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MULTIBODY AND CONTACT DYNAMICS: FROM SATELLITE CAPTURING TO PLANETARY ROVER TERRAINABILITY

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ABSTRACT

This paper gives a short overview of the multibody and contact dynamics based modelling and simulation activities performed at the German Aerospace Center. These cover two different applications, one in the orbital satellite servicing field and a second one in planetary explorations with rovers, specifically on Mars and Moon. Both topics require efficient and reliable contact dynamics modelling for both, satellite grasping and capturing and for the interaction between rover wheels and soft and hard planetary soils, i.e. the power transmission from the wheel actuators to the ground. Although the two applications areas, at first glance, are not necessarily common to each other, the contact dynamics modelling approach for both areas can rely on the same algorithms.

Keywords: multibody dynamics, contact dynamics, satellite capturing, planetary rover, terramechanics, mobile robotics.

INTRODUCTION

Grasping and capturing of telecommunications satellite by means of a servicer satellite for orbital life extension has gained increased importance during the past years. The Smart-OLEV (Orbital Life Extension Vehicle) mission is focusing right on these tasks. Its mission concept is based on a chaser satellite that docks to a client satellite (Fig. 1) and takes over the AOCS (Attitude and Orbital Control System) tasks of the mated configuration to perform orbital manoeuvres [1]. The most critical phase within this mission will be the soft docking of both satellites. The major docking parts consist of a Capture Tool (CT) and a deployment and retraction mechanism. Extensive simulations of this crucial phase have to be performed in order to detect critical issues of the docking strategy and to verify the technical feasibility of the mission. This requires modelling and simulation of the combined system consisting of the two satellites and the capture tool in between. Furthermore, this will advance and support the design of the appropriate grasping or capture tools and for demonstrating the feasibility of such novel operational manoeuvres. DLR has set up a simulation environment that is based on multibody system (MBS) dynamics for the three main body parts (two satellites and CT in between), and on a contact dynamics approach (PCM, Polygonal Contact Modelling, for rigidly assumed contact surfaces) for the capturing phase, the latter being an integral part of the MBS tool.

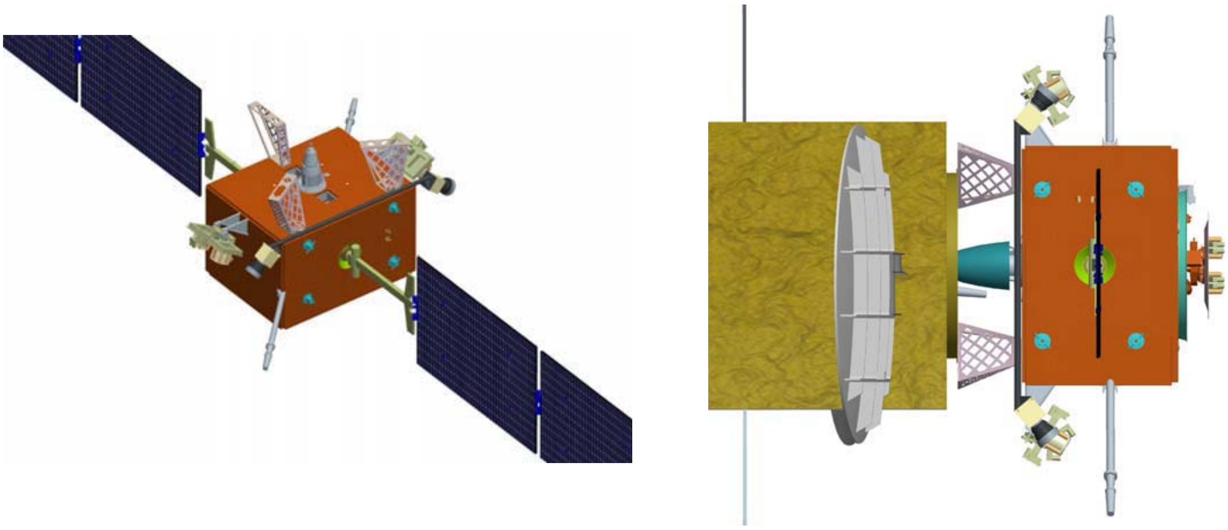


Fig. 1. Smart-OLEV spacecraft: (left) servicer (= chaser) satellite, (right) OLEV docked with client satellite

