Soft Soil Contact Modeling Technique for Multi-Body System Simulations

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Rover vehicles are being designed to deploy scientific instruments on planetary surfaces within a considerable radius around the landing site or to traverse long distances away from there. Current planetary missions like NASA's *MER* mission as well as future ones like NASA's *MSL* mission and ESA's *ExoMars* mission are typical examples for projects where robot mobility plays a crucial role.

For assessment of the rover locomotion performance the corresponding contact dynamics phenomena should be well understood. Hereby we have to consider various mobility systems like legged, wheeled or tracked vehicles moving on both, rocky and sandy planetary terrain. This paper will focus on the the specific contact dynamics problem of motions on dry and soft sandy terrain and the description of the corresponding modeling technique, which has been recently developed, implemented and applied at DLR's Institute of Robotics and Mechatronics.

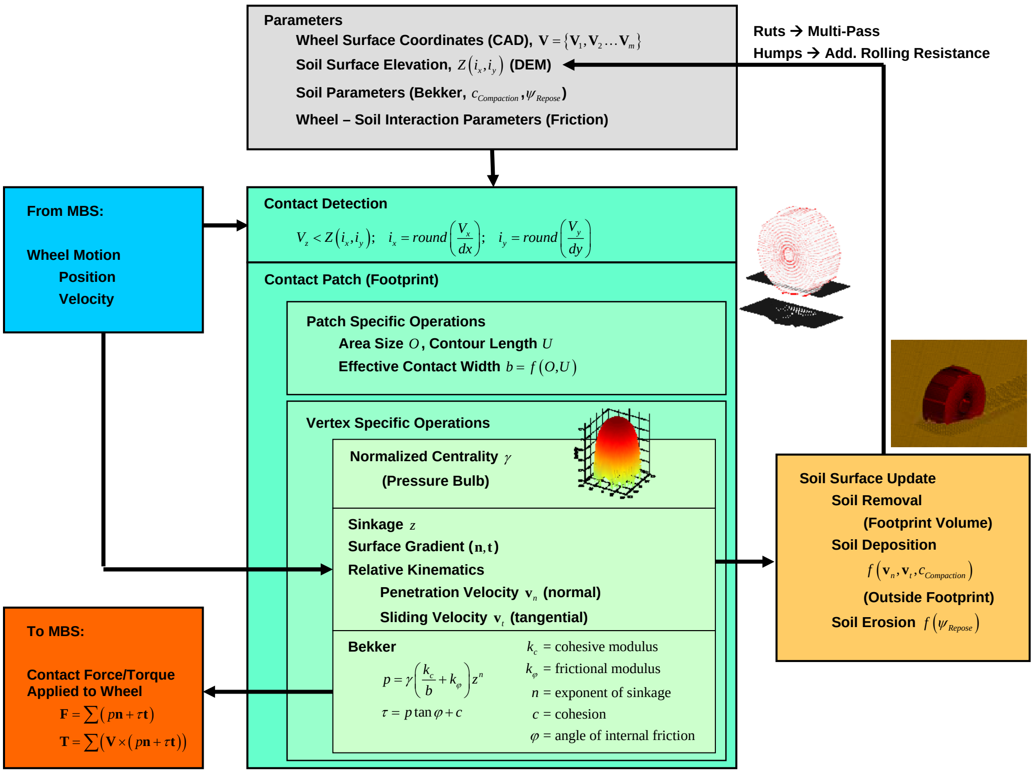

Figure 1: SCM Architecture with MBS Interface

The aim of developing the so called *Soil Contact Model* (*SCM*) was the implementation of classical terramechanics theories like those of Bekker [1] and Wong [2] in standard Multi-Body System (MBS) simulation engines (e.g. *SIMPACK*). The *SCM* tool provides a convenient way of modeling complex soil contact dynamics problems and to support full 3D MBS simulations at reasonable computational performance and high fidelity of the corresponding processes happening in reality.

The overview of the *SCM* architecture with a number of simplified equations is presented in Figure 1. *SCM* is implemented in the form of a MBS force element that computes relative contact forces between a plastically deformable soil surface and an arbitrarily shaped rigid or flexible contact object (e.g. wheel) based on (a) the relative kinematics states between object and soil and (b) a set of soil parameters. The soil surface is described by a Digital Elevation Map (DEM). The contact object surface is defined by a point cloud of surface vertices.

The computation of the contact forces consists of two major parts: In the first part the contact detection is performed. It is implemented as mapped vertex contact detection that is integrated in a hierarchical AABB tree algorithm. In the second part all required pre-requisites like (1) effective contact width, (2) normalized pressure distribution, (3) sinkage and (4) penetration and sliding velocity are computed in order to apply them for the well known soil pressure-sinkage function of Bekker and the corresponding equation for soil shear stress. The applied force/torque at the contact object can be calculated by integration of normal and shear stress over the entire contact region.

A novel feature of *SCM* is the incorporated, MBS compatible plastic soil deformation algorithm. It computes the soil displacement from the intersection volume of terrain and contact object. This is done based on penetration vector dependent soil flow fields. Thus, each DEM vertex in the surrounding region can obtain a portion of displaced soil from each DEM vertex in the contact zone. An erosion algorithm that takes into account the maximum angle of repose is completing the plastic soil deformation process. Supposing a wheeled rover, this feature enables *SCM* to implicitly compute typical terramechanical phenomena like (1) increasing rolling resistance caused by heaps in front, (2) lateral guidance inside ruts, (3) drawbar pull depending on slip and (4) multi-pass effects when wheels are rolling in a pre-deformed rut.

In the paper the *SCM* algorithm will be introduced and presented in detail. In a chapter on verification it will be demonstrated that the implemented terramechanics theory of Bekker can be reproduced with a satisfactory precision. Correlations of measurements taken from single wheel and rover system level tests with corresponding *SCM* simulation results (Figure 2) will give an overview of the general applicability of the tool. Moreover, a chapter on profiling of the *SCM* software will be presented. It will give information about time critical operations in the code and potential improvements by applying parallel computing techniques.

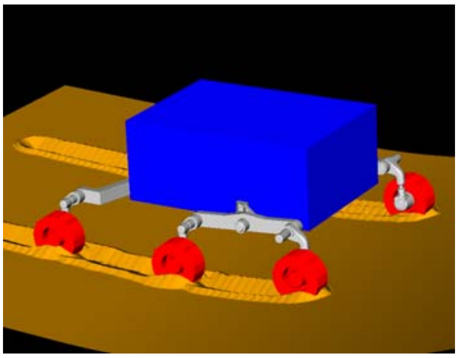

Figure 2: Rover System Level Simulation

References

[1] Bekker, M.G., *Introduction to Terrain-Vehicle Systems*, The University of Michigan Press, Ann Arbor (1969)

[2] Wong, Y.J., *The Theory of Ground Vehicles,* 4rd Edition, Wiley, New York (2008)