ECE 487 Final Report

Laser Instrument Development

for Planetary Surfaces Characterization

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April 2020

ODU Honor pledge

"I [we] pledge to support the Honor System of Old Dominion University. I [we] will refrain from any form of academic dishonesty or deception, such as cheating or plagiarism. I [we] am aware that as a member of the academic community it is my responsibility to turn in all suspected violation of the Honor Code. I [we] will report to a hearing if summoned."

Abstract

The goal of this project was to redesign an existing Raman spectrometer system for planetary surface investigations, through optimization of the spectrometer. The system was designed to support future space missions which require surface landing, and analysis of surface samples to determine their possible molecular compositions. The system focused on the acquisition of Raman signals using a 785 nm laser, and analysis of the produced Raman signals. During the interaction of the incident laser beam with the target, the molecules vibrate at a frequency that depends on their bonding. The difference between the frequency of the 785 nm wavelength laser and the shifted frequency caused by the molecules of the target sample creates a unique identification that can be used to classify each material that is analyzed. The Raman signals are collected through the spectrometer and analyzed. After preliminary optical re-design, a signal-to-noise ratio of 37 dB was achieved, surpassing our project goal of 25 dB. However, bandwidths at high-intensity wavelengths remained unsatisfactory, reducing system reliability in terms of usable data for future projects. Attempts to acquire Raman data from sulfur mineral samples using a 785 nm laser yielded no discernible intensity peaks and further re-design is necessary to achieve valid results.

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1. Introduction

1.1 Design Problem

The intent of this project was to optimize an already-existing design. The Raman laser spectrometer system, developed by NASA engineers at Langley Research Center in Hampton, Va., was developed to characterize planetary materials. Using a laser, a series of optics collects Raman scattering data from the object and, using the data and associated spectrometric software, the object's material composition can be determined by its interaction with the incident laser signal.

At the onset of our project, the spectrometer was assembled and used in limited capacity to gather calibration-level results. However, results were not fully optimized; the system was functioning, but previous results exhibited unacceptable levels of error and interference. Through material and optical adjustments, our team sought to improve system results to provide a better-functioning compact spectrometer usable by NASA in future experiments.

The Raman effect refers to the scattering of light at a frequency shift corresponding to the molecular vibration of the studied sample. A light wave consists of photons, each with a specific energy. When these photons interact with an object, they exchange energy with the molecules within the object and drop to a lower energy state. This causes a vibrational response within the object's molecules, placing the molecules into a virtual energy state different from its original state. After a short period of time, the molecules emit photons of higher or lower wavelength than the original incident photons depending on whether the molecules entered a higher or lower virtual energy state than their original condition. These scattered photons can be represented as reflected light from the object and propagate outward from the object. [1]

Raman spectrometry data can be classified based on its signal-to-noise ratio (SNR) and bandwidth of signal at high-intensity peaks. The signal's peak values are analyzed for intensity and stability. Around 25-50 spectrometry samples are recorded from a constant object. The intensity values of the Raman peaks are averaged together for one mean value. Then, the standard deviation (root-mean squared, or RMS) of the fluctuations in intensity peaks between samples is recorded. The mean intensity value is divided by the RMS, yielding an SNR value in decibels (dB). Is a commonly accepted method for quantitatively validating spectrometry results. Our group sought to make adjustments to spectrometer hardware and software to achieve an acceptable level of data acquisition. The objective was to achieve an SNR of at least 25, which falls at the low end of acceptable data. [2] Adjustments yielded an SNR of 37, much higher than our original goal and solidly within the acceptable spectrum. However, high-intensity bandwidth remained unacceptably wide, suggesting further calibration and re-design of system optics is necessary to improve signal clarity.

1.2 Design Function

The intent of this project was to redesign an existing portable spectrometer with the ability to interact with foreign objects, gather and analyze data to determine the material composition of the object for more accurate results. The laser spectrometer can perform in a wide range of roles from planetary surface characterization to medical testing to mineral deposit locating due to its versatile design. Despite being a complex alignment of optics, filters and refractors, it utilizes the rather simple principle of reflection to accomplish its mission.

Every material exhibits a unique Raman signal when contacted with the same wavelength light beam. For example: an object composed primarily of carbon molecules will scatter light with a different wavelength shift when exposed to a 785 nm laser when compared to the Raman effect of a silicon-based object. This phenomenon is useful when the specific composition of an object is complex or unknown, especially in a condition difficult for sample research to be conducted. It is a valuable asset for organizations such as NASA, who consistently conduct research in hazardous or completely inaccessible environments such as celestial bodies or meteorites. Further, the prospect of identifying the presence of carbon or water within a material found in space can lead to the discovery of alien life.

In order to achieve Raman scattering for data collection and analysis, an optical system must be developed to properly guide a laser of known frequency to the object and efficiently receive and amplify the scattered frequencies returned by the object. The conditions of the mission impact the design properties of the system as well; if the spectrometer isn't expected to be mobile or fit into a small area, the system can be designed to perform at optimum efficiency with little to no regard for size and weight concerns. However, if the system is expected to be transportable and rugged, the efficiency may be limited based on the durability and compact nature of the equipment. In this project, the expected delivered system must be as compact and energy efficient as possible for long-term missions in space. It must also be able to withstand harsh environments to allow for use in many different locations outside our own world.

1.3 Performance Objectives

Our project sought to improve data collection from the Raman spectrometer system by analyzing the collected data from a known source, comparing these results to expected data, and redesigning the system components and materials used to better reflect expected results. Our process involved three major phases of data analysis: acquisition and optimization of a 785 nm laser source, a neon lamp source and Raman scattering from a sulfur sample. The spectrum detected by the intensifying charge-coupled device camera (ICCD) within the designed spectrometer was analyzed for accuracy and sensitivity based on collected results vs. expected values and trends. Our group's original goal was to achieve an SNR of 25 or greater from test sources over the course of the Fall 2019 and Spring 2020 semesters as well as to redesign the spectrometer to reliably gather Raman data. Accomplishment of this goal required the redesign of optical equipment within the spectrometer as well as the design of software to interpret and analyze our data.

