Real-time modelling of vehicle's longitudinal-vertical dynamics in ADAS applications

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Abstract. We develop an efficient vehicle multibody model for longitudinal-vertical dynamics used in ADAS applications. The dynamic properties of the chassis, suspensions, and tires are considered and modelled, which results in accurate vehicle dynamics and states. This vehicle system is modelled using a semi-recursive multibody dynamics formulation, the vehicle kinematics and dynamics are obtained accurately via the system tree-topology. In addition, a fork-arm removal technique is proposed to reduce the number of bodies, relative coordinates, and loop-closure constrained equations. Finally, the dynamic simulations of the vehicle are performed on the bumpy and slope roads. The numerical results are compared with the reference data both in accuracy and efficiency. The comparative results verify the effectiveness of the proposed vehicle model.

Introduction

In recent years, several advanced driver assistance systems (ADAS) have been studied in terms of ride comfort, transportation safety, and efficiency. These ADAS applications require accurate and efficient vehicle models to acquire vehicle states and dynamic responses that can be used for intelligent control. In addition, vehicle multibody models must run robustly and in real-time on hardware with limited memory. For this reason, it is crucial to develop efficient multibody modelling techniques for autonomous vehicles.

Modelling of Vehicle Coupling Dynamics

The longitudinal-vertical dynamics of an autonomous vehicle is modelled using an efficient semi-recursive multibody method. This 7-DOF vehicle model based on the sophisticated 14-DOF model is created to reduce the size and complexity of the vehicle system for greater efficiency and its motion equations can be written as

$$\mathbf{R}_{\mathrm{z}}^{\mathrm{T}}\mathbf{R}_{\mathrm{d}}^{\mathrm{T}}\mathbf{M}^{\Sigma}\mathbf{R}_{\mathrm{d}}\mathbf{R}_{\mathrm{z}}\ddot{\mathbf{z}}^{i} = \mathbf{R}_{\mathrm{z}}^{\mathrm{T}}\mathbf{R}_{\mathrm{d}}^{\mathrm{T}}\left(\mathbf{Q}^{\Sigma} - \mathbf{T}^{\mathrm{T}}\bar{\mathbf{M}}\frac{d(\mathbf{T}\mathbf{R}_{\mathrm{d}}\mathbf{R}_{\mathrm{z}})}{dt}\dot{\mathbf{z}}^{i}\right) \tag{1}$$

where $\mathbf{T}$ is the path matrix. $\mathbf{R}_{\mathrm{d}}$ and $\mathbf{R}_{\mathrm{z}}$ respectively represent the first and second velocity transformation matrices; $\bar{\mathbf{M}}$ are the inertia matrices of the whole system. $\mathbf{Q}^{\Sigma}$ represents the accumulated external forces of the vehicle system; $\ddot{\mathbf{z}}^{i}$ and $\dot{\mathbf{z}}^{i}$ are the set of independent relative accelerations and velocities respectively.

In addition, a fork-arm removal technique is proposed. The fork-arm in the MacPherson independent suspension is viewed as the combination of two rigid rods. By using the rod-removal technique to remove those equivalent rigid rods, the fork-arm is represented by two equations with constant-length constraints.

Results in Accuracy and Efficiency

The dynamic simulations of the 7-DOF vehicle multibody model on both bumpy and sloping roads are conducted. A 14-DOF vehicle multibody model and the proposed vehicle model are compared in terms of their solution accuracy and efficiency. Their results of X- and Z-axis displacement and velocity, as well as pitch angle and rate are nearly identical when the vehicle traverses the bumpy road or the sloping road. And the CPU time for a dynamic simulation on bumpy and sloping roads is 4.806 s and 4.790 s, respectively. The respective efficiencies increased by 35.37% and 35.14% in comparison to the 14-DOF vehicle model. The dynamic simulations on bumpy and sloping roads verify the effectiveness of the proposed vehicle model and the efficiency of the simulation calculations.

References

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