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COMPUTATIONAL SIMULATION OF REGOLITH EXCAVATION DYNAMICS FOR SUSTAINABLE LUNAR AND MARTIAN INFRASTRUCTURE

Abstract

As humanity advances toward sustained lunar and Martian presence, efficient regolith excavation becomes a cornerstone for in-situ resource utilization (ISRU) and infrastructure development. Traditional Earth-based excavation methods are inefficient in reduced gravity and vacuum conditions, necessitating novel approaches tailored for extraterrestrial environments. This study presents a computational simulation framework to analyze the dynamics of regolith excavation under lunar and Martian conditions using ANSYS-based numerical modeling, providing insights into optimizing excavation strategies while minimizing energy consumption and equipment wear. To address regolith excavation challenges, we propose a hybrid system combining electrostatic beneficiation and modular autonomous robots. Electrostatic forces minimize dust adhesion and improve material transport, while robotic units coordinate excavation for adaptability and redundancy. AI-driven control and real-time sensors enhance efficiency and resilience in extreme conditions. We employ a multiphysics modeling approach integrating discrete element method (DEM) for regolith particle interactions, coupled with finite element method (FEM) for tool-soil interaction, and computational fluid dynamics (CFD) to account for dust behavior in reduced-pressure environments. The findings from our simulations will inform the design of next-generation excavation technologies for sustainable off-world infrastructure, supporting habitats, resource extraction, and construction efforts crucial for long-term lunar and Martian missions.