PLANETARY ROVER MOBILITY PERFORMANCE ON SOFT AND UNEVEN TERRAIN

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Summary Rovers on Mars or Moon for planetary exploration are obtainig increased importance within the spaceflight nations. To achieve full mission success, driveability and mobility in all kind of complex motion scenarios has to be guaranteed. Here, proper modeling and understanding of the complex wheel-soil interaction, i.e. the terramechanics for flexible and hard wheels interacting with hard, soft and loose soil, is a major driver for supporting reliably rover design and to assist in testing of the flight model. The physical contact models are integrated within a multibody system approach, and the performance of the rover mobility will be shown for various worst case driving scenarios on hard and soft soil.

MOTIVATION

Within ESA's (European Space Agency) Aurora programme for planetary exploration, powerful rovers (primarily ExoMars rover for Mars exploration with 3 axes and 6 wheels) with different capabilities will be developed. Since mobility has to be guaranteed for these rovers in rough and unknown terrain with almost fully autonomous motion planning, they need extensive all-terrain locomotion capabilities. To achieve successful mission and to enhance the overall rover mobility performance, efficient modelling and simulation tools are required that predominantly cope with the wheel-soil interaction and which regard the overall rover-chassis set-up based on a multibody system (MBS) approach, including all the various kinematic suspension and wheel mobility concepts for different rover types. Often, very unconventional suspension and wheel designs (hard or flexible ones) are investigated. The importance and strenghts of Multibody System (MBS) simulation allows uniquely to investigate a wide range of potential configurations and various terrains. Moreover, the importance of the dynamical effects can be efficiently taken into account. The main goal of the simulations is to reduce the amount of costly prototype developments and to give assistance in field experiments. A great advantage is the integration of the MBS simulation and the very complex wheel-soil interaction into the vehicle's conceptual design process. This ranges from kinematic investigations for gradeability, maximum step crossing and side slope driving towards the investigations of wheel-soil interaction with respect to wheel sinkage and rolling resistance.

TERRAMECHANICS AND MULTIBODY SYSTEM MODELING

For the design of the ExoMars rover chassis, simulation results of rover locomotion inside a representative planetary terrain were required. Hereby a terrain based on measurements taken during NASA's Viking I mission was defined as reference. It is described as a soil base with stones of different size classes and statistical distribution on top of the soil. Therefore the simulation software should include contact dynamics models, which are able to deal with two completely different physical contact configurations: The contact of the metal wheel a) with hard rigid rocks and b) with plastic soil.

In the past a large number of various terra-mechanics based modeling and simulation approaches were presented. For the simulation of locomotion in sandy soil most authors apply the empirically found soil stress-strain laws as introduced by Bekker [1] and Wong [2].

The goal of our new approach was to extend the state of the art of rover simulation such that a full 3D simulation inside the reference terrain of Viking I is possible by means of multibody simulation methods. Two major tasks had to be solved: (1) The implementation of a model for the interaction between hard rocks and the rover wheels: This contact problem was solved by applying the referenced terramechanics based approaches. However, an elegant solution of this problem was proposed by Hippmann [3] using the so-called Polygon Contact Model (PCM). (2) The implementation of a plastically deformable soil: Since FEM methods are hardly applicable for multibody dynamics formalisms, the solution of this problem was inspired from computer graphics algorithms for terrain generation, e.g. Olsen [4], and animating footprints in soil, e.g. Sumner et al. [5]. This second method, called SCM (soft and loose soil contact model), uses an elevation grid description, and can favourably be applied to simulate the famous multi-pass effect. Both methods have been set up and integrated inside a multi-body simulation tool.
rolling resistance.

SIMULATION RESULTS

Figure 1 shows the polygonal representation of the contact bodies, i.e. wheel and soil of the Viking I terrain scenario. An example for an actual result of plastic soil deformation including erosion is given in Figure 3. An example for the PCM simulation results of a rover on rocky terrain is shown in Figure 2. Here, the rover is equipped with six wheels, each of them has two actuators for driving and steering with an average speed of about 28 m/h. A completely different kind of simulation results is presented as example for an SCM application, Figure 4. Here the multi-pass effect of wheel pairs rolling inline was investigated, showing clearly the effect of loose soil displacement, deposition and erosion.

