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Design and dynamic study of a ROV with application to oil and gas industries of Persian Gulf

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ABSTRACT

Towed underwater vehicles are essential tools for providing safe access to the underwater world with many applications including ocean research, naval operations, inspection and repair of undersea structures. Remotely operated vehicle (ROV) is one of these vehicles which consists of a surface buoy, connecting cable and underwater vehicle. As ROV technologies and capabilities have improved, the offshore oil and gas industry has come to rely on ROVs and they are already involved with every aspect of offshore oil and gas production system installation. Studying of ROVs in Iran seas is an essential feature which is lacking in literature. In the present study, an effort has been made to study a ROV for inspection in oil and gas industries of Persian Gulf. Two commercially available buoys are also examined to find the better towing system with least instabilities in three selected sites of Persian Gulf with different wave climate conditions. The dynamic behavior of this ROV (translational and rotational motions and velocities plus sum of all forces acting on the system) is numerically investigated. After validating the method, it is found that ROV has more instabilities in middle part of Persian Gulf and buoy (2) performs slightly better than buoy (1).

1. Introduction

Towed underwater vehicles are essential tools for providing safe access to the underwater world. They have versatile applications including naval operations (Banerjee and Do, 1995; Ohkusu et al., 1987; Park et al., 2003), ocean research and exploration (Boe et al., 2013; Feng and Allen, 2004), acoustic surveying (Buckham et al., 2003), assembly, inspection and repair of undersea structures (Driscoll et al., 2000a; Kamali and Khojasteh, 2016; Khojasteh, 2015). ROV is one of these towed underwater vehicles. The complete ROV system generally consists of the underwater vehicle, which is connected to the topside surface support vessel, buoy or platform by an umbilical cable (for carrying power and transmitting control signals), a handling system to control the cable dynamics, and associated power supplies (Christ and Wernli Sr, 2013). ROVs can vary in size from small vehicles with video cameras for simple observation up to complex work systems, which can have several manipulators, tools and other equipment. Due to the importance of ROVs applications, a vast number of studies have been investigated to examine the dynamics of underwater vehicle, towing cable and surface vehicle. Park et al. (2003) presented a numerical and experimental investigation into the dynamic behavior of a towed low-tension cable, applicable to a towed array sonar system for detecting submarines. Feng and Allen (2004) suggested a numerical scheme to evaluate the effects of the communication cable attached to an underwater flight vehicle. Buckham et al. (2003) described the development of a numerical model that accurately captured the dynamics of a towed underwater vehicle system. Vaz and Patel (1995) represented a numerical solution for the transient motion of marine cables being towed from a ship with varying speeds. Driscoll et al. (2000b) investigated a one-dimensional finite-element lumped-mass model of a vertically tethered caged ROV system subjected to surface excitation in order to predict the motion of the cage and the tension in the tether at the ship. Wu and Chwang (2000) studied a three-dimensional model of a two-part underwater towed system to predict the hydrodynamic performance of a towed vehicle. Gobat and Grosenbaugh (2006) applied a computer program for analyzing the statics and dynamics of oceanographic cable structures by taking into accounts the effects of geometric and material nonlinearities and bending stiffness. Grosenbaugh (2007) examined the dynamic behavior of a towed cable system that resulted from the tow ship changing course from a straight-tow trajectory to one involving steady circular turning at a constant radius. Matulea et al. (2008) analyzed a numerical method based on finite differences in order to predict the static configuration of mooring or towing compound cables. Saout and Ananthakrishnan (2011) determined the open-loop directional stability of a near-surface underwater vehicle by solving the coupled sway and

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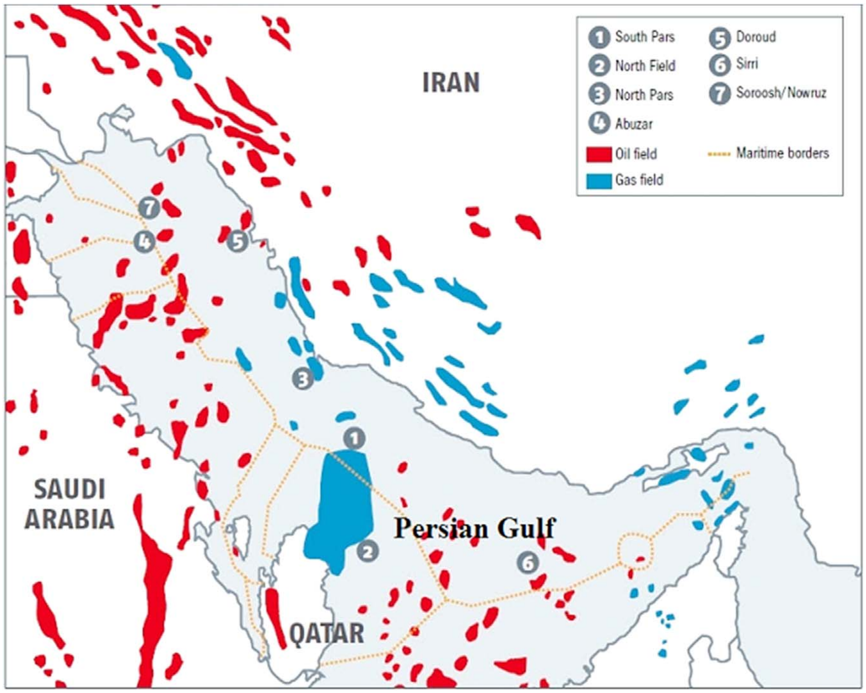

Fig. 1. Oil and gas fields of Persian Gulf (Oil and gas fields of Persian Gulf. Available from: http://meed.com/).

