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A 3D DEM NUMERICAL MODEL TO SUPPORT THE DESIGN OF EXPLORATORY ARTIFICIAL SYSTEMS

Abstract

Plant roots are natural soil explorers, moving by apical growth. Mimicking the growth of new cells at the apex of these organisms with a layer-by-layer addition of artificial material in bioinspired artificial intruders, we previously demonstrated the apical growth to be a favorable strategy for artificial soil diggers [1-3]. Together with the apical growth, roots display other features that might also be involved in effective soil penetration. Among many, the radial root thickening is hypothesized to generate voids below the tip and to anchor the body during forward motion. This study presents a 3D Discrete Element Model (DEM) developed to investigate the penetration performances of a root-inspired soil digger moving in a granular soil. Specifically, the study compares the system performances for the only axial growth with the penetration achieved by including radial expansion over different soil conditions (i.e., cohesionless granular and cohesive media). In addition, the effects of the system size (Droot) to median soil particle size (D50) ratio are analyzed for Droot/D50 in the range [0.03, 15]. Our findings highlight that a digger growing in axial and radial directions is more/less advantageous than an only axial growth in terms of forces experienced when moving in a dense/loose granular medium. In cohesive soil, the radial expansion results advantageous for a lower penetration depth compared to the granular soil case. Its benefit reduces with increasing inter-particle contact adhesion. As expected, penetration performances are strongly affected by the Droot/D50 value: for big Droot/D50, the intruder tends to perceive a constant soil resistance pressure during penetration, in agreement with pile foundation theory; for small Droot/D50, soil resistance forces tend to be constant. The proposed methodology can support the development of performant exploratory artificial systems providing a means to analyze design requirements (dimension, geometry, penetration strategy, and actuation system) given the soil characteristics. This approach can be adopted for exploration on Earth or Space, including Lunar or Martian-like soil exploration.

[1] Sadeghi, A., Tonazzini, A., Popova, L. and Mazzolai, B., 2014. A novel growing device inspired by plant root soil penetration behaviors. PloS one, 9(2), p.e90139.

[2] Sadeghi, A., Mondini, A. and Mazzolai, B., 2017. Toward self-growing soft robots inspired by plant roots and based on additive manufacturing technologies. Soft robotics, 4(3), pp.211-223.

[3] Sadeghi, A., Del Dottore, E., Mondini, A. and Mazzolai, B., 2020. Passive morphological adaptation for obstacle avoidance in a self-growing robot produced by additive manufacturing. Soft robotics, 7(1), pp.85-94.