L.A.S.E.R.S.
Raman Probe

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Abstract — **This project involves designing a handheld probe that can detect a Raman signal from a sample. The ultimate application is for *in vivo* measurements of human skin for identifying Raman spectra of cancerous skin. The project involves optics for Raman excitation and collection. Electronics integrated into the system will capture an image of the sample area, power the components, and provide safety measures. Software is included to analyze and display spectral results through a Graphical User Interface as well as for communication between components.**

Index Terms — **Cameras, in vivo, lasers, optical fibers, Raman scattering, software, spectroscopy.**

I. INTRODUCTION

Spectroscopy is a method of measuring the interaction of light and matter. When monochromatic light such as from a laser is incident on a material, the elastically scattered light, called Rayleigh scattering, has the same wavelength as the incident light. In-elastically scattered light, called Raman scattering, consists of both higher and lower wavelengths. Rayleigh scattering dominates Raman scattering, but the Raman signal is what is of interest.

Raman spectroscopy is a spectroscopic method that measures the unique spectrum that results when light incident on a material scatters at a different frequency due to the molecular vibrations of the material. This unique spectrum acts as a “fingerprint” that can be used to identify the material.

It is estimated that 87,110 new cases of invasive melanoma will be diagnosed in the U.S. in 2017, and melanoma only accounts for 1% of skin cancers (American Cancer Society). These patients must visit a dermatologist to have freckles, moles, or other abnormal skin lesions checked for the potential of being cancerous. This usually results in a biopsy of the skin to be sent to a pathologist who uses a microscope to check if the skin sample is cancerous or noncancerous – a process that may take several days to receive results. A biopsy is performed by cutting out or excising an area of the skin under consideration. This can be painful for the patient and may result in scarring. The stress of waiting for results is difficult for a patient waiting to hear potentially life-altering news. Further biopsies may need to be performed if the biopsy sample did not contain the abnormal cells, if the concentration of the cells was not high enough for an accurate diagnosis, or if the skin appears to change after the biopsy. Therefore, the motivation of the Live-Action Safe Examination Raman Spectrometer (L.A.S.E.R.S.) project is to provide a non-invasive alternative to a biopsy for skin cancer screening, all while maintaining the same standard of accuracy and reliability and reducing medical expenses.

Raman spectroscopy is appealing as a method of skin cancer detection and diagnosis. Current research [1]-[6] on the *in vivo* application of Raman spectroscopy promises a less invasive technique with fast results compared to a conventional skin biopsy. Our sponsor, Ocean Optics, wants a probe designed to collect Raman spectra of materials and to capture an image of the sample area.

An excitation laser will illuminate the skin sample. The scattered light from the skin will have a different frequency than that of the incident laser light. This scattered light will be collected and analyzed by a spectrometer. In fact, the scattered light from the sample will manifest a spectrum that is unique to the biochemical constituents of the sample. Using this sample “fingerprint” the Raman spectrum should be differentiable between that of normal skin and cancerous skin.

The optical components section includes lenses, a beamsplitter, mirror, longpass filter, optical fibers, laser, and spectrometer, and describes the purpose of each component necessary for detecting a Raman spectrum. A camera module mounted within the probe will be used to capture an image of the sample area, with an LED used to illuminate the sample area. Safety measures include a manual switch for firing the laser when the probe and sample are ready for measurement. Two additional LEDs mounted externally on the main body of the device will indicate the laser is firing and power is reaching the spectrometer, acting as a laser activation warning. The electrical system section will describe these functions and the printed circuit boards (PCBs) used to power the laser, microcontroller, camera module, and LEDs. The software section describes communication between the Raspberry Pi, PCBs, and the user interface. Spectral acquisition and analysis is also covered in this section. The graphical user interface should display the steps for acquisition, Raman spectrum, the image of the sample area, and analysis of results. An overall view of the system is shown below in Fig. 1.

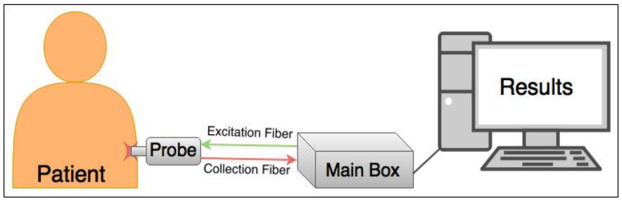

Fig. 1. Overall systemic view.

