UCF Senior Design I

RAID

<u>Group 2</u>

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1. Executive Summary

The initial theory and development of the Raman spectrometer will be discussed in this section. This innovative device provides a safe and effective way to detect a compromised beverage. The motivation behind developing a spectrometer to detect illicit substances in drinks stems from the alarming prevalence of drug-facilitated sexual assault incidents in America. According to the National Sexual Violence Resource Center (NSVRC), approximately 1 in 5 women and 1 in 71 men in the United States have experienced rape at some point in their lives. Furthermore, the Substance Abuse and Mental Health Services Administration (SAMHSA) reports that drug-facilitated sexual assaults, where drugs are used to incapacitate victims, contribute significantly to the overall incidence of sexual assault.

Implementing a spectrometer for drink analysis addresses a critical need for proactive measures against drug-facilitated sexual assault, providing individuals with a tool to safeguard themselves from potential harm. By incorporating advanced technology into social settings, this project aims to empower individuals and reduce the vulnerability associated with drug-facilitated crimes.

Traditional testing methods require extensive training, require the use of costly & and sophisticated lab equipment, and have lengthy processing times; all factors that are impractical given the situations in which these incidents take place. Our solution addresses these challenges via an affordable, user-friendly device that focuses on promptly identifying Gamma-aminobutyric acid (GABA). Similar tests are accomplished by cultivating cultures or reagent dye; our devices aim to provide accurate results by avoiding these methods while the tested fluid remains consumable.

To accomplish such a task, a detector must recognize the chemical construct of substances used in drug-facilitated sexual assault. The spectrometer utilizes a sophisticated optical detection mechanism to identify GABA in a drink. In our case, this involves illuminating the sample with 532nm light and subsequently measuring the Raman shift. The outcome is a distinct Raman spectrum of GABA. Initially, the raw spectral data is digitized by the sensor and transmitted to the microprocessor. The microprocessor then applies algorithms specifically designed for the identification of GABA absorption patterns. These algorithms compare the observed spectra with pre-determined reference spectra for GABA, enabling the microprocessor to discern the presence or absence of the substance in the drink.

Building the Raman spectrometer capable of detecting illicit substances in drinks involves comprehensive research into various key components. The optical subsystem requires careful consideration, focusing on high-quality light sources such as LEDs or lasers that emit specific wavelengths for optimal substance identification. Photodetectors, capable of accurately capturing the reflected or transmitted light, are crucial for precise data acquisition. The microprocessor, a critical component, was chosen for its processing power and ability to handle complex algorithms involved in substance identification.

Careful exploration of suitable materials for our project's construction, considering factors like durability, safety, and compatibility with different drink compositions, is vital. Thorough research into each component is essential to ensure the spectrometer's efficacy, reliability, and user-friendliness.

The project aims to develop a cutting-edge spectrometer designed to detect illicit substances, with a particular focus on enhancing safety in social settings. Utilizing advanced optical technology, the device can identify substances like GABA in drinks without compromising their consumability. The distinguishing feature lies in the dye-free method, ensuring the fluid remains safe for consumption. The microprocessor-driven system processes optical data efficiently, providing quick and reliable results. By combining research on optimal components, including precision optics, sensors, and robust algorithms, the project seeks to create an affordable, user-friendly solution that empowers individuals to proactively safeguard against drug-facilitated crimes in an accessible and non-intrusive manner.

2. Project Description

This project's main objective is to develop a Raman spectrometer designed for detecting illicit substances in beverages. This device utilizes a 532nm laser diode, chosen for its efficiency in Raman scattering and compatibility with a wide range of substances. This serves as the excitation source, illuminating the beverage and inducing a Raman effect – a shift in the frequency of scattered light, which is characteristic of the molecular composition of the substance in question.

The scattered light is then collected and analyzed using an optical fiber and a Czerny-turner spectrometer configuration. This setup is renowned for its high spectral resolution and accuracy, making it an ideal choice for the precise detection of various chemical compounds. The spectrometer is equipped with a charge-coupled device (CCD), which captures the spectrum of the scattered light and converts it into an electrical signal.

