WHEEL-TERRAIN INTERACTION MODELLING FOR DYNAMICS SIMULATION AND ANALYSIS OF WHEELED MOBILE ROBOTS

Ali Azimi[1,2], Daniel Holz[2], Jozsef Kövecses[1], Jorge Angeles[1], Marek Teichmann[2]
[1] *Department of Mechanical Engineering and Centre for Intelligent Machines (CIM), McGill University, Montreal, Quebec, H3A 2K6, Canada*
[2] *CM-Labs Simulations Inc., Montreal, Quebec, H3C 1T2, Canada*
Email: ali.azimi@mail.mcgill.ca

ABSTRACT

Appropriate modelling of the interaction between wheel and terrain is a key element in achieving representative simulation and analysis of wheeled mobile robots (rovers). In this presentation, we explain two terrain modelling approaches and their implementation in an advanced and real-time multi-body dynamics environment, CM-Lab's *Vortex*. The first approach is based on classical semi-empirical terramechanics models, while in the second approach, a novel model is developed based on continuum mechanics.

The multi-pass effect is also considered in our implementation by storing terrain deformation and changes in hardening of soil under the wheel. A high-resolution height-field (HF) is used for the terrain surface, and relevant information is stored in the HF vertices. For every wheel in contact with soft soil, two unilateral contact constraints are added to the solver for the normal direction and some additional constraints for the motion in the tangent plane. The properties of these constraints are set based on the soil reactions computed from either the semi-empirical or the continuum model, at every time-step of the simulation. In addition, rigid obstacles are also included using the standard unilateral point-contact constraints of Vortex. A collision detection algorithm identifies whether the wheel is in contact with the hard obstacle, soft soil or both, and appropriate constraints are added.

Semi-empirical terramechanics models are mainly based on the work of Bekker [1] and the bevameter in identifying wheel-terrain properties. The extensions made by a number of researchers, including Wong and Reece [2] and Ishigami et al. [3], are considered in our implementation. In addition, the lateral bulldozing force is computed using the *fundamental equation of earthmoving* (FEE) of Reece [4] and the method of trial wedges of McKyes [5].

In the alternative novel model, normal and shear stress distributions in the contact area are determined using continuum mechanics with an efficient technique compared to classical finite element modelling. The authors propose a velocity field in the vicinity of the contact area motivated by the physical nature of the problem. Using this field, the incremental changes to the stress field are computed by resorting to elasto-plasticity theory and an appropriate constitutive relation for soil. As opposed to classical finite element approaches, which model the soil in contact with the wheel as a high-resolution mesh, our approach focuses on the wheel-soil contact patch only. This highly localized simulation scheme provides the basis for roughly accurate but fast wheel-soil interaction modelling. By combining this approach with a height-field as terrain representation, elasto-plastic soil deformation and changes in the hardening state of soil are directly captured.

The new approach is computationally more demanding than the above-mentioned semi-empirical models, yet it is still appropriate for fast or real-time simulation of rovers. In fact, the proposed model is perfectly data-parallel in nature and, therefore, readily parallelizable. This makes our model well suited for execution on modern multi-core architectures. In addition, because of the elasto-plastic representation for soil, energy dissipation during soil compaction is directly captured, as opposed to the semi-empirical-based modelling, which usually requires an extra viscous damping term in dynamics simulation environments.

In addition, the proposed approach uses generalized velocities of the wheel as inputs, which makes it

compatible with dynamic models of multibody systems. The dynamic slip-sinkage behavior of the wheel and the semi-elliptical shape of the normal stress distribution under the wheel are natural outcomes of the proposed model. Experimental investigation of the proposed approach under various ranges of wheel slippage shows good agreement with the data available in the literature. The new model, however, is only developed for 2D motion of the wheel. The normal stress distribution determined based on this model is then used to find the lateral shear force, similar to the approach followed in semi-empirical models, for example in [3]. In addition, the bulldozing force can be considered in the lateral direction, as in the semi-empirical implementation.

We conducted simulation runs of the Sojourner using both modelling techniques, as shown in Fig. 1 for the semi-empirical Bekker model. In addition, we did experimental investigations with Neptec's Juno rover, as shown in Fig. 2. The results will be discussed in our presentation.

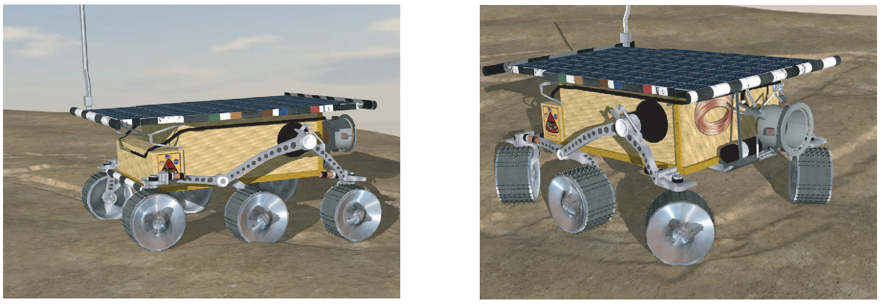
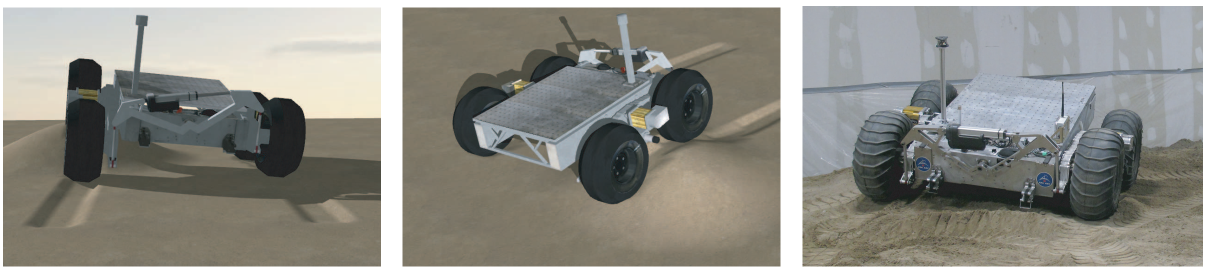


Fig. 1. Snapshots of Sojourner rover simulated in Vortex using the Bekker model.



(a) (b) (c)

Fig. 2. Juno rover: (a) and (b) are images from the simulation in Vortex, while (c) is a picture of the actual rover at Neptec facilities, captured during experiments.

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