Graduate School of Science and Technology Master's Thesis Abstract

Laboratory name (Supervisor)	Robot Learning (Takamitsu Matsubara (Professor))		
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Thesis title	Autonomous Rock Removal in Soil Using Sim-to-Real Reinforcement Learning with Privileged Information		

Abstract

Autonomous rock removal in soil is crucial for improving productivity and safety in mining and construction tasks performed by robotic systems such as excavators. This thesis addresses the automation of buried rock removal, in which obstacles such as rocks must be scooped from the ground under severe partial observability caused by soil coverage and complex soil-tool contact dynamics. Previous works have tackled this problem using data-driven approaches that focus on learning control policies robust to estimation errors in obstacle information. However, such approaches often lead to overly conservative strategies that avoid explicitly utilizing obstacle properties, thereby limiting task performance. In contrast, this thesis hypothesizes that removal performance can be improved by explicitly leveraging obstacle information inferred from the temporal interaction history among the robot, soil, and obstacle. Based on this insight, a hierarchical sim-to-real reinforcement learning framework with a two-stage learning strategy is proposed. First, in a particle-based simulation, a policy is trained with access to ground-truth privileged states, including obstacle pose and geometry, enabling the acquisition of stable lifting strategies that reliably extract the target obstacle. Second, to bridge the sim-to-real gap, a state encoder is trained to reconstruct these latent parameters solely from the history of proprioceptive signals and task-field depth observations. Extensive simulation studies and real-world experiments using a UR5e manipulator equipped with a bucket demonstrate that the learned policy achieves robust removal performance under severe partial observability.