Real-Time Multibody Simulation of Vehicle Wheel Suspensions of Different Topologies with Elastokinematic Properties

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EXTENDED ABSTRACT

The wheel suspension significantly influences the driving characteristics of passenger vehicles. It guides the wheel relative to the vehicle body and thus defines the wheel position. The wheel position in turn determines the tire forces acting on the vehicle in longitudinal, lateral and vertical direction. In vehicle technology, a variety of wheel suspension concepts with different topologies has emerged [1]. The wheel position is influenced not only by the kinematics, but also by the elastokinematics of these wheel suspensions. The bodies of wheel suspensions are often connected by elastic rubber bearings [1]. Thus, wheel suspensions have some compliance under the influence of external forces. This results in additional wheel position changes that are superimposed on the purely kinematic guidance of the wheel. An important part of vehicle dynamics development is therefore the design of the elastokinematics. The design aims either to compensate the resulting wheel position changes or to convert them into desired wheel position changes to increase ride comfort and safety [1].

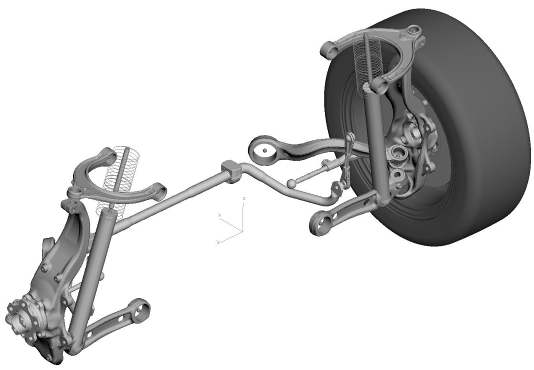

Figure 1: Multibody simulation model of a double wishbone front suspension

Virtual methods are becoming increasingly important in vehicle development. They enable a faster, more targeted and cost-effective development process. This also includes vehicle dynamics development. With multibody simulation models as in Figure 1, the movement of the wheel suspension and the acting forces are calculated. This information is used for the design of the suspension and its components. However, the driver's assessment of driving characteristics is very subjective. Therefore, driving simulators play a key role for further virtualisation of the vehicle dynamics development. Vehicle dynamics models for such real-time applications are often simplified in order to meet the required computation times. The simplifications often include the elastokinematic properties of the wheel suspension. In order to extend the validity of driving simulators and thus their applicability in the development process, vehicle dynamics models without simplification of their elastokinematic properties are therefore desirable.

Real-time multibody simulation of wheel suspensions considering their elastokinematic properties is challenging because of the high numerical stiffness of the underlying equation of motion. An equation of motion, or a differential equation in general, is numerically stiff if its eigenvalues have widely varying magnitudes. This means that the system is described by dynamics on different time scales. Rubber bearings usually have high stiffness and damping properties. This results in high-frequency and/or strongly damped motions of the relatively light bodies of the wheel suspension. In contrast, the dynamics of the wheel travel motion is slow. The correspondingly numerically stiff equation of motion is challenging in terms of real-time numerical integration. Explicit numerical integration methods usually fail because of limited stability properties. Implicit integration methods often have too high computational cost because they require the iterative solution of a system of nonlinear equations.

In literature, there are a couple of approaches for real-time simulation of wheel suspensions with particular focus on their elastokinematics. These include, for example, the description of the wheel suspension as a macro joint [2], a quasi-static approximation of the fast movement of light bodies [3], or reducing the stiffness of rubber bearings through additional stiffnesses and dampings [4]. In these approaches, the dynamics and/or elastokinematics of the wheel suspension are modified or simplified. Alternatively, non-iterative implicit integration methods can be used for real-time capable integration of numerically stiff equations of motion without prior model simplification. Such methods are, for example, the linear-implicit Euler method, W-methods or the non-iterative HHT-α-method [5, 6]. Instead of a system of nonlinear equations, only a system of linear equations must be solved here. This is possible with non-iterative methods which require comparatively less effort. For example, the linear-implicit Euler method is used for real-time integration of a vehicle dynamics model with a flexible vehicle body [7]. However, the wheel suspensions in this model are modeled without considering their elastokinematic properties.

In this contribution, we present a multibody simulation model for real-time simulation of the elastokinematics and dynamics of wheel suspension systems. Nonlinear bushing force elements are used to model the rubber bearings. In addition to the rubber bearings, the considered wheel suspensions have only a few ideal joints. They are replaced by appropriately parameterized bushing force elements. Thus, the equation of motion is formulated as a nonlinear ordinary differential equation. Furthermore, all bearing and joint forces and thus the loads acting on the component are directly calculated. The model is implemented in Matlab/Simulink. The underlying data model is table-based. Besides the numerical model parameters, the information about the model topology is also stored in the tables. Together with the model implementation, it is easily possible to simulate suspension systems of different topologies. For this purpose, only the parametrization of the model must be changed; a change of the actual model implementation is not necessary. In this contribution, we consider a double wishbone front suspension (see Figure 1) and a multi-link rear suspension as examples. For numerical integration of the numerically stiff equation of motion, non-iterative implicit integration methods are used. They enable real-time simulation of the elastokinematics and dynamics without requiring model simplifications. In previous studies, the integration method LSRT2 has been found to be a good compromise between accuracy and real-time capability [8]. Both considered suspension topologies can be simulated in real-time on a conventional PC. It is shown that computation times are further reduced if the suspension topology is explicitly taken into account when solving the system of linear equations of the integration method. The presented approach leads to an efficient treatment of this multibody simulation problem, which can also be applied to other multibody systems, such as robot structures.

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