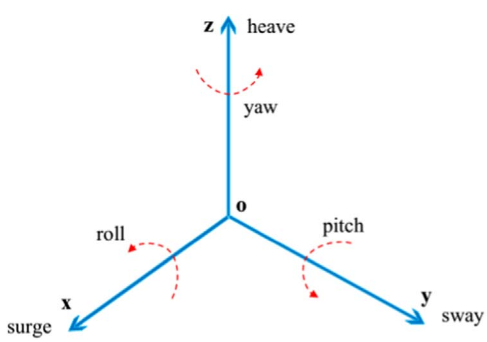

Fig. 2. A schematic of the coordinate system and the six degrees of freedom.

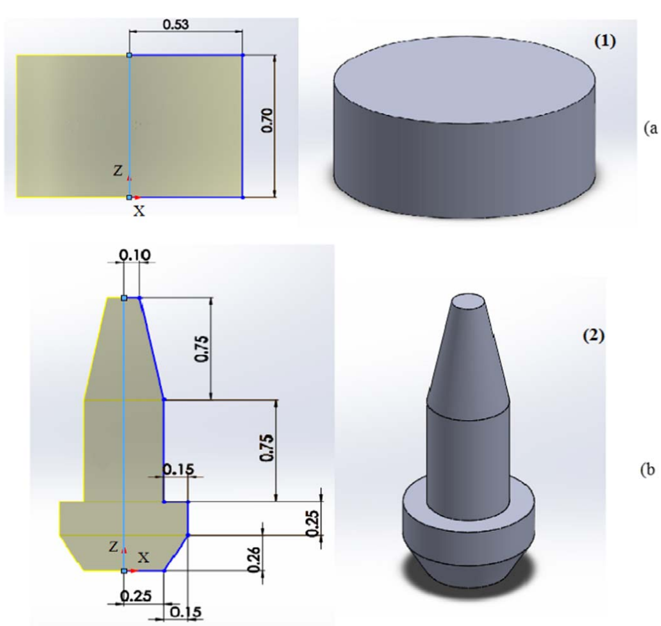

Fig. 3. Geometries of the considered buoys: (a) buoy (1), (b) buoy (2) (all dimensions are in m).

yaw equations of motion. Leong et al. (2015) developed a numerical model to simulate pure sway motion of an underwater vehicle at different lateral and longitudinal positions relative to a larger underwater vehicle, using computational fluid dynamics (CFDs). Wang and Sun (2015) parametrically simulated the dynamic response of a towed cable system to find the influences of three dimensionless parameters on towed cable system maneuverability. Hosseini and Seyedtabaii (2016) applied a sliding mode control method to track the position of a ROV. Drummen et al. (2009) studied the global load effects in a ship to find the responses of a containership in severe head seas. Wu et al. (2016) presented parametric studies of nonlinear irregular wave forces on large-scale submerged element solving three-dimensional diffraction potential and radiation potential associating with the motion of the floating body, using ANSYS AQWA. Fang et al. (2006) developed a hydrodynamic model including the characteristics of maneuvering and seakeeping to simulate the six-degree of freedom motions of the underwater vehicle steering near the sea surface. Sayer (2008) measured wave forces on a prototype ROV to predict hydrodynamic loads. Fang et al. (2007) applied a hydrodynamic model to simulate the six degrees of freedom motions of the underwater ROV including the umbilical cable effect. Curado et al. (2010) proposed using a two-stage towing arrangement that included a long primary cable and a secondary cable for addressing the problem of simultaneous depth tracking and altitude controlling of an underwater towed vehicle. Soylu et al. (2016) investigated the design, implementation and testing of a new precision guidance and control system for an inspection class ROV. Valentinis et al. (2015) presented a motion control system for tracking of altitude and speed of an underactuated slender-hull unmanned underwater vehicle. Xu and Zou (2015) proposed a flexible segment model as a robust dynamics calculation method for modeling underwater moving slender bodies. Jin-Kyu et al. (2015) studied a ROV to lay the optical-fiber submarine cables that connect the observatories with the control center. Shiosawa et al. (2010) theoretically and experimentally probed the mobility characteristic of a ROV with crawler system in steady running. Fan et al. (2012) evaluated the hydrodynamic coefficients and resistance calculation of ROV to find its maneuverability and control algorithm. Chin (2011) suggested a systematic dynamic modeling to simulate a ROV. Fang et al. (2008) reported a series of analyses