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The motion formalism for flexible multibody systems: A practical introduction

Olivier A. Bauchau, Alfonso Callejo, and Valentin Sonneville

Department of Aerospace Engineering
University of Maryland
College Park, MD, U.S.A.

This course provides a practical introduction to the analysis of flexible multibody systems based on the motion formalism. Theoretical foundations and numerical aspects will be covered. The course is intended for researchers interested in efficient simulation tools for flexible multibody systems.

The course will take place during the three days, Aug. 16–18, preceding The *ASME 2019 International Design Engineering Technical Conferences* (IDETC 2019) in Anaheim, California. A set of detailed lecture notes as well as illustrative software will be provided.

Program

When dealing with multibody dynamics, one of the core difficulties lies in the description of the kinematics of the system. The traditional approach has been to decompose motion into independent displacement and rotation fields, using the rotation tensor to represent the latter. In contrast, the motion formalism treats motion as a unified quantity. Several kinematic representations are available, such as homogeneous transformation matrices, motion tensors, dual quaternions, and screws. This unified framework comes with powerful mathematical tools that enable a deeper understanding of kinematics. All derivations can be performed without global parameterizations of motion, minimizing their importance. The motion formalism opens the door to novel, efficient numerical methods. In particular, it offers a simple and consistent way to describe rigid-body transformations, leading to the definition of frame-invariant relative motions in kinematic joints and deformation measures in flexible components. This approach also enables the formulation of frame-invariant equilibrium equations, called intrinsic equilibrium equations, that filter out geometric non-linearities. Finally, the systematic use of material frames leads to constant system matrices that reduce computation costs dramatically.

The following topics will be covered in this course:

- Motion formalism. Geometric description. Representations. Parameterizations.
- Flexible multibody formulation. Finite element approach. Intrinsic equations.
- Kinematic joints. Modal reduction. Floating frame of reference. Geometrically exact beams.
- Time integration. Domain decomposition. Parallel computing.
- Sensitivity analysis. Design optimization.

Schedule

Friday, Aug. 16 2019		
09:00	**Introduction**	Outline of the course Motivation
09:30	**Rigid body motion I**	Geometric description Derivatives
10:45	Coffee break	
11:00	**Rigid body motion II**	Representations Parameterization
12:15	Lunch break	
13:30	**Rigid body motion III**	Equations of motion Time integration
14:45	Coffee break	
15:00	**Implementation**	*Motion manipulation*
16:00	Coffee break	
16:15	**Implementation**	*Rigid body motion*
17:15		

Saturday, Aug. 17 2019		
09:00	**Kinematic joints I**	Flexible joint
10:15	Coffee break	
10:30	**Kinematic joints II**	Lower pair joints
11:45	Coffee break	
12:00	**Implementation**	*Double pendulum*
13:00	Lunch break	
14:15	**Modal superelement I**	Modal reduction
15:30	Coffee break	
15:45	**Modal superelement II**	Floating frame of reference
17:00	Coffee break	
17:15	**Implementation**	*Rotating beam*
18:15		

Sunday, Aug. 16 2019		
09:00	**Geometrically exact beam I**	Kinematics Equations of motion
10:15	Coffee break	
10:30	**Geometrically exact beam II**	Finite element interpolation
11:45	Coffee break	
12:00	**Implementation**	*Rotating beam*
13:00	Lunch break	
14:15	**Sensitivity analysis**	Direct method Adjoint method
15:30	Coffee break	
15:45	**Implementation**	*Design optimization*
16:45		

Suggested literature

[1] O. A. Bauchau, A. Callejo, S. L. Han, and V. Sonneville. *The Motion Formalism for Flexible Multibody Dynamics*. 2018. Course notes.

[2] Andreas Müller. Screw and lie group theory in multibody kinematics. *Multibody System Dynamics*, pages 1–34, 2017.

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[4] V. Sonneville, A. Cardona, and O. Brüls. Geometrically exact beam finite element formulated on the special Euclidean group SE(3). *Computer Methods in Applied Mechanics and Engineering*, 268(1):451–474, 2014.

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[8] O. A. Bauchau. *Flexible Multibody Dynamics*. Springer, Dordrecht, Heidelberg, London, New-York, 2011.

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[12] R. M. Murray, Z. Li, and S. S. Sastry. *A Mathematical Introduction to Robotic Manipulation*. CRC Press, 1994.

[13] M. Géradin and A. Cardona. Kinematics and dynamics of rigid and flexible mechanisms using finite elements and quaternion algebra. *Computational Mechanics*, 4:115–135, 1989.

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