2. Design Approach

2.1 Design Function

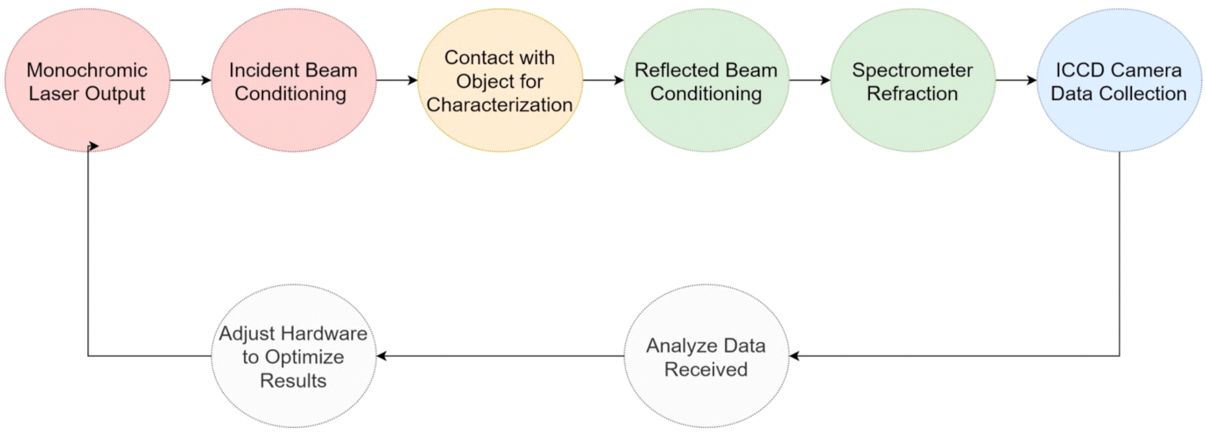

Figure 1: Spectrometer Data Analysis Flow Chart. An overview of the major components of a Raman laser spectrometer system and the theory this project's design model must incorporate in order to achieve desired results.

A system design was developed by NASA engineers as a compact spectrometer. The basic design involves a low-energy laser source attached to a power supply capable of controlling its pulse frequency and length. Power conservation and system losses are a concern and utilizing a controlled power supply which will ensure power is only consumed by the laser for the shortest necessary period to minimize the overall power supply requirements of the finished system.

The laser beam must be focused onto the object enough to generate a Raman signal which is both detectable and emitted toward the spectrometer inlet. Optics arranged in-line with the beam controlled the spread/resolution/shape of the incident signal. The shape of the contact surface, shape of the overall lens and surface coating all impact the collation, focus and transmission of incident and emitted wavelengths. For example, a simple spherical concave lens can spread an incident beam into a less-focused transmitted signal circularly projected at a target, but a cylindrical lens will instead transmit a slit pattern onto the target. A convex lens can focus an incident beam into a sharper, smaller-diameter transmitted signal. Proper combination of lenses produces a sharp, slit-formed incident beam onto the object.

A sharp, focused incident beam directed onto the object in-line with the spectrometer inlet will produce an ideal set of emitted signals from the object. The incident beam must cast a small diameter onto the object because the emitted signals from the object will exhibit a range of wavelengths in a pattern spreading outward spherically from the point of contact. Ideally, the emitted signals will propagate in a collimated pattern toward the spectrometer inlet slit, which can occur if the incident beam strikes the object as close to perpendicular as possible.

Finally, the emitted signals from the object must be collimated and directed to a refraction device capable of separating them into a spectrum of wavelengths to be recorded by a camera or photosensitive digital conversion device.

2.2 Quantitative Performance

Using a well-documented calibration source, the neon lamp, allowed us to properly analyze our calibration data by comparing our spectrometer’s output to expected values of wavelength. Ideally, our spectrometer would output an identical spectral graph as the known spectrum of neon light source with nearly-discrete intensity peaks. Numerical points of emphasis were percent-deviation of actual intensity-peak wavelengths vs. expected, as well as the bandwidth of these peaks. Signal-to-noise ratio was also a point of emphasis. We had determined our minimum SNR goal to be 25, an industry standard for minimum acceptable noise.

In addition to the calibration source, we sought to acquire a Raman signal for a sample of Sulfur equivalent to known Raman spectrum for the material. Sulfur also has a well-documented spectral output and exhibits higher-than-average-intensity Raman signals, making it an ideal material for testing the validity of this newly designed system. As with the neon calibration source, the goal was to acquire a Raman signal from Sulfur as close to expected as possible with minimal peak-intensity bandwidth and minimal deviation from expected wavelength.

2.3 Realistic Constraints

Based on the Triple Constraint model of project management, our potential constraints can be categorized in terms of time, cost and scope. [3] Time and funding constraints greatly affected our team's progress throughout the first few months; the 15-year-old camera used in the spectrometer was not compatible with any current NASA security-approved computers, which caused a significant delay in operating our system. The project's budget prevented us from simply purchasing a new camera, forcing us to wait for NASA staff to acquire us an approved PC with a legacy operating system.

Scope concerns applied to the size, layout and capabilities of the spectrometer. The system had to remain compact and light as a model for possible future fieldwork designs. Also, the system had to be oriented around an unknown object in order to be used to analyze materials abroad.

2.4 Alternative Designs

Initially, the prototype model we were given was oriented as a reflection-type spectrometer; the laser was mounted on top of the spectrometer housing and a series of optics were installed to guide the laser beam down to the object 180° with respect to the spectrometer. The incident laser then causes a scattered signal to emit from the object back toward the laser beam origin, which is received and conditioned by another series of optics for data gathering within the spectrometer. Alternatively, the laser could be oriented in-line with, and immediately behind, the object. In this case, the incident beam would still cause the object to emit a scattered signal for reception and conditioning by an optics array. However, a separate array to guide the laser to the object is not necessary; the laser source is already positioned parallel to the spectrometer. Also to consider: the emitted signals from a transmission-type system often emit higher levels of fluorescent scattering undesired in Raman data collection, requiring better filtering optics and software adjustment to eliminate the high-intensity laser signal which might bleed through the object into the spectrometer optics array. Two possible laser sources were available for implementation in our spectrometer system: 785 nm and 532 nm. Both sources are suitable for use in Raman spectrometers. The 532 nm laser provides a high-intensity signal of reliable wavelength and sharp Raman peaks, but this high intensity can often lead to an overabundance of fluorescent Raleigh backscattering. The 785 nm laser uses a near-infrared source, reducing the potential of fluorescent data contamination but reducing signal strength. [1]