The need for developing and using powerful rovers for planetary surface exploration is an upcoming and very promising domain that allows to strongly extend the scientist’s operational area compared to lander-only based operations. Besides the NASA owned four Mars rovers – i.e. the past and small-sized Sojourner rover, the current two MER rovers and the near-future and much larger MSL rover –, ESA also is aiming at operating rovers on Mars (ExoMars mission) and on Moon (NLL, Next Lunar Lander mission) in the far future (> 2018). The ExoMars rover (Fig. 2) is a six-wheeled rover under development for Mars exploration [2], being part of ESA’s Aurora Programme. For NLL, predominantly being a lander-based planned mission to Moon, also a smaller rover of 70 kg or less is to be considered in present studies. Such vehicles that drive up rocks, loose soil and general on slippery and uneven terrain often need high mobility capabilities.

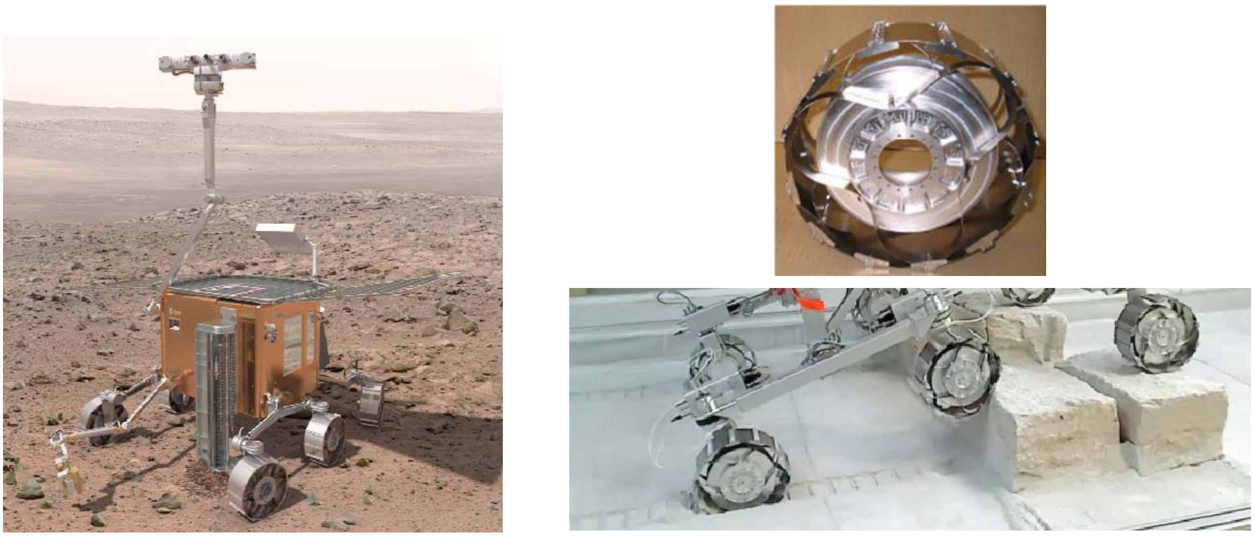
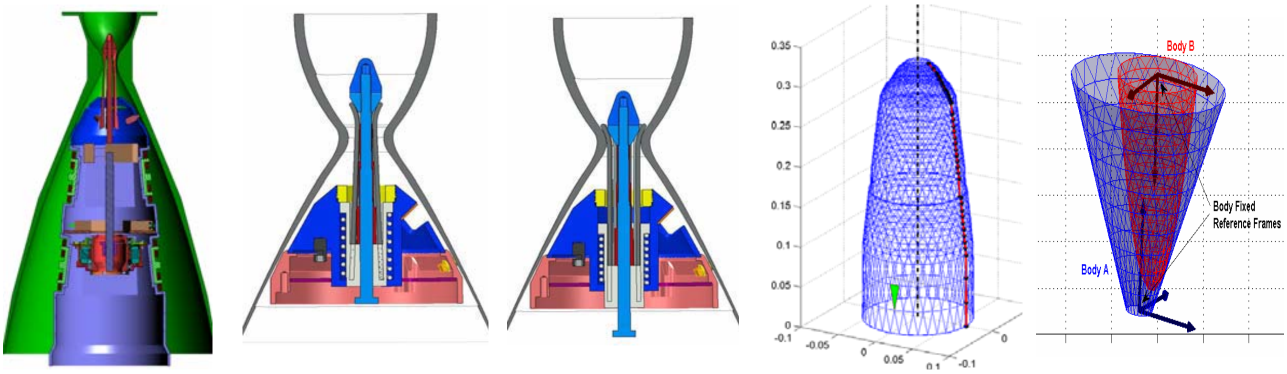


