LUNAR PARTICULATE MATTER CHARACTERIZATION USING OPTICAL SCATTERING.

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Introduction: Lunar dust will pose significant hazards to the long-term human and robotic presence on the Moon. Dust size distribution, shape, charge, composition, and dust cloud density are key inputs into methodologies and tools to mitigate these hazards. While analyses of Apollo samples have provided insights into dust characteristics [1,2], characteristics of near-surface lofted/levitated dust particles, particularly the fine fraction (i.e., <2.5 μm), and dust mobilization mechanisms, remain poorly understood yet are essential for operations and astronaut health. To expand knowledge in this domain, we are developing a small, low-mass, low-cost, and robust optical sensor capable of measuring size of single-particles and density of lofted and levitated lunar dust clouds.

The Instrument: The sensor, manufactured by Sharp Electronics (GP2Y1010AUF), can fit in the palm of one's hand—approximately 46 x 30 x 18 mm (L x W x D)—and weighs less than 50g (Figure 1) . It operates on principles of optical scattering. An infrared-emitting diode illuminates particles passing through the sensor, causing each particle to scatter light. The scattered light is detected and converted to an electrical signal by a photodiode, situated at 60° and 2 cm from the sensing region. Signal intensity depends on cloud concentration, particle size (and size distribution), shape, and composition.

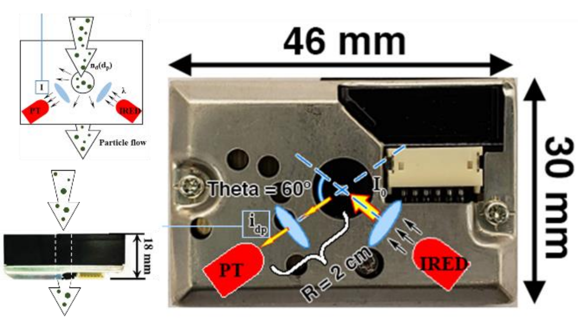

Figure 1: Sharp GP2Y optical sensor. Particles passing through the central hole are illuminated and magnitude of scattered light is detected.

Calibrations: A controlled atmospheric environment test assessed the relationship between sensor output and mass concentration. We evaluated the sensor's ability to measure dust cloud concentration by flowing lunar simulant (JSC-1A), dispersed as an aerosol, directly into the sensor and an industry-standard particulate matter monitor. A least-squares regression performed between the sensor output signal and the particulate matter concentration monitor shows a strong correlation ($r^2 = 0.83$)[3]. This regression defines a linear relationship between the sensor signal and mass concentration. The intercept is the detection threshold and the slope is the change in mass concentration per change in sensor output.

The proportionality between dust cloud concentration and light scattered, however, depends on the particle size distribution and composition of the dust cloud [4,5]. Therefore, as a next step, calibrations were performed with dust simulant aerosols of various size distributions and composition. Calibrations were performed by connecting an aerosol source to a ~1m^3 chamber, in which the sensor and research-grade reference devices for measuring size distribution were placed. JSC-1A and LHS-1D simulant aerosols were generated via direct entrainment in air and drying of dust suspension droplets (ultrasonic nebulization). The size distribution, particularly the geometric standard deviation of the distribution, had the most significant effect on the proportionality between sensor output and mass concentration. Changing the dust simulant affected the proportionality as well to a lesser extent, which may be partially attributed to a different size distribution and composition.

On the basis of these data, the optical sensor under development shows great promise for revealing near-surface lunar dust characteristics.

Future work: Because we aim to deploy the sensor in the ultra-high vacuum lunar environment, performance evaluation and calibrations in a laboratory vacuum environment are necessary. The sensor will be placed in a 16-liter vacuum chamber capable of attaining 10^{-6} Torr. Dust simulant particles will be injected into the chamber as an aerosol and will be measured by the sensor. An SEM witness plate will be placed directly beneath the sensor to serve as a reference, from which the total mass, size, and shapes of particles passing through the sensor can be measured. Preliminary results (Figure 2) at 1 atm in the vacuum chamber show that the injected dust aerosol induces a response from the sensor and subsequently deposits onto the witness plate. The sensor response will be converted to a mass through integration with respect to time and coupling with the aerosol-dependent proportionality constant obtained from atmospheric experiments. The sensor-derived mass will then be compared to the reference mass from the witness plate, obtained by systematically counting particles through an image-processing algorithm [6] and converting projected particle area to a sphere-equivalent volume.

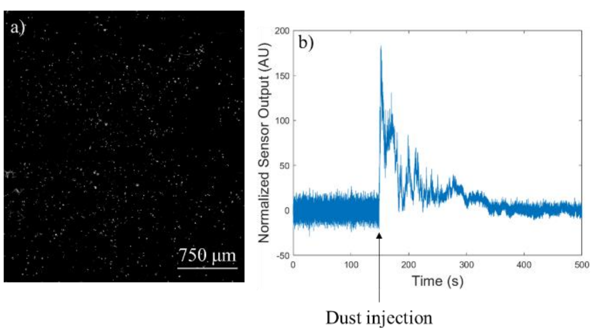

Figure 2: Preliminary results from dust injection into vacuum chamber. a) Panoramic view of dust particles deposited on SEM witness plate, b) Sensor response to dust injection.

Because levitated regolith particles may also be present in dilute concentrations (~50 m^{-3}) [7], it is important that the sensor is calibrated for measurement of single particles. A dust dropper will release individual mono-sized particles through the sensor and onto a witness plate. The pulse height output from the sensor will be related to the particle size through Mie and geometric light scattering theory. Homogeneous spheres will first be used, which are expected to conform to classical scattering theory. Next, the effect of shape and composition on sensor signal will be examined. Homogeneous non-spheres will be used, followed by dust simulant particles which are non-homogeneous non-spheres.

Additional parameters of interest (e.g., particle size distribution, composition, shape) can be constrained through modifications of the sensor. Light sources of varying wavelengths and different incidence angles will be implemented. Cloud/particle velocity can be measured by placing two of these sensors in sequence and calculating the time-of-flight. We look to develop further approaches and designs for deployment on the Moon and in crew habitats.

References: [1] Horányi, M. et al. (1998) *J Geophys. Res. 103*, 8575-8580. [2] Greenberg, P. S. et al. (2007). [3] Vidwans, A. et al. (2022). *Planet. Space Sci. 210*, 105392. [4] Wang, Y., et al. (2015) *Aerosol Sci. Tech. 49(11)*, 1063-1077. [5] Li, J., and Biswas, P. (2017). *Aerosol Air Qual. Res. 17(7)*, 1691-1704. [6] Ogliore, R.C. (2021) *Earth Space Sci. 8(7)*. [7] Colwell, J.E., et al. (2007) *J. Aerospace Eng. 22(1)*, 2-9.