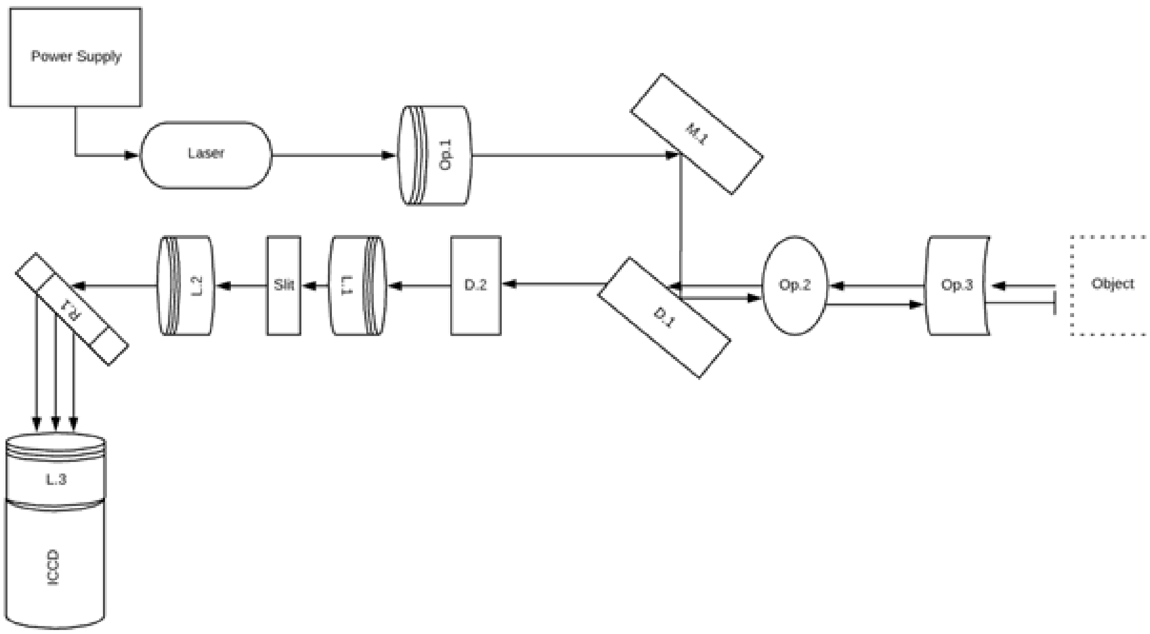

Figure 2: Raman Spectrometer with photons collection optics Diagram. A one-line diagram of the Raman spectrometer system developed at NASA Langley Research Center for characterization of materials. Optical components and laser hardware are labeled for ease of reference and described in detail in Section 4 of this report. Black arrows indicate propagation direction of signal from the laser, through the optical components and spectrometer, to the ICCD.

2.5 Design Selection

After initial tests using the pre-established reflection-method orientation of the spectrometer, our team decided to re-design the system as a transmission-type. A model of this design is included in the Design Specifications section (Section 4) of this report. This decision was derived from the relative difficulty in acquiring Raman data using the reflection method and the 785 nm laser; signal strength is generally weaker using a longer-wavelength laser source and our attempts to identify Raman scattering through reflection were not discernible on the WinSpec32 software via the PI-MAX model I ICCD. Previous student volunteers had experienced some success, albeit inconsistent, in acquiring Raman data using a 532nm source with this reflection system, however no previous success was documented using the 785nm laser. Therefore, a transmission system was developed vice the previous reflection setup in an attempt to improve our chances of acquiring Raman data. The 785 nm laser was selected as the laser source to be used for our spectrometer based on the needs of the project. This laser provided us with a weaker Raman signal but helped reduce fluorescent scattering, which posed an issue based on observations while operating the system. Persistent fluorescent scattering in the range of 532 nm occurred through the conditioning optics ahead of the spectrometer housing; the 785 nm source does possess some 532 nm bleed-though but it is much lower intensity than an actual 532 nm laser source and easier to deal with. To combat the 532 nm fluorescence, a 532 nm notch filter was added to the scattered signal-conditioning optics track ahead of the spectrometer housing.

Distance measurements along the optics array suggested the signal inflection point did not coincide exactly with the spectrometer entrance slit as needed to facilitate a proper Raman signal. Therefore, the distance between lens L.1 and the entrance slit was lengthened to ensure proper signal inflection.

2.6 Team Organization and Performance

The workload was divided between software and hardware. Tom managed the majority of the spectrometer hardware re-design and installation, making adjustments and optical replacement as necessary based on many calibration cycles. Using relevant optical theory, he developed a model for potential acquisition of Raman data through a transmitted system and rebuilt the system according to this design. Constantinos managed the installation and execution of the WinSpec32 software, adapting the system’s parameters to properly display the spectral analysis graphs necessary for system development and adjustment. Also, he produced 3D models of the system during the redesign process and developed various methods of displaying and analyzing recorded intensity data using Microsoft Excel and MatLab software.

3. Project Deliverables

3.1 Tasks and Responsibilities

In order to meet project goals, our team was tasked with redesigning the reflection-type spectrometer to consistently acquire reliable Raman data. This goal included any hardware modification/installation in the spectrometer's optical array as well as any software installation/operation and coordination with on-site security and IT departments for compliance with NASA regulations. Technical difficulties experienced with attempting to use the PI-MAX model I ICCD also involved hours of coordination and communication with Princeton Instruments tech support.

3.2 Team Organization

Our team regularly met two times each week for three hours each session at NASA Langley Research Center. Over the winter break period, meetings were increased to three times weekly. All work was conducted in a secured Raman spectrometry lab on-site under direct supervision by Dr. M. Nurul Abedin. Due to laser safety concerns, work was seldom performed without both team members present.

3.3 Milestone Timeline

10/2/19: Granted security clearance and access to NASA Langley Research Facility.

10/16/19: Initial concerns from NASA on-site IT and security departments about our need to use a Windows XP 32-bit operating system to run ICCD software. Site is phasing out all previous versions of Windows and will not allow us to use a virtual machine to run a previous version of the operating system.

11/6/19: 785nm laser used in our spectrometer design determined to not be listed on approved hardware list for our lab. Awaiting approval to use laser source. Continued to make design changes based on research: possible installation of biconvex lens at optical output before object; possible addition of 532nm notch filter to reduce fluorescent Raleigh scattering from laser bleed-through; possible removal of obsolete concave lens at laser output; possible replacement of spectrometer inlet lens L.2 to produce better signal at holographic grating.

11/20/19: 785nm laser approved for lab use. Laser tested for proper function. Lab safeguards tested as well (door interlocks, etc.).

12/18/19: Aligned 785nm laser source through optics to properly interact with objects. Installed biconvex lens at optical output immediately before object to produce optimal slit-shaped signal at object. Observed significant 532nm bleed-through signal from 785nm laser. Determining best place to install 532nm notch filter to improve signal.

