Benchmarking of multibody formalisms for the simulation of manoeuvres with underwater cables

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Fishing trawls are complex mechanical systems comprised of several elements with dissimilar physical properties and behaviours (Fig. 1). The fishing net is linked to the ship that drags it with cables whose length varies during operation due to winding and unwinding. This length can be up to several kilometres long. These cables are in turn connected to other bodies, e.g. doors, to ensure proper deployment and buoyancy of the net. The system elements are subject to the effect of hydrodynamic forces and contact with the seabed. The efficient and accurate simulation of such systems is an exacting task that requires the application of modelling techniques and numerical solution strategies that suit the dynamics of each component.

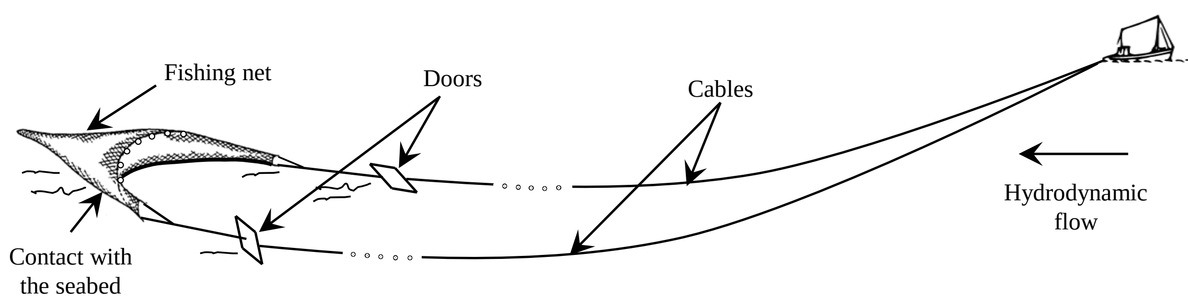

Fig. 1: Components of a fishing trawl net

This work focuses on the benchmarking of multibody formulations in the context of the simulation of cables that undergo let-out and heave operations under the above mentioned conditions. When the cable axial stiffness is high enough, a possible approach is to model the cable as a series of N rigid links connected by spherical joints; the change in cable length during the winding process can be represented using variable-length links [1]. Employing natural coordinates [2] to describe a cable composed of N links leads to a set $\mathbf{q}$ of $3N$ generalized coordinates related by N variable-distance constraint equations $\mathbf{\Phi} = \mathbf{0}$. The corresponding system of dynamics equations can be efficiently integrated using global formulations such as the augmented Lagrangian and Hamiltonian ones described in [3], and the index-3 augmented Lagrangian with velocity and acceleration projections in [4].

Two simulation scenarios are proposed as benchmark problems. The first one consists of a single, N-link chain with one of its tips linked to the origin of the global reference frame via a spherical joint. A point mass m is attached to the free end of the chain. The cable is initially aligned with the global x-axis and moves under the action of gravity and hydrodynamic forces. Two variations of this problem have been studied: without including contact with the seabed and winding, denoted as case 1A, and considering these effects, denoted as case 1B. The second scenario (case 2) is a double chain that models the cables of a system like the one depicted in Fig. 1. The fishing net and the doors are modelled in a simplified way with point masses and spring-damper systems. In all cases, the results were compared in terms of efficiency and accuracy using a reference solution obtained with an experimentally validated model of the cable [5]. This model represents the cable as a set of lumped masses connected with linear springs of variable natural length.

A 1000 m long cable modelled with N rigid links was selected in this study as test problem for case 1. The simulation of case 1A consisted in a 2400 s motion of the cable from the initial configuration until it reached a steady state. For case 1B, a 300 s winding manoeuvre with constant winch velocity was considered. In this latter

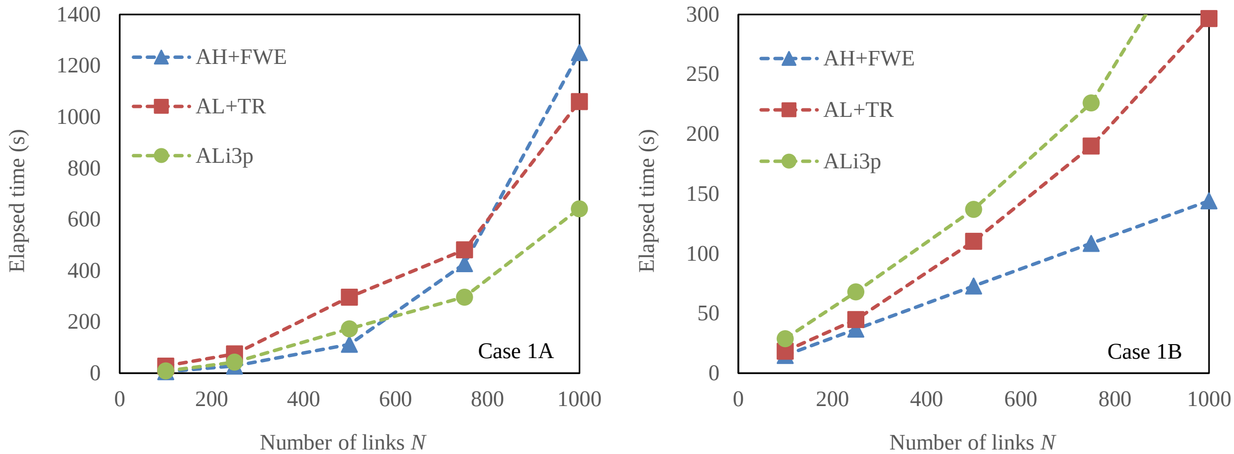

Fig. 2: Effect of the number of links N on the time required by the simulation of cases 1A and 1B with the three tested algorithms

case, the cable experienced contact with the seabed, modelled as a horizontal plane at a fixed depth of 100 m. Fig. 2 shows the times elapsed during the forward-dynamics simulation of both cases using three different algorithms: the augmented Hamiltonian method proposed in [3] combined with an explicit forward-Euler integration scheme (AH+FWE), the augmented Lagrangian method also described in [3] integrated with the trapezoidal rule (AL+TR), and the index-3 augmented Lagrangian method with projections discussed in [4] (ALi3p). Only fixed step-size integrators were considered in this study. The dynamics of case 1A is slow, and so the methods with implicit integrators could use relatively large integration step-sizes, which resulted in better performance when the system is discretized using a larger number of links N. However, this advantage is lost when winding and contact with the seabed need be considered. Only the AH+FWE method was able to yield correct results in all the simulations without decreasing the integration step-size. This result agrees with the conclusions in [6]. Similar results were obtained for the double chain example in case 2. In all cases the use of multibody formulations resulted in significant savings in the computation time required by the simulations with respect to the lumped-mass model of the cable used to obtain the reference solution.

Ongoing work includes the comparison of the selected global formulations with recursive multibody methods like the Articulated Body or the Divide and Conquer Algorithms.

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