OPTIMISING THE OPERATION AND PERFORMANCE OF A STAND-OFF RAMAN INSTRUMENT DEVELOPED FOR PLANETARY AND LUNAR EXPLORATION.

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Introduction: Raman spectroscopy is a chemical and structural identification technique based on the vibrational modes of molecles. The technique is fast, non destructive and capable of detecting organics and biogenic materials within unprepared samples [1]. Raman spectroscopy is widely used in many fields (such as biology, chemistry, pharmaceuticals, security/defence and the nuclear waste industry) with instruments spanning a range of configurations from microscopic [2] to telescopic systems [3].

Stand-off Raman spectroscopy is the application of the standard Raman technique over a large distance (more than 120 m in some cases) [4]. The stand-off technique has proven to be a valuable tool in the fields of geology and mineralogy [5] and over the last decade efforts have been concentrated on developing mature, robust, low mass, low volume stand-off systems suitable for planetary exploration [5].

Recently, stand-off Raman spectroscopy was listed as a potential reconnaisance feature of future exploration of planetary surfces such as Mars, the Moon and Europa [6] as it facilitates the acquisitionof detailed mineralogical information from a remote distance, enabling a rover to access regions of interest (that might normally be inaccessible) without the need to re-locate and use limited rover resources. Stand-off Raman spectroscopy has been used to successfully detect carbonates and (hydro-) sulphates (such as calcite, barite, gypsum and other geologically important minerals that provide information geological processes) at a distance of over 10 m [7].

Clegg et al. suggested that an integrated stand-off sytem of complementary techniques such as Raman and Laser Induced Breakdown Spectroscopy (LIBS), operating from the mast of a rover, would be capable of context mineralogy, fine scale imaging, and fine scale elemental composition [8]. Also, in light of the recent Science Definition Report on Europa [9], Sharma et al. reported that a stand-off Raman instrument, similar to existing proto-types, would be capable of measuring and identifying various salts, organic and CO_2 ice on the surface of Europa, potentially to a depth of a few centimetres [10].

It is these advancements [11] that have led to the recent selection of a stand-off Raman instrument (SuperCam) for the NASA 2020 Mars mission payload [7].

A Radiometric Model: One of the many challenges associated with developing a stand-off Raman system is the reduction of various sources of noise that can compromise the relatively small signal collected by the instrument (due to the large distances between the sample and instrument. Background noise in a system can often be reduced by implementing complex operating modes. However complications arise due to the potential impact of radiation damge on the instrument and the limited time, processing power and memory available to efficiently/sucessfully execute the operating modes.

In order to understand the many interrelated parameters, the complicated trade-offs and the impact they have on the overall instrument performance, we have developed a sophisticated radiometric model.The model describes all aspects of the system performance by simulating instrument operation and all of the physical processes involved. For example, the model uses a monte carlo simulation to generate a Raman and fluorescence signal emitted by a sample based on parameters such as the Raman cross section of the sample, laser power, distance to the sample and collection optic configuration. The model then generates levels of ambient light both local to the detector and collected by the instrument. The simulated signal is then convolved and dispersed according to a particular spectrograph deisgn.

The simulation then accounts for specific CCD operations such as pre-scan, integration, post-scan and readout (i.e. as implemented for windowed operationse), and quantum efficiency, read noise and dark current, all of which impact the signal to noise ratio achieved by the instrument.

Radiation induced detector defects can also be accounted for in the model, the effects of which become apparent during the readout stage of operation and in the final simulated image.

The radiometric model offers a method of comparing the performance of various instrument configurations i.e. the performance of an instrument that uses a pulsed lasers and gated detectors (a component with a relatively low TRL currently) compared with a non-gated detector system.

Results: The radiometric model was used to assess three separate stand-off instrument configurations. The first configuration incorporated a continuous laser and a non-gated detector (similar to an in-situ Raman instrument). The second configuration ultilised a pulsed laser and a non-gated detector and the third incorporated a pulsed laser with a gated detector (the current configuration of instruments such as Super-Cam [5])

Using the model, the SNR values from three different samples were obtained under three different levels of ambient light (low, medium and high). The sample used in the initial stages were sulphur, acetaminophen and β-carotene as they exhibit increasing levels of fluorescence respectively.

Initial results show, as expected, that a high SNR can be obtained with a gated detector (with a pulsed laser) in all cases.

However, the results from a number of the models also indicate that under certain fluorescence and ambient light conditions, a reasonable signal to noise ratios can also be achieved without using a gated detector. Since a gated detector is of relatively low TRL compared to non-gated detectors, identifying scenarios where they may not be required is important in order to reduce system expense and complexity and to increase robustness and reliability..

The radiometric models that are described here have also been used to investigate how the effects of different operating modes (such as frame stacking), detector temperature and energy density at the sample can effect the observed signal to noise ratio, for a given system configuration and operating environment. For example, Figure 1 shows the SNR achieved by the instrument as a function of total integration time. A frame is acquired every 80 seconds (the optimised integration time calculated by the simulation for a given signal). The relationship between SNR and total integration time is shown for three different levels of collected ambient light for two system configurations; a pulsed laser configuration and a continuous laser configuration. It is clear from the results obtained that, while operating in low level ambient light, stacking a frame can significantly decrease the SNR value achieved by the instrument. It is also clear that if the total integration time is limited the SNR may not return to its initial value (the SNR value before the frame was stacked). The plot also shows that the increased excitation energy provided by a pulsed laser consistently generates a higher signal to noise ratio over various ambient light levels. The power of the excitation laser however is often limited due to sample degradation and destruction.

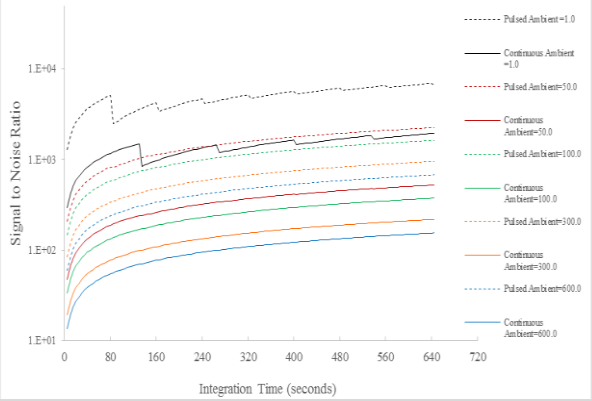

Figure 1: The relationship between the SNR achieved by an instrument and the total ingration time of stacked images.

On-going Work: Current work is focused on introducing the impact of radition damage onsystem into the configuration and environmental comparison work described above, in order to evaluate the SNR values achived by a particular instrument configuration during a mission lifetime.

The model is currently being validated using spectra obtained by the different configurations for materials such as quartz, calcite, various plagioclases, pyroxenes, feldspars and olivine. These material compose >90% of most lunar rocks [12] and will provide a method to assess the performance of a stand off isntrument during a lunar mission.

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