12/23/19: Installed 532nm notch filter in optical track between 45° mirror and 45° 785 nm dichroic lens. Realized reflection of 532nm signal from coating could potentially end up re-entering laser and damaging equipment; moved 532nm notch filter in front of 785nm notch filter on lower optical track before spectrometer inlet slit.

1/15/20: Able to borrow a Windows XP 32-bit laptop from a different project which is not yet slated for Windows 10 upgrade. Installed WinSpec32 software. Able to acquire a test spectral signal from a white light source. This marks the first time we have been able to take actual spectral data.

1/17/20: Began calibration of spectrometer using Neon lamp source by comparing observed signal to known Neon spectrum. Adjusted lens L.1 position closer to inlet slit; verified current position at 75mm from slit to be optimal. Recorded 50 spectral graphs from Neon source to determine system signal-to-noise ratio. SNR calculated at 37: original goal was 25.

1/22/20: Changed lens L.2 to x1.4 magnification and infinite focal length. Rotated holographic grating to 50°. Both design changes produced our best Neon source spectrum to-date.

1/24/20: Removed 785nm filters and used 785nm laser as calibration source to begin determining proper conversion from pixels to wavelength for spectrum graphs. Observed crisp peak for 785nm source and recorded data for analysis.

2/14/20: Compared all recorded Neon source spectrums to determine optimal settings for lens L.2 and refraction grating. Attempted to derive pixel-to-nm conversion based on Neon data vs. known Neon spectrum. Calculations were inadequate; decided to use two laser source of different wavelength and determine conversion equation from those instead.

2/19/20: Used Nd:YAG 632nm neon laser source. Clear peak recorded at 406 pixels. Previous 785nm source peak recorded at 718 pixels. Used both data points to determine pixel-to-nm conversion of: λ=0.49(pixel)+432.9nm. Conversion equation puts Neon source peaks from 513.26nm to 753.85nm with the highest-intensity peak at 691.62nm. These results make sense based on the known Neon spectrum.

2/26/20: First attempt at acquiring Raman data using a Sulfur sample. Signal is too weak to detect with current spectrometer set-up. Need to re-design to acquire Raman data.

3/6/20: Re-designed system as transmitted laser source. Attempted to acquire Raman data but failed. Increased ICCD acquisition number and gain to determine if a faint Raman signal can be deciphered from the high-intensity laser signal bleeding through. Removed 785nm notch filter; the lens was significantly weakening all transmitted signals instead of just the 785nm signal from the laser. Determining best redesign to filter out laser bleed-through and acquire low-intensity Raman signal.

4. Design Specifications

4.1 Details of the Engineering Design

To achieve our goal of improving spectrometric output, our team re-designed the system, adding a 532 nm filter (N.1) to reduce inherent laser bleed-through, changing the spectrometer housing's inlet lens for a shorter focal length, removing an obsolete concave lens (Op.1) at the laser's output, increasing the distance between the housing's entrance slit and the external optical array to accommodate for proper signal inflection and changing the refraction grating's pitch angle to ensure a sharper set of images at the ICCD's input.

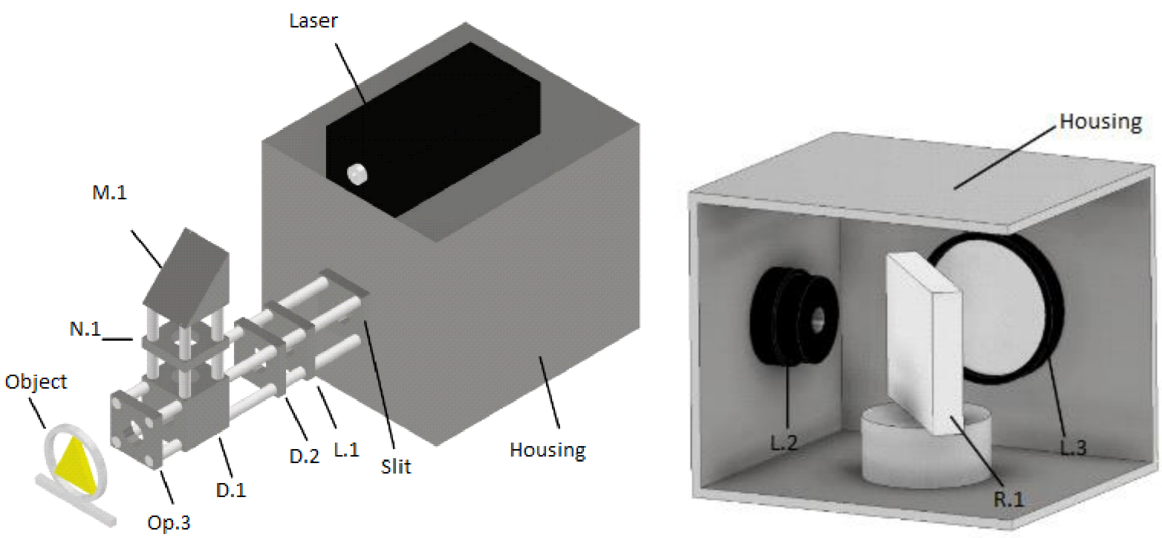

Figure 3: Raman Spectrometer 3D backscattered model. This model depicts our team's reflection design of the Raman Spectrometer in NASA Langley Research Center for characterization of materials. Components are labeled for ease of reference and detailed in Section 4.2.

Since the 785 nm Q switched-pulsed laser source is using a near-infrared source, the signal it produces lacks in strength, which makes Raman data collection significantly harder using the reflection design. To overcome this problem, our team decided to change the system to a transmission design. By placing the laser behind the object, the incident beam will still cause the object to emit a scattered signal for conditioning and reception. Furthermore, since the source is in-line with the spectrometer, there is no need for additional optics to guide the laser to the object. The 532 nm filter was also moved in alignment with the other filters in place of the 785 nm notch filter (D.2).

