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Comparison of Integration Methods for Real-Time Capable Multibody Simulation of an Elastokinematic Wheel Suspension System

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Abstract

Virtual development methods are becoming increasingly important. Physical prototypes are replaced by virtual prototypes in order to continuously verify the design of technical systems. Decisions in the development process can thus be made more quickly and in a more targeted manner. This requires valid simulation models that represent the system behavior with sufficient accuracy. Also in the vehicle dynamics development for passenger vehicles, virtual methods are gaining importance. In addition to quantifiable evaluation criteria, the subjective evaluation plays a decisive role regarding driving characteristics. Testing with driving simulators is therefore the key to extensive virtualization. For this, vehicle dynamics models do not only have to be accurate but also have to satisfy hard real-time requirements for usage in driving simulators.

Multibody simulation (MBS) models are well suited to represent driving characteristics in terms of lateral, longitudinal and vertical dynamics. MBS models of wheel suspensions represent the suspension topology in detail. They consist of several bodies, connected by idealized joints or force elements representing the functional properties of components such as springs, dampers and bushings. In wheel suspension systems of passenger vehicles, the bodies are usually connected by elastic bushings. They are specifically designed to tune the elastokinematic properties for better driving characteristics. However, their stiffness and damping properties in combination with the low inertia of the suspension rods lead to high eigenfrequencies. In contrast, other eigenfrequencies of, for example, the wheel travel is much lower in comparison. This leads to a high numerical stiffness of the system's differential equation.

Real-time capable integration of numerically stiff systems can be challenging. On the one hand, explicit integration methods are usually well suited for real-time applications due to their a-priori known computational effort. However, their stability and accuracy is limited for numerically stiff systems. On the other hand, implicit methods have better stability properties but their computational effort can be too high for real-time requirements. An alternative for stable and real-time capable integration of numerically stiff systems are linear-implicit integration methods. Such a method is the linear-implicit Euler method [3, 6]. It is based on the implicit Euler method and utilizes the linearized form of the equation of motion. Its key feature is that only a linear equation has to be solved in each integration step instead of a nonlinear equation. Its solution can be achieved with less computational effort in an a-priori known time. Thus, the linear-implicit Euler method can enable real-time capability. However, its accuracy is limited in complex applications [2]. Higher accuracy can be achieved with Rosenbrock-Wanner methods or W-methods. They are the linear-implicit form of Runge-Kutta methods, where in W-methods, in contrast to Rosenbrock-Wanner methods, the Jacobian of the differential equation is approximated [5]. The linear-implicit Euler method can also be seen as a special case of these methods [2].

Recently, Kim et al. [4] proposed a non-iterative HHT-α integrator for real-time analysis of multibody systems. It is based on the conventional implicit HHT-α integrator. Similar to the formerly mentioned linear-implicit methods, the linearized representation of the equation of motion is utilized to achieve a non-iterative integration procedure. Accuracy and stability of the proposed method are analyzed in [4] using simple test systems with high damping or stiffness properties and a non-linear double pendulum system.

This contribution presents a real-time capable MBS model of a representative double wishbone front suspension of a passenger vehicle. The model is implemented in Matlab/Simulink. Due to the model

topology and the representative parameter values, this large scale multibody system exhibits a high numerical stiffness. A former version of the model was shown in [1], where the equation of motion was integrated with the linear-implicit Euler method. The focus of this contribution is to compare the accuracy of the non-iterative HHT-α integrator recently proposed in [4] and of different W-methods for such a complex MBS system. To this end, dynamic suspension tests are performed. Load cases are derived from representative full vehicle maneuvers. Furthermore, artificial load cases in the form of wheel force frequency sweeps and step inputs are considered. Simulation results obtained with an implicit stiff differential equation solver available in Matlab/Simulink serve as a reference for the accuracy analysis. Based on the time histories of the wheel motion and of characteristic forces, error values are calculated and compared. Computation times for the different integration methods are compared and approaches to reduce them are discussed. It is shown that the considered integration methods can achieve higher accuracy than the linear-implicit Euler method without increasing the computational costs.

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