CraterGrader: Autonomous Planning and Control For Leveling Unstructured Lunar Terrain

B. Younes[1], A. Pletta[1], R. Wong[1], J. Harrington[1], R. Lee[1], and W. Whittaker[1]. [1]The Robotics Institute, Carnegie Mellon University, 5000 Forbes Ave, Pittsburgh, PA, (Contact: byounes@andrew.cmu.edu)

Introduction: U.S. interest in a sustained presence on the Lunar surface necessitates technologies for preparing and maintaining infrastructure in hostile and remote environments. Significant worksite preparation and leveling is a prerequisite for building and maintaining the landing pads, roads, and foundations for such presence. Contemporary terrestrial grading relies on discretion and experience of highly trained operators to move earth, which does not extend to fully remote, 300-hour continuous operation in alien environments. Earth-based automation enabled approaches leverage brute force and massive energetics, unavailable in Lunar environments, and use basic levels of localization and control.

Sitewide autonomy planners for grading vehicles outside of simulation have yet to be developed in a meaningful way in SOA, and the Lunar environment imposed mass and localization constraints further constrain the problem. The work herein addresses aforementioned pain points by developing a novel terrain understanding and planning worksystem for autonomous manipulation of deformable terrain, coining and abiding by the term “patient work”, to level terrain slowly but robustly and optimally for long periods under minimal-to-no supervision.

Methodology: The approach described in this abstract, referred to as CraterGrader, leverages priors in robotics and SOA earthmoving automation-enabled techniques. CraterGrader is an autonomy and sensing suite built upon a flight-facing worksystem comprising of a mobility platform and a quiver of tools. The system is in development at Carnegie Mellon University’s Robotics Institute, being tested in a 600 square foot “moonyard”; stocked with Lunar-like simulants that are tunable for specific surface morphologies. The moonyard is equipped with motion capture and laser scanning technology for ground truth of vehicle localization and worksite topography. The technical crux boils down to robust 3D pose estimation with limited sensing modalities and external infrastructure, mapping changing terrain, and planning how to manipulate terrain to flatten and prepare a worksite.

Results: The backbone of CraterGrader’s pose estimation comes from time-of-flight positioning sensors placed at worksite initialization, in combination with traditional sensor fusion, visual odometry, and SLAM techniques for online scene understanding. The proposed approach generalizes to any robotic vehicle attempting to operate in a high slip, millimeter precision environment and can be adapted to work vehicles for the Lunar surface which may be designed to: compact, load, haul, 3D print, or trench.

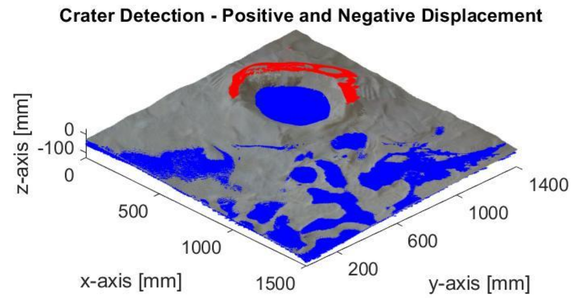

Figure 1. CraterGrader Lunar Site Map

Terrain sensing is manifested as stereo correspondence in the visual spectrum. Point clouds are handled onboard in real time, filtered, and combined into a semantic feature representation of the worksite. This semantic map consists of labeled deviations from the desired worksite plane and contains information about location and volumetric displacement.

The planner leverages terrain topography features to generate skill and motion primitives that achieve time and energy-efficient terrain manipulation. The architecture is centered on a nodal cost map encoding volume, shape, and location of local optimums. The worksite is decomposed into a hybrid configuration space to capture variable planning and motion constraints. The planner uses the earth mover’s distance metric to optimally plan node manipulation subject to configuration space constraints. These plans are then converted to preferential skill primitives that range in complexity depending on terrain detection certainty and complexity. A transition model is used as a heuristic for manipulated material until the terrain is again sensed and fused by the perception subsystem.

Conclusions: Establishment of sustained Lunar presence will require robust in-situ autonomous construction worksystems, central to which are terrain understanding and planning algorithms as presented in this work. Insights gained from the proposed algorithms may illuminate terrestrial construction planning methods and may push SOA in multiple domains.