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Grey-box modeling of a motorcycle shock absorber for virtual prototyping applications

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Abstract

There is an increasing use of virtual prototyping tools in the motorcycle industry, aimed at reducing the development time of new models and speeding up performance optimization, by providing the designer with an in-laboratory virtual test track. Virtual prototyping software are multibody simulation software, which require the availability of models of all the vehicle components. The choice of the model is then of paramount importance, since it heavily affects the accuracy and reliability of the simulation results. Conventional models (like linear models) are often inadequate to describe the behavior of complex nonlinear components, so that it is necessary to appeal to different modeling approaches. This is actually the case when dealing with motorcycle suspension systems, given that their most critical part, the shock absorber, exhibits nonlinear and time-variant behavior.

In this paper, a grey-box model of a racing motorcycle mono-tube shock absorber is proposed, which consists of a nonlinear parametric model and a black-box, neural-network-based model. The absorber model has been implemented in a numerical simulation environment, and validated against experimental test data. The results of the validation show that the model is able to reproduce the real behavior of the shock absorber with an accuracy that matches or even beats that of other models previously presented in the literature. The interfacing of the proposed model to the ADAMS virtual prototyping environment is also discussed.

Keywords: Automotive; Mechanical systems; Grey-box models; Identification; Neural networks

1. Introduction

The use of virtual prototyping tools in the automotive industry is getting more and more important. The availability of software tools such as [19,23,15], which allow to perform virtual tests on the vehicle, plays a crucial role in reducing the development time of new models and speeding up performance optimization. Virtual vehicles are described by highly detailed mechanical models where all of the vehicle components (chassis,

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suspensions, tires, powertrain, etc.) are represented so that the software can accurately reproduce the very complex behavior of real vehicles. To be used for testing purposes, the simulation environment has to provide both a means of describing the interaction between the vehicle and the environment (course of road, weather conditions, etc.) and a control system that emulates the driver, so that appropriate test maneuvers can be executed.

The lack of a sufficiently reliable motorcycle virtual driver delayed for a while an intensive use of virtual prototyping tools in the motorcycle industry. Indeed, driving a motorcycle is a more demanding task than driving a car, and the difficulty obviously lies in keeping the motorcycle upright while following a desired path. These two goals are often in contrast: In order to lean the motorcycle in the turn, one has first to steer it the opposite way to generate a centrifugal force that pushes the motorcycle in the right direction. Recent studies on guidance systems for bicycles and motorcycles [9,10,25,6,7,22] allowed to develop highly efficient guidance algorithms, and nowadays virtual motorcycle drivers are able to perform also the aggressive maneuvers typical of racing competitions.

In virtual prototyping applications it is essential to have adequate descriptions of all of the vehicle components. The choice of each component model is of paramount importance, since it heavily affects the accuracy and reliability of the simulation results. Given the main goal of a virtual prototyping environment, namely, to be able to virtually perform the same operations that one would perform with a real vehicle on a test track, three requirements are particularly relevant in the choice of the model structure:

(1) the model has to be preferably given in terms of the same quantities that engineers use to tune each system component;
(2) the model has to be accurate enough to describe all the relevant behaviors of each component;
(3) the overall complexity of the virtual vehicle model has to be such that a reasonably short simulation time is required to perform the virtual tests.

A typical situation where to meet the aforementioned requirements is particularly challenging is the modeling of a motorcycle suspension system. As can be easily understood, when analyzing motorcycle dynamics, it is very important to characterize the behavior of its suspensions. The suspension system is described in terms of the mechanical structure that defines its geometry, the spring, and the shock absorber. The most difficult suspension element to be modeled for simulation purposes is the shock absorber since it exhibits nonlinear and time-variant behavior. Conventional models (like linear models) are often inadequate to describe the behavior of complex nonlinear components, as is actually the case in the situation at hand. On the other hand, the inclusion of detailed descriptions of hysteresis and friction terms leads to overly complex models, that are also very difficult to identify from experimental data. Furthermore, such models are difficult to be introduced in virtual prototyping environments.

In this paper we address the problem of deriving a model of a mono tube shock absorber to be used in racing motorcycles. We present a *grey-box* model of a mono tube shock absorber that consists of a nonlinear parametric model and a black-box, neural-network-based model. In the parametric part, the total shock absorber force is obtained as the sum of three contributions, namely the friction, gas, and hydraulic force. Both the friction and the gas force models are given in terms of parameters that can be obtained from standard tests on the shock absorber. The hydraulic model is a mass, spring, and shock absorber model where the parameters are nonlinear functions of some of the system states, and are derived from the experimental data by means of optimization algorithms. The black-box, neural-network-based part of the system is introduced to describe the highly nonlinear, high frequency behaviors that are not captured by the parametric model. This is achieved by training the neural network on the prediction residuals of the parametric model.

The absorber model has been implemented in a numerical simulation environment, and it has been validated against experimental test data. The results of the validation show that the model is able to reproduce the real behavior of the shock absorber with an accuracy that matches or even beats that of other models previously presented in the literature. The interfacing of the proposed model to the ADAMS virtual prototyping environment [19] is also discussed.

The paper is organized as follows. In Section 2 a physical description of a monotube shock absorber is briefly given. In Section 3, the main approaches to shock absorber modeling proposed in the literature are