II. OPTICAL COMPONENTS

Raman scattering from a sample is considerably weak with only 10^{-7} of the incident photons scattered compared to 10^{-4} photons scattered by Rayleigh scattering. Therefore, it is imperative that the probe be designed using optical components that effectively reduce the Rayleigh scattering signal in order to detect the Raman scattering signal. Additionally, proper alignment is crucial in detecting the weak Raman signal.

A 785 nm, spectrum stabilized laser is used to excite the sample. Approximately 100 mW is delivered to the sample through a 105 µm core optical fiber. This excitation fiber is connected to the Raman probe. Within the probe, a plano-convex lens, AR coated for the NIR wavelength range 650 - 1000 nm, collimates the light diverging from the excitation fiber. This light is then transmitted through an AR coated, dichroic beamsplitter, positioned at a 45-degree angle. The beamsplitter is coated to transmit wavelengths below 788 nm and reflect wavelengths above 823 nm (cut-off wavelength of 805 nm). An AR coated plano-convex lens at the sample is used to focus the light onto the sample. This sample lens has a high numerical aperture of 0.42, which is sufficient to capture the Raman scatter from the sample. The collected signal is then collimated back into the probe where it is reflected by the beamsplitter to an AR coated mirror. The mirror directs the light through a longpass filter with an 800 nm cut-on wavelength, and through a third plano-convex lens that couples the light into a 200 µm core optical fiber (0.22 NA). This collection fiber delivers the Raman signal to an Ocean Optics USB2000+ spectrometer. Fig. 2 below shows a schematic of the optical components within the probe.

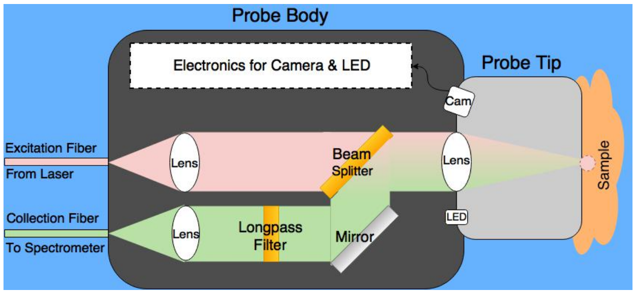

Fig. 2. Schematic of optical components within the probe.

This setup currently acquires the Rayleigh scattering from the sample. After careful alignment, Raman scattering has been detected for a diamond sample and wooden spoon. As shown in Fig. 3, the diamond sample exhibits a peak at roughly 1333 cm^{-1} as is expected.

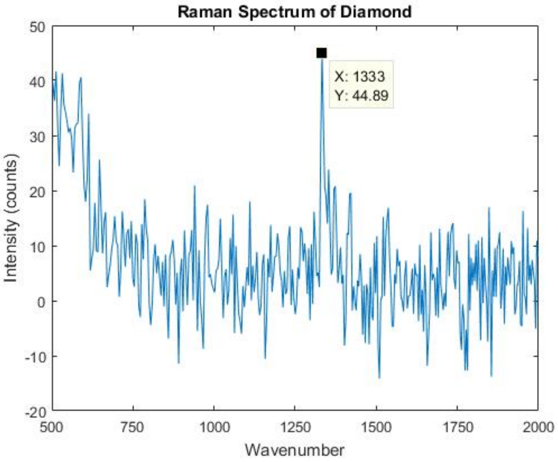

Fig. 3. Raman spectrum of the diamond sample, exhibiting the characteristic peak at 1333 wavenumbers.

The following Fig. 4 shows the Raman spectrum of the wooden spoon, exhibiting a peak around 204 cm^{-1}. The Raman spectra of the diamond and wooden spoon taken with our probe agree with the spectra as measured from a commercial probe (InPhotonics).

