NASA Lunar Excavation Simulation Report

April 30 2007 End Of Project Deliverable

Written by DM3D Studios, for DigitalSpace, April 27th 2007

Overview

The Phase I scope of work called for DigitalSpace to conduct the following tasks:

DS1: Develop driveable, real-time simulation models for four distinct mobile lunar excavation platforms.

DS2: Develop tool to capture statistical / engineering data from real-time lunar excavation simulation.

DS3: Create and integrate new DigitalSpace platform tool to enable variability of physics parameters (e.g., wheel torque, soil parameters, etc.)

DS4: Create and implement approximations of excavator-soil interaction in DigitalSpace simulation

DS5: Create and implement a waypoint capture tool

DS6: Create and implement a failure model using mean time between failure (MTBF) criteria that disables system components

DS7: Investigate the feasibility of implementing a terrain modification

DS1: Drivable simulation models of excavation platforms

This Deliverable provides three excavation platforms. Using a common mobility design, the Clam-Shell, Front End Loader and Bucket Wheel excavator designs are available. The Bucket Ladder design is in development.

By default, each of these excavators is operating under automatic control. This is further described in DS5.

Each of these excavators may be manually controlled. Vehicle mobility can be controlled by selecting the vehicles name from the Vehicle Agent Control window, then using either the W,A,S,D keys or a joystick to drive. The excavation system can be controlled using the keyboard keys, as specified on the Joint Control GUI.

These models are still in development status and can easily be taken outside their stable range. Examples of this is digging too deep causing flipping and gradual lowering of excavator arms. To prevent the commonest of these outcome, bucket/soil interaction is only modeled at the surface of the terrain. Lowering the digging surface completely through the terrain surface will cause the bucket to move freely once more, and prevent overloading the joints due to calculated soil weight.

DS2: Capture statistical/engineering data from simulation

The deliverable uses a centralized logging system, and outputs the data in a text based, key to value format.

The logging system also presents the option to be enabled or disabled. It starts in the disabled state. Stopping then starting logging will cause it to continue output to the same file. Exiting or reloading the simulation will cause the data log file to be reset.

The logged data includes joint velocities, target velocities, maximum forces applied by motors, and friction forces.

Logging Specification

The Logging System outputs collected statistics every 100ms (10 heartbeats). Values provided are the average for that 100ms (from samples taken up to every 10ms, ie each heartbeat).

There are four types of samples being tracked in the logging system. All types of samples are prefixed with a timestamp and the name of the sample source. We were not able to use the naming convention that was suggested to us, due to time constraints.

Joints

For every joint in the simulation, these properties are tracked:
Motor Force - The force or torque being applied to this joint
Linear Velocity - In the case of a linear joint (slider), the speed of the joints motion along its axis. In the case of an angular joint (hinge) this will be zero.
Angular Velocity - In the case of an angular joint (hinge), the speed of the joints motion around its axis. In the case of a linear joint (slider) this will be zero.
NOTE: In the current simulation, all the joints are hinge joints.
Motor Velocity - This is the speed the joint "should" be moving at. The physics simulation uses a force up to the value of Motor Force to accelerate/decelerate the joint to this velocity.

Linear Friction

Applied only to rocks, this is the parameters of the force being used against the object.
Velocity - This is the current velocity of the object, and is used to calculate the direction the resistance force should be applied
Resistance - This is the maximum force that the physics simulation is to use to attempt to keep the object stationary.
The Resistance value is specified per "jello volume" in the simulation. Each of these volumes is represented by a translucent area, with the areas opacity indicative of its relative resistance.
These samples are only provided for objects that are currently within a friction volume. Specifically, if a rock is removed from the volume by an excavator, linear friction will no longer be applied to it, and there will be no logged entry for it, until it is dropped into the volume again.