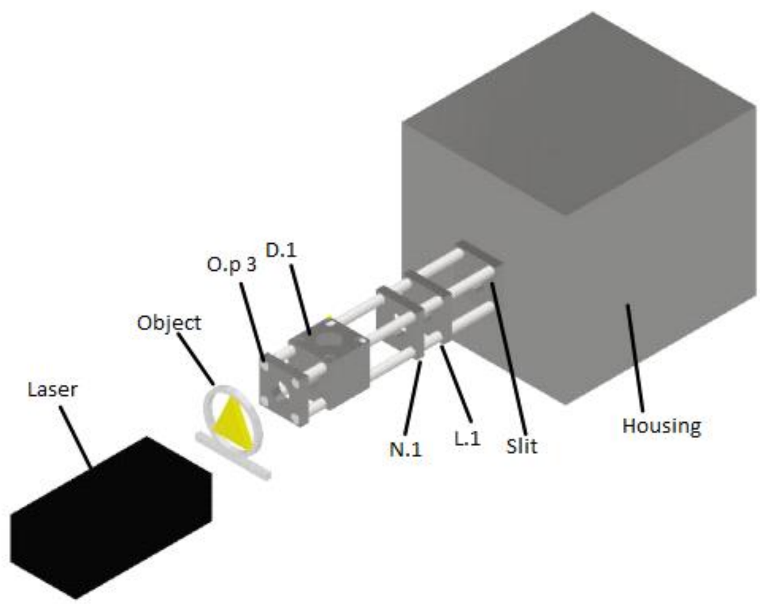

Figure 4: Raman Spectrometer 3D transmission model. This model depicts our team's transmission design of the Raman Spectrometer in NASA Langley Research Center for characterization of materials. Components are labeled for ease of reference and detailed in Section 4.2.

4.2 Hardware/Software

The laser used for this project is the CrystaLaser® Q-switched QL-785-500 nm laser. Two notch filters, a 0-degree 532 nm **N.1** and a 45-degree 785 nm **D.1**, were used to filter out the 785 nm and 532 nm laser lines from the Raman signals. Two convex lenses, a biconvex **Op.2** and plano-cylindrical **Op.3**, were used to condition the scattered signals into a focused and collimated beam. A pair of biconvex lenses, **L.1** and **L.2,** were used to focus the beam further to cause a signal inflection precisely at the spectrometer's entrance: a 100 μm slit. A holographic refraction grating, **R.1**, was used to diffuse the signal into its component wavelengths. This separated signal was gathered by a biconvex lens, **L.3,** at the inlet to the **ICCD**, which captured the signal. Components **L.2** and **R.1** are internal to the spectrometer housing and the **slit** is located on the housing itself.

Winspec32 is the software used for the purpose of analyzing and displaying the data gathered by the spectrometer. It controls the **ICCD** cameras temperature, focus, accumulations, gain, and all other settings that help the system acquire the Raman data. It also generates raw footage of the data, as well as intensity vs. pixel graphs of the signals gathered

4.3 Engineering Standards

ANSI Z136.3-2018 [11]: Safe Use of Lasers in Health Care. This standard describes the practices of safe laser use for any laser associated project. Raman spectrometry is driven by a laser source and proper safety must be used.

NASA-STD-(I)-007 NASA Computer-Aided Design Interoperability [12]: This standard is used by us to recreate the system and obtain the results from the previous team. It can also be used by future engineers to create the parts essential to the operation of this project, as a means of generating the same data that we did. "This Interim Standard establishes the format and content of two-dimensional (2D) drawings and three-dimensional (3D) models so that rework of these products by collaborating organizations is minimized." [12]

NASA-STD 8739.6 Implementation Requirements for NASA Workmanship Standards [13]: When handling high level voltage sources, extreme caution must be taken. If the necessary precautions, like grounding the laser is performed incorrectly, it may be proven fatal. "Sets forth quality requirements for the manufacture of electronic assemblies and for electrostatic discharge (ESD) control." [13]

IEEE 1394-2008 IEEE Standard for a High-Performance Serial Bus [14]: This communication standard must be considered when a serial connection between the ICCD Camera and the data collection terminal is made so the project can process the gathered data.

ISO 11254-2:2011 [15]: Lasers and laser-related equipment – Test methods for laser-induced damage threshold. This standard was very important to the project, as it is very heavily relying on the use of optics for the spectrometer. If the power output of the laser is too strong for the optics, it can cause loss and distortion of data, as well as damage to the optics themselves.

ASTM E1840 - 96(2014) [16]: Standard Guide for Raman Shift Standards for Spectrometer Calibration. This standard must be followed when lasers are involved in the project. The standard provides shift values for several substances that can be used for comparisons. Calibrating the laser and making sure the beam is guided to the correct point of impact, is crucial for data gathering, and the project's whole functionality.

5. Design Performance

The calibration of the system began with a white light source similar to a household flashlight. Since the white light source has a high intensity signal with a full spectrum scope, we used it to make sure the system could acquire a signal for processing. An output featuring identifiable intensity peaks denotes the ICCD is working properly.

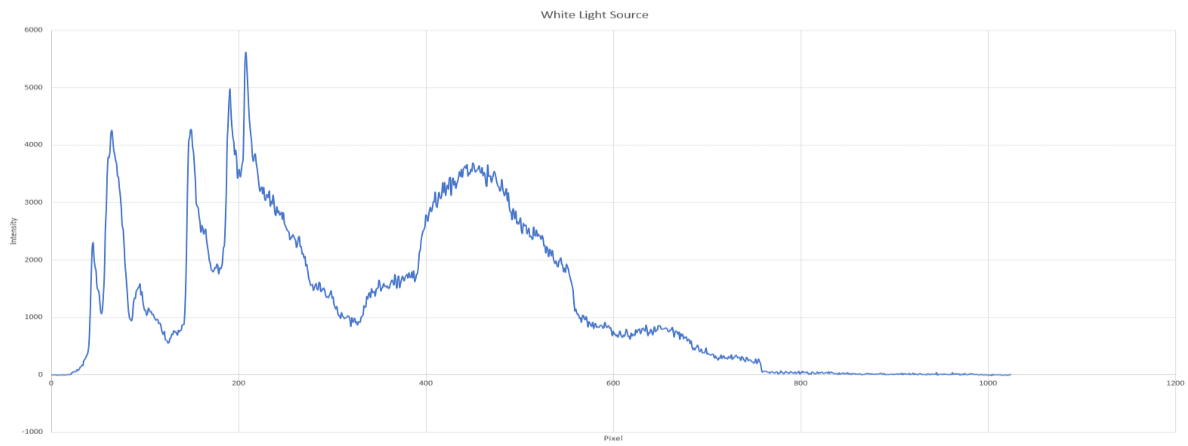

Figure 5: White light source graph, Intensity (y-axis) vs. Pixel (x).

Following our results with the white light source we used the laser as a source. Because the laser has an intense signal at one specific wavelength, it was used to make sure the system is able to acquire a refined and crisp peak signal. A very sharp intensity peak at one-pixel location denotes minimal signal interference through the spectrometer's optics and refraction grating.

