Abstract #832

English

Considering Effects of Gravity on Planetary Excavators

Introduction: Excavating on the Moon and Mars enables in situ resource utilization (ISRU) and extrater-restrial contruction. However, lightweight planetary operation, due to low mass and reduced gravity, hin-ders excavation and mobility by reducing the forces a robot can effect on its environment. This work shows that continuous excavators (bucket-wheels, bucket chains, etc.) are more suitable than discrete excavators (front end loaders, scrapers, etc.) for planetary excavation. A wide assortment of planetary excavator prototypes have been developed in recent years, of both the continuous and discrete variety. The wide variability in prototypes and approaches highlights the need for a framework to analyze, test, and classify planetary excavators. Planetary excavation has been tested almost exclusively in Earth gravity with full-weight exca-vators. Only a single set of experiments has been published for excavation with a scoop in reduced gravity. This work presents novel experiments that for the first time subject excavators to gravity offload (a cable pulls up on the robot with 5/6 its weight, to simulate lunar gravity) while they dig. Effects of Gravity on Traction and Excavation: Freitag showed experimentally that traction normalized by weight is approximately constant with changing wheel load (i.e. changing W but keeping scale and gravity constant, as with gravity offload). This is because both thrust and resistance are reduced under lower loads; the former due to reduced frictional shear-ing, the latter due to reduced sinkage. On the other hand, changing W by reducing gravity reduces the traction to weight ratio. Note that in this case, encountered in real planetary operations as well as in reduced-g flights, the regolith is also subject to reduced gravity. Kobayashi's reduced-g parabolic flight experi-ments showed that wheel sinkage is not reduced when driving in low gravity, though thrust still is. Boles compared excavation resistance forces measured in Earth gravity to resistance forces measured during reduced-g parabolic flights (for otherwise identical experiments), showing that excavation resistance in 1/6 g could be anywhere between 1/6 and 1 of the resistance experienced in full Earth gravity; 1/3 on average. Testing in Earth gravity implicitly assumes these excavation forces will reduce proportionally (i.e. best case) while gravity offload implicitly assumes no reduction (i.e. worst case) as the longitudinal forces are not directly affected by offloading weight. Gravity offload is a more balanced test for planetary excavators because it underestimates detrimental effects of low gravity on traction but overestimates detrimental effects on excavation resistance. Tests in full Earth gravity, on the other hand, underestimate the detrimental effects of low g on both traction and excavation. Gravity offload experiments: Gravity offloaded excavation experiments were set up at NASA Glenn Research Center's (GRC) Simulated Lunar OPErations (SLOPE) lab. The facility contains a large soil bin with GRC-1 lunar simulant. This research developed an experimental apparatus for achieving gravity offload. Winch speed was matched to the robot’s speed, keep-ing the offload cable vertical. For constant speed tests, winch speed was set open loop. For tests where the excavator entered into high slip, winch speed was manually matched to the robot's decreasing speed. Continuous bucket-wheel and discrete bucket excavation was performed using the Scarab robot, with excavation tools mounted to the robot's structural chassis. Continuous and discrete excavation experiments were conducted at equivalent nominal production rates of approximately 0.5 kg/s, and at equal speeds of 2.7 cm/s. The excavator's position was tracked using a laser total station at a data rate of 1 Hz. Three or four runs were conducted for each test condition. Excavator speed was calculated from total station data. In 1 g continuous and discrete excava-tion both achieve successful performance, maintaining constant speed and collecting approximately 45 kg of regolith over a 2.5 m test. On the other hand, in gravity offloaded 1/6 g, while continuous excavation again maintains forward progress and collects approx. 45 kg, discrete excavation fails from degraded mobility and stalls after collecting only 15-20 kg of regolith. Conclusions: Gravity offload is an important and practical class of test for planetary excavator proto-types. Though not an ideal representation of low gravi-ty operations, without the effects of gravity on regolith, this is a more balanced test than excavating in full Earth gravity, which can misleadingly overpredict performance. Omitting gravity considerations from planetary excavator development misses important distinctions between classes of excavator configuration, such as the advantages of continuous over discrete excavation.

French

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