The electrical signals from the CCD are processed to extract the Raman spectrum, which is then compared against a pre-loaded database of spectra for various illicit substances. This comparison enables rapid identification of the presence of any such substances in the beverage sample. The results of the analysis are displayed in real-time on an integrated LCD display. This display will inform the user of the presence of absence of illicit substances.

The primary application of this Raman spectrometer is in venues such as bars, clubs, and social events, where the risk of drink tampering is a significant concern. This project's development and deployment could have a substantial impact on public health and safety, offering a new tool for the fight against substance abuse.

2.1. Project Motivation

Drug-related incidents in bars and clubs pose a threat to public safety and well-being. Therefore, there is an urgent need for innovative solutions to combat this issue. This project proposes the development of a Raman spectrometer designed for the rapid and accurate detection of illicit substances in drinks. The designed Raman spectrometer aims to provide a user-friendly, efficient, and reliable method for the public, to ensure the safety of the drinks they consume.

The motivation behind this project stems from a critical and growing concern for public safety in social environments. Drink spiking, a form of substance abuse where individuals unknowingly consume drinks laced with drugs or other illicit substances, has seen a disturbing uptick in recent years. Such actions can lead to severe health consequences, including hospitalization, and in extreme cases, even death. Moreover, the psychological impact on victims and the broader societal implications makes this issue a public safety priority.

Raman spectroscopy offers several advantages over existing detection methods for identifying illicit substances in drinks. One of the most significant benefits of Raman spectroscopy is its non-destructive nature. It does not require the sample to be altered or prepared in any way, meaning the drink can be tested then consumed as normal if no illicit substances are detected. Also, it can typically provide results in seconds. This quick turnaround is crucial in busy bar and club environments. Raman spectroscopy is also highly sensitive and can detect even trace amounts of substances, as well as identify a wide range of illicit substances that might be used in drink spiking. In contrast to other methods, Raman spectroscopic devices are straightforward to operate, meaning little technical expertise and training is required. Although the initial investment in a Raman spectrometer might be higher than other testing methods, its durability, minimal maintenance costs, and the lack of need for consumables (like test strips or reagents) can make it more cost-effective overtime.

In conclusion, the Raman spectrometer project is driven by the need to improve public safety in bars and clubs, with technology offering a practical, efficient, and versatile solution to the challenges posed by current substance detection methods.

2.2. Project Goals & Objectives

Table 1 - Goals

Basic Goals
Acquire a spectrum

Filter out the pump
Advanced Goals
Acquire a calibrated Raman Spectrum
<1 nm resolution
Stretch Goals
Make product compact/portable
Test more than one drug
Calibrated for spectrophotometry, able to determine concentration of drugs

The project aims to achieve a set of structured objectives, organized into basic, advanced, and stretch goals, to develop a robust and versatile optical device.

Initially, the basic goal is to acquire a spectrum. This involves capturing the broad spectrum of light from a sample, which is fundamental in understanding the material's optical properties. Following this, it's essential to filter out the pump. The pump, typically a source of light used to excite the sample, must be carefully separated from the signal to ensure clarity and accuracy in the spectral data obtained.

Moving towards more sophisticated objectives, the advanced goals include acquiring a calibrated Raman spectrum. Raman spectroscopy is a powerful technique for identifying the molecular composition of a sample. Achieving a resolution of less than 1 nanometer in this context is crucial for distinguishing closely spaced spectral features, which can be critical for accurate material identification.

The stretch goals of the project are ambitious and aim to significantly enhance the device's capabilities and applications. Making the product compact and portable is a key objective, aiming to transition the technology from a bulky, stationary setup to a more accessible, field-deployable form. This portability would greatly expand the potential use cases, including on-site analysis in various environments. Additionally, the ability to test more than one drug expands the device's utility in pharmaceutical applications, allowing for broader screening and analysis capabilities.

The ultimate stretch goal is to calibrate the device for spectrophotometry, enabling it to determine the concentration of drugs. This involves not only identifying the substances present in a sample but also quantifying them with high precision. Such a capability would be invaluable in quality control, research, and regulatory settings, where accurate measurement of drug concentrations is paramount.

