REMOTE RAMAN SYSTEM FOR PLANETARY LANDERS: DATA REDUCTION AND ANALYSIS.

Introduction: Landers and rovers are an increasingly important element of NASA’s solar system exploration program. Raman spectroscopy is typically envisioned as an in situ analysis technique. The potential for performing Raman analysis remotely has been explored theoretically [1] and experimentally [2]. Our concept of measuring Raman spectra remotely from a planetary lander [3] lends itself to combination with other techniques such as laser-induced breakdown spectropscopy (LIBS) [4] and atmospheric analysis with Raman lidar.

Laboratory System: A laboratory version of the remote Raman spectroscopy system has been assembled consisting of: a Spectra Physics laser operated at 488 nm, a CVI ¼-meter imaging spectrograph, a Photometrics CCD imager (1024x256 pixels), a 4½ inch, f/4.2 portable Newtonian telescope, and a data collection computer. An optical fiber bundle, which is formed into linear fiber array at one end, is used to connect the telescope to the spectrograph. The linear fiber array of twenty-five 50 µm fibers acts as the spectrograph slit dispersing the received light across the entire cooled (-105°C) CCD array (1024x256). A holographic super-notch filter is inserted between the collimating lens at the output of the telescope and the lens focusing scattered light at the end of the fiber. The super-notch filter is adjusted to attenuate the elastically (Rayleigh) scattered and diffuse reflected laser light.

The laser and telescope have been focused upon the same sample spot at a distance of 4.8 m from the telescope primary mirror. Combinations of laser power and integration time were investigated to derive a reasonable compromise of SNR and data acquisition efficiency. Current nominal operating specifications are: 130 mW laser power at the sample and 60 sec integration for light colored samples and 180 sec integration for dark samples. The system has recently been moved into a larger laboratory in which we will be collecting remote data at 9-10 m from the sample.

Data Collection and Processing: Adapting standard radiometric imaging techniques, all data are acquired in full-CCD image mode. This allows application of standard image processing methods to correct for array nonuniformity of offset and dark current (read-noise dominated), bad pixels, and cosmic ray hits. Bad pixels and cosmic rays are corrected by applying a local 5x5 median filter to each affected pixel. Flat-fielding of the image is accomplished by using a radiometrically calibrated source, a Labsphere integrating sphere, which corrects nonuniformity of array responsivity and also allows us to calibrate the observed signal to radiance. Figure 1 illustrates the sequence of steps involved in the data acquisition and reduction process.

Figure 1. A dark image (1a) is acquired and subtracted from both the sample spectral image (1b) and the flatfield image (1c). The response function of the system is calculated from the flatfield image an a line-by-line basis and divided into the dark-subtracted sample image to produce the flat-fielded, calibrated sample image (1d) in spectral radiance units (Wm^-2 sr^-1 µm^-1)

The final remote Raman spectrum is then produced by averaging the entire image along the slit direction, for significantly improved SNR. Wavelength calibration is achieved by performing a quadratic fit to the derived spectrum of a sample with well-known spectral peaks, usually calcite (marble). Figure 2 shows the reduction process in the spectral domain, although all steps are actually performed in the image domain.

Raman Intensity Calibration: Raman spectra are calibrated to spectral radiance, L(λ) (Wm^-2 sr^-1 µm^-1). In order to determine the Raman scattering efficiency, the laser power delivered to the sample is required. The current experimental setup assumes the following nominal parameters: laser power (P) = 150 mW; laser wavelength = 488 nm; laser spot size= 2 mm diame-
At a distance of \( r \) (4.8 m), one steradian covers an area of \( r^2 \) (23.04 m²), and the telescope field of view subtends a solid angle of \( 3.76 \times 10^{-4} \) steradian (\( \theta_{\text{solid}} \)). Pixel bandwidth (\( \Delta \lambda \)) is derived from the wavelength calibration of a known sample. The Raman scattered energy (\( E_r \)) received from the target is given by:

\[
E_r = L(\lambda)TA_{\text{laser}}\theta_{\text{solid}}\Delta \lambda
\]

and the Raman scattering efficiency is:

\[
R_{\text{eff}} = \frac{E_r}{E_0}
\]

Figure 3 shows the results for a marble sample as per the parameters given above. It should be noted that the intensities of the Raman lines strongly depend on orientation of crystals [5]. In fine-grained materials one could assume random orientation of grains, and the Raman efficiency of strong Raman lines may show only small (∼10%) variation from sample to sample [6]. We are evaluating effects of large grain size on the Raman scattering efficiency of various minerals.

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**References:**

**Figure 3.** Raman scattering efficiency of calcite as measured remotely at a distance of 4.8 m.