A New Unified Integration Scheme for the Simulation of Multibody and Hydraulic Dynamics

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1. Introduction

Several years ago, the authors proposed a method for the efficient simulation of the dynamics of multibody systems [1]: the modeling of the system was carried out in natural or fully-Cartesian coordinates (dependent and absolute coordinates), the equations of motion were stated as an index-3 augmented Lagrangian formulation, the numerical integration was performed through Newmark-type algorithms, and the resulting velocities and accelerations were projected into their corresponding constraint manifolds. The formalism showed to be robust and efficient: it worked properly in mechanisms with singular configurations or changing topologies, and provided successful results for large and complex industrial problems, like the detailed models of cars and excavators. Some years later [2], the method was extended so as to consider the modeling in joint coordinates (dependent and relative coordinates), taking advantage of the recursive kinematics and dynamics allowed for such an approach, which led to a method with improved efficiency for large systems.

Hydraulic actuators play a relevant role in many industrial fields, like heavy machinery, aircraft or entertainment [3], [4]. A common simplified technique to include the behaviour of hydraulic actuators within simulations of multibody dynamics consists of kinematically guiding the variable length corresponding to the distance between the ends of the hydraulic actuator [5]. The guidance law which provides the actuator length as function of the driving inputs (provided by, let's say, the machine operator) may be just a linear mapping or may account for force or speed limitations and other characteristics of the real power system.

However, a more detailed modeling is required when the hydraulic dynamics of the actuators should be taken into account [6], [7]. This can be done through linearized or fully nonlinear differential equations, depending on the level of detail required in the solution. When addressing the nonlinear approach (pressures in the hydraulic chambers are coupled with the system motion), two different methods have been followed. The first one combines the hydraulic and multibody dynamic equations, thus yielding a unified system of differential equations which is integrated in time by means of a single integration scheme [8], [9]. The second one applies co-simulation, so that each problem is separately solved by means of a different integration scheme, and information is exchanged between the two processes: typically, the multibody problem leads the solution process, since its lower stiffness allows for larger time-step sizes [7], [10]-[13].

2. The new integration scheme

In this work, the first method is applied: both the hydraulic and multibody dynamic equations are combined within the formalism described in the first paragraph in a unified approach. The resulting formalism is developed, and the raised numerical issues are discussed.

Three simulations of an academic example are performed, which serve to compare the complexity and efficiency of the proposed method with two other solutions, obtained by simulating the system with traditional schemes: the simplified method (kinematic guidance) on the one hand, and the co-integration of the hydraulic piston dynamic equations and the multibody dynamic equations in a multi-rate scheme.

The kinematic guidance is imposed by including a rheonomic constraint in the constraints vector. This new constraint reads the positions of the actuator obtained through the unified scheme so that the motion of the system is replicated. Comparison between both approaches shows the additional time required by the unified scheme, which can be seen in Table 1.

In the multi-rate scheme, the integration of the multibody system leads the integration with a time-step size of 10 ms. The hydraulic equations are integrated with a time-step size of 0.1 ms, employing a forward Euler integration scheme under the assumption that the elongation speed of the actuator remains constant between two steps of the multibody integration. Comparison between this approach and the unified scheme enables to assess the accuracy and efficiency of the latter. The histories obtained through both methods for the pressures and elongation of the actuator show a good agreement.

Table 1: CPU-times for the compared approaches.

Simulation	**CPU-time (s)**
Kinematically guided	0.338
Unified integration	0.389
Multi-rate integration	11.634

3. Conclusions

At the view of the results, the following conclusions can be established:

- The augmented Lagrangian formulation traditionally used to address multibody dynamics problems, conserves its robustness when facing combined multibody and hydraulic dynamics problems in a unified approach. For the academic example studied, a large time-step size of 10 ms could be taken while keeping good convergence properties in spite of the hydraulic equations stiffness.
- The increase in computational cost motivated by the inclusion of the hydraulic equations when compared with the simplified modeling of the hydraulic problem through kinematic guidance of the actuators is moderated (about a 20% in the considered example), and due mainly to the larger resulting problem size and the non-symmetric character of the approximated tangent matrix. Therefore, it can be affirmed that the efficiency is not substantially altered when moving from a simplified to a detailed approach.
- The unified approach is largely more efficient than the multi-rate co-integration scheme due to the lower number of evaluations of the hydraulic equations required. However, discrepancies between the solutions provided by both methods are not relevant.

4. References

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