The 2nd Joint International Conference on Multibody System Dynamics
May 29-June 1, 2012, Stuttgart, Germany

Efficient Modeling of Frictional Contacts with Absolute Nodal Coordinate Formulation and the Parallel GPU Implementation for Simulation of Large Flexible Body Systems

Naresh Khude[#], Dan Melanz[*], Justin Madsen[*], Dan Negrut[*], Jay Paramsothy[°]

[#]MSC Software
2300 Traverwood Drive
Ann Arbor, MI, USA, 48105
naresh.khude@mscsoftware.com

[*]Dept. of Mechanical Eng.
University of Wisconsin-Madison
1513 University Avenue,
Madison, WI, USA, 53706-1572
[melanz, jcmadsen]@wisc.edu,
negrut@engr.wisc.edu

[°] US Army Tank Automotive Research, Development and Engineering Center (TARDEC)
Warren, MI 48397
paramsothy.jayakumar.civ@mail.mil

Abstract

This contribution discusses how a Differential Variational Inequality (DVI) formulation can be used to model frictional contact between flexible bodies formulated with the Absolute Nodal Coordinate Formulation (ANCF), to simulate large flexible multibody systems. The numerically robust velocity-impulse complementarity-based solution method is used to solve the DVI problem. This allows the use of large integration step-sizes for the nonsmooth dynamics problem of frictional contacts, and thus overcomes a major drawback of the penalty based contact formulations. The results of frictional contact between the ANCF beam and plate/shell elements using DVI are compared with those obtained using the penalty based contact formulations. Furthermore, since the computational effort associated with these problems is significant, the analytical framework is implemented to leverage the computational power available on commodity Graphical Processing Unit (GPU) cards.

1. Theoretical Background

The ANCF approach, based on the nonlinear theory of continuum mechanics, has been used in many multibody systems applications [1]. Although ANCF has been an active area of research for more than a decade, little contribution has been made in the area of modeling frictional contacts with ANCF. The penalty based approach, especially the Hertzian contact model, has been used to model frictional contact between ANCF beams in [2]. The penalty based approach, though easy to implement, requires a very small integration step-size to maintain the stability and accuracy of the numerical solution. Moreover, it is always challenging to find the values of penalty parameters which minimize contact constraint violation. To overcome these drawbacks, a DVI based approach for the analysis of frictional contact problem between flexible bodies is introduced. The DVI formulation has been used in modeling frictional contact between rigid bodies in the context of simulation of granular particles in [3, 4]. In this work, this approach is extended to model the frictional contact between the ANCF beam and plate/shell elements.

The velocity-impulse based time stepping scheme used in the DVI approach is combined with a Coulomb friction model to formulate a Cone Complementarity Problem (CCP) [3]. At each time step, the solution of the CCP gives the reaction impulses for all the active contacts and generalized nodal velocities. For the case of frictionless contact the DVI formulation can be posed as a Linear Complementarity Problem (LCP) which can be easily solved using standard iterative solvers.

The conventional contact discretization schemes (e.g. node-segment, segment-segment, etc.) often used by commercial finite element codes limit the number of colliding flexible bodies which can be handled at a single time. In this work we use a spherical decomposition approach (for details see [2]), which allows for self contact and multiple contacts between the flexible bodies.

Being computationally very intensive, the DVI and ANCF methodologies stand to benefit from the use of parallel computation. In the simulation of complex mechanical systems with many flexible beams (e.g. hair or polymer simulation), the equations of motion of each beam can be solved in parallel. The computation of the nonlinear internal forces as well as the external forces can also be done in parallel at the element level. Using the spherical decomposition approach, contacts between flexible bodies can be easily detected in parallel, and the complementarity problem can also be solved in a parallel for each active contact. All these aspects are anticipated to lead to significant reductions in simulation times for large flexible body systems.

2. Preliminary Results

In this study the simulation results of frictional contact between a long flexible beam and a rigid cylinder (for details see [2]) using the DVI and penalty based approach are compared. The comparison of beam-tip coordinates is shown in Figure 1. The DVI results, obtained using larger time steps, are in good agreement with the penalty based approach. It should be noted that the penalty based approach is already validated against ABAQUS and FEAP results in [2]. The preliminary GPU scaling results are reported in Figure 2. These simulations t contain up to 270,000 flexible beams where each beam is pinned at one end and made up of 8 ANCF elements. The parallel implementation on GPU leads on average to a 250 fold speed up in simulation of this large system.

