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“A geometric local frame approach for flexible multibody system dynamics”

The notion of frame is ubiquitous in the kinematic description of flexible multibody models. In this work, a differential-geometric framework is selected to describe frame operations in a rigorous and systematic way. A frame transformation is thus seen as an element of the special Euclidean group SE(3), which can be represented by a four by four transformation matrix, and frames operations, such as spatial interpolation or time integration, rely on non-linear but analytical expressions in which translation and rotation contributions are inherently coupled. Based on this formalism, geometrically exact formulations of many classical components used in flexible multibody system modelling, including the rigid body, kinematic joints, a flexible beam, a flexible shell, corotational elements and a super-element, have been developed.

As opposed to most popular techniques in the literature, a local frame representation of the equations of motion is adopted in this work. This means that the unknown kinematic variables such as the motion increments, the velocities and the accelerations, as well as the generalized forces are all expressed in a local frame attached to the body. Such quantities are naturally reached by working with the left invariant vector field on SE(3). The spatial semi-discretization of the equations of motion into finite elements is performed using appropriate differential-geometric tools, such that the non-linear and non-commutative nature of the configuration space is consistently accounted for. After spatial semi-discretization, the equations of motion of a multibody system take the form of differential-algebraic equations on a Lie group which can be conveniently solved in a global parametrization-free approach using a Lie group integration scheme.

Numerous arguments to recommend this framework for the development of efficient codes for the numerical simulation of flexible multibody systems are presented. On the one hand, the proposed framework leads to interesting analytical aspects. For instance, it features a naturally singularity-free description of large rotations and it leads to inherently shear-locking free beam and shell finite elements. On the other hand, the formulation leads to efficient computational properties. The geometric non-linearities are naturally filtered out of the equilibrium equations such that non-linearities are significantly reduced, as compared to classical formulations. In particular, the iteration matrix, which is used in implicit integration schemes, is insensitive to overall large amplitude motions and is only affected by local relative transformations, such as deformations in flexible elements and relative motions in kinematic joints.