Flexible multibody system dynamics with fracture propagation using peridynamics

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EXTENDED ABSTRACT

1 Introduction

Classical continuum mechanics is based on partial differential equations (PDEs), that fail to describe structural discontinuities, such as cracks. This limitation has led to the development of peridynamics (PD), reformulating the classical PDEs into integrodifferential equations [1].

In PD, each material point interacts with its neighbours inside a characteristic length-scale through bond-interaction forces. PD can address complex multi-physics and non-linear phenomena. However its integration in the study of mechanical systems is still limited. This work presents a novel framework, incorporating PD into an existing 2D multibody dynamics formulation [2] to enable the integration of flexible structures described by PD into mechanical systems.

The flexible body can be described by a collection of point masses connected with non-linear springs, in analogy with the typically used meshless collocation scheme for bond-based peridynamics discretizations. The kinematic joints that connect the flexible body with the neighbouring bodies are defined using the virtual bodies methodology, complemented by a rigid-flexible joint.

The implementation of the methodology proposed is demonstrated by different mechanisms with varying levels of complexity, and some scenarios include the simulation of fracture. The effect of structural damping is discussed and the importance of using a strategy to correct the violations of the constraints is highlighted.

2 Methods

In this section we describe our new approach to flexible multibody dynamics, where flexible bodies are discretized using peridynamics.

For a material point $\mathbf{x}$, the PD equation of motion is given as

$$\rho V \ddot{\mathbf{x}} = \int_{H_{\mathbf{x}}} \boldsymbol{f}(\boldsymbol{\eta}, \boldsymbol{\xi}) dV' V + \mathbf{b} V \tag{1}$$

where $\mathbf{f}$ is the pairwise force density, developed between the material point a neighbour material point, $\mathbf{b}V$ is the body force vector, $H_{\mathbf{x}}$ is the horizon of material point $\mathbf{x}$, ρV is the material point mass and $\ddot{\mathbf{x}}$ is its acceleration. Notice how, in peridynamics, the equilibrium of internal forces is changed from the divergence of the stress tensor to an integral over an horizon of points, where discontinuities such as cracks, which lead to singularities in the classical PDE's, do not produce any problems in the PD equations. PD has shown high capabilities in predicting and simulating crack propagation, which, in the context of flexible multibody dynamics is not yet explored.

A multibody model is commonly defined by a collection of rigid or flexible bodies connected by kinematic joints and force elements. The multibody formulation used in this work relies on the use of Cartesian coordinates. The position of a body i relative to the global reference frame is expressed by the vector $\mathbf{r}_i = [x \quad y]_i^T$ while the orientation is expressed by the angle θ_i. The position and angular coordinates form the vector of the coordinates of the body $\mathbf{q}_i = [x \quad y \quad \theta_i]_i^T$

The system of the equations of motion of a multibody system is expressed by

$$\begin{bmatrix} \mathbf{M} & \mathbf{\Phi}_{\mathbf{q}}^T \\ \mathbf{\Phi}_{\mathbf{q}} & \mathbf{0} \end{bmatrix} \begin{Bmatrix} \ddot{\mathbf{q}} \\ \boldsymbol{\lambda} \end{Bmatrix} = \begin{Bmatrix} \mathbf{g} \\ \boldsymbol{\gamma} \end{Bmatrix} \tag{2}$$

where $\mathbf{M}$ is the mass matrix $\mathbf{\Phi}_q$ is the Jacobian matrix, $\boldsymbol{\gamma}$ is the right-hand side of the acceleration equations, $\boldsymbol{\lambda}$ is the vector of Lagrange multipliers, $\ddot{\mathbf{q}}$ is the acceleration vector and $\mathbf{g}$ is the force vector.

In order to include peridynamic flexible bodies in a multibody system dynamics framework, the authors propose the formulation presented herein. We believe that, in order to leverage the capabilities of PD, its discretization must be done at a meshless collocation level. This implies that, as shown before, the integral of the internal forces is taken as a discrete summation of forces between each point and its neighbours. A commonly used analogy is to think about the bond connections between particles as springs. Therefore, each PD point particles can be treated as a rigid body connected to its neighbours by spring links, in the multibody framework, as shown in Figure 1.

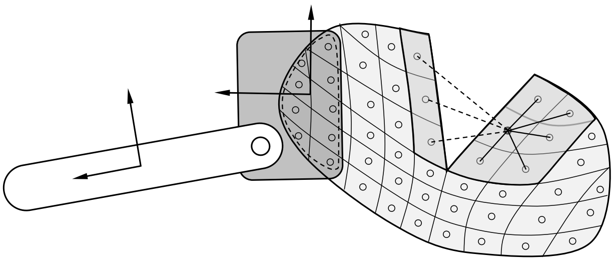

Figure 1: Rigid bodies connected to a peridynamic flexible body

To account for the flexible body in the multibody formulation, the mass of each particle in equation (1) is accounted in the **M** matrix of equation (2), resulting in a lumped mass matrix. The PD equilibrium of internal forces term in the right hand side of equation (1) contributes to the vector **g** in equation (2).

3 Results

In this section we present results of a multibody simulation using our approach. In the current example a pre-notched plate, discretized using peridynamics, is connected to two virtual bodies, at the left and right sides of the plate, where rotation is imposed.

In Figure 2 snapshots of the simulation display the crack propagation at 5 instants. The potential of the presented flexible multibody approach is clearly illustrated.

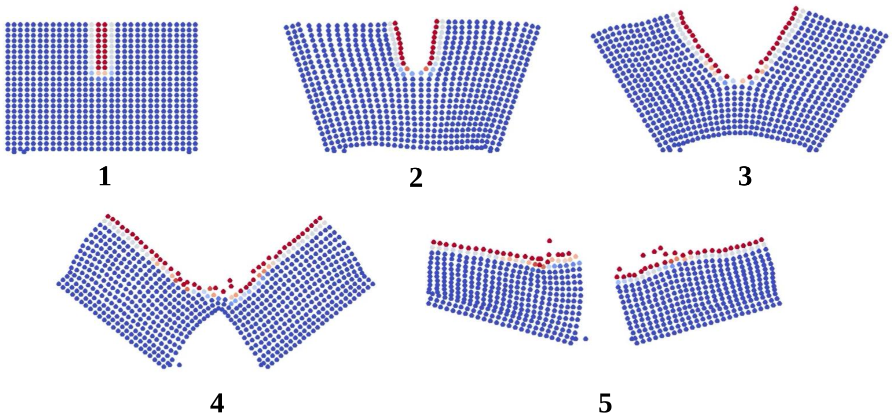

Figure 2: Crack propagation in a pre-notched plate with imposed rotation at the left and right sides

4 Conclusions

In the present work we present an alternative approach to flexible multibody dynamics where peridynamics is used to discretize the flexible body. This approach allows to incorporate fracture and crack propagation in the dynamic simulations. The authors believe this to be a significant contribution that broadens the range of application of multibody simulations. Results illustrate the potential of the methodology, in particular the capability to capture highly-nonlinear phenomena, including crack propagation, in a multibody framework.

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