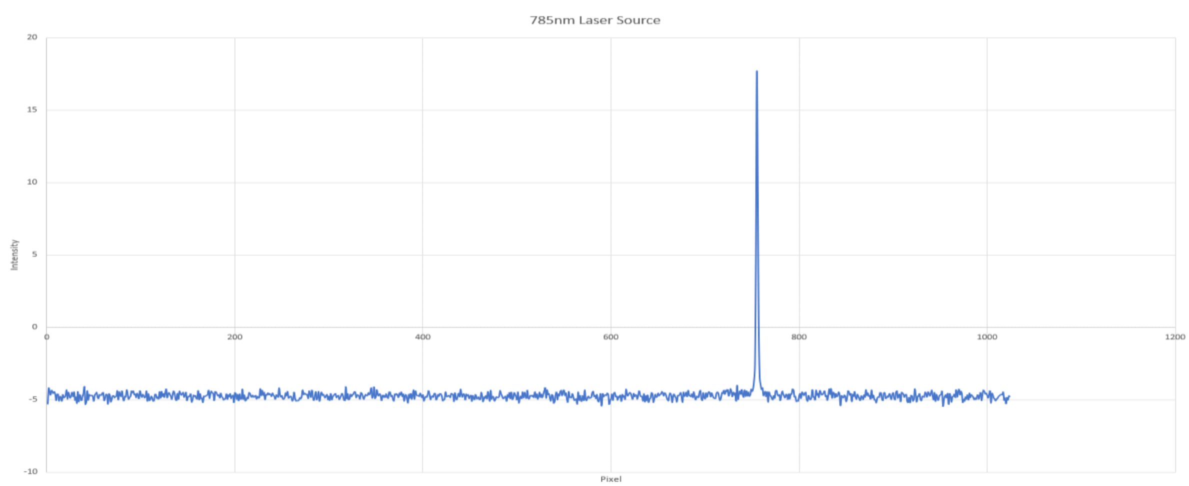

Figure 6: 785 nm laser signal graph. Intensity (y-axis) vs. Pixel (x-axis).

In order to understand the results, we were acquiring, a pixel-to-wavelength conversion formula was necessary to allow us to compare ICCD output to known spectral data for further calibration. To develop the conversion formula, a set of laser intensity peaks was acquired. The intensity peak for the 785nm laser was observed at the 718 pixel and, using a 632nm Nd:YAG laser source, a second laser intensity peak was observed at the 406 pixel. Comparing these two intensity peaks and wavelengths yielded a first-order linear relationship used as a pixel-to-wavelength conversion equation:

Finally, a neon lamp source of known component wavelengths was used as a basis for optical re-design and calibration. Using this conversion formula we were able to compare the data that we collected through the system to the expected neon data and make adjustments to the system as needed to bring the two data sets as close to each other as possible. This process encompassed seven major data acquisition points. For our first data set, the focal length of L.2 was adjusted to infinity. For the second data set, L.2 magnification was changed to be times 0.4. For the third data set we covered the system to remove any outside light, and adjusted L.2 magnification to times 1.4. For data sets four through seven we rotated the refraction grating from 65° to 60° to 55° to finally 50°. Our final data set was within a ± 50 nm range from the expected neon data.

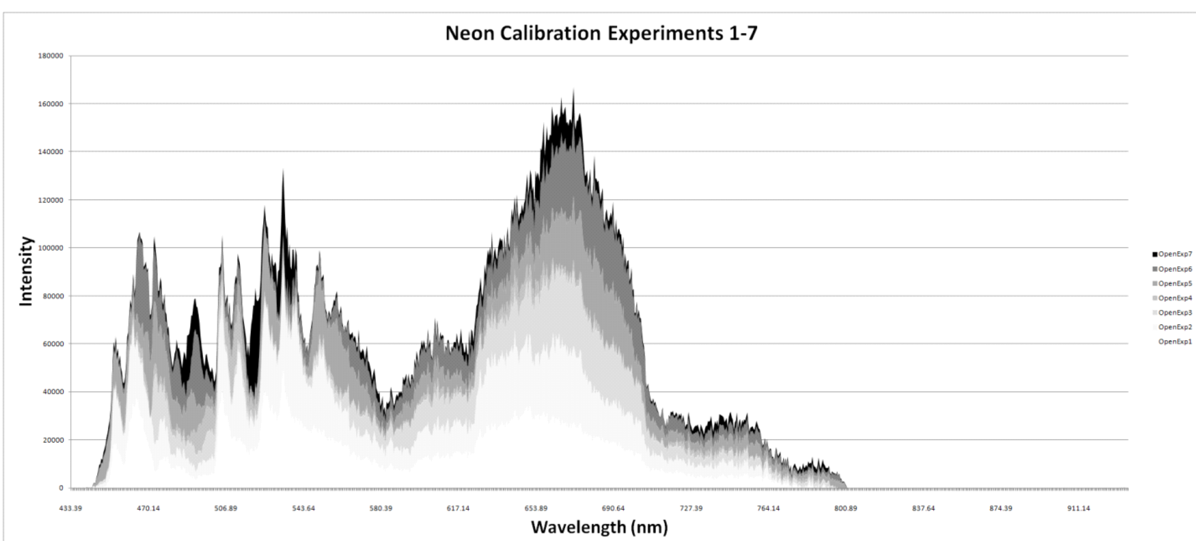

Figure 7: A graphical representation of the seven acquisition points used for neon source calibration.

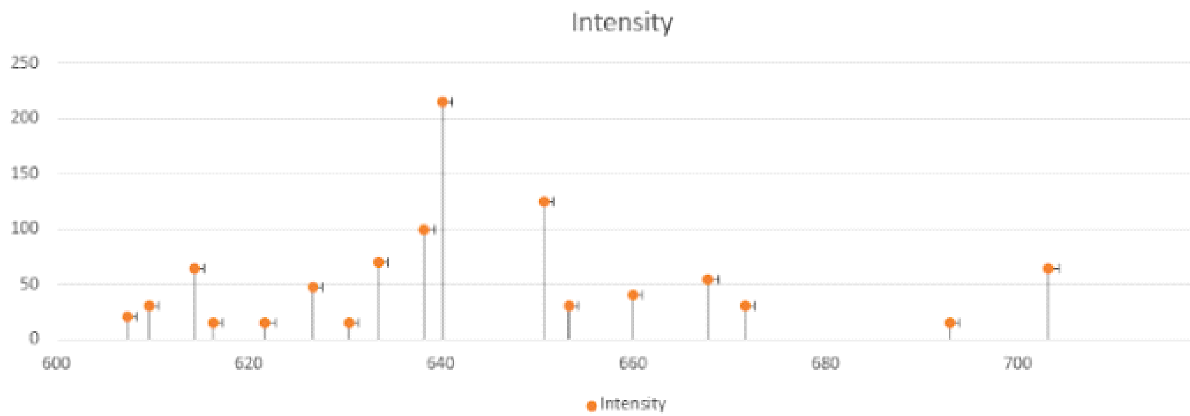

Figure 8: Discrete intensity vs. wavelength graph for known neon lamp spectrum. Intensity values are arbitrary to demonstrate relative intensities.

