Next Generation Sensing Technology on the Moon

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Introduction: As this generation embarks on a mission to the Moon, it is fitting that we go with this generation's technology. The continued miniaturisation of electronics has enabled various sensing platforms. Notably, single board computers using cheap micro-controllers, and radio transceivers have been deployed as networked nodes in distributed sensing networks. Such topologies offer numerous advantages over traditional low-volume highly-customised design solutions; such as accommodation of iterative development, upgrades, and ease of design and development. Furthermore the requirement of high-reliability (long MTBF) components is de-emphasised as the networked system relies on R-process selection (statistical probability of survival of a fraction of a large number of components)[1]. This is critically important in the aerospace industry, where systems are always pushing the envelope of operational environments, and where designing for high-reliability is expensive and/or exploratory, without guaranteed mission assurance.

The Great Lunar Expedition for Everyone (GLEE[4]) is a proposed student-led mission, being run out of the Colorado Space Grant Consortium (COSGC) at the University of Colorado, Boulder; which seeks to leverage these strengths, via the use of 'LunaSats'. GLEE aims to deploy 500 LunaSats on the lunar surface by 2023, to conduct science, and improve student engagement in STEM, as well as in planetary and space sciences. As Artemis seeks to inspire the next generation of explorers, the mission of GLEE dovetails well with the objectives of the Artemis program, and defines a scope for collaboration. Artemis would potentially be able to retrieve the LunaSats deployed via an earlier GLEE mission - and conduct studies on space weathering of hardware in the lunar environment, as well as deploy new networks to study everything from seismology, to radio science and space weather monitoring.

Mission Concept: LunaSats are 50mm x 50mm x 1.7mm spacecraft that stemmed from a project at Cornell University Space Systems Design Studio (SDSS) utilizing the same form factor. Iterating off of the flight heritage[2] from Cornell's project, the LunaSats are designed with commercial off the shelf (COTS) sensors, that are able to conduct scientific research on the Moon. Their small form factor, low cost, ease of design, and distribution allow the LunaSats to be employed for a variety of applications.

The LunaSats are designed to be deployed at the South Pole of the Moon to maximize scientific return, from hitherto sparsely explored Aitken basin. This mission will be a technology demonstration of the LunaSat architecture and will also conduct scientific research on the lunar surface. The data that the LunaSats collect and return to Earth as part of GLEE will be available for anyone to access and analyze internationally, both among scientists but also between scientists & space enthusiasts; accelerating collaborative discovery.

Science Opportunities: The Science that GLEE seeks to conduct can be broadly classified into two top-level categories: Planetary Science and Spaceflight Science. The low cost of the GLEE mission, allows for the LunaSats to serve as technology test beds that validate the expansion of operational envelopes of COTS sensors, to incorporate the harsh lunar environment. The engineering return from these investigations is termed 'Spaceflight Science'. This can include investigations of different materials to ascertain their resistance to space weathering - caused by micrometeoroid impacts, dust, and radiation. Degradation of solar panel materials over time can also be investigated by retrieving the LunaSats and performing material characterisation studies in Earth based laboratories, helping to identify the types of high-efficiency solar cells which may have spaceflight use. In addition, with 500 individual spacecraft, GLEE will be able to perform a significant statistical analysis of the comparative performance of integrated circuit components from different manufacturers and of different architectures, in order to identify those COTS products which are most immune to the lunar environment (especially radiation effects).

Currently, the LunaSats are equipped with three sensors for performing Planetary Science observations of the lunar environment. These include a temperature sensor, accelerometer and magnetometer. The temperature sensor shall record a time series of the local temperature of the lunar surface, which is thermally (conductively and/or radiatively) coupled to the LunaSat. This is assuming a good thermal and mechanical coupling with the regolith, an assumption that is currently being investigated. This data can be used to characterize the thermal properties of the regolith and construct a high resolution spatio-temporal temperature map.

Despite the absence of a global magnetic field, a magnetometer (which has an appropriate sensitivity to low strength fields) can be used to obtain magnetic field measurements, and flux measurements in the vicinity. The current geological inertness of the Moon is hypothesised to have preserved paleomagnetic fields in the forms of lunar swirls - artefacts of a primordial magma-dynamo-driven global magnetic field. It is envisioned that having magnetometers distributed across multiple LunaSats would be able to confirm the presence, and map the spatial structure of these swirls.

The accelerometer will, by virtue of being mechanically coupled to the local underlying terrain as the LunaSat lies on the regolith, be capable of measuring local seismic activity. While the Moon is not considered to be geologically active, sources of seismic activity include diurnal thermal expansions and contractions, tidal stress, and anthropogenic activity in the vicinity.

Lastly, the radio transceiver and antenna can be used to determine how radio waves propagate close to the surface, within the tenuous, charged surface boundary exosphere of the Moon. Tests are currently being conducted to verify these sensors' effectiveness - both in terms of sensitivity for the expected signal ranges and survivability in the lunar South Pole. Early results show that these sensors will be effective and able to return beneficial scientific measurements about the Moon.

Finally, GLEE will be accepting custom sensors from teams around the globe that fits the missions requirements. Some of the nascent ideas for these scientific payloads include: thermopiles, chip-based spectrometers, UV sensors, passive material coatings (investigation of weathering & regolith/surface boundary exospheric interaction), dust detectors, electric field monitors and total dose radiation sensors.

Investigation through an Artemis Interface:

There are two main ways LunaSats could be incorporated into the Artemis mission. Firstly, if Artemis lands where the LunaSats from the GLEE mission were deployed, Artemis astronauts would be able to physically retrieve the LunaSats, for laboratory study/human inspection. While it would require the crew's time, it is very likely that this would not require a recalibration of either mission's design, since the stated targeted landing zone for Artemis is also the lunar South Pole. A highly conservative estimate is that approximately 700cm^3 and 2.5kg would be sufficient for 500 LunaSats. This is minute, in the context of Artemis, and the expected inspirational, and diplomatic values of distributing spacecraft that have been to the Moon's surface back to the teams involved with them, yields a disproportionately high benefit when compared to the costs.

The second way LunaSats could be incorporated into the Artemis mission would be to incorporate a fresh set of LunaSats, as a scientific payload, on an Artemis surface mission. These would be deployed on the lunar surface either during EVAs. These LunaSats will be fully operational, and can augment the science goals of the Artemis surface mission. The LunaSats can serve as a suite of complementary, and expendable sensors - perhaps for exploratory scouting prior to the deployment of more specialised, mission-specific, and expensive equipment. A deployed network of LunaSats will also be able to function as surface radio-relays, helping increase the spatial extent of the lunar surface which can safely be explored by the crew, while still remaining in communication with mission control. Once deployed, the LunaSats would also be able to function independently (aside from the use of a communications link via Artemis) and even be able to carry out a second GLEE mission (beyond Artemis), or be retrieved at the end of the Artemis mission, for return to Earth, and dissemination.

Conclusion: As is evident based on the arguments in this paper, both the Artemis mission and GLEE stand to benefit from mutual cooperation, to increase science return and public engagement that will sustain and pave the way for continued space exploration.

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References:

[1]V. Adams and M. Peck, "Chipsats: R-Selected Spacecraft," Available: 10.31224/osf.io/wxhpt

[2] Z. Manchester, M. Peck, A. Filo, "Kicksat: ... demonstrate the world's smallest spacecraft"Available: http://digitalcommons.usu.edu/smallsat/2013/all2013/111/

[3]D. Barnhart, "Very Small Satellite Design for Space Sensor Networks", 2008, University of Surrey

[4] The Great Lunar Expedition for Everyone, www.GLEE2023.org