Fig. 2. (left) Artist's view of the ExoMars rover (courtesy: ESA) scheduled for launch in January 2018; (right top) prototype flexible wheel design; (right bottom) ExoMars breadboard chassis driving in testbed (courtesy: RUAG Space, Zurich, CH) over sandy soil and hard rocks

Within the ExoMars mission preparation phases, DLR is responsible for modelling, simulating and testing the entire mobility behaviour of the rover, specifically its terrainability, i.e. its capability to travel on any kind of soft, hard or mixed planetary surface, or to negotiate certain obstacles like rocks and pebbles of various geometric shape. Similarly to satellite capturing, the major goal again requires a multibody dynamics approach for rover chassis, wheel suspensions and the flexible or rigid wheels itself. Moreover, for simulating wheel traction performance on the various planetary surface soils, appropriate models for modelling the interaction between wheels and surface are required that are able to cope with different terrains. And that finally allow to demonstrate their performance of transmitting optimally the wheel actuator power to the ground. This has been solved by making use of the contact dynamics model approach, applied very successfully to satellite capturing, for rigid soils and travelling over rocks. For soft and sandy-like soil terrain, a different contact dynamics approach has been followed that makes use of the so-called Bekker empirical equations, while modelling the two contacting partners in a different way (SCM, Soft Soil Contacts Modelling, [4]). Both contact approaches allow to detect multiple point contacts, which is not state-of-the-art in wheel-soil modelling.



a) b) c) d) e)

Fig. 3. Capture Tool (a) diving into apogee motor cone; locking crown in open (b) and locked (c) configuration; contact shape definition CT alone (d) and CT with apogee motor cone (e)

CONTACT DYNAMICS

The contact dynamics models that have been implemented in our simulation environment for both applications are derived from the so-called Polygonal Contact Model (PCM, [3]), for rigidly assumed contact contours, and adapted to the particular application inside the respective simulator. The PCM applies the Elastic Foundation Model theory for contact force computation between two rigid bodies with elastic surfaces in between. The general idea of PCM is based on three major steps:

1. Discretisation of the contact body surface by polygon meshes and assignment of contact relevant geometric and dynamics parameters individually to each polygon.
2. Detection of polygons, which are in contact with their counter part.
3. Calculation of contact forces/torques based on the relative kinematics states of the contact polygons under respect of the assigned geometric and dynamics parameters.

With the pre-requisites, namely the dynamics parameters of the polygons and the current relative kinematics states, we are able to calculate the actual contact forces, individually for each contact polygon by the sum of the following components (for simplification reasons only as scalar description):
Normal force due to linear surface stiffness, $F_c = c \cdot s$, and due to linear damping, $F_d = d \cdot v$; tangential force due to Coulomb friction, $F_t = \mu \left(F_c + F_d \right)$; where c, d and μ are the stiffness, damping and friction coefficients, s is relative penetration depth and v is relative velocity between two adjacent polygons. The total contact force applied to the contact bodies is then calculated by integration over all polygons of the contact shape (compare Fig. 3 for the CT contact modelling, and Fig. 4 for CT and apogee motor cone contact modelling, and wheel and planetary surface modelling).