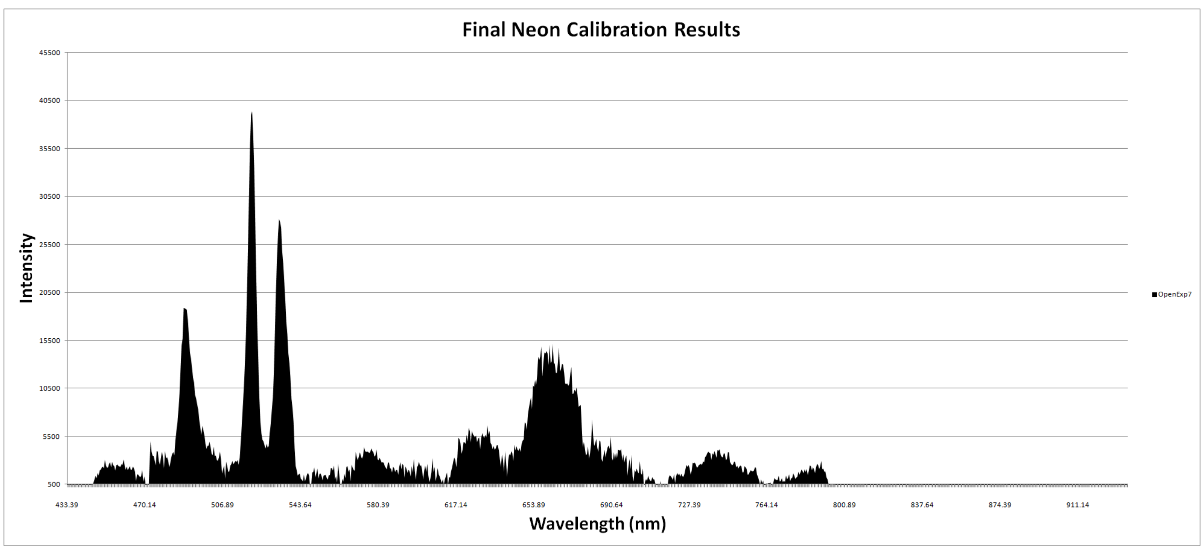

Figure 9: Final Neon Calibration Data. Using the best (OpenExp7) data from Figure 7, and chopping out noise below 500 intensity, this represented our closest attempt to matching expected neon signal pattern.

While system calibration and re-design based on known sources yielded a better-functioning optical system, acquisition of Raman data from a Sulfur sample using the transmission technique is still on-going with no discernable Raman signal intensity peaks within signal noise. Further redesign of the optical system, as well as many additional hours of trial-and-error calibration, are needed to perfect the system. However, due to our significant early delays and the shutdown of LaRC during the COVID-19 pandemic, our research window was simply too short to accomplish this.

6. Project Broader Impact

6.1 Ethical

As Raman spectroscopy has many uses, its main goal in this project is to aid NASA research in the development of future surface characterization systems. After NASA was able to confirm that water was indeed flowing on the surfaces of Mars [20], the possibility of humanity inhabiting Mars was brought once again in light. The first and ninth IEEE codes of ethics pursue the paramount safety, health, and welfare, as well as avoiding injury of the public [17]. Continuing the path that this project might lead to; humanity will most likely violate both codes by bringing the consequences of having humanity inhabit a different planet.

6.2 Contemporary Issues

The primary function of this system is to analyze planetary surfaces using spectroscopy. In addition, Raman spectroscopy can also be used for a variety of other fields of research. The previous designs for the system used bulkier builds for the spectrometer, as well as stronger lasers. These components may have gotten in the way of using Raman spectroscopy by one of the fields mentioned above for cancer diagnosis [21]. With a laser of 785 nm which is easier on samples and not strong enough to damage them, as well as a more refined and lighter spectrometer, our system could be properly utilized for these kinds of research and can easily be adapted to biological studies.

6.3 Lifelong Learning

6.3.1 Constantinos Manolakas

Much of the information that I was able to apply to the project came from courses that I took as part of my degree of Electrical and Computer Engineering at Old Dominion University. Courses like PHY-232 helped me to partly understand the necessary theory behind our project, and with the help of Tom I was able to fully grasp it. A few other courses that helped me shape the project so far, were ECE 202, ECE 302, and ECE 381, which gave me the necessary knowledge on how to apply MATLAB to gather and manipulate the data generated for analysis.

Before I started working on this project, Raman spectroscopy was an unknown subject to me. After I started working under Dr. Abedin, and with the teamwork Tom and I have learned to appreciate Raman spectroscopy for what it is and does. Through the guidance of my mentor and peers, I was able to grow to the point of understanding what needs to be done and how. As the project continues, I will be able to gather a lot more information and experience that will surely help me develop as both a researcher and an engineer.

6.3.2 Tom Ash

This project presents a different challenge than I have encountered in my previous coursework at Old Dominion as an Electrical Engineering undergraduate. Working with laser and optical principles will provide me with experience complementary to the education I am receiving; very little coursework has touched on the fundamentals of this Raman spectrometer system and learning as much as I can about how it works will only bolster my overall education.

Almost all relevant spectrometer theory I have applied to this project has been acquired through hours of self-study both at NASA Langley and at home.

The majority of my professional experience is rooted in military and government work. With six years of Navy nuclear power experience and over a year as an electrical test engineering co-op at Newport News Shipyard, the latter of which has developed into a permanent position post-graduation, I am comfortable in the Langley Research Center working environment and feel additional exposure to government-based work will increase my professional portfolio.

6.4 Broader Impact

6.4.1 Economic Impact

"Going to Mars, the stars and beyond requires a vision for the future and innovative technology development to take us there. Today, it costs $10,000 to put a pound of payload in Earth orbit. NASA's goal is to reduce the cost of getting to space to hundreds of dollars per pound within 25 years and tens of dollars per pound within 40 years." [22] Since sending something to space is expensive these days, the goal of this project is to keep the spending on a limit, and keep the system as lightweight as possible, without affecting any of the systems functionalities.

