Adapted UA Tyre Model for Computationally Efficient and Stable Dynamic Simulations of Road Vehicles

Pedro Millan[1], Jorge Ambrósio[1]

[1]IDMEC, Instituto Superior Técnico
University of Lisbon
1044-001 Lisbon, Portugal
[pedro.millan, jorge.ambrosio]@tecnico.ulisboa.pt,

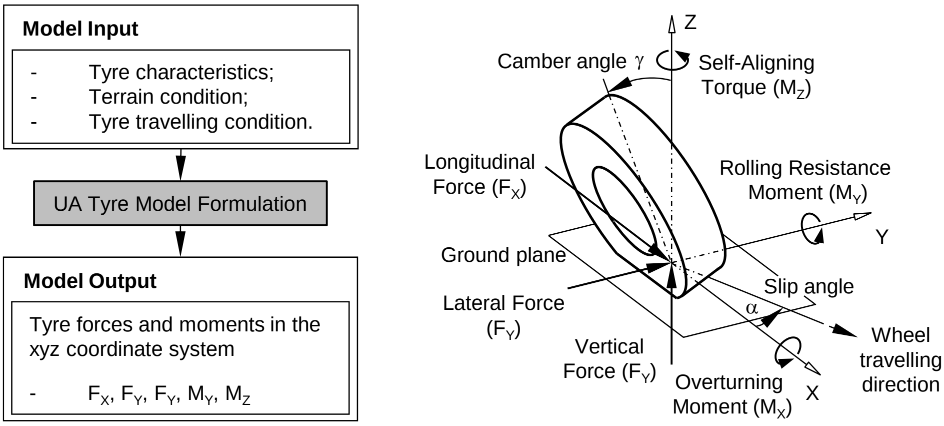
EXTENDED ABSTRACT

1 Introduction

Multibody simulations are widely used to study the dynamic behaviour of road vehicles, including handling, ride and NVH, requiring the accurate representation of the tyre-road contact phenomena. Several tyre models for dynamic applications are described in the literature and available in commercial software, allowing to obtain the tyre-road contact forces based on the tyre-road kinematics [1]. Typically, these models can be divided in three main groups, the simplified models, the empirical models and the physical models [2]. The first provide a simplified representation of the tyre-road contact phenomena, being limited to static and quasi-static dynamic analysis. The empirical models can be very accurate, allowing to study non-linear handling and ride, but require extensive testing to tune a vast number of parameters, often with reduced physical meaning, to fit the empirical curves to the experimental results. The physical models, on the other hand, also allow to study the non-linear handling and ride of vehicles but require selecting fewer parameters that have a greater physical significance. The UA tyre model, developed by Gim and Nikravesh [3–5], is included in the last category and requires the selection of a reduced number of parameters that can be easily obtained without the need for extensive testing. However, the analytical equations of the UA tyre model produce force discontinuities that are strongly unwanted in the multibody simulation, causing problems in the stability and efficiency of the integration of the equations of motion. This works proposes an adaption of the UA tyre model to smooth the force discontinuities, improving the numerical stability and efficiency of the tyre model within multibody dynamic simulations without affecting the quality of the results.

2 Methods

The UA tyre model, considered in this work, is an analytical model that allows to calculate the tyre-road contact forces based on the tyre-road kinematics and some inputs related to the tyre and road geometric and physical properties [3–5]. The model can be used to study the tyre forces at pure and combined slips, thus, allowing to simulate the vehicle in traction/braking and steering manoeuvres. In contrast to the empirical models, the UA tyre model requires only the selection of few tyre and road geometric and physical properties that may be obtained with few experimental tests. Figure 1 illustrates the UA tyre model input and outputs and the tyre-road contact forces.



(a) (b)

Figure 1 – Schematic representation of (a) UA tyre model inputs/outputs and (b) tyre-road contact forces.

