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Optimal docking pose and tactile hook-localisation strategy for AUV intervention: The DIFIS deployment case

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ABSTRACT

The DIFIS project has proposed a new solution for the immediate intervention directly on tanker wrecks so as to contain any leakages and prevent eventual pollution. The method could be extended also to oil well-blow-out cases such as the recent accident in the Gulf of Mexico. The DIFIS deployment typically requires the use of ROVs and dedicated dynamic-positioning ships that increase the cost significantly and make the operations weather-dependent. Eventual AUV use would result in much more efficient and flexible deployment procedures. The scenario studied here consists of a hook-grasping task that is part of the DIFIS mooring procedure. The overall objective is to automate certain processes enabling the use of AUVs or, at least, enhancing the currently foreseen ROV operations. A two-step method is presented consisting of a genetic algorithm for the determination of the optimum docking pose for the vehicle, and a particle filter algorithm that runs on a later stage for the tactile localisation of the hook. The method proposed is rather generic and can be extended to several steps of the DIFIS Deployment procedure, or even to other AUV intervention missions in a semi-structured environment. Results from the two algorithms are also presented and discussed.

1. Introduction

The increasing oil and gas demand is forcing oil companies to explore new drilling areas leading offshore platforms to sites of constantly bigger depths, several kilometres below the sea surface, with all the related risks. Blowouts such as the one in the Gulf of Mexico in May 2010 cannot be excluded. Regulations and new methods of prompt containment interventions at the seabed, right at the source of the pollution, will be required for sustainable offshore hydrocarbon exploitation.

Triggered from another recent catastrophe, that of the PRESTIGE, the DIFIS (Double Inverted Funnel for Intervention System) project proposed a new solution to deal with tanker wrecks and preventing environmental disasters (DIFIS; Andritsos et al., 2007, 2008; Cozijn et al., 2008; Konstantinopoulos and Andritsos, 2008). The basic concept relies on gravity forces to channel the flux of spilt fuel towards the surface. Leaking fuel is collected by a moored fabric *dome* covering the wreck and channelled through a large riser tube to an open inverted reservoir, the *buffer bell*, 20–30 m below the sea surface. The buffer bell serves for buffer storage, as a separator and, through its buoyancy, keeps the whole system in tension. Fig. 1 shows an initial conceptual model of the dome and the buffer bell. DIFIS, with some re-engineering to take account of the methane gas, can be applied to contain deep sea oil well blow-out accidents.

DIFIS system has many advantages: it is simple, entirely passive (apart from the periodical off-loading of the collected oil from the buffer bell), once installed does not require operations with Remotely Operated Vehicle's (ROVs) and it is rough weather tolerant. However, its deployment requires substantial preparation and intense underwater remote manipulation activities supported by specialised equipment and dynamic positioning (DP) vessels. This represents a significant part of its overall cost.

Optimising the deployment procedures and, in particular, using Intervention-Autonomous Underwater Vehicles (I-AUVs) instead of ROV-based activities would decrease the overall DIFIS intervention cost and add substantially to its flexibility. I-AUVs possess certain advantages such as the significant reduction of the size of the support vessel, while no DP vessel is needed, and the fact that it is not required to remain on site for the entire mission. Thus, the cost of the mission is reduced accordingly. Moreover, since I-AUVs can operate untethered, their deployment can be immediate regardless of the sea-state on site, while such a *free-to-move* vehicle could prove more successful in a complex environment, avoiding umbilical management. In the framework of DIFIS, several ROV underwater operations have been envisioned for the Dome Deployment Stage, namely:

- Installation of transducers for a Long Base Line (LBL) acoustic positioning system,

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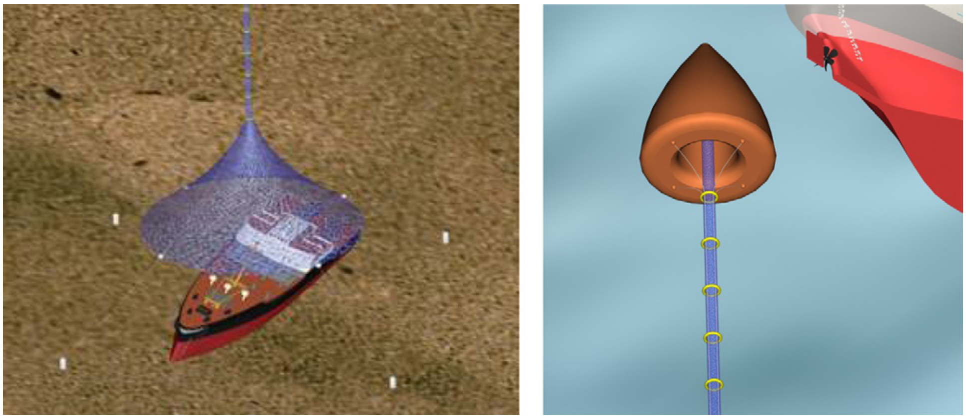

Fig. 1. DIFIS Dome (left) and Buffer Bell (right) deployment.

