficient for operating in shallow waters with high waves and currents. Development of new robotic capabilities is necessary to support large scale MRE operations for construction/roll out, Inspection Repair and Maintenance (IRM), monitoring and control of MRE installations. Such MRE installations are by design located in dynamic, high energy sites where the wind, current and wave energies offshore are maximized. Service robots are essential to allow the nascent MRE sector to develop and grow in an economically viable manner. The IRM operational conditions for MRE will under many circumstances be above operating limits of current ROV platform technology (O'Connor, Lewis, & Dalton, 2013; Omerdic, Toal, & Leahy, 2010). The motivation thus, is to research and develop ROV systems and control techniques for IRM operations in current and wave regimes of increasing strength and specifically deal with challenges in the performance and control of ROVs at high energy MRE sites (Omerdic, Toal, Dooly, Miller, & Coleman, 2012; Toal, Omerdic, & Dooly, 2011). Referring to Fig. 1 we wish to develop robot control capability to move away from the origin in the 3D plot moving along each of the axes.

Since the beginning of the 90's the topic of autonomous underwater manipulation has been attracting the attention of various researchers. The OTTER (Wang, Rock, & Lees, 1995) and AMADEUS (Lane et al., 1997) projects were among the first to tackle this research area. Antonelli (2014) provided a good theoretical background for underwater manipulators from the modelling and control point of view. More recent progress has been achieved within the TRIDENT FP7 project (Simetti, Casalino, Torelli, Sperindé, & Turetta, 2014) where an electric robot arm manufactured by Graal Tech mounted on an AUV has been used for autonomous detection and retrieval of an object from the sea floor (Ribas et al., 2015). However, for work-class ROV intervention work, such electric manipulators are not designed or available with sufficient power as specified by ocean engineering contractor requirements, e.g. the manipulator-operated torque tool, which uses the wrist rotate function of the manipulator to generate the required torque is used to operate ISO 13628 Class 1 (67 N m) and 2 (271 N m) (ISO 13628-8:2002, 2002) interfaces without the need of a hydraulically operated torque tool (Christ & Wernli, 2014). Actuation forces of subsea hydraulic and electric manipulators are presented in Table 2, and the weight of typical ROV operated tools used in the offshore oil and gas industry are summarized in Table 1. Analysis of these two tables leads to the conclusion that the majority of electrical manipulators would struggle even to lift, let alone intervene with most of the tools. One of the few research groups that have been working with a commercial underwater manipulator (Schilling Orion 7P) is DFKI-Lab Bremen where automated plugging of a deep-sea connector in a wet laboratory testbed has been conducted within the CManipulator project (Hildebrandt, Kerdels, Albiez, & Kirchner, 2009). As outlined, the majority of academic research experiments in the field of autonomous underwater manipulation have been carried out on electrical robotic arms which are either prototypes or recently commercialized. Additionally, all those advanced subsea autonomous manipulation solutions found in literature (Cieslak, Ridao, & Giergiel, 2015; Evans, Redmond, Plakas, Hamilton, & Lane, 2003; Marani & Yuh, 2014) are related to intervention AUVs, which are not industry standard but rather a concept in development and are also considerably power constrained. Not all subsea operations can be performed with electric arms which is why these prototype manipulators are not ready for adoption in offshore industry. There are sound reasons why all work-class ROVs use hydraulic manipulators (depth rating, very high carrying capacity and torque, straightforward field maintenance, etc.). Despite the significant advances achieved by the academic community over the years, the autonomous approach has not been adopted by the commercial ocean engineering sector which still employs traditional telemanipulation approaches with human pilot in the loop for work-class ROVs. Since commercial work-class ROVs are equipped as standard with hydraulic manipulators, which are considerably underdeveloped in the sense of autonomy in comparison with stationary industrial robot arms used in factories, our challenge and goal is to develop advanced control systems that can be employed on these robotic arms with little to no hardware modification. This paper presents investigations, development and adaptation of industrial robot arm (visual) servo control approaches used for typical industrial manufacturing applications and the transfer of these techniques to challenging underwater robotics tasks. For the first time, a solution that works with standard commercial systems already employed in the industry and the global fleet of work-class ROVs is presented. The novelty and contribution of this paper is as a first in the development and implementation of the approach of visual servo control in the subsea manipulator field for the existing marine industry standard commercial work-class ROVs. Our system is able to replicate what an ROV pilot does by the traditional

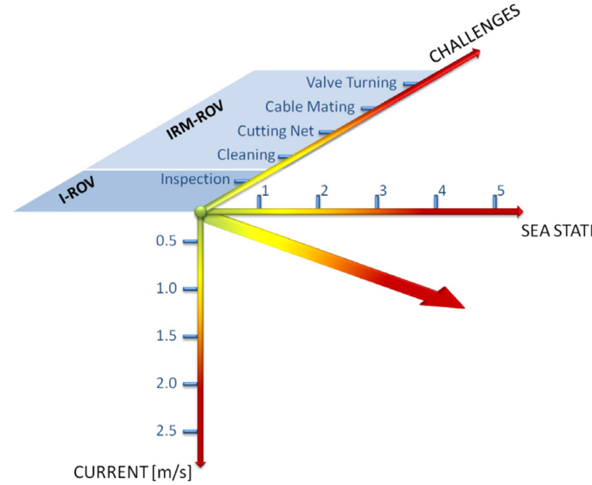

Fig. 1. Difficulty matrix classification with increasing current strength, sea state and challenges of robotic target applications.