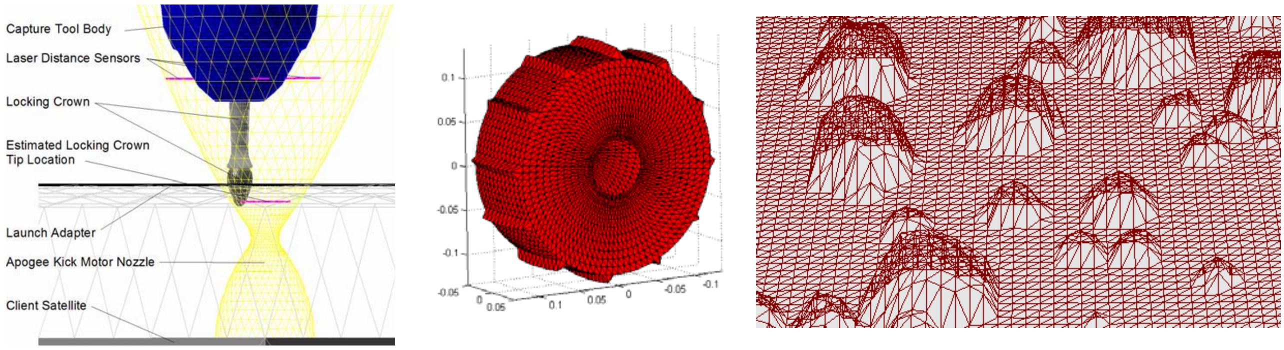


Fig. 4. (left) Initial simulation configuration for CT and apogee motor cone; polygonal representation of (middle) rover wheel with 12 grousers used for PCM contact detection, and (right) of Viking-1 Mars reference terrain

The contact problem between rover wheels and soft soil is modelled differently from rigidly assumed contact contours (Fig. 5). Generally, it can be described as the contact between a plastically deformable body (soft soil) and a rigid one (wheel). Dominant features in this approach are (1) soft soil surface description, (2) contact detection, (3) contact force calculation that is based upon the well-known Bekker theory, and (4) finally the plastic deformation of the soil (soil displacement, temporary deposition of soil, erosion of soil, multipass effects). A comprehensive description of this approach is to be found in [4].

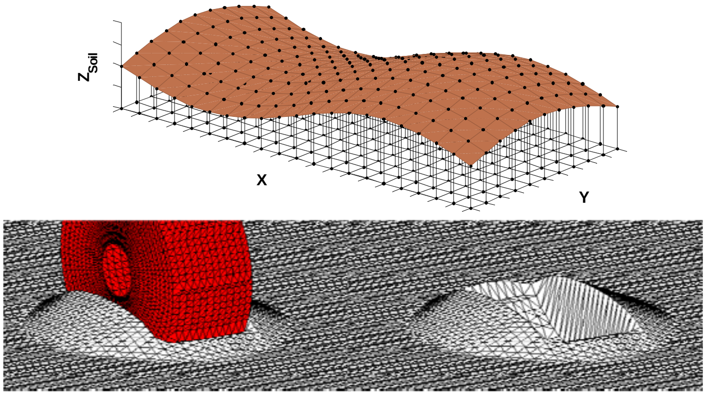


Fig. 5. (top) Soil surface elevation grid; (bottom) polygonal representation of single wheel footprint with eroded sand

MULTIBODY DYNAMICS

Multibody system dynamics formulation is used to set up models for both applications, satellite capturing and for rover chassis and locomotion subsystem. In case of Smart-OLEV, modelling and simulation is based on Matlab/Simulink environment, whereas for planetary rover we use the commercial software tool Simpack that also includes the contact modelling based on PCM. In case wheel deformation is expected to have some remarkable influence on contact dynamics, appropriate modelling modifications are currently underway. One promising modelling technique is based on multibody systems approach, where the rigid wheel circumference is partitioned into smaller rigid wheel parts (Fig. 6).