Balovnev Resistance

Applied only to the cutting surfaces of the excavator buckets. In this case, the Name entry for the sample has an identifier for the "blade" appended. In the case of multiple blade buckets (ie the Bucket Wheel) this identifies which blade the calculated force is applied to.
Depth - The distance between the surface of the regolith and the cutting edge of the bucket blade.
Beta - The angle of the bucket blade. An important point is that this is always in the range of 5 degrees to 90 degrees (although it is displayed in radians).
Resistance - This is specified as (H, V, T), where these are Horizontal and Vertical components of the Total force being applied. It should also be noted that these are not specified in world coordinates, but in the local coordinate system used in the Balovnev calculation.
These values are only output when Balovnev friction is being applied to buckets. Due to the range of values accepted by the Balovnev calculation, no values are applied (or logged) when Beta is below the radian equivalent of 5 degrees. Thus, when the blade of a bucket is almost parallel with the surface, no Balovnev friction is applied.

Failure

This entry is logged when a failure state is reached. See DS6 for more details on how this occurs.

The Name entry is the name of the excavator, and has one property, Failure, which will be set to 1.

DS3: Enable variability of physics parameters

A GUI is presented allowing adjustment of the Balovnev Parameters used for calculation of Balovnev friction forces. Existing GUI allow adjustment of excavator wheel to regolith interactions, although this panel is hidden by default.

It was requested that if possible these parameters could be loaded from an external file, to facilitate batch processing, however due to time constraints this has not been possible.

The only parameters for the Balovnev equation that are adjusted in real time are Depth and Beta, which are the depth and angle of the bucket blade. All other parameters are common across the simulation. This includes parameters that relate to bucket dimensions, which are not visually consistent across all excavator models.

DS4: Approximate excavator-soil interaction

The Balovnev friction model is being used in real time to calculate the friction forces applied to the excavator buckets when interacting with the regolith.

Issues with the appropriateness of this method of force modeling for certain excavator designs have been identified.

DS5: Waypoint capture tool

The excavator vehicle and joint states can be automatically controlled by a predefined series of target positions. This is enabled by default, causing each of the excavators to move through an excavation cycle.

This is not captured from user data, instead each of the target positions is specified inside the script file responsible for each excavator.

It was requested that if possible these sequences could be loaded from an external file, to facilitate batch processing, however due to time constraints this has not been possible.

The waypoint control code detects when a user takes manual control of a vehicle, and also when the user stops controlling that vehicle. When resuming control from the user, the waypoint code returns the excavator to the first target position, to ensure a clean execution of the sequence.

DS6: Failure model

The possibility for system failure has been included in the waypoint control code. For each of the excavators a panel is displayed, allowing the selection of a probability model and parameters for that model.

Each of the probability models provides up to two parameters used in the calculation of the probability, as well as a threshold value. When the probability calculation exceeds the threshold, the excavator is considered to have failed, and the waypoint control code stops its movement. These parameters may be changed, and are not used by the simulation until the Apply button in the lower-right of the panel is pressed. The probability model that is currently displayed will be applied, using the parameters that have been entered.

The failure simulation is provided on a per excavator basis, not on a per joint or component basis. As a failure of any component would result in the same visual result (specifically, the excavator stopping movement), and due to time constraints, this simplified model was deemed sufficient for this prototype.

It was requested that if possible these parameters could be loaded from an external file, to facilitate batch processing, however due to time constraints this has not been possible.

DS7: Investigate terrain modification

The report on the potential for terrain modification is provided in a separate document.

Additional work done

Random suspension of rocks

Rocks are scattered by a script through the volumetric friction layer. These rocks collide with excavator wheels and buckets, and may be picked up or pushed out of the way.

Documentation of ODE Physics Engine

Documentation has been provided detailing the way the ODE Physics Engine (which is used in Digital Spaces) works internally.

Joystick for manual excavation control

The default first axis of a joystick is by default mapped to vehicle movement. If you use a joystick with additional axis and buttons, along with software/drivers that allow the axis/buttons to be mapped to keyboard keys, this may allow manual excavation control. As we do not have this equipment available, we were not able to test this thoroughly.