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A Particle Filter Approach for Identifying Tire Model Parameters From Full-Scale Experimental Tests

Mathematical models simulating the handling behavior of passenger cars are extensively used at a design stage for evaluating the effects of new structural solutions or control systems. The main source of uncertainty in these type of models lies in tire–road interaction, due to high nonlinearity. Proper estimation of tire model parameters is thus of utter importance to obtain reliable results. This paper presents a methodology aimed at identifying the magic formula-tire (MF-Tire) model coefficients of the tires of an axle only based on measurements carried out on board vehicle (vehicle sideslip angle, yaw rate, lateral acceleration, speed, and steer angle) during standard handling maneuvers (step-steers, double lane changes, etc.). The proposed methodology is based on particle filtering (PF) technique. PF may become a serious alternative to classic model-based techniques, such as Kalman filters. Results of the identification procedure were first checked through simulations. Then, PF was applied to experimental data collected using an instrumented passenger car. [DOI: 10.1115/1.4035186]

Introduction

Mathematical models simulating the handling behavior of vehicles are extensively used at a design stage for evaluating the effects of new structural solutions or control systems.

Contact forces depend on several variables such as longitudinal slip, slip angle, camber angle, vertical load, inflating pressure, wear, and adherence conditions and thus they represent the main source of uncertainty in simulation models.

A widely used semi-empirical tire model to calculate steady-state contact forces in simulations of vehicle handling is the so-called Magic Formula (MF)-Tire model [1,2]. It is a convenient set of analytical formulas that interpolates measured tire data rather than modeling the tire structure itself. Therefore, several laboratory tests are needed to correctly identify MF coefficients [2,3], which however do not account for unavoidable differences between outdoor and indoor conditions [1,4,5].

To overcome these issues, direct identification of tire characteristics from road tests has been considered in the literature [3–9]. In most of the cases, the algorithm for identification employs a very familiar tool within vehicle dynamics, the Kalman filter. In Ref. [6], an extended Kalman filter (EKF) for off-line identification of MF-Tire coefficients of the tires of an axle was proposed. In Ref. [3], a similar EKF algorithm was inserted into a two-step procedure able to identify individual tire parameters including vertical load dependency and implicitly compensating for suspension geometry and compliance. In Ref. [9], a two-stage procedure was developed to estimate vehicle model parameters for a tractor–trailer combination. A dual extended Kalman filter (DEKF) was implemented on purpose. Axles' cornering stiffness and trailer yaw moment of inertia are estimated in the first stage, while trailer center of gravity (cog) position and roll moment of inertia are identified in the second stage. In Ref. [8], an adaptive EKF was designed to estimate in real-time vehicle states (sideslip angle, yaw rate, and roll angle) during handling maneuvers. To compensate for tire force nonlinearities, state vector was augmented including adaptive states, i.e., tire cornering stiffness. An EKF was instead presented in Ref. [7] to identify individual load-dependent tire model parameters.

A different approach is proposed in the present paper, based on particle filtering (PF) technique [10–19]. Particle filter is a sequential Monte Carlo algorithm, i.e., a sampling method for approximating a distribution that makes use of its temporal structure. It can be used to solve the state estimation problem of nonlinear systems with non-Gaussian noise and thus it can represent an alternative to classic model-based techniques, such as Kalman filters. As an example, in Ref. [10], PF technique was applied to estimate vehicle yaw rate and sideslip angle. In this paper, PF technique was employed to identify the MF-Tire model coefficients of the tires of an axle based only on the measurements carried out on board vehicle (vehicle sideslip angle, yaw rate, lateral acceleration, speed, and steer angle) during standard handling maneuvers (step-steer, double lane change, etc.).

Results of the identification procedure were first checked through simulations. Then, PF was applied to the experimental data collected using an instrumented passenger car.

The paper is structured as follows: first, an overview of PF technique is presented. Then, its application to the estimation of the MF-Tire model coefficients is described. Finally, results of the proposed estimation procedure applied to both numerical and experimental data are provided.

Particle Filter Overview

Particle filter is a sequential Monte Carlo algorithm, whose aim is to track a variable of interest as it evolves with time, typically with a nonGaussian and potentiality multimodal probability density function (PDF). The basis of the method is to construct a sample-based representation of the entire PDF.

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