Numerical Modeling of Cable-winch System for ROV Launching and Recovering Processes based on the Finite Element Approach

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ABSTRACT

This paper presents the dynamic modelling of a rigid-flexible tether management system (TMS) of ROV (Remotely-operated Underwater Vehicle) during the ROV launching and recovery processes. In the present study, modelling of TMS includes rigid-flexible multibody dynamics of a ROV, a tether and a rotating winch. The mathematical model of tether cable is developed based on the nonlinear finite element method called Absolute Nodal Co-ordinate Formulation (ANCF). Hook model was used to calculate the normal contact forces around the winch circumference, and the Coulomb model was used to calculate the friction forces. By applying the above, the simulation of launching and recovering process was carried out.

KEY WORDS: Motion analysis; ROV; Tether Cable; ANCF; Winch; Tether management system; Multibody dynamics.

INTRODUCTION

The seabed contains mineral resources such as oil, natural gas, cobalt rich crust, submarine hydrothermal deposits, and rare earth mud. The technology development is carried out to utilize these resources effectively. ROV is used for research and development of these resources. ROV is an underwater vehicle that is connected to the mother ship by a tether cable consisting of signal lines and power lines. Because of its low bending stiffness and complex composition, its motion greatly affects the maneuverability of the ROV, and consequently, it complicates the job of a human pilot. Therefore, the pilots must have a competency and adequate training experience to operate the ROV in any scenario. For this purpose, an accurate ROV simulator is a promising and effective tool for training the operators.

In the literature, the motion analysis of ROV and tether cable has been carried out mostly using the lumped mass method (Buckhum et al. 2003 and Quiang et al. 2008). This method, has an advantage of ease of implementation exercises to the simple formation of mass matrix which is, in most cases, a diagonal matrix and stiffness matrices. On the other hand, the disadvantage is that the accuracy of describing the flexible bodies declarations decreases as the number of elements increase and deformation becomes larger and this does not lead to exact modeling of the mass matrix of the beam in case of an arbitrary rigid body motion. A numerical motion estimation method for ROVs including tether cable using ANCF were studied in (Suzuki, et al. 2017, 2018 and Htun, et al. 2019).

In practice, during the ROV launching operation and recovery processes, a winch is used to draw-in and pay-out the tether cable. Thus, understanding the interactive motion of the cable and winch is also essential when developing the simulator. A dynamic simulation of string winding using the lumped mass method is provided by Horie et al. (1999). Imanishi et al. (2003) conducted a dynamic simulation of the winch and wire rope taking into account the coupling with the hydraulic system. Truss elements which do not consider bending rigidity are used for the wire rope. Takehara et al. (2016) were conducted a numerical simulation of wire rope and pulley and demonstrated the usefulness of the model for simulation by comparing with experimental results. A spring-damper element is used for the normal contact force, and a Quinn method based on Coulomb friction is used for the friction force. In the literature, a rigid-flexible tether management system (TMS) of ROV, which studies the coupled motion of ROVs, cables and winches, is a new topic and has not been published before. In this study, a numerical TMS model is developed using ANCF for discretizing the tether continuum, calculating inertia forces, external forces such as hydrodynamic forces by surrounding water and buoyant forces. The interaction between the tether and winch is described by applying the normal contact forces, internal forces of cable, and friction forces along the cable contact points on the winch circumference. It is considered that frictional force of the cable and tension at the end of the cable act on the winch. Taking these forces into account, the rotational motion of the winch was calculated. Meanwhile, the rigid body motion of ROV is calculated using the hydrodynamic coefficients obtained from (Suzuki et al. 2013). The overall system motion is studied, thereby, applying the constraint equations at the upper and lower boundary points of the tether, i.e., between the tether and winch, and between the tether and ROV.