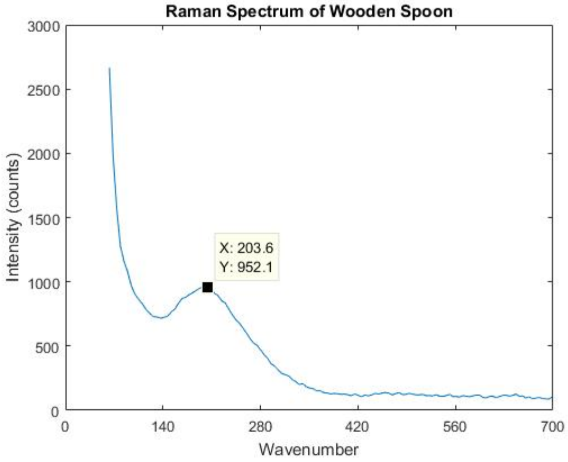

Fig. 4. Raman spectrum of a wooden spoon, exhibiting a peak around 204 wavenumbers.

The collimation lens at the excitation fiber has an NA of 0.125. The focusing lenses at the sample and at the collection fiber have NA's of 0.42, which will capture scattered light from the sample at a much larger acceptance angle. One future improvement would be to replace the 0.125 NA lens with a third 0.42 NA lens in order to increase the power delivered to the sample. This, in turn, may also improve the signal-to-noise ratio of the spectra.

III. ELECTRICAL SYSTEM

The electronics components of the device focus on safely powering all major device components and implementing add-on functionality. A modular setup that allows the proper rated power to reach each component is a must to improve safety, heat distribution, and to implement a logical overall design. The device consists of two PCBs as well as a camera module.

A. Power Control and Safety

PCB A consists of components for power delivery as well as safety features. This PCB is encased within the main body of the device, close to the laser, fan, microcontroller, and spectrometer. Below in Fig. 5 is the board layout of PCB A.

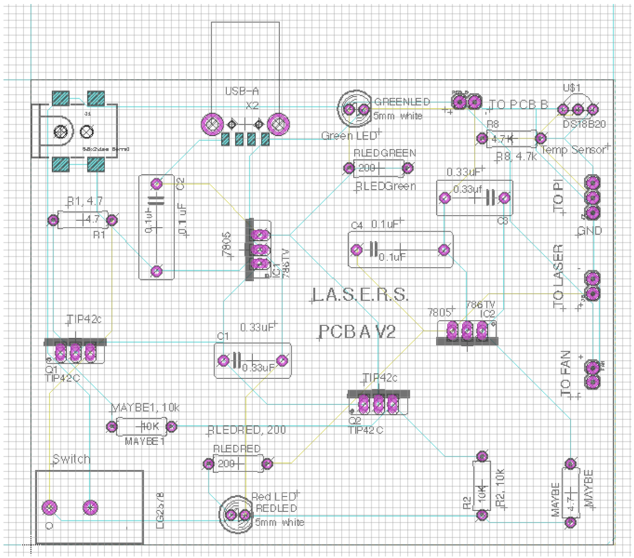

Fig. 5. PCB A Board Layout Configuration

The main purpose of this portion is to take in power from a wall wart and safely deliver the proper amount of power to major components such as the microcontroller, laser, and PCB B. This circuit utilizes 5 V, 1.5 A linear regulators in order to step down and better control the power entering the system. Transistors were essential to increase the current to a proper amount to power the microcontroller as well as to minimize the potential for short-circuiting. While linear regulators can become warm, the device has multiple heat regulating components to be discussed later in this document. An important piece to the heat regulation is to have a heatsink directly connected to every element in the device in the TO-220 family, including the voltage regulators and transistors used.

This PCB contains two LEDs that, when the correct amount of power is delivered to the spectrometer and the laser, will illuminate to further ensure the user that the device is ready to be used. For safety, a switch is installed so that power is not delivered to the laser and spectrometer immediately when the device is plugged into a wall outlet.

Additionally, this PCB contains a temperature sensor, the DS18B20. This temperature sensor is small and relatively simple to interface with the microcontroller. A temperature sensor is necessary to read real-time device temperatures to ensure safety and to ensure that the fan, also powered in PCB A, is working properly. The fan will work with heatsinks in order to ensure that the safest device temperature possible will be maintained.

B. Microcontroller

The Raspberry Pi 3 Model B was selected to implement the user interface, process the data received from the probe, and coordinate the actions of the entire system. The quad-core 1.2GHz processor will be powerful enough for our system to coordinate tasks in real-time, as to ensure the safety and reliability of the project.