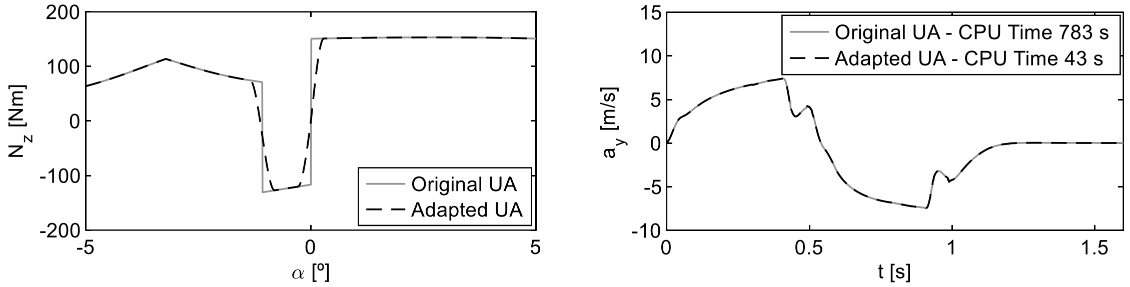
Based on the camber angle, slip angle and the slip conditions that can be derived from the tyre-road kinematics there are different states to which correspond different analytical equations to calculate the contact forces. The transition between these states, and thus, the analytical equations, produces force discontinuities. These discontinuities are very undesirable in the multibody simulations, causing problems in the integration of the equations of motion. In this work, the transitions between states corresponding to force discontinuities are identified and an adapted model to include the smoothing of the forces in the vicinity of the discontinuities is proposed. The smoothing is defined by the following cubic function:

$$\begin{aligned} y(x) &= y^- + (y^+ - y^-)(3r^2 - 2r^3), \\ r &= (x + \Delta x)/(2\Delta x) \end{aligned} \tag{1}$$

where Δx is the transition domain where the smoothing applies and y^- and y^+ are the function values in the vicinity of the discontinuity, corresponding to the negative and positive abscissa at the transition, respectively.

3 Results

The original and adapted UA tyre models are implemented and a series of results are evaluated. The quasi-static results for the implemented models are compared with the results obtained by Gim et al. [5] to validate the implementation and assess the effect of the smoothing. The results, omitted here for the sake of brevity, show a perfect agreement between the original and adapted models and the results by Gim et al. The quasi-static results highlighting the discontinuities in the original model and the effect of the proposed smoothing are also studied. Figure 2 (a) shows the self-aligning torque as a function of the slip angle for the original and adapted UA tyre models. The torque discontinuity is clear for the original model while a smooth transition is accommodated by the adapted model with the cubic smoothing. Preliminary dynamic simulations, using the multibody in-house code MUBODyn are performed to assess the impact of the proposed smoothing methodology in the efficiency and stability of the simulations and the dynamic behaviour of vehicles. Figure 2 (b) shows the lateral acceleration at the chassis for a full multibody model of a car during a steering manoeuvre, both using the original and adapted tyre models. While the lateral acceleration is identical for both models, the computational time is drastically lowered for the adapted model. This occurs due to the necessity of the time integrator to reduce drastically the time step to accommodate the force discontinuities produced by the original model. Other preliminary results, omitted here for the sake of brevity, show the simulation crashing when using the original model in opposition to the successful completion of the simulation when adopting the adapted model.



(a)

(b)

Figure 2 – Plot of (a) self-aligning torque as a function of slip angle and (b) lateral acceleration at the chassis for a full multibody model of a vehicle during a steering maneuver, using original and adapted UA tyre models.

4 Preliminary Conclusions

The present work proposes an adaption of the original UA tyre model for more efficient and stable dynamic multibody simulations of road vehicles. Force discontinuities in the original UA tyre model are problematic from the point of view of the integration of the equations of motion, leading to numerical instability. For that purpose, the scenarios corresponding to force discontinuities are identified and an adapted model is developed that smooth those transitions. The results stress the limitations of the original model and highlight the potential of the adapted model for a more robust and efficient implementation within the multibody environment. Not only significantly faster simulations were obtained but also simulation crashing is avoided.

Acknowledgments

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