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High hops on sand influenced by added mass effects

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ABSTRACT

Various animals exhibit locomotive behaviors (like sprinting and hopping) involving transient bursts of actuation coupled to the ground through internal elastic elements. The performance of such maneuvers is subject to reaction forces on the feet from the environment. On substrates like dry granular media, the laws that govern these forces are not fully understood and can vary with foot size and shape, material compaction (measured by the volume fraction, f) and kinematics of intrusion. To gain insight into how such interactions affect jumping on granular media, we study the performance of a self-actuated spring mass robot with a 7.62-cm flat circular foot. We compare performance between two jump strategies: a single-cycle sine-wave actuation (a “single jump”) and a counter-movement pull-up phase proceeded by a single jump (a “stutter jump”); both jump methods perform well on hard ground. We systematically vary F at fixed actuation parameters for both strategies, and find that both of these jumps perform similarly poorly in loose-packed granular media, reaching only 44% of the close-packed jump height. Introducing a delay time between the pull-up phase and the push-off phase of the stutter jump (the delayed stutter jump) results in significantly improved jump heights at low volume fraction, achieving 77% of the close packed height. A 1D simulation of the robot jumping on granular media reveals that the commonly used depth dependent and velocity dependent model of granular intrusion force is insufficient to reproduce experimental jump heights. To gain insight into the behavior of the granular media during these impulsive events, we image a foot through a transparent sidewall, recording high speed videos at different packing states (F = 0.58-0.63). To monitor grain flow, we adapt particle image velocimetry techniques to perform a 2D particle tracking velocimetry analysis on these images. A region of grains moving with similar downward speed to the intruder emerges. Subsequently, we implement an added-mass model, an effect observed in fluids, to our granular jumping simulation and find agreement with experiment.