- Intervention on the existing leaks in order to limit the oil flow,
- Connection of the mooring lines on the dome.

Hereafter, the connection operation of the mooring lines on the dome, listed above, is described more in detail. During the deployment stage the dome initially remains folded as it is lowered into the water. A set of mooring concrete cubes are released by the support vessel. Three of these cubes would serve as anchoring points for the dome and the rest would aid to unfold and retain under tension the dome itself. A hook that would be connected to each cube through a rope has to be used to anchor the dome. According to the current planning, an ROV, as illustrated in Fig. 2, is used to execute this task.

During the process, the pilot has to identify the cube, dock on it using suction cups, localise the hook, grasp it and attach it to the dome. A method that would turn the overall process to a partially or fully autonomous process would benefit from the use of an I-AUV for these tasks or even favour the current ROV operations.

2. Navigation, localisation and docking techniques

The envisioned scenarios for the I-AUV operations presented in Section 1 are harsh as the shipwreck is typically situated on the seabed, possibly under strong currents and heavy oil leakage. Hence, in order to perform the mooring task in an as-wide-as-possible set of scenes, the robot has to be able to choose among multiple strategies to accomplish each of the identified subtasks. Before the actual manipulation takes place, the procedure done by the robot can be divided into three subtasks, namely, navigation and on-site localisation, robot docking, and hook localisation.

2.1. I-AUV navigation and on-site localisation

Regarding the navigation and the localisation of the vehicle on the site, previous related works envisioned the adoption of an LBL Acoustic Positioning System. Several algorithms have been proposed for AUV localisation using such a system. Miller et al. (2010) presented a robust navigation system for AUVs combining the inertial measurement unit of the vehicle and the localisation measurements from the LBL, while Scherbatyuk (1995) proposed an algorithm for position and velocity estimation using range data from only one transponder.

Navigation could also be achieved through other acoustic methods, mainly based on sonar guidance and common navigation sensors such as DVL, IMU etc. A homing method on an acoustic target was proposed by Stokey et al. (1997) for the docking phase of REMUS AUV. The method, although reliable for long range navigation, becomes impractical at close ranges due to the high update rates required.

Thus, for close-range navigation and especially for the robot docking phase, the use of mainly acoustic guidance is not sufficient and the methods discussed in the literature usually utilise both acoustic and vision techniques (Krupinski et al., 2008).

2.2. I-AUV docking

As discussed by Grosset et al. (2002) and Weiss et al. (2009), in order for the I-AUV to perform a fine intervention, it is necessary to dock near the target, since dynamic-positioning control would not provide the adequate error compensation in the presence of sea currents. Even in the case of ROVs, docking is preferred over other solutions, due to the higher accuracy guaranteed by such method.

As described above, AUVs docking methods combine acoustic and vision localisation techniques. Generally, vision-localisation techniques can either use passive or active targets. Adopting passive vision techniques, Evans et al. (2003) studied the trajectory control problem during the homing of an I-AUV on an intervention-panel, and proposed a pose-estimation algorithm based on sonar and camera data to control the robot. Negre et al. (2008) proposed a docking method for AUVs using self-similar landmarks on the target so that the vehicle could self-localise using the camera. Palmer et al. (2009) proposed a system for I-AUV short-range navigation in order to approach and dock on an offshore intervention panel using data from a camera-based technique for feature extraction and common navigation sensors.

As for the active vision techniques, Lee et al. (2003) introduced a method for AUV docking using one camera on the vehicle and an array of lights on the docking station. Krupinski et al. (2008) introduced a method to perform I-AUV docking on an intervention panel by coupling sonar data with visual information using active markers. Though active markers require an energy source on the docking platform itself, it is rather robust compared to passive vision techniques especially in limited visibility situations.

2.3. Autonomous localisation of the target and manipulation

Regarding the autonomous localisation of a target object for manipulation purposes, a combination of underwater cameras and ultrasound motion trackers has been proposed by Marani et al. (2009). Vision provides absolute pose estimation of the object, but at low sample rate and with the need of a light source, which could significantly reduce AUV autonomy. On the other hand, motion trackers can provide reliable and high sample-rate