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Heterogeneous, multi-tier wheel ground contact for planetary exploration

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Abstract

Today's growing scientific interest in extraterrestrial bodies increases the necessity of extended mobility. Thus planetary exploration systems are facing new challenges in terms of mission planning, obstacle and soil traversability. In order to fit the tight schedules of space missions and to cover a large variety of environmental conditions, numerical simulation models are used as virtual prototypes.

In this context we present an integrated simulation environment for the heterogeneous simulation of the wheel ground contact using tiered contact models, specially designed for and used in planetary exploration missions. These models range from simple but real-time capable, rigid-body approximations, over penetration and soil deformation approaches, to very accurate but slow Discrete Element Method (DEM). Having these techniques available in one environment allows us both, to apply one technique per simulation and to correlate the corresponding simulation results, as well as to mix the techniques within one simulation model.

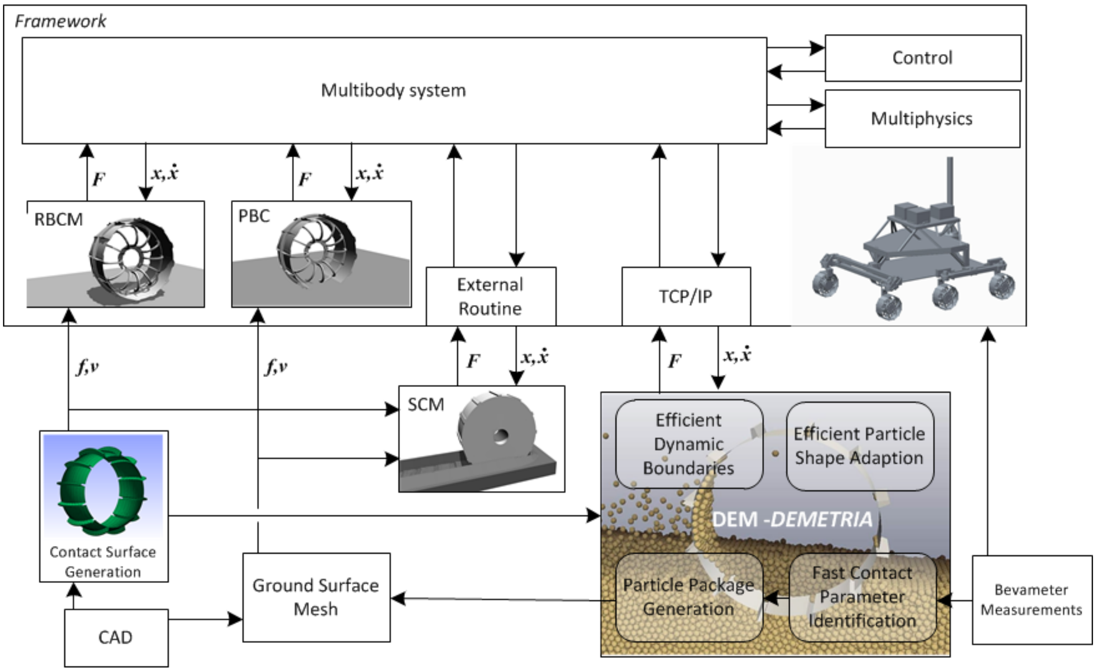

Figure 1: Structure chart of the overall system, showing the connections between different parts of the simulation framework.

The simplest multi-body dynamics are typically based on idealized, non-deformable rigid bodies. The contact dynamics computation considers only impuls energy exchange during impact while maintaining the non-penetration constraint.

While neglecting many effects of real objects, the results are still sufficiently accurate for many applications. The big advantage of this approach lies in the required simulation time: with modern desktop computers even complex scenarios, such as complete rover dynamics while driving over rough terrain, can be simulated in real time [2].

More accurate results can be achieved by incorporating the elasto-plastic surfaces of real bodies. Depending on the simulation focus, impact points are modeled by spring damper elements. For simple contacts only penetration depth is used, more complex models also use penetration area or even penetration volumes. Real-time capability of these simulations is dependent on specific models [2].

Up to this point ground was not actually displaced. An important effect for the simulation of planetary rovers is the plastic deformation and displacement of soil caused by wheels. In our simulation framework we use the SCM-Algorithm (Soil Contact Model) for the simulation of soil contact forces, plastic deformation and displacement. SCM is a highly specialized extension of the Bekker-Wong method for 3D / 6 degree of freedom applications [3].

The most detailed DEM based simulations allow to model regolith directly as granular material and are suitable for both, surface and subsurface locomotion. Thus the DLR-SR particle dynamics framework "DEMETRIA" (Discrete Element Method Enabled Terramechanics Interaction framework), based on the particle simulator Pasimodo, is also incorporating systematic particle scaling and parameter estimation. Thereby DEMETRIA enables to use particle-based terramechanics on workstation PCs. A typical application for DEMETRIA is the detailed analysis of wheel-soil interaction phenomena as presented in [4]. Moreover it was applied to InSight's [1] subsurface locomotion system, the HP^3-Mole, using DEM-MBS co-simulation [5]. Due to the high accuracy, the particle models are also suitable for low-level optimization of subsystems, like planetary rover wheels. Furthermore by the coverage of grain-level effects, additional insight on the underlying effects of the interaction is gained. Verification of different tiers is already performed for rovers [3] and validation for the HP^3-Mole [5] is carried out using data provided by DLR Institute of Space Systems.

Finally it is shown, how the availability of diverse simulation techniques in a unified environment can be exploited to improve both, required computation time and simulation result accuracy. Coupling fast and slow modeling techniques can drastically improve simulation times with negligible influence on the quality of the desired results. E.g., when simulating an eight-wheel rover on soft soil, one may replace seven slow DEM-based wheel models with faster SCM-based models and keep just one wheel with low-level DEM. Thereby the simulation time, compared to the time required for full rover DEM, can be reduced to approximately the same time as required for a single DEM-modeled wheel. On the other hand one can analyse the details of wheel-soil contact dynamics at the single high-accuracy DEM-model but in the context of a full system like the rover chassis. Additionally our framework allows us to make detailed soil contact models accessible in higher level simulations of the entire rover or even as part of complete mission scenario simulations. Thereby the framework is providing a basis for all kinds of engineering, ranging from the development of low level hardware controllers for motor drivers to artificial intelligence approaches of the mission path planning.

References

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