Wheel-soil Interaction Modelling for Dynamics Simulation of Rovers

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Abstract
Mobile robotic systems represent key elements for future planetary exploration. Envisioned applications cover many different situations, ranging from small rovers assisting astronauts to large pressurized vehicles transporting humans and cargo. Such mobile robots have to operate on various different types of unstructured terrain, among which soft deformable terrain is of particular interest. In order to investigate the effect of deformable terrain on the performance of rovers, appropriate models are required to represent the interaction between wheel and terrain. In this context, it is required to know soil reactions based on the generalized coordinates and velocities of the wheel. In this presentation, a summary of the research that has been recently performed will be reported. This includes application of semi-empirical models in real-time simulation of rovers, utilizing FEM-based commercial packages in investigating wheel-soil contact, and developing a novel approach based on the theory of plasticity, which is suitable for fast implementation in multibody dynamics simulation environments.

The Bekker model [1, 2] and the extension made by Wong and Reece [3], which are semi-empirical models developed in the terramechanics literature, are considered as state of the art for performance evaluation of rovers. However, these models are developed for steady-state operation of the wheel, not for the full dynamic range of operations. Therefore, numerous modifications are needed for implementation of these models in our multibody dynamics simulation environment, Vortex [4]. Based on these models, the normal and shear stresses in the contact area of the wheel and soil are computed. Then, the reaction forces and moments are calculated by integrating them over the contact area. This results in having soil reactions as functions of sinkage and slip ratio of the wheel. However, the component of wheel centre velocity normal to the terrain surface is not accounted for in the terramechanics models. Therefore, direct use of these models cannot damp any wheel oscillation in the direction normal to the terrain, for which a damping term is included in our implementation. In addition, when the wheel either starts from rest or stops, direct use

4. http://www.vxsim.com/

of terramechanics relations may cause instability in the simulation. This is a major concern that limits the direct use of terramechanics relations in a multibody dynamics simulator. Therefore, a complementarity approach is employed in our simulations to implement the soil reactions that are related to shear stress distribution around the wheel. Using this implementation, performance of three rover concepts are investigated under various manoeuvres with both the Bekker and the Wong and Reece models. These include: (1) straight line motion on a flat terrain or climbing a given slope and (2) climbing over a rock with the wheels of one side while those of the other side move on flat or inclined terrain.

Another possibility in modelling wheel-soil interaction is by modelling soil as a continuum. In this context, wheel-soil contact can be analyzed by considering an appropriate constitutive relation for soil and using the Finite Element Method (FEM) to calculate stress distribution and soil deformation in the contact area. Even though this is not a suitable approach for a real-time or fast implementation, FEM-based simulations can still be helpful as a validation tool in model development. In this regard, wheel-soil interaction is simulated using Abaqus/Explicit, and the Drucker-Prager constitutive relation with cap hardening is employed to model soil plastic behaviour. Various motion conditions and different ranges of slip ratio have been simulated. Our results show that for a frictional soil with negligible cohesion, stress distribution is closer to the Wong model, whereas in a cohesive-frictional soil, the Bekker model can be more representative.

The main question here is how a continuum-mechanics approach can be employed for fast simulation of rigid wheel-soil interaction. To answer this question, a novel approach is developed that is based on the assumption of a prescribed velocity field in soil mass around the contact area. By calculating the velocity gradients, the incremental strain tensor is obtained for any point in the vicinity of the contact area. Using the above-mentioned Drucker-Prager constitutive relation and utilizing finite strain elastoplasticity theory, the stress tensor is obtained for the areas in contact. The normal and shear stress distributions in the contact area are then readily calculated. Integrating these stresses results in soil reactions in the form of forces and moments, applicable in our multibody dynamics simulation environment. Despite employing a rather simple velocity field, the slip-sinkage phenomenon, an important behaviour observed experimentally in wheel-soil interaction, was one of the outcomes of this approach. In addition, the multipass effect can be readily implemented. Another interesting feature of this approach is its ability to simulate transient motion, which is essential in the simulation of multibody systems involving wheel-soil interaction.

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