Lunar Subsurface Exploration Technologies at the University of Glasgow: capabilities and the 'i-Drill' case study

Conference or Workshop Item

Lunar Subsurface Exploration Technologies at the University of Glasgow: capabilities and the 'i-Drill' case study. R. Timoney[1], K. Worrall[1], P. Harkness[1], S. J. Barber[2], S. Sheridan[2] and N. Murray[3]. [1]School of Engineering, University of Glasgow, Glasgow, UK. G12 8QQ, r.timoney.1@research.gla.ac.uk [2]School of Physical Sciences, The Open University, Milton Keynes, UK. MK7 6AA. [3]Dynamic Imaging Analytics, Milton Keynes, UK. MK16 6GD.

Introduction:

A recent European focus on the exploration of the Moon, may provide the scientific community with opportunities to further understand our nearest neighbour, both in its own right and as an indicator of the rich history of our Solar System. Numerous missions are planned, starting with in-situ robotic exploration but envisaged to later involve sample return and new human sorties to the lunar vicinity.

Many missions will target previously unsampled high-latitude and/or Permanently Shadowed Regions (PSRs), in a quest to provide ground truth for orbital measurements that suggest elevated concentrations of water and other volatiles associated with these low-temperature environments. Such species are of high intrinsic scientific value; moreover the use of these materials as a potential feedstock within the emerging field of in-situ resource utilisation (ISRU) additionally makes them of particular interest to future mission planners. To this end, the authors propose technologies capable of the extraction and analysis of these volatiles, as candidate payload elements on these upcoming missions.

Drilling and Sampling Technologies:
Ultrasonic Planetary Core Drill (UPCD)

The University of Glasgow has experience in the development and testing of robotic planetary drilling and sampling systems which utilise a number of different technologies. The Ultrasonic Planetary Core Drill (UPCD) project [1], funded by an EC FP7 grant, ran from 2014-2017 and saw a consortium of European partners develop a drilling and caching system, based upon the ultrasonic-percussive technique, capable of autonomously extracting core samples of still-frozen regolith simulant as depicted in Figure 1.

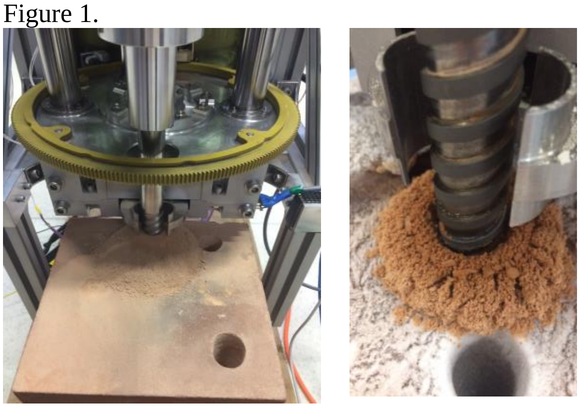

Figure 1: UPCD sampling dry (L) and saturated (R) Locharbriggs sandstone

This technology was tested at Coal Nunatak, Antarctica (73° S, 68° W) in December 2016 and proved to be a promising technology for use in potential Sample Return scenarios, capable of assembling, disassembling and caching in excess of three 10 mm core-containing drill bits, requiring 50 W of power on average to achieve this.

Percussive Rapid Access Isotope Drill (P-RAID)

The technologies developed for the UPCD project proved to be an excellent baseline for the development of a new system, the Rapid Access Isotope Drill (P-RAID), in collaboration with the British Antarctic Survey [2]. This cam-hammer driven rotary-percussive mechanism (Figure 2) was developed in order to sample subglacial bedrock cores – a longstanding aim within the field of paleoclimatology. Making use of the planetary drilling approach, P-RAID offers a solution to the problem which has a substantially lower resource demand than conventional, industrial approaches.

Figure 2: P-RAID architecture (L) and core samples of sandstone, limestone and microgabbro (R)

This technology has been tested in laboratory settings and also in a thermal vacuum chamber and has proven to be a robust means of obtaining samples of simulated planetary terrain, capturing cores with a diameter of 25 mm and as long as 300 mm. This can be achieved with as little as 70 W average power.

