Guest Editorial

Special Issue: Multibody Dynamics for Vehicle Systems

It is our pleasure to present this special issue on Multibody Dynamics for Vehicle Systems containing 14 papers that span diverse topics from quad rotor parameter estimation, soft soil mobility, automotive tire models, railway vehicles, traffic flow stability and seating comfort, real time simulations and vehicle model reduction, and sensitivity analyses for design optimization.

Vehicle systems have represented the primary area of interest and application in the multibody dynamics community for a very long time. The complexities and diversity of such systems provide rich platforms for the development of new modeling theory and techniques, new computational approaches and methodologies, and new research directions in general. The literature accumulated over the years in treating various aspects of vehicle systems in a multibody dynamics context is vast and broad in topics covered. While it is not feasible to aim at creating a comprehensive volume of multibody dynamics studies for vehicle systems, by putting together this special issue, the editors would like to bring into the spotlight current related research efforts and advanced approaches. Thus, a collection of high quality technical papers discussing state-of-the-art research in multibody dynamics investigations, methods, algorithms, and other scientific tools with direct applications to a variety of vehicle systems is presented here. It is interesting to notice the wide range of vehicle systems applications, as well as the research needs identified as future directions for each of them.

An important aspect in transportation, which has not been typically addressed in a multibody dynamics framework, is the traffic flow stability. This topic is addressed in this special issue in the paper “Model and Stability of the Traffic Flow Consisting of Heterogeneous Drivers,” which focuses on model and stability analysis of the heterogeneous traffic flow including drivers with characteristics such as sensitivity and cautiousness. A homogeneous optimal velocity car-following model is developed into a heterogeneous form to describe the heterogeneous traffic flow including the four types of driver. The simulations reveal which drivers are the most unstable or the most stable. The simulations also indicate that the wider extent of the driver heterogeneity can attenuate traffic wave.

One of the most complex and important vehicle subsystems is the tire. In this special issue, two studies focus on tire models. The paper “A Consistent, Hybrid-Dynamical-System, Lumped-Parameter Model of Tire-Terrain Interactions” establishes the internal mathematical and energetic consistency of a hybrid-dynamical-system, lumped-parameter, planar, physical model for capturing transient interactions between an elastically deformable tire and an elastically deformable terrain. The analysis characterizes generic transitions between distinct phases of contact uniquely in forward time and proves that all internal state variables remain bounded during compact intervals of contact.

The behavior of the model is further illustrated through an analytical and numerical study of two instances of tire-terrain interactions under steady-state condition. In the paper “Longitudinal Tire Dynamics Model for Transient Braking Analysis: ANCF-LuGre Tire Model,” a flexible tire model based on the in-plane ANCF elastic ring tire model is integrated with LuGre tire friction model for evaluation of the longitudinal tire dynamics under severe braking scenarios. The ANCF-LuGre tire model developed allows for considering the nonlinear coupling between the dynamic structural deformation of the tire and its transient tire force distribution in the contact patch using general multibody dynamics computer algorithms. Several numerical examples are presented to demonstrate the use of the in-plane ANCF-LuGre tire model for the longitudinal transient dynamics of tires under severe braking scenarios.

For systems operating in soft soil conditions, the simulation must also account for the properties of the terrain. Illustrating the incorporation of semi-empirical terramechanics models in multibody dynamics environments, this special issue includes the paper “A Multibody Dynamics Framework for Simulation of Rovers on Soft Terrain.” For every wheel in contact with soft soil, unilateral contact constraints are added to the solver in both the normal and the tangent plane. The forces associated with the tangent plane are formulated as set-valued functions, where their properties are determined by deregularization of semi-empirical terramechanics relations. This leads to the dynamics representation in the form of a linear complementarity problem, based on which stable simulation of rovers is achieved.

Real-time simulations and improved computational efficiency of simulations for vehicle dynamics represent the focus of many studies. This special issue contains three papers that investigate this topic. The paper “Real-Time Dynamic Simulations of Large Road Vehicles Using Dense, Sparse and Parallelization Techniques” presents three multibody formulations with improved efficiency in order to achieve real-time simulations for the forward dynamic of two real-life road vehicles. Two topological and semi-recursive formulations are used, as well as a global formulation based on the use of Euler parameters and flexible joints. In the paper “Validation of a Real-Time Multibody Model for a X-by-Wire Vehicle Prototype Through Field Testing,” the experimental validation of a real-time vehicle multibody model with rigid bodies is described. Two low-speed maneuvers involving the longitudinal and lateral vehicle dynamics have been performed several times also have been simulated with the multibody model, in a simulation environment using inputs measured experimentally. The results of the comparisons show good correlation between simulation predictions and experimental data, thus allowing to extract useful guidelines to build accurate real-time rigid-body models of vehicles. The paper “Reduction of Multibody Dynamic Models in Automotive Systems Using the Proper Orthogonal Decomposition” discusses an approach for improving computational efficiency through model reduction using proper orthogonal decomposition. Interesting results are presented that compare the reduced model with higher fidelity models of the nonlinear vehicular system. The
paper also discusses computational savings achieved by using this approach to reduce the complexity of the vehicle model.