The 4 USB ports, 1 HDMI port, and 40 GPIO pins allow for all of the necessary connectivity required by our system. The USB ports will allow for user input, and connection to the spectrometer, while the 40 GPIO pins will allow for the device to connect to the embedded system fans, camera system, and temperature sensors in the system.

With the removable SD card, we are also ensuring that this part is easily replaceable if such an event should arise. The overall collection of these characteristics allow for the Pi to be ideal for our design, combining raw computing power with functionality.

C. Probe Functionality

Two major electronic systems exist within the probe: PCB B and the Raspberry Pi Camera V2 module. Powered by PCB A, PCB B supports an LED beam that improves visibility of the area of interest on the skin/sample. The camera, connected to the Raspberry Pi for power and data, allows for a real time look at the view from the front of the probe, making the task of guiding the device to the proper spot more simple. The camera will take a photograph of the area of interest and allow the medical team to have a visual of the potentially affected area of skin.

IV. HARDWARE DESIGN

Casing was designed for both the handheld probe and main box containing the components of the system not needed within the probe. The components – laser, spectrometer, and probe – are configured in a modular format, which allows the team to prevent issues such as overheating or diagnostic frustration. Having the components in their own separate spaces gives the team the ability to detect errors in hardware and allow for quicker replacements, as well as have them preconfigured to work as stand-alone components.

A. Probe Casing Design

Due to the nature of the medical examination, the probe casing is designed to be handheld. The user will be able to easily maneuver the probe onto various sample areas of a patient due to its ergonomic design.

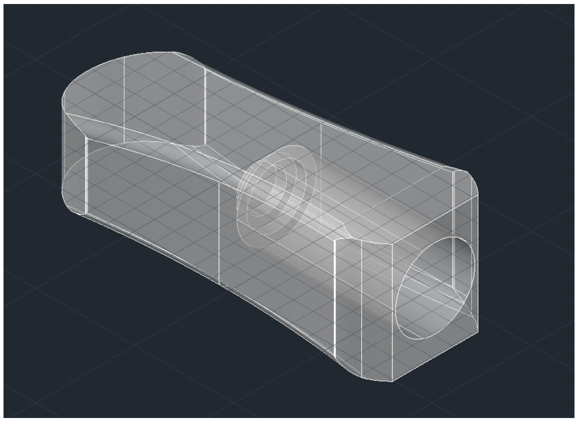

Fig. 6. Probe Casing Design - Orthogonal View

Fig. 6 is a CAD representation of the probe. The circumference of the probe handheld is smaller than its circumference of the front and back, allowing for a better grip of the handheld to enhance its stability. The camera module, LED for sample illumination, and optics are contained within the probes front, which will also provide better handling due to the weight distribution on the probe encasing. The back of the probe encasing will have two holes that allow for an excitation and collection fiber to deliver the laser into the probe, as well as collect data from the sample.

As for the interior of the probe, it is imperative that the optics are securely mounted inside to remain properly aligned to deliver the excitation laser light and collect the Raman scatter. Because of this constraint, the construction of the probe was done starting from the inside, and working its way out. The probe interior houses the lenses and mirrors, and are placed at the center of the probe body on a frame. This frame ensures that the probe be handled without any misalignment from the optical components.

To control the beam LED, a smaller PCB (PCB B) was created to be placed inside the probe to eliminate wire traffic going to and from the handheld as well as to eliminate long LED leads that may be unstable. The PCB will be housed on the opposite end of the probe case to maintain alignment and reduce interference with the optical frame.

A protruding tip at one end of the probe will have a length approximately the focal length of the sample lens. The probe tip is to be placed in contact with the sample. This design consideration will ensure that the sample is in the focal plane of the lens, resulting in a maximum Raman signal. Fig. 7 is a graphical representation of the probe tip, and its key components. The indicator LED and the camera will be placed at an angle so that it does not impede with the probe tip and maintain its integrity, all while securely holding the individual components safely with little room to shift out of place.

