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A new contact and road model for multi-body dynamic simulation of wheeled vehicles on soft-soil terrain

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EXTENDED ABSTRACT

1 Introduction

The tire/soft-soil interaction and the corresponding modeling is of utmost importance in order to properly predict the mobility of vehicles in a wide range of engineering applications. In typical multibody and vehicle simulations, semi-empirical models are employed in order to represent the tire/soft-soil interaction, thus resulting in fast execution and low memory allocation of the simulation code. The main focus in these models is placed on properly describing the pressure-sinkage and the shear stress-shear displacement relationship through analytical equations, which are based on experimental observations [1-3].

The new modeling approach acts as a linkage between the classical and well-established principles introduced by Bekker/Wong/Janosi and Hanamoto and the current capabilities of multi-body system (MBS) solvers. More specifically, a new, fast and memory-efficient, road and contact model is developed in this work, based on these principles. Using the new techniques, a full 3D modeling of the tire/soft-soil interaction is achieved, enabling the use of complex terrain geometries and the execution of complicated simulations incorporating spatially varying soil properties as well as multipass effect related phenomena.

Lastly, the proposed contact and road model is implemented in Altair MotionSolve, a multibody simulation software for complex mechanical systems, in order to ensure the validity and demonstrate the effectiveness and applicability of the new techniques. For this, two different models are developed. Namely, a single-wheel test bed and a four-wheel rover model. Moreover, the extracted numerical results are compared with the experimental data obtained by Ishigami et al. [4].

2 Road and contact model

Within this work, the road surface is represented by a height-field (HF), thus enabling the use of complex terrain geometries. More specifically, a rectangular structured grid of deformable springs in the vertical (z-axis) direction is employed (see Fig. 1), resulting in fast execution of the simulation code. Therefore, using this approach, each spring represents a small road patch for which the necessary information is stored. Typical parameters that are stored as properties of each spring include the soil elevation, the soil properties as well as information regarding the compaction of the soil. Consequently, the HF data structure is augmented with the soil properties as well as with the soil history parameters. Based on this, complicated simulations incorporating spatially varying soil properties and phenomena related to the multipass effect can be properly handled by utilizing the new road model. Moreover, a distinct difference of the new road model lies in its ability to handle large road scenarios by allocating the memory for each spring, when it is necessary, thus resulting in low overhead on computer memory.

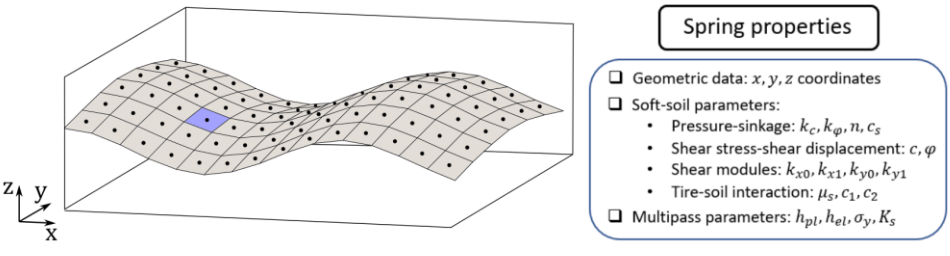

Figure 1: Road modeled as a height-field data structure, augmented with the soil properties and multi-pass parameters

In addition, a high-performance tire/soil contact model, which enables the use of complex irregular terrain profiles, is proposed in this work. More specifically, instead of performing the necessary calculations on a per-node basis, the terrain surface is locally approximated with a suitable equivalent plane. Therefore, a simple wheel/plane intersection problem is derived, which can be resolved in a much easier and computationally efficient way. For this, two different strategies are proposed. Namely, the Radial Basis Function (RBF) interpolation method and the 3D Enveloping contact model [5].

In the first case, the springs enclosed in the tire contact patch area are collected (see Fig. 2) and their soil elevation values are utilized in order to produce an equivalent plane that describes the current tire/terrain interaction in a proper way. For this, an RBF interpolation process is employed by assuming that the tire contact patch area consists of n spring regions, with coordinates $(\underline{x}_i = (x_i, y_i), z_i)$, $i = 1, \dots, n$. Then, the weights w_i, $i = 1, \dots, n$ are initially determined using the equations

$$z(\underline{x}_j) = \sum_{i=1}^{n} w_i \varphi(r), \quad j = 1, \dots, n, \quad r = \|\underline{x}_j - \underline{x}_i\| \tag{1}$$

Following that, the interpolated value for the soil elevation is derived using the equation

$$z(\underline{x}) = \sum_{i=1}^{n} w_i \varphi\left(\left\|\underline{x} - \underline{x}_i\right\|\right) \tag{2}$$

Moreover, the local inclinations of the road surface are calculated in an efficient way. In addition, a prominent feature of this contact model stems from its ability to easily adapt on the application's needs, based on the selection of the radial basis function.