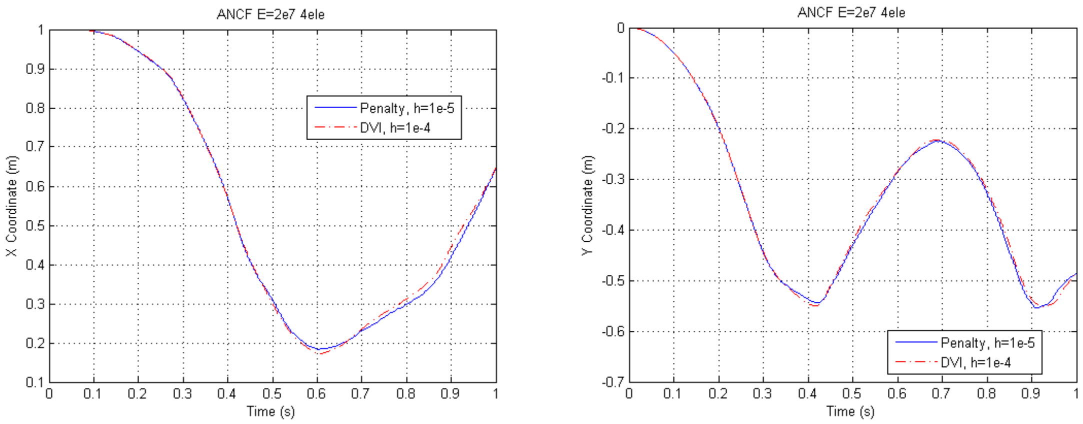

Figure 1: Global X and Y coordinate of a beam-tip (penalty-based and DVI comparison)

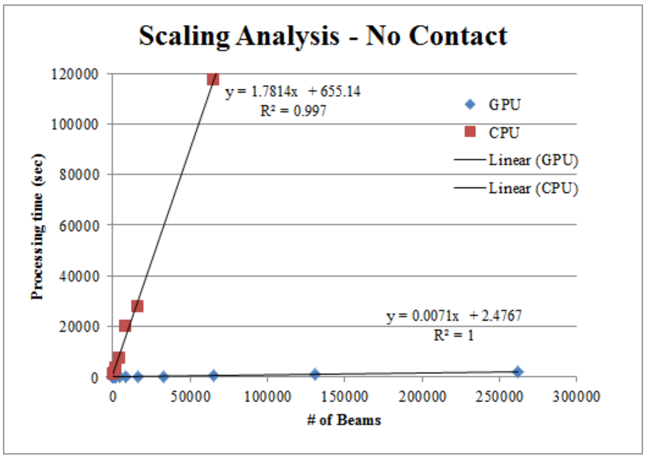

Figure 2: Processing time for the CPU and GPU implementations for ANCF beams (no contact).

The final version of the paper will report scaling results for applications which include hair simulation, where tens of thousands of ANCF beams interacting through friction and contact, and a tire-terrain interaction model, where tire belt is modeled using ANCF beam elements. Since both the collision detection and the dynamics solution will be implemented in parallel, the GPU approach proposed has the potential to increase the relevance of flexible multibody dynamics in addressing challenging real-life design problems across a spectrum of engineering disciplines.

References

1. Shabana, A.A., *Dynamics of Multibody Systems*. 3rd ed. 2005: Cambridge University Press.
2. Khude, N., D. Melanz, I. Stanciulescu, and D. Negrut. *A Parallel GPU Implementation of the Absolute Nodal Coordinate Formulation with a Frictional/Contact Model for the Simulation of Large Flexible Body Systems (DETC2011-48816)*. in *Proceedings of the ASME 2011 IDETC & CIE Conference* 2011. Washington DC.
3. Tasora, A. and M. Anitescu, *A matrix-free cone complementarity approach for solving large-scale, nonsmooth, rigid body dynamics.* Computer Methods in Applied Mechanics and Engineering. **200**(5-8): p. 439-453.
4. Tasora, A., D. Negrut, and M. Anitescu, *A GPU-based approach for simulating rigid body dynamics with frictional contact.* Journal of Multi-Body Dynamics, 2008. **222(K4)**: p. 315-326.