Real-time multibody simulations based on a symbolic erosion process

Marine Boxus, Paul Fisette, Nicolas Docquier

Institute of Mechanics, Materials and Civil Engineering
Université catholique de Louvain
Pl. de l'Université 1, 1348 Ottignies-Louvain-la-Neuve, Belgium
[marine.boxus, paul.fisette, nicolas.docquier]@uclouvain.be

Abstract

The availability of real-time or fast multibody models is currently a growing need for many scientific and industrial applications. This ranges from the optimisation of walking robots [3] whose algorithmic convergence requires thousands of simulations, to the hardware-in-the-loop control of a railway vehicle semi-active suspension [2]. In this context, the symbolic Robotran software [1] makes the most of the recursive form of the equations to generate the dynamic models of - tree-like or closed loop - multibody systems (MBS) in the most concise way. The goal now is to develop a process uncovering and removing the symbolic equations that have a low impact on the targeted results. We name this process: symbolic erosion. A preliminary result is presented to illustrate the principle and the potential of the method.

The Robotran software, developped at UCLouvain, is capable of formulating symbolically the dynamic equations of large MBS using relative joint coordinates. It is based on the Newton-Euler recursive scheme and the coordinate partitioning technique to produce a single list of interdependent symbolic equations stored in a unique computer function [1]. The latter computes the relative accelerations in each joint, $\ddot{q}$, from their given positions, q, velocities, $\dot{q}$, and external forces/torques applied to the MBS (Fig. 1). At this level, the model has already been highly condensed by Robotran using standard symbolic simplifications such as null multiplication/addition, trigonometric formulae, etc.

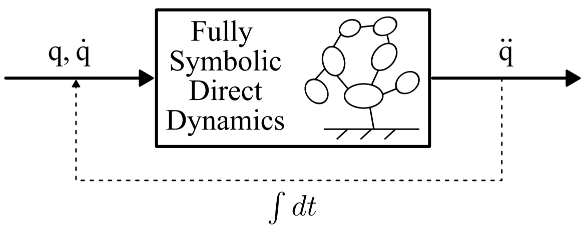

Figure 1: The direct dynamics of - tree-like or closed loop - MBS is computed symbolically by Robotran as a unique function ready for time integration.

Despite the existence of other effective formulations (ex: using barycentric quantities or based on an Order N recursive scheme, etc.), it is no longer possible to significantly simplify the model in terms of arithmetic complexity. Therefore the idea is to uncover, among all recursive equations ($\sim$10000 for a 34 dof railway vehicle), those with negligible impact on the accelerations $\ddot{q}$ (and thus on the subsequent simulations and analysis). It is worth noting that the resulting so-called *eroded* model will depend on the study case. For instance, odometry focuses on the train longitudinal behavior, stability results from lateral motion whereas comfort considers the carbody vertical response. Each situation can benefit from its own equational erosion. In other words, rather than relying on physical considerations to eliminate negligible terms, such as low Coriolis acceleration or low inertia product of bodies, we propose to flesh out the current Robotran symbolic engine with this erosion process (Fig. 2).
Starting from the original symbolic model (Step 1), the erosion process relies on a first numerical step quantifying the errors incurred by the removal of recursive equations. This error is computed for a large and/or randomized set of initial conditions representative of the study case (Step 2). On the basis of an error leniency, the targeted equations can be removed and the symbolic eroded model can be regenerated by Robotran (Step 3).
The method is currently tested on abstract MBS made of either series or parallel topologies. The last one is shown in figure 3 with preliminary results: the erosion process highlights two sets of equations: those with little influence ($\sim$ 30%) and those ($\sim$ 5%) which clearly have no impact on the MBS dynamics.

