Toward Optimization of Flexible Multibody Systems: How to Open the Simulation Black Box?

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Detailed simulations of flexible multibody systems are currently exploited in many application fields including robotics, automotive systems, aeronautics, deployable structures or wind turbines. The description of rigid and flexible bodies, the kinematic constraints at the joints and the dynamic interactions with control systems lead to a formulation of the equations of motion as strongly coupled and nonlinear differential-algebraic equations (DAEs). Using state-of-the-art numerical techniques, see [1, 2], the dynamic response of a given system can be evaluated in the time-domain with a high fidelity for given load cases and given initial values.

However, in many practical cases, the engineer does not have a precise knowledge of the mechanical design, the loading conditions and the initial state. This situation occurs for example in structural optimization, optimal control, experimental identification and health monitoring problems. The formulation of these optimization problems require a dynamic model of the system and involve a potentially high number of design variables. The solution can be obtained using gradient-based optimization techniques provided that the sensitivities of the dynamic response can be efficiently evaluated.

In this context, one cannot expect satisfactory performances if the sensitivities are computed by finite differences from black box simulation runs since the computation cost would then grow fast with the number of design variables. In contrast, acceptable performances can be expected using semi-analytical sensitivity analysis techniques such as the direct differentiation or the adjoint variable method. However, those methods are usually not available in high-fidelity simulation packages and an important obstacle for their implementation comes from the complexity of the dynamic model formulation.

A current challenge is thus to elaborate simplified and more efficient modelling strategies in flexible multibody dynamics in order to enable efficient computation of sensitivities for the resolution of large scale optimization problems. For that purpose, we propose to follow a Lie group approach for the formulation and the resolution of the equations of motion in a parameterization-free setting. This approach not only leads to an intrinsic representation of the motion but it also significantly simplifies the treatment of large rotations and of geometric nonlinearities when modelling flexible multibody systems. We show that sensitivity analysis algorithms can then be efficiently developed and implemented, which opens new perspectives for the optimization of 3D flexible multibody systems.

References

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