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Coaching MASCOT for broad-jumping: Multi-criterial optimization of the arm trajectories for MASCOT's hopping locomotion

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After a cruise phase of four years, MASCOT will land on the asteroid 1999JU3. Due to the complex interaction of the lander with the terrain in low-gravity environments, a certain orientation of MASCOT after descent cannot be achieved directly. Thus the mobility unit developed in the DLR Robotics and Mechatronics Center enables MASCOT to upright into the nominal position and to relocate by hopping motion.

As the dependence of the desired jumping trajectory on the trajectory of the mobility eccentric arm is complex, a suitable trajectory cannot be determined beforehand. As even parabolic flight campaigns do not allow for sufficiently long low-gravity phases, it is also not possible to define the trajectories based on measurements. Additionally the zero or low gravity phase during parabolic flights needs to be quite precise. Thus MASCOT's multibody dynamics model is used to check a priori created trajectories. Therefore the model has been verified using both parabolic flight campaigns as well as high precision reaction force measurements in order to determine the applicable frequency range the model is able to reproduce. These comparisons have shown, that the range important for jumping is covered by the model and only higher frequency structural vibrations are not covered yet. As contact dynamics between the lander and the asteroid are crucial to cover the post-impact behaviour, the ground contact has been modeled as an elasto-plastic surface based on the currently available but yet limited knowledge on 1999JU3.

Applying the aforementioned model to multi-criterial optimization enables to systematically search for suitable trajectories in an automated process. Using the optimization framework MOPS (Multi-Objective Parameter Synthesis) developed by DLR Institute of System Dynamics and Control it is possible to find global optima for the trajectories using evolutionary strategies. The objectives for this optimization are specifically defined for the hopping scenario. Due to the micro-gravity environment it is also crucial to keep the upwards velocity safely below the escape speed. By using the multi-criterial approach it can be always maintained that MASCOT's escape velocity is never reached and minimized, while also improving performance and reliability of the hopping locomotion. As the evolutionary algorithms usually need a certain number of individuals to find optima, these numerous simulations can be used in order to further investigate the complex low-gravity interaction of the lander and the asteroid.

Using these preliminary sets of training data, MASCOT's short mission phase can be supported and enhanced by the deeper insight into the dynamic interaction between lander and Asteroid.