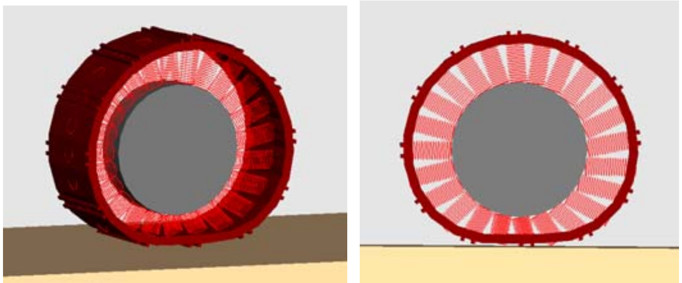


Fig. 6. Elastic wheel modelling by means of multiple rigid wheel parts and springs

SIMULATION RESULTS

Fig. 7 shows typical results gained for planetary rover terrainability on soft soil for one wheel only (left figure), for a 4 wheels (middle figure) and a 6 wheels locomotion configuration (right figure). Moreover, a mixed terrain surface consisting of a combination of soft soil (SCM contact modelling) and hard rocks (PCM contact modelling) demonstrates the feasibility of the underlying approach as well.

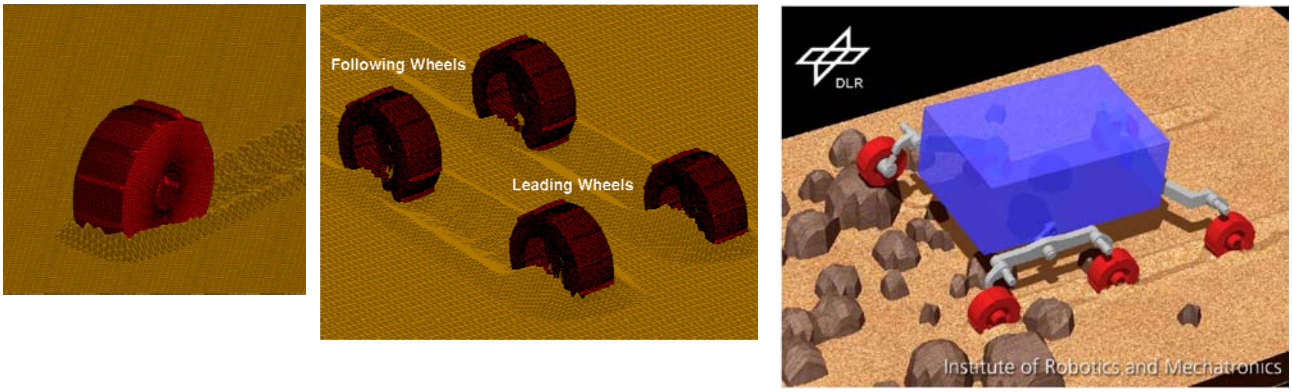


Fig. 7. Simulation results for planetary rover travelling on soft and hard soil

For Smart-OLEV docking and capturing manoeuvres, we could show that in all simulations the docking was performed successfully. It was proven, that the accuracy of the proposed sensors at the Capture Tool as well as the performance of the proposed boom and Locking Crown actuators (Fig. 3) have been designed adequately. Furthermore, according to the simulation results the force/torque impact at the client satellite is quite moderate and definitely less than the applicable force/torque limits.

CONCLUSIONS

The combination of a multibody system dynamics modelling approach with efficient contact dynamics models proved to be a powerful means in order to reliably and efficiently predict any contact dynamics motion behaviour, be it docking and capturing of two satellites or the terrainability demonstration of any kind of planetary rover on uneven soft and hard surfaces. One issue that requires still further attention is the experimental determination of underlying system parameters with regard to contact dynamics. These parameters, stiffness and damping between rigidly assumed contacting bodies or the soft soil Bekker parameters, influence strongly the simulations results, and have to be carefully obtained from extensive testing.

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