MBS Simulations and Performance Testing of Planetary Rover Locomotion

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DLR's Institute of Robotics and Mechatronics is involved in robotics mobility through a number of research activities like mobile platform design and control, vision based navigation (see examples in Fig. 1, Fig. 2 and Fig. 3) but also modeling, simulation, optimization and testing of planetary locomotion subsystems. The close interaction between the institute's terrestrial and space project groups provides fruitful inspiration and benefits for both groups and their respective applications.

Fig. 1: Rollin' Justin

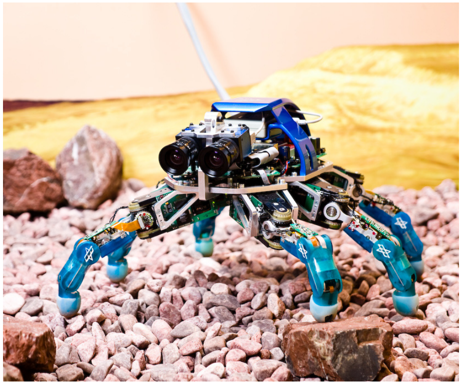

Fig. 2: DLR's Crawler

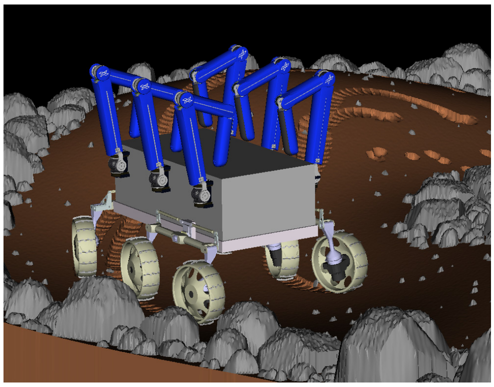

Fig. 3: Study of Hybrid Locomotion Concept

Currently, the major projects regarding planetary mobility are related to ESA's *ExoMars* (Fig. 4) and *MoonNext* (Fig. 5) missions, which include classical rovers as mobility systems, and *Mascot*, which is a hopping landing module for an asteroid mission. The common topics of these activities are design support and proof of performance of various locomotion subsystems by modeling, simulation and experimental testing. The contact dynamics between the mobility subsystem (wheels, legs) and the surface of the planetary body (soil, rocks) as well as the corresponding soil mechanics (Fig. 6) are of major interest and subject of dedicated research activities. The philosophy and the details of the modeling approach are introduced in the following paragraphs.

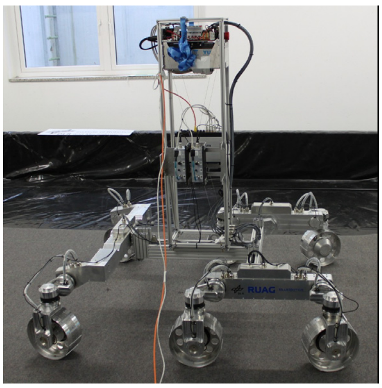

Fig. 4: ExoMars Rover Breadboard BB2

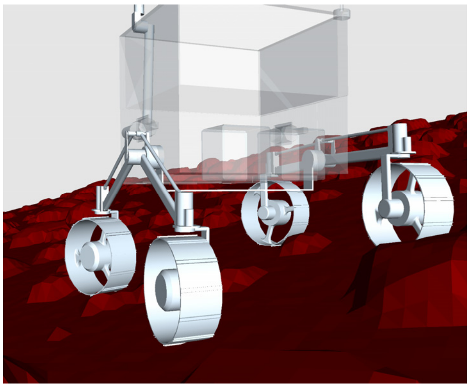

Fig. 5: Rover of NextLunarLander (Subsystem of MoonNext)

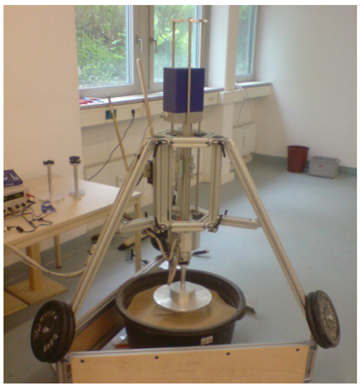

Fig. 6: Bevameter for Soil Parameter Identification

In many rover system simulators the terramechanical models of the dynamics interaction between the terrain (rocks, sand) and the mobility system (e.g. wheels, legs, tracks) are often significantly simplified due to constraints like real-time requirements or due to focusing mainly on other simulation aspects like rover locomotion control and navigation (e.g. [1],[2]). The opposite extremes are Finite Element and Discrete Element like volumetric approaches, which promise quite accurate results. However, they generate heavy computational loads and are in praxis limited to specific tasks like wheel design optimizations.