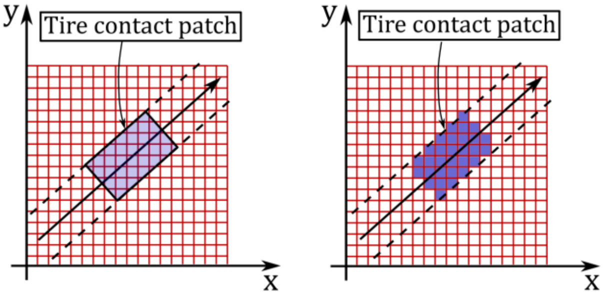

Figure 2: Tire contact patch (left) and springs enclosed in the tire contact patch area (right)

In the second case, a well-established contact model for rough non-deformable (rigid) terrain, namely the 3D enveloping contact model [5], is utilized. The main idea of this method is founded on employing a series of ellipses in order to scan the road profile and, thus, produce an effective road plane, as shown in Fig. 3. Consequently, the same technique is used here for deriving an equivalent plane that locally approximates the irregular profile of a deformable terrain.

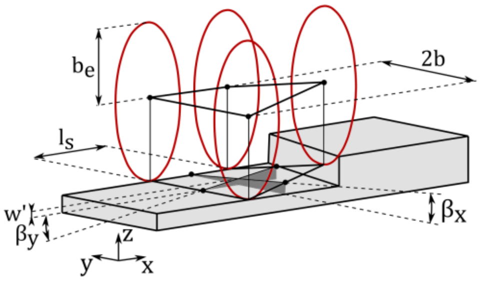

Figure 3: 3D Enveloping contact model [5]

3 Numerical results and discussion

Finally, the proposed contact and road model is implemented in Altair MotionSolve and two example models are developed for testing the new techniques. More specifically, a single-wheel test bed is initially utilized and the resulting forces at the wheel-soil interface are compared to the experimental data extracted in [4], as shown in Fig.4 (a). Subsequently, a full rover model is employed in order to demonstrate the applicability of the new approach in complicated simulations. The extracted numerical results (Fig. 4 (b)) illustrate the validity and effectiveness of the proposed techniques in large-scale engineering problems.

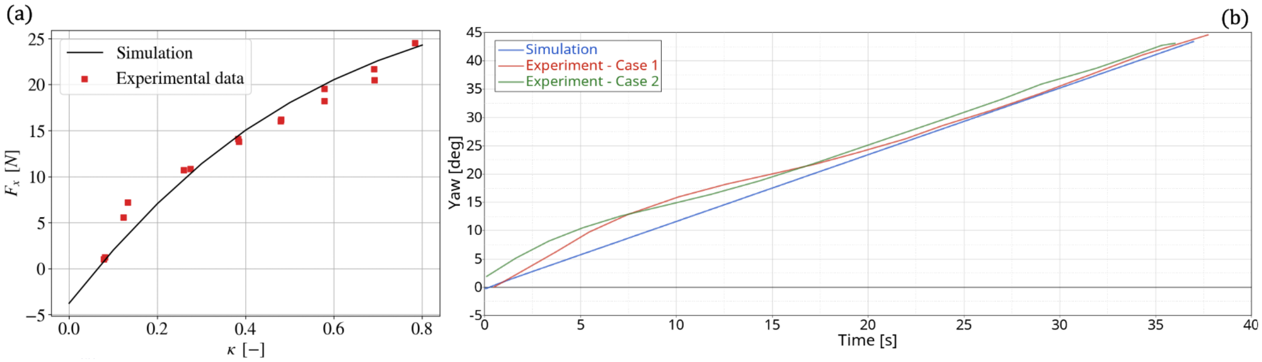

Figure 4: Typical results for (a) single-wheel test bed and (b) four-wheel rover model

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