ECCOMAS Thematic Conference on Multibody Dynamics
June 29 - July 2, 2015, Barcelona, Catalonia, Spain

Efficient Formation and Solution of Equations of Motion for Multibody Systems with Bodies of Mixed Definition Using DCA

Jeremy J. Laflin[*], **Kurt S. Anderson**[*], **Imad M. Khan**[#]

[*]Rensselaer Polytechnic Institute
110 8th Street, Troy, NY, USA
laflij@rpi.edu, anderk5@rpi.edu

[#]Ford Motor Company
Dearborn, MI, USA
ikhan21@ford.com

Abstract

Although there has been significant progress associated with modeling and simulating dynamic systems in an adaptive manner [3, 4, 5, 6, 7, 8], which ideally considers only those degrees-of-freedom that are deemed important, there are still opportunities for significant further computational savings. Ideally, an adaptive simulation of complex systems should self identify and utilize different model types which are best suited to the nature of the local behavior of each subdomain. As such a complex system may ultimately be comprised of rigid-bodies (no deformation), flexible bodies (small deformation), and highly-flexible bodies (large deformations). A decrease in computation labor may be achieved by adjusting the definition of the computational model to best match the needs of the associated subdomain, which results in fewer degrees-of-freedom without loss in the accuracy of predicting the system's behavior.

In some cases flexible bodies may accurately reproduce the aggregate behavior of many rigid-bodies with significantly fewer degrees-of-freedom. Similarly, highly-flexible bodies can be replaced from a number of flexible bodies which all undergo small displacements, resulting in still fewer degrees-of-freedom. With intelligent internal metrics guiding adaptive adjustments in local model resolution and type, such adjustments could take place anywhere in the system. Therefore, an automatic method to form and solve the equations of motion for a system comprised of a mixture of these body/model types must seamlessly perform these operations with bodies (subdomain models) of any type. Then, aggregating various bodies into a body (subdomain) of a new type is a matter of monitoring various degrees-of-freedom, making a determination of which degrees-of-freedom to add or remove and changing the resolution of the model to reflect the desired change. The decision to add or remove various degrees-of-freedom may be based on a variety of indicators including, but not limited to, statistics collected from the degrees-of-freedom, physics-based metrics, or knowledge-based metrics.

It has been demonstrated that the DCA can form and solve the equations of motion for the state derivatives associated with a system comprised of rigid-bodies and flexible bodies undergoing small deformation. Additionally, the DCA has been used to similarly form and solve the equations of motion for systems of highly-flexible bodies where the Absolute Nodal Coordinate Formulation (ANCF) has been used to spatially model the large nonlinear deformation of the body [2]. However, the DCA cannot readily form and solve the equations of motion for systems comprised of rigid or flexible, and highly-flexible bodies where the ANCF is used to model the large deformations. This is because the ANCF formulation uses global slopes as a state variable instead of rotation coordinates and is largely incompatible with the rotation coordinates generally used with rigid-bodies and flexible bodies undergoing small deformations that are modeled with a Floating Frame of Reference (FFR) formulation, which is used in most multibody formulations [1].

This places a restriction on the type of systems simulated with the adaptive DCA framework; highly-flexible bodies must be heavily substructured and a method suitable for small deformations, such as the Floating Frame of Reference (FFR) is used to model the flexibility of each substructure. This results in an undesirable increase in the number of bodies in the system and a compounding increase in the number of degrees-of-freedom. Alternatively, special computational tools would have to be put in place to transform the state variables used with ANCF to those compatible with rigid and flexible bodies. Furthermore, implementing such tools to facilitate adaptive changes in model fidelity and definition may add significant computational burden. Therefore, the Geometrically Exact Beam Formulation (GEBF) is used to model highly-flexible bodies in the current adaptive DCA framework due to this method's ability

to correctly handle large nonlinear flexible-body deformations, while still using rotation coordinates that can be integrated more easily into the current framework.

A simple numerical example is included to demonstrate the ability of the GEBF to be used in a Divide-and-Conquer scheme to allow the formation and solution of the equations of motion for multibody systems comprised of a mixture of bodies with various definitions. This test problem will include a rigid-body, a flexible-body, and a highly-flexible body. This simple example will demonstrate that the DCA can be used to recursively assemble and disassemble the inverse inertial properties in an automatic way in the process of solving the system equations of motion for the system. The automatic assembly and disassembly of inverse inertial properties of highly-flexible bodies with those of rigid-bodies and flexible-bodies is necessary for adaptive changes in model resolution.

References

[1] O. A. Bauchau, S. Han, A. Mikkola, and M. K. Matikainen. Comparison of the absolute nodal coordinate and geometrically exact formulations for beams. *Multibody System Dynamics*, pages 1–19, 2013.

[2] I. M. Khan and K. S. Anderson. Divide-and-Conquer-Based Large Deformation Formulations for Multi-Flexible Body Systems. In *Volume 7B: 9th International Conference on Multibody Systems, Nonlinear Dynamics, and Control*, page V07BT10A002. ASME, Aug. 2013.

[3] I. M. Khan, M. Poursina, J. J. Laflin, and K. S. Anderson. A Framework for Adaptive Multibody Modeling of Biopolymers. In *ASME 2013 International Design Engineering Technical Conferences and Computers and Information in Engineering Conference. Volume 7A: 9th International Conference on Multibody Systems, Nonlinear Dynamics, and Control*. ASME, Aug. 2013.

[4] S. Morin and S. Redon. A Force-Feedback Algorithm for Adaptive Articulated-Body Dynamics Simulation. In *Robotics and Automation, 2007 IEEE International Conference on*, pages 3245–3250, Apr. 2007.

[5] M. Poursina, K. D. Bhalerao, S. C. Flores, K. S. Anderson, and A. Laederach. Strategies for articulated multibody-based adaptive coarse grain simulation of RNA. *Methods in Enzymology*, 487:73–98, Jan. 2011.

[6] M. Praprotnik, L. Delle Site, and K. Kremer. Adaptive resolution molecular-dynamics simulation: changing the degrees of freedom on the fly. *The Journal of chemical physics*, 123(22):224106, Dec. 2005.

[7] S. Redon, N. Galoppo, and M. C. Lin. Adaptive dynamics of articulated bodies. *ACM Trans. Graph.*, 24(3):936–945, July 2005.

[8] R. Rossi, M. Isorce, S. Morin, J. Flocard, K. Arumugam, S. Crouzy, M. Vivaudou, and S. Redon. Adaptive torsion-angle quasi-statics: a general simulation method with applications to protein structure analysis and design. *Bioinformatics (Oxford, England)*, 23(13):i408–i417, July 2007.