

FY21 IRTD Final Report Summary

Project Title: Simulated Excavation Environment for Lunar Operations

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Project Description: With new pushes to reach and establish long term presences on both the Moon and Mars, significant effort has begun to develop methods of In-Situ Resource Utilization. Many of these methods involve excavation and manipulation of local regolith and, at this time, many of these missions are in the early planning phases. As such, simulations provide both an inexpensive and relatively easy method to perform high level proofs of concept and mission overviews along with an environment to perform machine learning for rovers and other robots.

The Simulated Excavation Environment for Lunar Operations (SEELO) was born out of this need for consolidated capabilities. SEELO seeks to provide accurate life mission environments and regolith interaction mechanics while remaining lightweight enough to run in faster than real-time. These combined features allow SEELO to be used for mission planning purposes that offer an environment for lunar robots to perform Machine Learning on moving, digging, and various other activities. Using the Real-Time Development Platform (Unity) to utilize regolith excavation models created by Intelligent Capabilities Enhanced-Regolith Advanced Surface Systems Operations Robot and lunar surface data collected by NASA's Lunar Reconnaissance Orbiter, SEELO has been able to provide NASA with a tool to plan, train, and even devise lunar missions.

Closeout Summary: A set of Key Performance Parameters (KPP) were established prior to the development of Simulated Excavation Environment for Lunar Operations (SEELO) to ensure the quality of the simulation. Three KPPs determined to be indicative of SEELO's success and how they were reached are detailed below.

Note: The following KPPs were attained and assessed in a 1g environment (Earth's gravity) using the Regolith Test Bin at Kennedy Space Center's Swamp Works facility. Should data be attained which reflect a $\frac{1}{6}$ g environment, SEELO will adjust its models to account for this change in gravity.

KPP 1: Regolith ingestion of the simulated rover should be within 10% of test data's regolith ingested.

With its focus on creating an excavation simulation, a KPP of SEELO is that its primary excavation rover (RASSOR 2.0) ingests an accurate-to-life amount of regolith depending on its actions. Two test runs within SEELO were used to demonstrate the accuracy of the training models with the first test run excavating regolith in the simulation compared to the real-life regolith excavated with a 2.07% error, and the second simulated test excavating regolith compared to the real-life regolith excavated with a 6.80% error. With these percent errors both being within the 10% error margin specified by the KPP, it was reasoned that this KPP has been met.

KPP 2: Simulation runtime should be within 10% of test data's operation runtime.

Time steps in the Unity software (0.02 frames per second) are different than time steps in test and training simulation data (0.00001 - 0.01 data points per second), and it must be ensured that SEELO handle this disparity. In order to avoid this from occurring, SEELO keeps track of the amount of time that has passed in the

simulation and processes input data which match the time stamp. Vital input data is not thrown out when this occurs as SEELO keeps track of the values of time stamps it 'skips' and factors the values into calculations. The percent of error was determined to be less than 0.1% on test data due to the algorithm mentioned above.

KPP 3: Power consumption of the simulated rover should be within 10% of test data's power consumption.

To allow for modeling and tracking of power consumption, SEELO must ensure that various actions such as rover wheel rotation, arm movement, and drum rotation all draw an accurate amount of power from the rover's battery. The acceptable margin of error is 10%, the same as regolith ingestion and simulation runtime .

The main focuses of power consumption from the robot were its arm movement, drum rotation, wheel rotation, and hotel power. Two test runs were performed and both tests produced less than 10% error. It was determined that this portion of the KPP was met. These tests involve driving the rover straight but driving that involves turns will result in an over than 10% error. Further variables could be added in the future to SEELO's current equations to accurately model turning or turning in place; however, it was determined that this straight driving was sufficient to meet the KPP.

While SEELO currently allows the import of custom assets, the user experience is not the best and there is a high level of difficulty. A plan for the future would be to streamline this process and allow for simple importing of models into a SEELO interface or separate application which could take a CAD model or similar type of model and transform it into a Unity usable asset. This would also open the door to allow users to specify custom measurements, which the simulation could track and record for playback.