6.4.2 Environmental Impact

Since the very first Human spaceflight program Project Mercury [23], and the space race that followed, space missions were growing in numbers. These space missions taxed Earth's environment by using limited resources that in the end either got lost, destroyed, or forgotten in space [24]. The Moon's and Mars' environment also get affected by the resources being left alone and rotting on their surfaces.

6.4.3 Societal Impact

When people hear the terms Raman spectroscopy, NASA, and space, the first thing that comes to their mind is life detection beyond Earth. Even though what everyone envisions is grey aliens with black eyes and long fingers, a more realistic version of life outside Earth would be microorganisms. This project makes the quest for detection of life more realistic by providing a system that can identify mineral, organic materials and other biomarkers.

7. Summary

The acquisition of Raman data is a precise, tedious process involving detailed optical design, adjustment and calibration. Significant administrative setbacks greatly delayed our work on this spectrometer, thus delaying our ability to properly acquire a Raman signal from even the most intense samples. However, system calibration and re-design has yielded a sharper signal than previously achievable by the initial reflection model. Fine-tuning of re-designed optics and a slow, deliberate increase in ICCD accumulations/gain will likely lead to reliable Raman data through our re-designed transmission system.

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Appendices

Appendix A: Executive Summary

The goal of this project was to improve an existing Raman Spectrometer system for planetary surface investigations, through optimization of the spectrometer. The system was designed to support future space missions which require surface landing, and analysis of surface samples to determine their possible molecular compositions. The system focused on the acquisition of Raman signals using a 785 nm laser, and analysis of the produced Raman signals. During the interaction of the incident laser beam with the molecules of the target sample, the molecules vibrate at a frequency that differs from that of the laser. The difference between the frequency of the 785 nm laser and the shifted frequency caused by the molecules of the target sample creates a unique identification that can be used to classify each material that is analyzed. The Raman signals are collected through the spectrometer and analyzed. After preliminary optical re-design, a signal-to-noise ratio of 37 dB was achieved, surpassing our project goal of 25 dB.

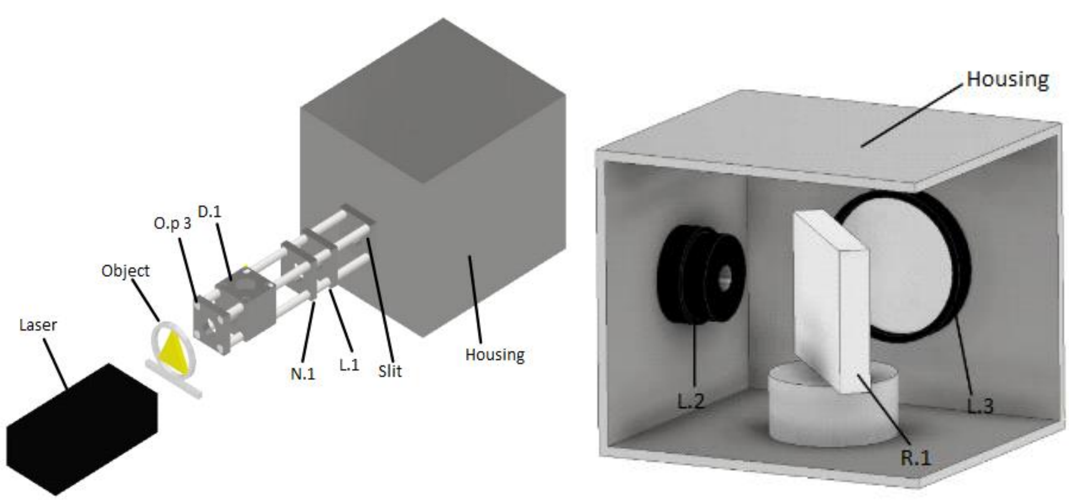

Figure: Raman Spectrometer 3D model. This model depicts our team’s transmission design of the Raman Spectrometer in NASA Langley Research Center for characterization of materials. Components are labelled for ease of reference.

A neon lamp source of known wavelengths was used as a basis for optical re-design and ICCD camera calibration. Using a conversion formula we were able to compare the data that we collected through the system to the expected neon data and make adjustments to the system as needed to bring the two data sets as close to each other as possible.

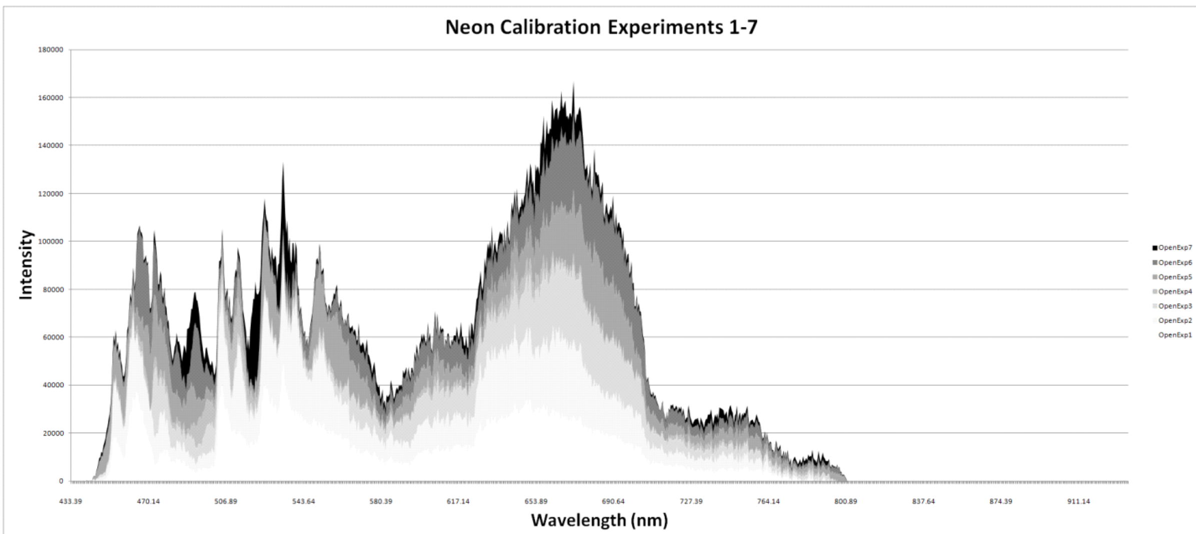

Figure: A graphical representation of the seven acquisition points used for neon source calibration.

System calibration and redesign has yielded a sharper signal than previously achievable by the initial reflection model. Fine-tuning of redesigned optics and a slow, deliberate calibration process over the course of several weeks, or even months, will lead to stable, reliable Raman data acquisition.