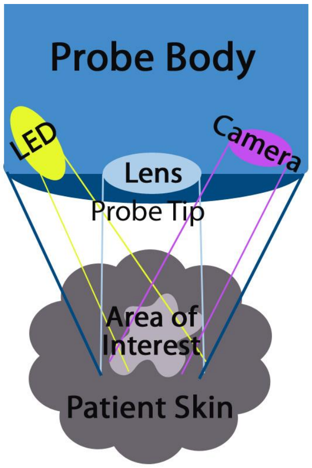

Fig. 7. View of probe main component placement in relation to tested area.

B. Main Electronic Box Design

The main box has been designed to house the laser module, spectrometer, PCBs, and Raspberry Pi, as well as the entirety of the cooling system. The laser and spectrometer are connected to the probe via optical fibers for excitation and collection.

The main considerations in this space are overall space, to accommodate for parts, while also providing adequate cooling. The box design is currently large enough to house all the components which should be integrated, but will be finalized in a metal casing custom fit for our purposes.

Outer connections for this case should be a DC input jack, two USB jacks (for connection to the Raspberry Pi), and a HDMI jack (for display connection). Power and data connectivity to the probe will run through one end of the main box to the probe. This should allow the user to be able to connect all necessary devices without reaching inside the box, which can be unsafe, while power is running.

C. Cooling Design

One of the largest considerations for the project is the overall heat buildup of the system. The system can quickly become unstable if heat is not dissipated quickly, and that can result in both a loss of accuracy, as well as safety hazards for the end users. It is important to maintain safe rated temperatures across individual parts so that each component functions as expected.

The first step to reduce the overall heat buildup is attaching heat sinks to each component to remove the heat from the vital parts of the component, which will also allow the fan to remove heat from the system as quickly as possible. The laser donated by Ocean Optics has a heat sink built into it. Items in the TO-220 package are prone to emitting a high amount of heat due to their main functions: regulating voltage and current. A variety of heatsinks are sold that help to dissipate excess heat from the component. Below in Fig. 8 is an example of the TIP42C transistor with its heatsink attached.

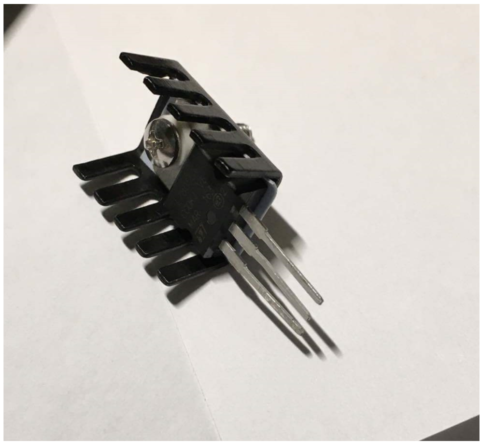

Fig. 8. TIP42C - Attached Heatsink

The second step to reduce the heat buildup is by attaching temperature sensors to vital components which are the most heat sensitive. The necessary components are the laser, and the power PCB. With large amounts of heat buildup, both devices can cause catastrophic damage to both the system and end user. The Raspberry Pi will monitor these key components, and regulate fan speed accordingly.

The team initially utilized a 12 V voltage input. As the design changed, the team realized that a 9 V AC to DC adapter would suffice for the needs of the system. This design change greatly decreased the amount of excess heat across the components, enough so that a smaller heat sink would suffice for the individual components. The excess wattage decreased to a value around 4 W instead of an initial value of 7 W, enough to significantly improve the thermal flow of the overall system. This lower baseline also allowed for smaller, more manageable heat sinks to be introduced in the design.

The final step to dissipate the heat is by attaching several fans to the system, which will be controlled via the Raspberry Pi and input from the temperature sensors. Using variable speed control, the Pi will dictate the necessary fan speed to keep heat within tolerances, and to keep noise and power draw to a minimum.

V. SOFTWARE

A. Control Software

Due to the levels of coordination needed to ensure accurate and reliable results. The Raspberry Pi will be synchronizing these actions through a Java-powered control software system. This program utilizes OmniDriver, a Ocean Optics spectrometer driver suite, and the Pi4J library, which is an embedded system to control the GPIO pins of the Pi.

