National Aeronautics and Space Administration

Rover-Deployable Distributed Acoustic Sensing

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Program: FY21 R&TD Topics **Strategic Focus Area: Lunar science**

Objectives

Most seismic networks consist of discrete sensors that are hand-placed for tight ground coupling. These networked sensors often have a spatial density of one sensor to cover multiple square kilometers. DAS is fully dependent upon the layout of a tether, but can have a density of measurements along the cable at ~1 m spacing and up to thousands in number. At current maximum length (and techniques are improving regularly), a DAS system can make measurements fully along a 55 km tether. As Axel has a pre-existing tether with embedded optical fibers, we can simultaneously take DAS and DTS measurements upon deployment. Rather than needing to deploy a massive and power-hungry instrument at every desired sensing location, the DAS interrogator instrument can remain at the lander, and only the fiber needs to be deployed, providing a dense network of seismic data.

This effort had two objectives:

- Evaluate Axel's deployment and operation of a >300 m DAS fiberoptic tether to enable ~1 measurement/meter in two configurations: (a) horizontal and (b) under strain.
- Evaluate the SNR of a > 1 km tether with multiplexed fibers containing both data and DAS signals at a density of greater than 1 measurement / meter.

Background

Few seismic monitors have been placed on planetary surfaces, and, like InSight's SEIS, they can be very complex and delicate devices. Distributed Acoustic Sensing (DAS) is a robust and novel method to interrogate optical fibers with a laser-based instrument to determine seismic activity along the fiber. This method allows for simultaneous measurements every ~1m up to 55km in length using current commercial technology (yielding >50,000 simultaneous seismic measurements). This newly developed technique that transforms fiber optic cables into linear arrays of ground-motion sensors. Recently, it has received significant attention in the oil and gas industry, and several research groups, including the proposers, have explored the potential of DAS in passive seismology using distant earthquakes. As a dense seismic network, DAS can not only record earthquakes, but can potentially provide high-resolution structural images of the crust and mantle. Funded by KISS and Caltech's Space Innovation Council, Caltech conducted numerical simulations of lunar seismic wave propagation to show that a DAS array would help suppress noise from shallow Moon heterogeneities and provide significantly clearer images of the lunar interior than previous studies. Thus, DAS will likely play an important role in many fields of passive seismology in the near future.

Figure 1: The axel rover with pre-existing tether deployed out the back. Here, the tether is under tension, decoupling it from the ground, but allowing the rover to travel over challenging terrain. In Year 2, we will evaluate the use of tether deployment over both challenging and flat terrain.

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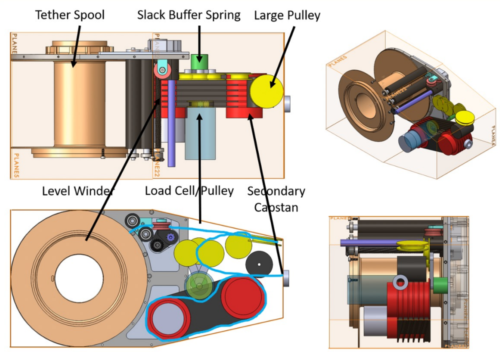

Figure 2: The novel tether management system (TMS) for Axel to manage the lengthy DAS fiber developed during Year 1 of this effort. The TMS will support DAS testing in late Year 1 and throughout Year 2.

Approach and Results

We utilized existing commercial DAS instruments and the Axel rover to perform the tasks in this effort. Axel is a two- wheeled rappelling rover that has been developed under JPL's RTD program and has demonstrates extreme-terrain access on a range of steep and rocky terrains for science exploration. Axel houses a spool that can support a 300–350 m tether with a diameter of 4 mm that can support its ~60 kg mass. Tethers in excess of 1 km tethers require smaller diameters used for surface deployments only (not rappelling), or an alternate spooling mechanism. For objective 1), early examination of Axel tethers revealed that one short tether had several splices that would impact DAS measurements. Because the existing Axel tether management system is limited in both tether diameter and length, a new mechanism was design and manufactured, with planned testing in early FY2022. In addition, tether ground-coupling was evaluated using available samples from a fiber manufacturer. An idealized tether coupling was identified and fiber delivered. Field testing in the next FY will evaluate the use of DAS with both the new fiber and Axel configuration.

Meanwhile, at Caltech, a DAS instrument was integrated with the existing Caltech / Pasadena fiber loop. Here, initial simultaneous DAS and multiplexed data testing was completed (both on-lab and off). Initial indications show that data will be able to be shared with DAS measurements with little to no degradation. Multiplexors have been matched to what is used with Axel for easy integration of hte systems in the next phase.

Significance/Benefits to JPL and NASA

NASA and JPL have long sought a lunar seismic network, beginning with the Surveyor and Apollo missions. These discrete terminals provided approximately eight years of data, detecting shallow and deep moonquakes, meteoroid impacts, and thermal moonquakes [1]. Like NASA's InSight lander, these lunar networks have previously relied on point-source measurements, requiring multiple deployments or landers to obtain multiple measurements. More recently, even NASA's Technology Taxonomy recognizes the ability for robotic mobility to contribute to networked instruments as the category of "collaborative mobility" is specifically called out to enable seismic networks.

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Even on Earth, most distributed networks rely on widely spaced highly-sensitive sensors that must be individually placed, although studies in recent years have demonstrated the potential of dense networks of simple sensors [e.g., 3]. Axel and DAS seek to revolutionize this field by providing a high-density seismic network exploiting assets already in place – Axel's existing tether, or even a lunar base's telecommunication network. DAS arrays also open up active source techniques, which rely on dense network recordings of known seismic sources potentially supplied by vibrational sources on a lander or controlled impacts.

Acknowledgements

Travis Brown, Fernando Mier-Hicks, Patrick Mcgarey and the Axle team were fundamental in the progress made during FY 2021 to accommodate a longer tether, which required significant redesign of the spooling mechanism. Both Haley Sanders and Shrikeshav Deshmukh served as interns with deep involvement in the redesign process. In addition, Luis Pereira da Costa worked with Prof Zhan to take advantage of the Caltech / Pasadena fiber network for characterization of shared data / DAS fiber lines.

References

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[4] W. Wu, Z. Zhan, M.P. Panning, & A. Klesh, Fiber seismic network on the Moon, in preparation, Icarus, 2021.

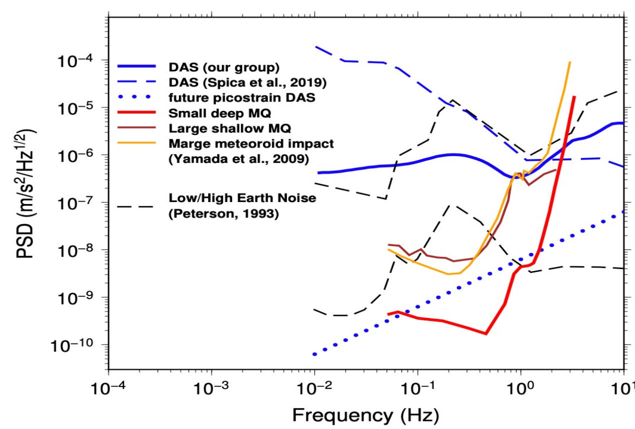

Figure 3: DAS noise figures as measured at Caltech and in comparison to other groups. Sensitivity is shown against various depth and magnitude. Results from W. Wu, Z. Zhan, M.P. Panning, & A. Klesh, Fiber seismic network on the Moon, in preparation, Icarus, 2021.

Clearance Number:
RPC/JPL Task Number: R21102