An ALE cable formulation applicable to multibody systems

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Cables are part of many engineering applications such as suspended bridges or electrical wires. Often, cables are not simply attached at both ends to withstand a traction force, but they can move, slide and even make contact with the structure they interact with. It is namely the case in reeving systems, deployable space structures or soft robotics. They can be modeled as elastic bars or elastic beams depending on the application.

In order to numerically simulate these mechanical systems, a nonlinear finite element method (FEM) is often followed. In applications where the cable enters in contact with a structure, for instance in reeving systems where the cable is in contact with a pulley, there is a need for a fine discretization of the cable to accurately take contact and friction into account. This fine discretization of the cable is only needed in some key regions, *i.e.,* the pulley in this case. However, because the cable is moving along the pulley with time, one is often constrained to work with smaller elements than needed along the whole cable length. In order to circumvent this difficulty, a popular option is to work with an arbitrary Lagrangian-Eulerian (ALE) formulation. This setting is widely used in fluid mechanics, such as fluid-structure interaction problems, where the flow is usually analyzed using an Eulerian viewpoint, whereas the structure deformation is analyzed using a Lagrangian viewpoint.

In multibody dynamics, the ALE formulation was applied to already discretized versions of the equations of motion by considering specifically the element needed for the simulation. Noticeably, a joint ALE-ANCF approach for a beam element has been developed to model reeving systems (Escalona, J.L., "An arbitrary Lagrangian–Eulerian discretization method for modeling and simulation of reeving systems in multibody dynamics", in *Mechanism and Machine Theory*, vol. 112, pp. 1-21, 2017). Other authors have developed ALE elements to represent the part of the cable in contact with a pulley, for instance.

In this work, an existing formulation (Kuhl, E. *et al.*, "An ALE formulation based on spatial and material settings of continuum mechanics. Part 1: Generic hyperelastic formulation.", in *CMAME*, vol. 193, pp. 4207-4222, 2004), starting from Hamilton's principle in a continuous setting, is applied to multibody systems by the addition of constraints and the finite element modeling of cables as a unidimensional structure with a uniform distribution of strains in the cross-section. It brings a new perspective to develop the multibody equations of motion starting from a continuous formulation, inducing a well-posed problem in terms of the spatial and material equilibria. Numerical examples are presented, such as a cable-pulley system and a cable-actuated soft finger model.