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Mobility Evaluation for Hybrid Robot Motion on Deformable Terrain via Physics-Based and Data-Driven Modeling Approach

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Navigating the unmapped environment is one of the ten biggest challenges facing the robotics community. A vision-based navigation system embedded in the mobile robot can only help to negotiate obstacles, which are well described by geometrical features, like sharp-edged stones and rocks. Other aspects like sand, snow, and challenging terrains, are challenges for motions that robots cannot avoid during missions. Thus, designing and selecting effective gaits to navigate over terrains that may not be well describable by geometry is crucial for robot exploration. Wheeled robots can move fast on flat surfaces but suffer from loss of traction and immobility on soft ground. However, legged machines have superior mobility over wheeled locomotion when they are in motion over flowable ground or a terrain with obstacles but can only move at relatively low speeds on flat surfaces. A question is: If legged and wheeled locomotion are combined, can the resulting hybrid leg-wheel locomotion enable fast movement in any terrain condition? Investigations into vehicle terrain interaction fall in the area of terramechanics. Traditional terra-mechanics theory can help capture large wheel vehicle interaction with the ground. However, legged or hybrid locomotion on a granular substrate is difficult to investigate by using classical empirical terra-mechanics theory due to sharp-edge contact. Recent studies show the continuum simulation can serve as an accurate tool for simulating dynamic interactions with granular material at laboratory and field scales. Therefore, to investigate the rich physics during dynamic interactions between the robot and the granular terrain, a computational framework based on the Smooth particle hydrodynamics (SPH) method has been developed and validated by using experimental results for single robot appendage interaction with the granular system. This framework has been extended and coupled with a multi-body simulator to model different robot configurations. Encouraging agreement is found amongst the numerical, theoretical, and experimental results, for a wide range of robot leg configurations, such as curvature and shape. The sensitive dependence of robot performance on different gaits has been investigated by parametric space exploration.

The above mentioned physics-based simulation can serve as a high-fidelity tool to uncover clues about the underlying mechanism of dynamic interactions between robots and soft terrain. However, real-time navigation in a challenging terrain requires fast prediction of the dynamic response of the robot, which is useful for terrain identification and robot gait adaption. Therefore, a data-driven modeling framework has also been developed for the fast estimation of the slippage and sinkage of robots. The data-driven model leverages the high-quality data generated from the offline physics-based simulation for the training of a deep neural network founded on long short-term memory (LSTM) cells. The results are expected to form a good basis for online robot navigation and exploration in unknown and complex terrains.