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Torsional Mechanics in Dynamics Simulation of Low-tension Marine Tethers

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ABSTRACT

A finite element model of a ROV tether is presented that makes use of a twisted cubic spline element form with torsional stiffness and a lumped mass approximation. In existing works, the torsional contributions to the low-frequency tether motion are disregarded. The primary objective of this work was to explore the role of torsional stiffness in the simulated low-tension tether dynamics during typical ROV maneuvers. Thus, a representation of the tether's torsional rigidity was included in the model to capture the complete dynamics of the low-tension tether. The motion of a small ROV was experimentally captured during operation in tank trials. Using the measured towpoint motion to drive the tether dynamics simulation, it was readily apparent that tether twist significantly affects the disturbances predicted at the ROV. For the purposes of virtual-reality ROV pilot training, the torsional effects are thus necessary to ensure fidelity of the model. The small elements necessary to capture the tether curvature induce high-frequency motions that limit the step size of any numerical integration schemes used. Two integration methods were implemented in attempts to eliminate these unwanted high-frequency components and garner the associated improvement in the model execution time: a variable step size explicit Runge-Kutta method and an implicit Generalized-α technique. The large number of small cable elements required for convergence created a practical limit on the execution speed of the Generalized-α approach.

INTRODUCTION

Currently, forays to the deep ocean are made on an intermittent basis, but efforts are under way to establish a more continual human presence in the deep ocean. Examples include proposed submerged oceanographic observatories such as the NEPTUNE project. The predominant technology for the installation and maintenance of such underwater networks will likely be remotely operated vehicles (ROVs). For modern ROVs equipped with robotic appendages, a neutrally buoyant tether or umbilical provides real-time, high-bandwidth telemetry and a physical link, or lifeline, to the surface. Given the need for human reasoning in the control loop, the tether is a necessity for the ROV operation. To minimize the disturbances exerted on the vehicle by the tether, excess tether is often deployed to ensure a slack or low-tension state. However, the environmental forces that accumulate over the tether can at times significantly affect ROV motion and complicate the job of the human pilot (McLain and Rock, 1992). Given the increasing demand for ROV interventions, ROV simulators are an intriguing means to increase a novice pilot's exposure to the intricacies of ROV flight. The focus of the work presented in this paper is the development of a complete tether dynamics model for the simulation of low-tension tethered vehicles for this application.

The dynamics modeling of marine cables has been studied extensively since the early 1960s for the analysis of mooring line tensions (Walton and Polacheck, 1960), and the positioning of towed vehicles (Chapman, 1984). However, the topic of low-tension cable dynamics is of more recent interest. Howell (1992) presented the inclusion of a cable's bending and torsional stiffnesses in a discretization of the governing cable dynamics equations based on a finite difference technique. Grosenbaugh et al. (1993) simulated the low-tension tether motion of a ROV in 2 dimensions also using this finite difference approximation to the tether motion equations. An alternative to the finite difference approach is the lumped mass strategy. Buckham and Nahon (2001) presented, and validated through experimentation, a lumped mass formulation for low-tension cables that appends a bending stiffness model to a standard lumped mass formulation previously developed by Driscoll (2000). An advantage of the lumped mass method is the ease in coupling the formulation to other numerical models, specifically to nonlinear vehicle models as in Lambert et al. (2003).

A drawback to the existing low-tension lumped mass formulation is an inability to capture the effects of a nonzero torsional stiffness. While existing model formulations (Burgess, 1993; Howell, 1992), make provision for torsional stiffness in the continuous equations of motion, there have been no instances where nonzero torsional effects have been considered in discrete analyses of spatial tether motion. It thus remains to demonstrate

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