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Force generation during rotational intrusion into granular media
CHEN LI, YANG DING, Georgia Institute of Technology, PAUL UMBANHOWAR, Northwestern University, DANIEL GOLDMAN, Georgia Institute of Technology —
When legged locomotors move on granular media their limbs intrude into the substrate along paths more complicated than simple vertical or horizontal trajectories. To investigate force generation for paths more representative of typical limb-ground interaction, we rotated simple objects (plate, sphere, rod, c-shaped leg) into granular media and measured the resulting resistive force, F, as a function of the angle, θ, from maximum penetration depth. For all objects, greatest F occurs not at maximum depth ($\theta = 0$) as expected from the linear dependence of force on depth for vertical penetration, but substantially earlier ($\theta \approx -15^\circ \sim -30^\circ$). The location and magnitude of maximum F depend on intruder geometry. For plate and rod, F is primarily opposite displacement, while for sphere and c-shaped leg F has a substantial inward radial component and is significantly larger than for plate and rod geometries with similar extent. Our data suggest that in granular media, larger yield stresses at fixed depth and with the same projected intruder area can be obtained by adjusting intruder geometry to maximize normal stress. This in turn provides hypotheses for locomotion biology and guidance for design of legged robots and other mobile devices.

Chen Li
Georgia Institute of Technology

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