Sensitivity analysis and design optimization are currently very active research directions. This special issue presents two studies on these topics. The paper “Sensitivity-Based, Multi-Objective Design of Vehicle Suspension Systems” describes the dynamic response optimization of mechanical systems, based on the computation of independent state sensitivities. The dynamic behavior of a coach is analyzed in detail so as to improve its response in terms of handling and ride comfort behaviors. To that end, the coach is modeled as an 18 degree-of-freedom multibody system, whose equations of motion are posed using an efficient semirecursive formulation based on Maggi’s equations. A direct-automatic differentiation formulation for the computation of design and state sensitivities is developed. Handling and ride comfort objective functions are defined and used to carry out a multi-objective suspension design optimization process, substantially and efficiently improving the vehicle response. The paper “Dynamic Response Optimization of Complex Multibody Systems in a Penalty Formulation Using Adjoint Sensitivity” presents a gradient-based optimization performed in order to find local minima. The adjoint sensitivity approach of multibody systems in the context of a penalty formulation is developed. The new theory is demonstrated on a five-bar mechanism and on a 14 degree-of-freedom vehicle model. The new approach is shown to perform sensitivity analysis and optimization for large and complex multibody systems with respect to multiple design parameters with high efficiency.

Parameter estimation is very important when direct measurements are not feasible. In the paper “Hybrid Low-Cost Approach for Quadrotor Attitude Estimation,” a new approach to estimate the orientation of a quadrotor using single low-cost IMU sensor is introduced. The proposed hybrid solution uses two extended Kalman filters with a Direction Cosine Matrix algorithm. The performance of the proposed hybrid approach is tested and compared with other commonly used methods. The results show an improvement in the estimated quadrotor’s state.

The paper “Development of a Multibody Model to Predict the Setting Point and Interfacial Pressure Distribution in a Seat-Occupant System” discusses improvements on a previous model for seat static comfort analyses using the hip-joint (H-Point) location to calculate force distributions on the seating foam. The seating foam model is improved by modeling it using a series of discrete nonlinear viscoelastic elements. The nonlinearity is modeled using higher order polynomials using experimentally obtained parameters. The interface loads are calculated from the foam model and H-Point location of the occupant’s multibody model. Qualitative comparison between experimental and model-based force distributions is presented.

Among vehicle systems, railway vehicles form a significant category. This special issue contains three railway vehicles studies. In the paper “Parameters Study of Hopf Bifurcation in Railway Vehicle System,” a roller rig is employed to compare the characteristics of Hopf bifurcation for two railway vehicles. A suspended railway wheelset model with lateral and yaw degrees-of-freedom was used. The continuation method is used to study the features of bifurcation of the railway vehicle system. According to the study results, the characteristic of bifurcation changes with the variation of parameters significantly, such as the longitudinal stiffness of primary suspensions, equivalent conicity, spin moment of inertia of wheelset, and axle loads of railway vehicle. A cross region of parameters is found, where the type of Hopf bifurcation is very sensitive to the parameters, and will transform from one type of Hopf bifurcation to another with the variation of parameters during practical railway operation. In the paper “Development of Vehicle Dynamics Simulation for Safety Analyses of Rail Vehicles on Excited Tracks,” a simulation model to calculate the rocking of vehicle and the guardrail work to prevent derailment in time of large earthquake is developed. A simple vehicle track model represents the rocking mechanism. The simulation results were validated experimentally, concluding that the simple guardrail model sufficiently represents the dynamic interaction of wheel/guard rail. In the paper “On the History of Lateral Ground Vehicle From a Multibody Dynamics View,” the historical development of modeling approaches for lateral vehicle dynamics in the context of multibody dynamics techniques is presented. It is shown that simplified models are very useful as benchmarks for checking more complex systems, too.

We would like to thank the authors for submitting their work to this special issue. We also thank our reviewers for their time and effort, as well as the journal staff for their dedication and support in preparing this issue. Special thanks go to Professor Ahmed Shabana, the Editor of the journal, who provided us with guidance and support throughout the process.

We hope that the readers will find this special issue timely and welcome, that they will enjoy the articles presented, and that these excellent studies will spark new ideas and open new frontiers in the world of multibody dynamics for vehicle systems.

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