Towards Autonomous Lunar Resource Excavation via Reinforcement Learning

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To continue on a sustainable and flexible path, NASA needs to address the challenge of collecting and moving large amounts of regolith at the destination. NASA's Regolith Advanced Surface Systems Operations Robot (RASSOR) [1] is principally designed to mine and deliver regolith for In-Situ Resource Utilization (ISRU) processing. RASSOR's design enables it to efficiently collect and deposit regolith, return collected material for processing, and myriad related ISRU activities. To reliably perform these operations on the lunar surface, RASSOR software and sensory systems need to be robust and maximize the information extracted from a reduced sensor payload. Herein, we present preliminary findings from the Intelligent Capabilities Enhanced RASSOR project [2]. We created reduced-order simulation environments to develop autonomous trenching controllers via reinforcement learning and prototype state estimation architectures. The goal of reinforcement learning is for an agent to learn a policy (task strategy) through interactions with an environment. When the agent performs an action, a change occurs in environment state and a numerical reward is received which informs the agent whether the action performed was good or not. Since reinforcement learning algorithms learn through trial-and-error, a simulation is a desirable first environment for development and learning. We developed two simulations, the first is a 2D excavation simulation developed to facilitate parameter selection, and a 3D simulation developed using a game physics engine, to simulate simplified soil interactions and increase the fidelity of the dynamic models of the robotic agents. The development of this 3D simulation has enabled the training of additional sensing capabilities and research both at the granular mechanics and operations levels. We experimented with various virtual sensor payloads to identify a combination that enabled efficient excavation operation and learning. Our reward function is based on how much material is excavated per step. A penalty is also received for leaving the dig site and to smooth the acceleration of the drum arms. We implemented pseudo time-of-flight sensors to report distance from each drum to ground and the height above ground which was found to be more efficient than existing solutions. Our findings suggest that reinforcement learning for autonomous operations has learned viable trenching strategies within 3000 training episodes in our simplified 2D environment and helped identify desirable sensing capabilities, arrangements, and considerations such as the positioning of time-of-flight sensors. Future work includes expanding our simulation to more complex environments and scenarios, and transfer learning from simulation to RASSOR 2.0 hardware for deployment in the Regolith Test Bin at NASA's Kennedy Space Center.

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