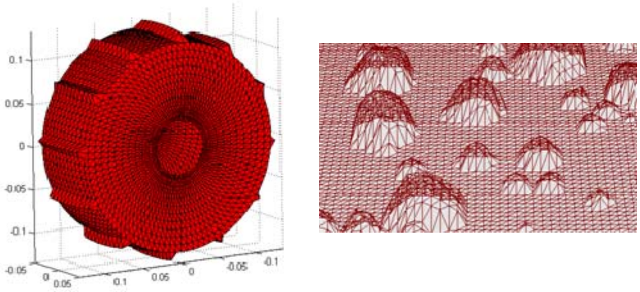

Figure 1. Polygonal representation of rover wheel used for PCM contact calculation (left), and of Viking I reference terrain (right)

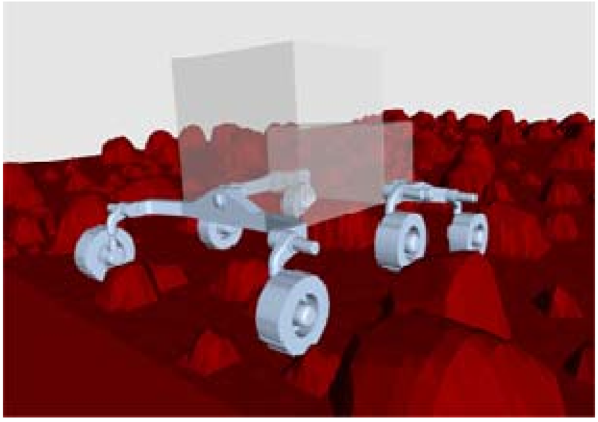

Figure 2. MBS model of Exomars rover on rocky Mars reference terrain; PCM contact model.

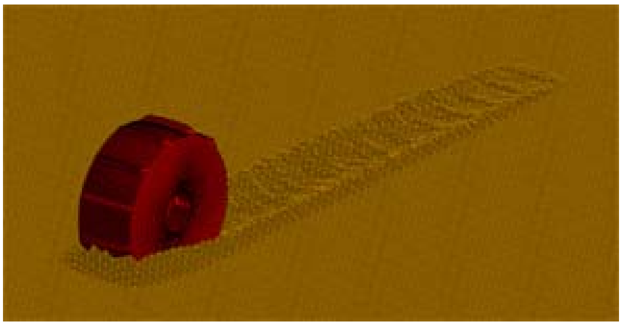

Figure 3. Soil Displacement, deposition and erosion; SCM contact model.

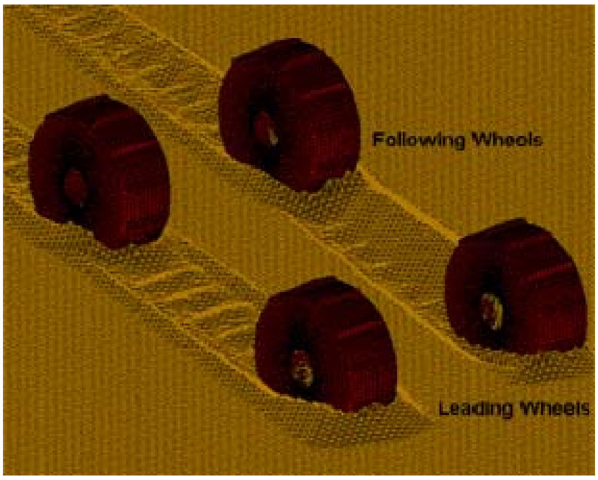

Figure 4. Wheel configuration for multi-pass investigation.

CONCLUSIONS

The presented MBS simulation environment allows the mobility performance investigation of rover configurations under various kind of complex planetary surface terrain conditions. Two models for the simulation of the wheel-soil interaction were introduced. In future work both methods will be combined in order to significantly enlarge the capabilities and reliability of the rover locomotion simulation by means of multibody simulation tools.

References

[1] Bekker M.K.: Introduction to Terrain-Vehicle Systems. The University of Michigan Press, Ann Arbor, USA, 1969.
[2] Wong J.Y.: Theroy of Ground Vehicles. Wiley, New York, 3rd Edition, 2001.
[3] Hippmann G.: Modellierung von Kontakten komplex geformter Körper in der Mehrkörpersimulation. Dissertation, TU Wien, Austria, 2004.
[4] Olsen J.: Realtime Procedural Terrain Generation. IMADA, University of Southern Denmark, 2004.
[5] Sumner R.W., O'Brien J.F., Hodgins J.K.: Animation Sand, Mud and Snow. Computer Graphics Forum, Vol. 18, No.1, 1999.