Ultrasonic Penetration of Granular Materials

The application of ultrasonic vibration to classic penetrometry tends to reduce both the overhead force and power required to insert the device to the required depths within granular terrain. Glasgow has developed a knowledge base in this area through a longstanding expertise in the development of ultrasonic devices. Testing of these devices in settings such as the ESA ESTEC Large Diameter Centrifuge (LDC) suggests that they may be particularly suitable for use in low gravity environments [5]. Given that the reduced gravity found on the Moon may have a profound impact on the ability of lightweight landers and rovers to penetrate beneath the surface, ultrasonic penetrometers may be particularly useful. Furthermore, the fluidisation of granular material by the action of ultrasonic vibration may provide a useful means of conveying material against the direction of the gravity vector while benefiting from a reduction in mechanical complexity when compared to convention screw conveying/augering.

Ultrasonically Assisted Drilling (UAD)

In a manner not dissimilar to the previously discussed ultrasonic penetrometry, the application of ultrasonic vibration directly to a drill bit will reduce the weight on bit required to penetrate a target material [6]. While this technology has predominantly seen application in industrial-scale machining, testing at Glasgow suggests that it may be beneficial to apply this technology to planetary exploration.

'i-Drill' – an instrumented drill

i-Drill is an instrumented drill concept optimised to access the upper ~1 m of the lunar regolith. Thus i-Drill accesses both the surface layer that may exhibit signatures of transient surficial volatile enhancement and/or of contamination from the host spacecraft, and the deeper subsurface probed by remote sensing observations such as neutron detectors.

The concept shares many of its objectives with the Luna-27 PROSPECT package [3], with regolith being sampled by a drill and volatiles being released by heating for analysis in a mass spectrometer. However, whereas PROSPECT employs a complex, coring drill and an intermediate sample receiving and manipulation device to seal the cored sample and release volatiles by heating, i-Drill removes the need for precise robotic manipulation. This is accomplished by i-Drill employing a hollow drill-string, such that volatiles bound to the regolith are released through the drilling process and diffuse up the string for analysis in a (PROSPECT-type) ion trap mass spectrometer supplied by The Open University (OU). Further advantages accrue because the drill can be operated for maximum penetration performance, and the resultant heat generated is beneficial in enabling efficient release and transfer of evolved volatiles. This is in contrast to a coring drill, which must be operated carefully in order to minimise the generation of heat at the bit that may introduce unwanted thermal alteration of the sample.

i-Drill also supports imaging of the sampled lunar regolith, enabling the volatiles profiles obtained to be interpreted in the wider geological context of the site. Imaging of the bottom of the borehole and of the cuttings is proposed and shall be achieved through the use of a dual camera suite of LUVMI heritage [4] and provided by Dynamic Imaging Analytics (DIA).

i-Drill was conceived at Glasgow, OU and DIA in response to a ESA RFI call on European payload contributions for future lunar missions. Harnessing knowledge gained through a rich heritage of technology development in their respective fields of subsurface sampling, in-situ analysis tools and space imaging, i-Drill provides a low resource solution for locating and extracting volatiles on future lightweight landed missions. Crucially, it occupies a 'sweet-spot' in the trade between payload mass/power requirements and its capability in terms of accessing ~1 m sub-surface and performing crucial volatiles investigations supported by contextual imagery. It is envisaged that this package of drill integrated with powerful and complementary mass spectrometer and imagers shall form a mass- and power-efficient payload applicable to various near-term small lunar landers.

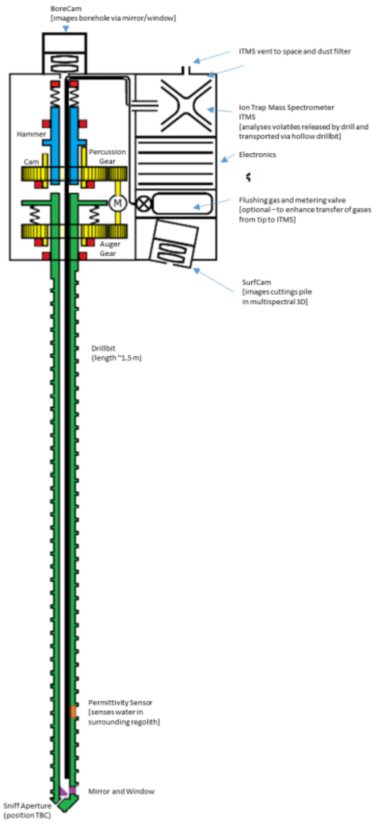

Figure 3: i-Drill Conceptual Schematic

References:

[1] Worrall K. et al. (2017) ASTRA 2017. [2] Timoney R. et al (2018) AGU Fall 2018. [3] Trautner R. et al. (2018). IAC 2018. [4] Urbina D. et al. (2017) IAC 2017. [5] Firstbrook D. et al. (2017). Royal Soc. [6] Firstbrook D. et al. (2017) Springer.