The Raspberry Pi is connected to the USB2000+ spectrometer via a high-speed USB connection, and can be controlled using OmniDriver supplied by Ocean Optics. This gives full control of the spectrometer to any computing device capable of running the applicable code. Our use of the Raspberry Pi is due to the ability to process large sets of data quickly (reducing overall run-time) while also having standard GPIO pins to control non-standard devices, such as our CMOS camera sensor and our internal cooling systems.

B. Testing Algorithm

The overall testing algorithm is a derivative system based off the testing algorithm used by Ocean Optics to identify key chemicals in the test subject. Through a series of steps, we have been able to reduce the amount of noise and extraneous data results to give the user a clear and concise representation of the skin area being tested.

At first, the system will measure the dark spectrum, which is the Raman emission spectra without the laser powered on. The system will take an average of 20 of these scans to reduce any noise.

Second, the system will take in the Raman spectrum with the laser powered on, and will average together 100 of these scans, with an approximate run-time of about 30 seconds. The average of these 100 scans will reduce the Signal-to-Noise ratio by a factor of 10.

Lastly, the system will reduce the noise further by removing any non-linearity, which can be ignored due to the nature of Raman signals. This process of smoothing will give the user a more comprehensible graph, which can then be later be interpreted with less focus on small local peaks-and-valleys, which should direct the user to the larger data trends which is the relevant data for our project.

C. Graphical User Interface

The Graphical User Interface will have an intuitive design, while providing the user with all of the necessary information and settings to allow end-user confidence in the system.

The current design focuses on a black design with large buttons, that should provide the user with a simple to follow flow.

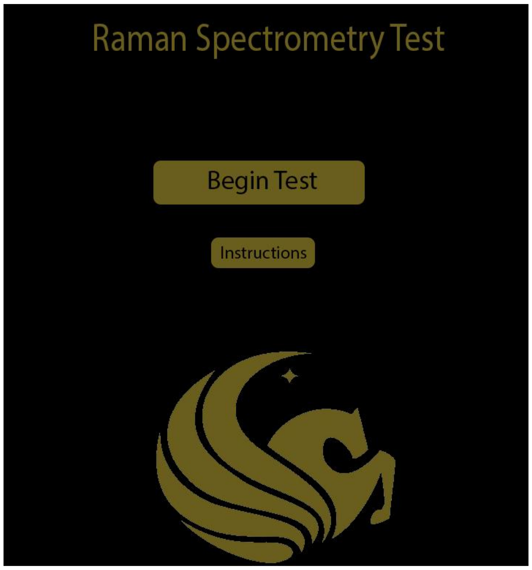

Fig. 9. Design example of GUI

VI. SAFETY

A. Laser

This product contains a Class IIIa laser, and as such is considered hazardous without the correct handling procedures. Never look directly at the laser, or aim the laser at an unintended target, as this can cause health and safety risks.

B. LEDs

This product contains several LED’s used to illuminate subject material, or indicate the status of the laser in the probe system. Both LED’s should not be stared at directly, and can cause eyesight problems if proper safety precautions are not taken.

C. Electrical Hazard

This product uses wall output power to provide the needed electrical connection to all of the components. Use proper handling procedures when handling all wires in the system. Including but not limited to: system power connection, Raman probe connection, and any other component connections. Any frayed/exposed wires are to be considered unsafe until a technician is able to verify they are safe.

D. Temperature

This product contains several components that are able to build up large amounts of heat and these components are kept in relatively tight quarters. Therefore, before touching any piece of the system, test the temperature by quickly touching the surface before grabbing it. This will allow you to get a quick idea of the overall temperature of the system you are picking up.

If the temperature is not safe to the touch at any part of the system (probe, controller encasing, etc.), please consider powering off the device at a natural stopping point. Do not attempt to continue to use until the system has returned to standard operating temperature.

VII. PRODUCT ASSEMBLY, BASIC FUNCTIONALITY PROCEDURE

A. Assembly

Set the spectrometer system on a flat surface. Plug the Raman probe into the spectrometer using the connector. The connector will only fit one way, so be sure to not force the connector in. Attach the laser fiber connection to the Raman probe. Plug the necessary components into the microcontroller (display and input device). Once the Raman system is assembled, power can safely be attached.

