Using superposition of local soil flow fields to improve soil deformation in the DLR Soil Contact Model - SCM

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Locomotion on soft sandy soil poses high risks to planetary rovers. Especially the embedding of the rover SPIRIT [1] greatly shows these risks. Since scientifically interesting regions may be in or behind sand patches tools to predict locomotion on this terrain are important. To evaluate motion on a sandy terrain a simulation of the full system with a capable terramechanical model is needed. Discrete Element Methods (DEM) show great potential for a detailed component analysis, but full system simulations would take too much time to be used in an efficient way[2]. Single point models based on BEKKER's are useful for a first evaluation of the situation. If effects like multi-pass, rutting or other terramechanical effects are of interest, a different type of modeling approach is essential. Tools like Artemis [3, 4], the elastoplastic approach in [5] or the Soil Contact Model - (SCM) use a discretization of the wheel, the soil or both to integrate more effects into the model.

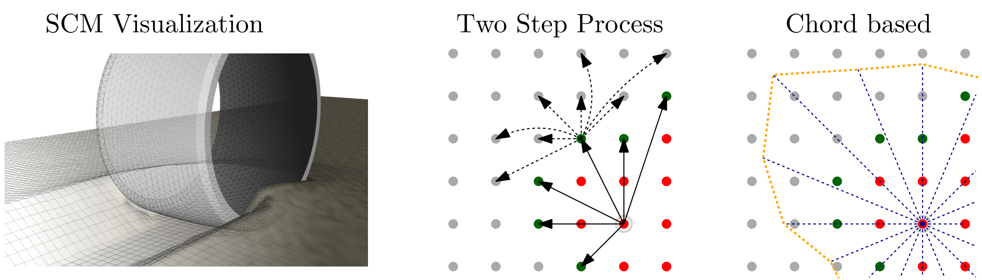

Fig. 1: A SCM Visualization on the left. SCM's old soil distribution two step process in the middle, where soil gets distributed to the border nodes (green) and is then further distributed outwards. As well as the new chord based process where each contact node(red) spans a polygon (orange) in which the soil is displaced. The polygon is spanned by calculating the estimated shear state along a set of chords (blue).

The Soil Contact Model - (SCM) was developed originally by KRENN in 2008 [6] with the goal of incorporating effects induced by soil deformation like rutting and slip sinkage into a multi body environment. As visualized on the left in Fig.1 SCM uses the intersection of an object mesh with a soil grid to calculate the resulting force and the surface deformation. Each point in the grid, called node, represents the volume of soil beneath. This functionality is divided in two major parts, a contact dynamics, and a soil update function. During the contact dynamics call the reaction force onto a contact object is calculated based on its kinematic state and the soil states. The soil update function updates the soil geometry and internal states based on the intersection during previous contact dynamics calls. The original SCM algorithm was the extended in 2016 [7] to improve the soil deformation. The improved algorithm showed a good match for full system simulations but was not able to reproduce single wheel experiments at high slip ratios without violating some physical parameter bounds.

The reason for these shortcomings lays in the two step soil distribution algorithm within the soil update (Fig. 1, middle) used in the original and extended algorithm. The displaced soil is distributed from each contact node onto the surrounding border nodes. During this first step geometric features of the surface between the contact node and the border node are ignored. The second step then distributes the accumulated soil from each border node further onto encompassing non contact nodes. These two steps, especially the missing consideration of geometric features lead to the underrepresentation of soil shearing effects at high slip ratios. To counteract the drawbacks a new approach was developed (see Fig. 1, right). By directly distributing soil from contact nodes without an indeterminate step, the representation of features close to the node in the resulting distribution pattern was improved. To allow the algorithm to efficiently capture the geometric properties of the surface, an approach was selected which evaluates the geometry and soil states only in discrete directions, called chords. On each chord the assumed depth of shear

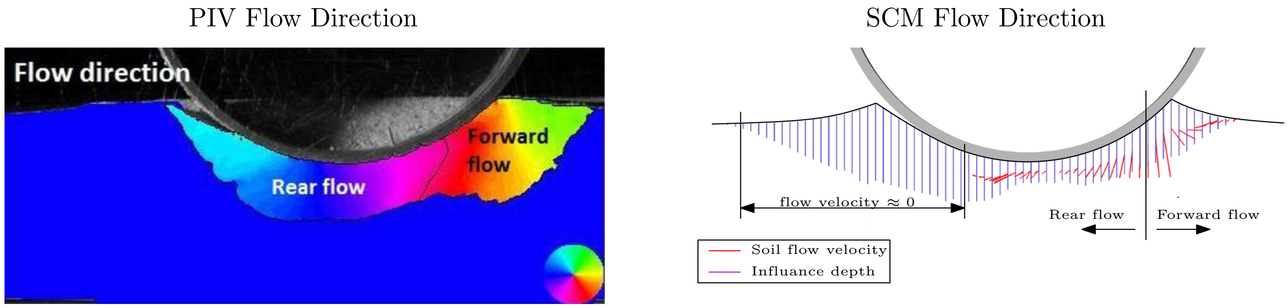

Fig. 2: Comparison between soil flow direction in PIV data on the left against SCM Simulation results on the right. PIV image from ([8])

failure as well its propagation angle is calculated. Afterwards a polygon is spanned by these chords. Through interpolating onto all nodes within the polygon from the nearest chords a good approximation with reasonable effort is computed. This results in a local soil flow field for each contact node. By superimposing these fields of all contact nodes a complete flow field is formed. The resulting field now regards surface features. The approach introduces four additional parameters which are currently independent and must be selected manually. An algorithm or rule for selecting those is the topic of current work. The resulting flow has been verified against academical examples like a long beam or a simple BEVAMETER experiment. Fig. 2 shows a comparison of the flow field captured with particle image velocimetry (PIV) measurements taken in [8] and simulation results generated by SCM. A good match between the soil flow velocity (red) and the influence depth(purple) can be observed in front of the wheel. The flow behind the wheel extends further back in SCM but has a very minimal soil velocity behind the wheel. A newly designed force law is based on BEKKER's pressure - sinkage relation, MOHRCOULOMB failure criterion and JANOSI-HANAMOTOS shear stress - shear length relation and uses the previously described soil flow field. A validation campaign against singe wheel experiment measurement data is currently in progress.

The computational effort of the new algorithm slightly increased in comparison to the previous implementation. However its formulation is more suitable for parallelization which results in total in a slight performance increase. An additional benefit of the new formulation is its ability to increase the time step between instances when the soil update has to be executed, potentially increasing the performance drastically.

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