Efficient and Accurate Multibody Simulation for Cable Pulley Systems Based on ALE Formulation and SDF Contact Detection

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EXTENDED ABSTRACT

1 Introduction

Cable pulley systems, such simple structural components but being able of distributing and transferring load over a long distance through a complex geometric path with the superiority in their lightweight, flexibility, high-tensile strength, and other advantages, are widespread in various complex and advanced structures. Considering the complex processing of moving contact/impact between cable and components with large possible contact range and small actual contact range, it is extremely challenging to accurately and efficiently predict system dynamic behaviors. For the multi-body dynamic model of such engineering problems, the large deformation and large rotation of cables in space and material flow need to be considered, while the description of contact local details, such as geometry and the interaction between cables and pulleys, is also crucial[1]. Especially, for the non-ignorable complex geometric shape of the pulley with out-of-plane cable wrapping, the frictional contact calculation of penetration depth and contact detection are challenges for cable pulley system.

2 Modeling method based on ALE

The Arbitrary Lagrangian Eulerian(ALE) elements are adopted to solve the moving contact and variable length problems of cable.The mass matrix of ALE cable elements is singular caused by the dependence of the generalized coordinates for each cable node[2]. Therefore, an additional constraint equation for position or material coordinates has to be introduced to relate some of them and eliminate the singularity. It makes ALE cable element flexible and elegant. Taking advantage of ALE cable element, the mesh in contact area is modeled using event-driven dynamic mesh, and the non-contact area is modeled using material coordinate scale constraint. An efficient and invariable topology cable model is established, as shown in Fig.1.

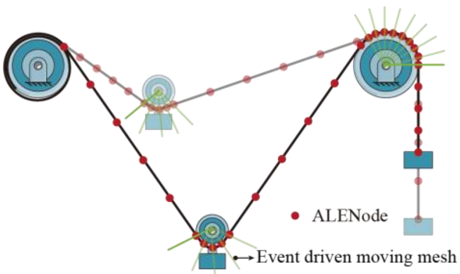


Figure 1: Multibody model of cable pulley system based on ALE formulation

For the contact area, the spatial coordinates of the nodes in contact area follow the pulley according to its location in order to accurately capture the contact behavior between them. For the non-contact area, the material coordinates of the nodes in non-contact areas are constrained using proportional constraints[3]. In this model, the inner nodes are evenly distributed within this segment, the number of cable elements remains unchanged with time, which automatically keep the invariable topological characteristics of the system.

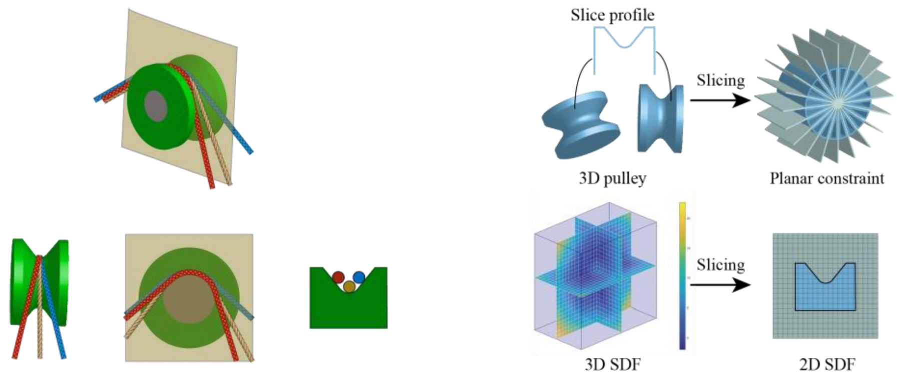
3 SDF Contact detection

Based on the ALE cable model, the dimension of three-dimensional pulley friction contact problem is reduced, and the two-dimensional contact detection strategy without search is constructed by drawing on the signed distance fields (SDF) theory.

the friction contact force at the Gauss integral point can be expressed as

$$\mathbf{F}_c = \mathbf{F}_{cn} + \mathbf{F}_{ct} = F_{cn}\mathbf{n} + \mu_f F_{cn}\boldsymbol{\tau}, \quad F_{cn} = \begin{cases} 0 & \delta \le 0 \\ K\delta^e + C\dot{\delta} & \delta > 0 \end{cases} \tag{1}$$

Where δ is penetration depth and $\mathbf{n}$ is the normal vector of contact detection point at SDF slice.



a) b)

Figure 2: a) Possible position of rope winding on pulley, b) Pulley slicing and its signed distance field

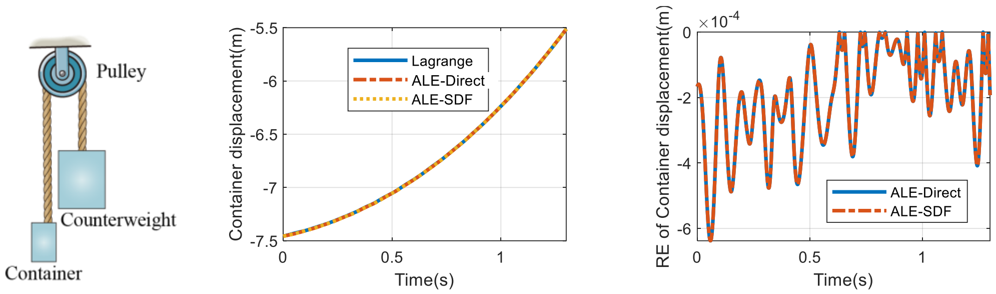
Based on SDF theory, the penetration depth δ and the normal vector $\mathbf{n}$ can be expressed as

$$\delta\left(\mathbf{x}_P\right)=\sum_A V_A d^A \varphi\left(\mathbf{x}_P-\mathbf{x}_P^A\right),\ \mathbf{n}=\frac{\partial \delta\left(\mathbf{x}_P\right)}{\partial \mathbf{x}}=\sum_A V_A d^A \frac{\partial \varphi}{\partial \mathbf{x}}\left(\mathbf{x}_P-\mathbf{x}_P^A\right) \tag{2}$$

where $\varphi(\mathbf{x})$ is kernel function[4-6].

4 Case study

As shown in Figure 3, a simple numerical example of cable-pulley system is presented to validate the accuracy of the dynamic model based on ALE formulation and SDF contact detection, compared with Lagrangian formulation and ALE formulation with direct search detection.



a) b) c)

Figure 3: a) a single cable pulley simulation obtained b) the displacement of container and c) relative error compared with Lagrange model

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