B. Power Up

Press the power button into the "on" position. The internal microcontroller and spectrometer will power on with no input from the user. Flip the on/off switch on the laser to the on position. The Raman probe will show no signs of power until the user begins the test. When the test begins, the user will have time with the camera targeting system before the laser actually fires.

C. Power Down

There is no native "Power off" functionality on the spectrometer. This device will power off by pressing the power button into the "off" position and unplugging the power cord. When you are ready to power off the microcontroller, there will be another program available on the desktop called shutdown that will run a pseudo command to power off the Raspberry Pi. Flip the on/off switch on the laser to the off position.

D. Test Procedure

The testing procedure steps outlined below should be completed in order to ensure the system receives all of the data it needs. Please ensure all devices are connected and powered on. The provided power brick should be plugged into the Raman system, and the spectrometer probe should be plugged into the Raman system also. The power button on the Raman system should be pressed, powering on the embedded microcontroller. Running the LASER.jar file will begin the program.

If you are a new user, please select the clickable "Instructions" button as shown. This screen will provide new users with a step-by-step tutorial on how to use the product. If you are an experienced user, please select the clickable "Begin Test" button which will begin the necessary on-screen prompts.

The first scan will ask for a section of skin that is clear of any issues. There should be no moles, pimples, or other types of possible inflammation at the testing site. This measurement provides the system with a current baseline to compare the other skin sample to. The second scan will be the scan during which the abnormal skin sample should tested. This measurement provides the system with the affected areas spectrum to compare the first scan to. For all scans use the camera attached to the probe as a secondary viewfinder to ensure that the intended area is indeed the targeted area.

Once all scans have been completed, please allow between 30 seconds to 1 minute for all data to be processed as necessary. Once all data has been processed, a results page will appear indicating the systems results. You can then select to view the detailed results by selecting the "View Detailed Results" button on the same page. If you have selected to view the detailed results, a graph will appear showing your test results, displaying both the results from the first test and the second test. These results can be further analyzed by a medical professional.

VIII. CONCLUSION

Raman spectroscopy requires sensitive alignment and high resolution, and the components necessary are expensive. Our Raman probe design proved to be both educational and challenging. What made the Raman probe design educational as well as challenging was the amount of constraints that the components had individually, as well as the overall systemic constraints when integrating everything.

The importance of testing components and understanding datasheets is always essential to successful implementation of a design. Additionally, understanding how heat and temperature distribution impact device elements is crucial for safety and functionality of all electronic elements of a device. Heat across the entire device as well as individual components must be considered.

One major factor to the team's success was their open and frequent communication amongst each other. Teamwork was a driving force to get results.

ACKNOWLEDGEMENT

This project was made possible by our sponsor, Ocean Optics, and by support from CREOL, The College of Optics and Photonics, University of Central Florida. Ocean Optics provided valuable guidance for our project, as well as the laser source and spectrometer. CREOL provided optical mounts and other testing supplies. The team would additionally like to thank Dr. Kyu Young Han and Dr. Peter J. Delfyett, University of Central Florida, for their technical advice and support.

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BIOGRAPHIES

Stephen Esposito is a Computer Engineer graduating in August of 2017. He was the lead engineer for data analysis and the user interface. His role in this project was implementing system control, including data capture, processing, and output. He will be pursuing a career in Computer Vision with a focus on self-driving automobiles.

Michael Gonzalez is an Electrical Engineer graduating in August of 2017. He was the lead engineer for the physical designs of the probe, as well as support engineer for electronics and retrofitting. He will be taking a larger role in his current job as an Applications Engineer in South Florida, where he will help manufacture, code, and retrofit different electrical and industrial automation solutions.

Chelsea Greene is an Electrical Engineer graduating in August of 2017. She was the lead power engineer. Her role in this project was to design and implement power delivery as well as integrating camera functionality. She has a passion for safety and accessible technology with a focus on improving systems to be useable by all.

Megan Melvin is a Photonic Scientist and Engineer graduating in August of 2017. She was the lead engineer for the optics and laser safety. Her role in this project was to design, build, and test an optical setup for capturing the Raman spectra of materials. She has accepted a job as a Manufacturing Engineer Associate with Lockheed Martin Missiles and Fire Control in Orlando, Florida, from which she plans to transfer into an optics design department.