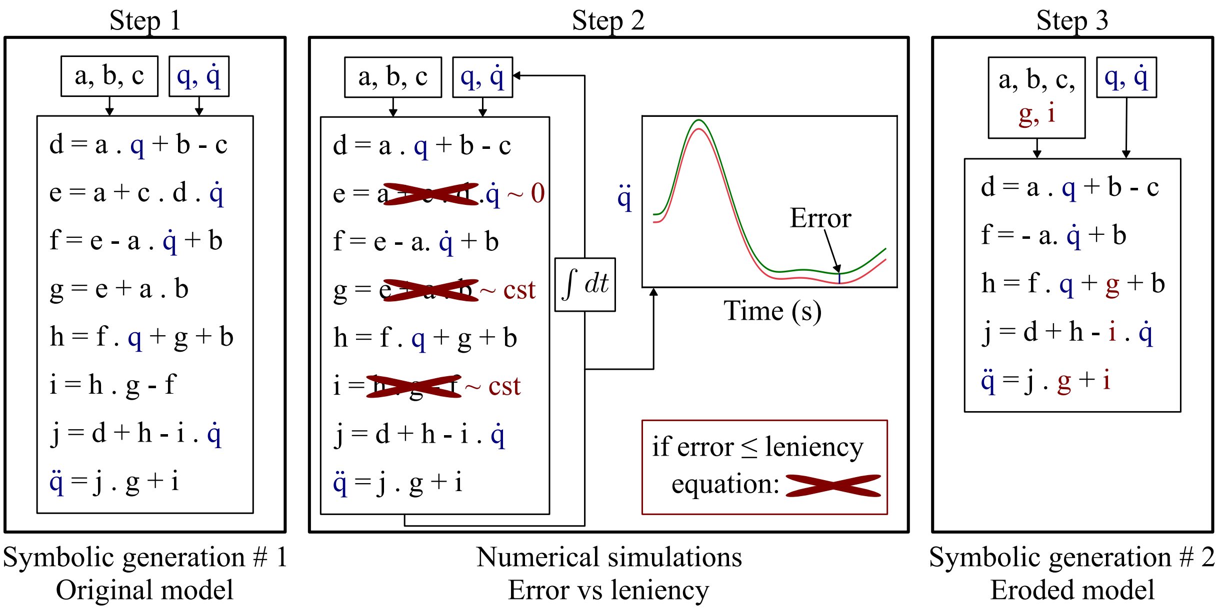

Figure 2: Erosion process: symbolic elimination of limited impact equations.

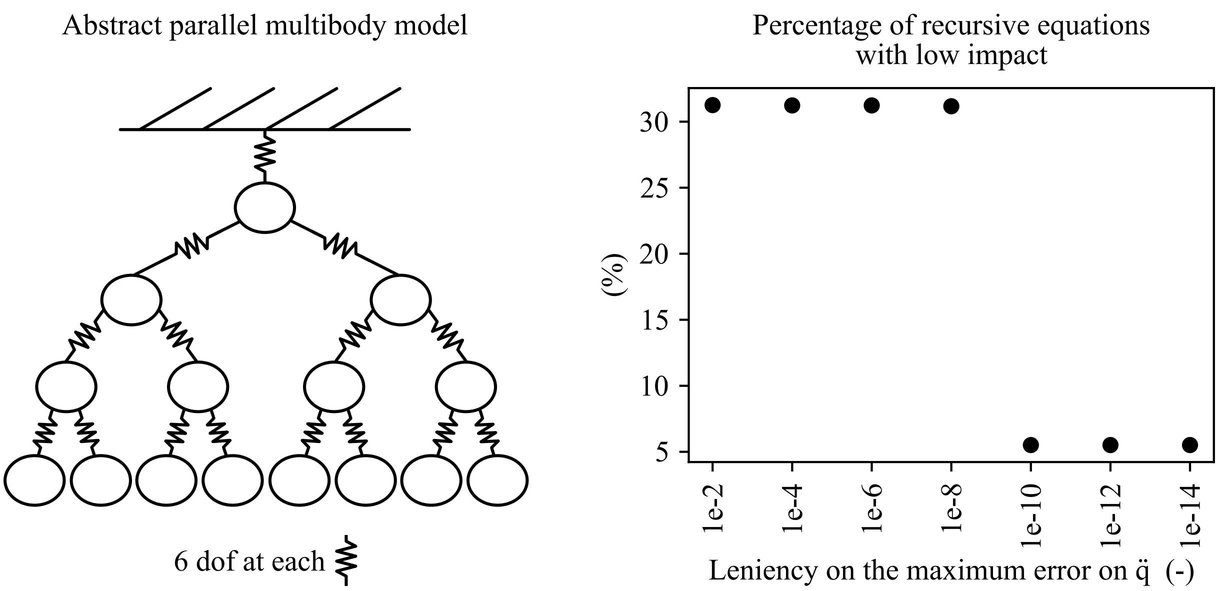

Figure 3: The erosion process applied on a 90 dof parallel MBS highlights that 30% of the equations can be reasonably discarded.

This research aims to push the symbolic capacities to its limits in order to condense models according to a prescribed error leniency. It uncovers and erodes the equations of the original model which will of course retain its role as a reference model for the entire study. As our intended applications are in the railway domain, the oral presentation will show the simulation results and the performances of the erosion process for a 3D railway vehicle of 34 degrees of freedom. In the next future, the eroded real-time version of the model will feed hardware-in-the-loop applications, as carried out in [2].

References

[1] Docquier, Nicolas ; Poncelet, Antoine ; Fisette, Paul. ROBOTRAN: a powerful symbolic generator of multibody models. In: Mechanical Sciences, Vol. 4, no. 1, p. 199-219 (2013)

[2] Fu, B., Di Gialleonardo, E., Liu, B., Bruni, S. Modelling, hardware-in-the-loop tests and numerical simulation of magneto-rheological semi-active primary suspensions in a railway vehicle. In: Vehicle System Dynamics, 62(6), 1471–1494. (2023)

[3] Van der Noot, Nicolas. Rich and robust bio-inspired locomotion control for humanoid robots. Prom. : Ronsse, Renaud ; Ijspeert, Auke (2017)