Trajectory and Attitude Control of a Tethered Underwater Robot

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ABSTRACT
In this paper a three-dimensional hydrodynamic and control model is presented to simulate a tethered underwater robot system. The fluid motion around the moving robot main body with running control ducted thrusters is governed by Navier-Stokes equations. These nonlinear differential equations are solved numerically with CFD code Fluent. From numerical solution we obtain hydrodynamic loadings on the robot and control forces issued from the thrusters. A control algorithm is applied to manipulate the tethered robot in order that the robot can travel at a designated orbit with demanded attitude. In the model the governing equation of umbilical cable linked to the robot is based on the Ablow and Schechter (1983) method. The six-degrees-of-freedom equations of motion for underwater vehicle simulations proposed by Gertler and Hagen (1967) are adopted to estimate the hydrodynamic performance of the underwater robot, and a controller based on sliding mode control theory for the active control ducted thrusters attached to the tethered underwater robot is also incorporated into the model. The hydrodynamic behaviors of the robot under definite trajectory and attitude control manipulations are observed numerically based on the established hydrodynamic and control model.

KEY WORDS: Underwater robot; umbilical cable; ducted thruster; sliding mode control; CFD; trajectory and attitude control

INTRODUCTION
Tethered underwater robot is a kind of apparatus which is extensively used for undersea observation and research. The trajectory and attitude of tethered underwater robot is usually manipulated by user on board sending control signal through an umbilical cable to actuate the control ducted thrusters attached to the robot. When the trajectory and attitude control problem of a tethered underwater robot is studied it is necessary to couple the main body of underwater robot, umbilical cable and control ducted thrusters together forming an integrated hydrodynamic model so that the robot is in a comprehensive dynamic equilibrium condition, a suitable control algorithm is then jointed into the hydrodynamic model constructing a hydrodynamic and control model for the tethered underwater robot system. Only in this way the hydrodynamic nature of trajectory and attitude control to a tethered underwater robot can be described objectively.

In studying trajectory and attitude control performance of a tethered underwater robot, different mathematical models or numerical approaches have been proposed to observe robot’s hydrodynamic and control behavior (Feng and Allen, 2004; Fang et al, 2007; Bagheri, and Moghaddam, 2009; Bessa et al, 2010). However since their research points are different, these models or approaches focus on different aspects. When trajectory and attitude manipulation problems of a tethered underwater robot are discussed the research emphases usually focus on the robot’s control topic, and the hydrodynamic models are paid relatively less attention. Nevertheless it is believed that predicting accurately the hydrodynamic characteristics of a tethered underwater robot under the joint hydrodynamic influence of umbilical cable, active control mechanisms as well as main body of the underwater robot itself is a fundamental key for understanding comprehensively the control nature of the underwater robot when the robot is driven by some kinds of control mechanisms such as attitude control ducted thrusters.

In this paper a cuboid figuration of underwater robot with the hydrodynamic effect of attitude control ducted thrusters, umbilical cable and robot main body being considered together is taken as the research object, the hydrodynamic response of this kind of tethered underwater robot system under the manipulation of robot’s control ducted thruster operation and the influence of undersea environment such as ocean current is investigated. In the research the equation of motion for umbilical cable is established based on the Ablow and Schechter (1983) method; hydrodynamic behavior of underwater robot is described by the six-degrees-of-freedom equations of motion for submarine simulation proposed by Gertler and Hagen (1967); hydrodynamic loadings on the robot and control forces issued by running control ducted thrusters are determined by the Navier-Stokes equations whose values are obtained by solving the equations with CFD code Fluent. In establishing the hydrodynamic model of tethered underwater robot system, governing equation for umbilical cable is given first, kinematic condition at the up end of cable above water surface and the dynamic equations of underwater robot combined with control ducted thrusters conjunct with the lower end of cable are taken as the boundary conditions for the governing equations of the cable. After the hydrodynamic model is established a controller based on sliding mode control theory for the active control ducted thrusters is incorporated into the model constituting a hydrodynamic and control model for the tethered underwater robot system.