The soft soil contact modeling technique called *SCM,* which was developed, implemented and applied at DLR, is driven by the requirement to be integrated in multi-body system simulations since they are well known for their good compromise regarding simulation fidelity and computational efficiency. *SCM* can be applied in parallel with other approved contact dynamics models like the Polygonal Contact Model *PCM* for contact with hard rocks in order to realize general simulation scenarios as shown in Fig. 7. Unlike PCM, which is already well documented in [3] and integrated in the commercial MBS software package SIMPACK, SCM is a quite novel, user defined add-on, which is addressed here.

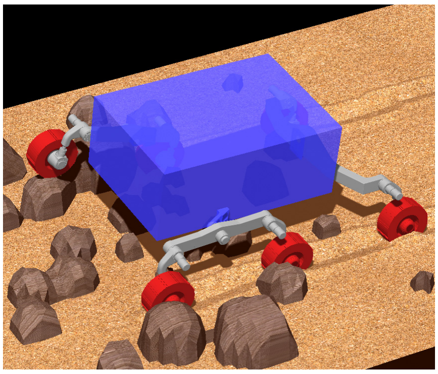

Fig. **7**: SCM Simulation of Rover Locomotion in Planetary Terrain

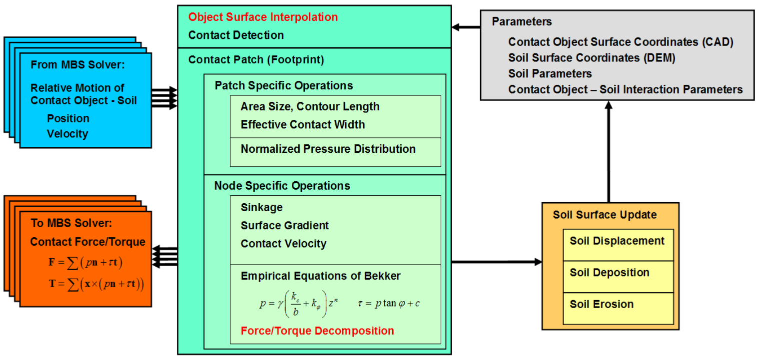

Fig. 8: SCM Architecture for Flexible Contact Objects

The overview of the SCM architecture is presented in Fig. 8. The model is implemented in the form of a MBS force object that computes relative contact forces between a plastically deformable soil and rigid or flexible contact objects based on (a) the relative motion inside the contact patch and (b) a set of soil contact dynamics parameters. The soil surface shape is described by a Digital Elevation Map (DEM). The surface shape of the contact object is defined by a fixed (rigid body) or a variable (flexible body) surface mesh grid.

In SCM the calculation of the contact forces consists of two major parts (Fig. 8, green block). In the first part the contact detection is performed by a vertex mapping algorithm. The second part is focused on the detected contact patch. Here, the required values of effective contact width, normalized pressure distribution, wheel sinkage and contact velocities are computed in order to apply them to the well known contact pressure-sinkage relationship of Bekker [4] and the corresponding equations for soil shear stress.

A key component of SCM is the computation of plastic soil deformation (Fig. 8, yellow block) during the contact and the continuous update of the soil DEM at each time integration step of the simulation (e.g. ruts in Fig. 7). This algorithm computes the soil displacement from the contact intersection volume based on penetration vector dependent soil flow fields and the soil deposition around the contact zone. An erosion algorithm that takes the maximum angle of repose into account is completing the plastic soil deformation process. This feature enables SCM to implicitly compute specific terramechanical dynamics phenomena of wheel-soil interaction like bulldozing resistance caused by heaps in front, lateral guidance inside ruts, multi-pass effects of wheels rolling inline and slippage dependent thrust forces.

The validation of this modeling technique is an ongoing work, which will be performed based on results from experimental locomotion subsystem tests in the context of the rover projects mentioned above.

References

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