Three-dimensional deployment of cable nets for active removal of space debris

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Abstract. Deployable cable nets are promising capture systems for the active removal of space debris. We propose a finite element model of the cable net with lumped nodal masses and first-order cable elements. The nodal positions are assumed as the main unknowns of the problem. Large displacements and finite deformations are considered through the Green-Lagrange strain tensor. Cable elements are assumed to react only in tension through a hyper-elastic constitutive law. The governing equations are solved numerically by means of the Runge-Kutta method with variable time step. As an example, the three-dimensional deployment is simulated of a planar, square-mesh net. The proposed approach turns out to be computationally effective and accurate.

Introduction

Remediation activities set out for the disposal of massive objects abandoned around the Earth are needed to secure the most valuable orbital regions. For active debris removal (ADR), the development of an effective capturing mechanism is still an open issue. Among several proposals, cable nets are light, easily packable, scalable, and versatile. Nonetheless, guidance, navigation, and control (GNC) aspects are especially critical in both the capture and post-capture phases [1].

Several theoretical models have been proposed to describe the deployment and capture processes. Benvenuto et al. [2] and Botta et al. [3] modelled the net as a system of concentrated masses connected to each others by spring-dampers. In their models, springs react only in tension and infinitesimal strains are considered. Shan et al. [4] compared the simple lumped mass-spring model with a more refined one based on the absolute nodal coordinate formulation (ANCF) proposed by Shabana [5]. They used a third-order cable element, and considered finite strains through the Green-Lagrange strain tensor. The lumped mass-spring and ANCF models predicted similar overall behaviour of the net, but the ANCF model was much more computationally expensive.

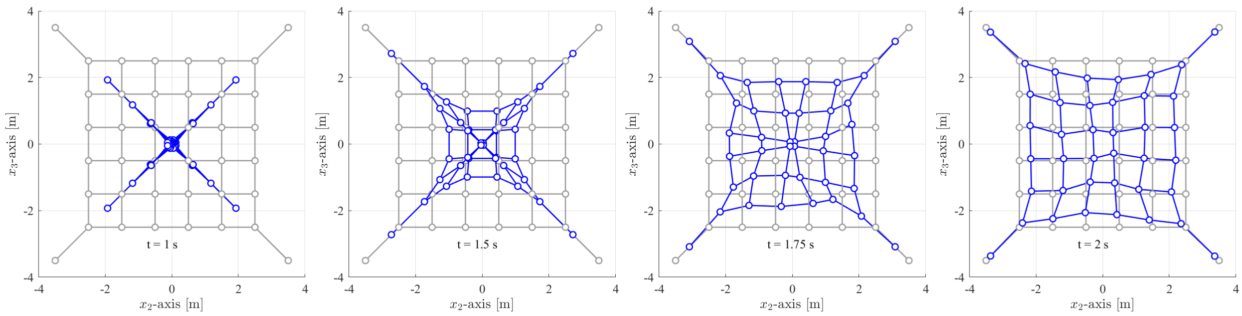

Figure 1: In-plane deployment of the cable net. Grey and blue lines represent the reference and current configurations, respectively.

Results and discussion

We propose a finite element model of the cable net with lumped nodal masses and first-order cable elements. In line with the ANCF, we adopt the nodal positions as the main unknowns of the problem, obtaining a symmetric secant elastic stiffness matrix [6]. Large displacements and finite deformations are considered through the Green-Lagrange strain tensor. Cable elements are assumed to react only in tension according to a hyper-elastic constitutive law [7]. Global damping is introduced into the model according to Rayleigh's hypothesis. The governing equations are solved numerically by means of the Runge-Kutta method with variable time step.

As an illustrative example, we present the simulation of the three-dimensional deployment of a planar, square-mesh net. The proposed approach turns out to be computationally effective and accurate.

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