2.3. List of Known Constraints

In the development of a Raman spectrometer, several critical constraints must be considered to ensure the functionality, safety, and effectiveness of the final instrument. This section outlines the key limitations and challenges faced during the design and assembly process, providing insights into the trade-offs and considerations necessary for the successful implementation of a Raman spectroscopy system.

1. **Safety Concerns with Laser Usage:** The utilization of high-power lasers as the excitation source in Raman spectroscopy presents significant safety hazards, including the risk of severe eye injuries. Ensuring safe operation involves implementing rigorous safety measures, such as proper enclosures, safety goggles, and adherence to established laser safety standards.

2. **Budgetary Limitations:** The acquisition of high-quality optical components, detectors, and other necessary equipment often involves substantial financial investment. Budget constraints may necessitate compromises in the selection of components, potentially affecting the spectrometer's performance and resolution capabilities.

3. **Optical Alignment and Stability:** The precision alignment of optical components is crucial for optimal light collection and signal detection. Misalignment can lead to reduced signal-to-noise ratios and diminished sensitivity. Additionally, the system's thermal stability impacts measurement accuracy, necessitating measures to mitigate temperature-related fluctuations.

4. **Fluorescence Interference:** Fluorescence from the sample when excited by the laser can obscure Raman signals. Selecting an appropriate laser wavelength and implementing optical filtering or spectral processing techniques are necessary to minimize this background interference, adding complexity to the system design.

5. **Spectral Resolution and Range Considerations:** Achieving high spectral resolution requires careful selection of the dispersive element and slit width, with a trade-off between resolution and signal intensity. High-resolution configurations may compromise system throughput. The spectrometer's spectral range is determined by the grating selection, detector sensitivity, and optical filters, with extensions to the range requiring compromises in other performance areas such as resolution or sensitivity.

6. **Detector Sensitivity and Noise:** The spectrometer's performance is significantly influenced by the detector's sensitivity and noise characteristics. Implementing cooling

mechanisms for the detector can enhance performance but increases the system's complexity and cost.

7. **Light Collection Efficiency:** The efficiency of scattered light collection depends on the collection optics' design. Balancing the numerical aperture of the collection optics with the desired spatial resolution and collection efficiency presents a considerable challenge.

8. **Software and Data Analysis Requirements:** Developing or procuring software for system control, data acquisition, and spectral analysis is a non-trivial challenge that includes implementing algorithms for noise reduction, spectral processing, and system calibration.

9. **Calibration and Validation:** Accurate and reliable Raman measurements require regular system calibration using known standards, a process that can be challenging due to the availability of these standards and the calibration procedure itself.

10. **Regulatory and Standards Compliance:** Ensuring compliance with industry or research standards for measurement accuracy, repeatability, and documentation can pose significant challenges, particularly for custom-built systems intended for specific applications.

Addressing these constraints involves a complex balance of trade-offs, where improvements in one aspect of the system's design or performance may negatively impact another. Through careful planning, innovative design solutions, and strategic decision-making, it is possible to navigate these challenges and develop a Raman spectrometer that meets the desired specifications and application requirements.

2.4. List of Requirements and Specifications

Table 2 - Requirements and Specifications

Raman Excitation and Collector	
Laser power	80-200 mW
Peak wavelength	586 nm
Spectrometer	
Resolution	< 1 nm
Grating lines	1200 lines/mm
Optical Fiber	multimode
Integration time	~30 sec

2.5. Project Block Diagram

The RAID project's primary hardware components are depicted in Figure 2.5, where each block is color-coded to indicate the respective team member's responsibility. The system consists of three main subsystems. The first is dedicated to capturing Raman signals and transmitting the received information through an optical fiber. The second subsystem involves the spectrometer, where these transmitted Raman signals are then processed through a CCD. The CCD works with the microcontroller and in-house software to create a detailed analysis of Raman spectra. The third subsystem integrates the analyzed data into a user-friendly interface displayed onto an LCD screen. This project requires extensive system integration, with the spectrometer phase demanding interdisciplinary collaboration to ensure the successful completion and functionality of the entire project.

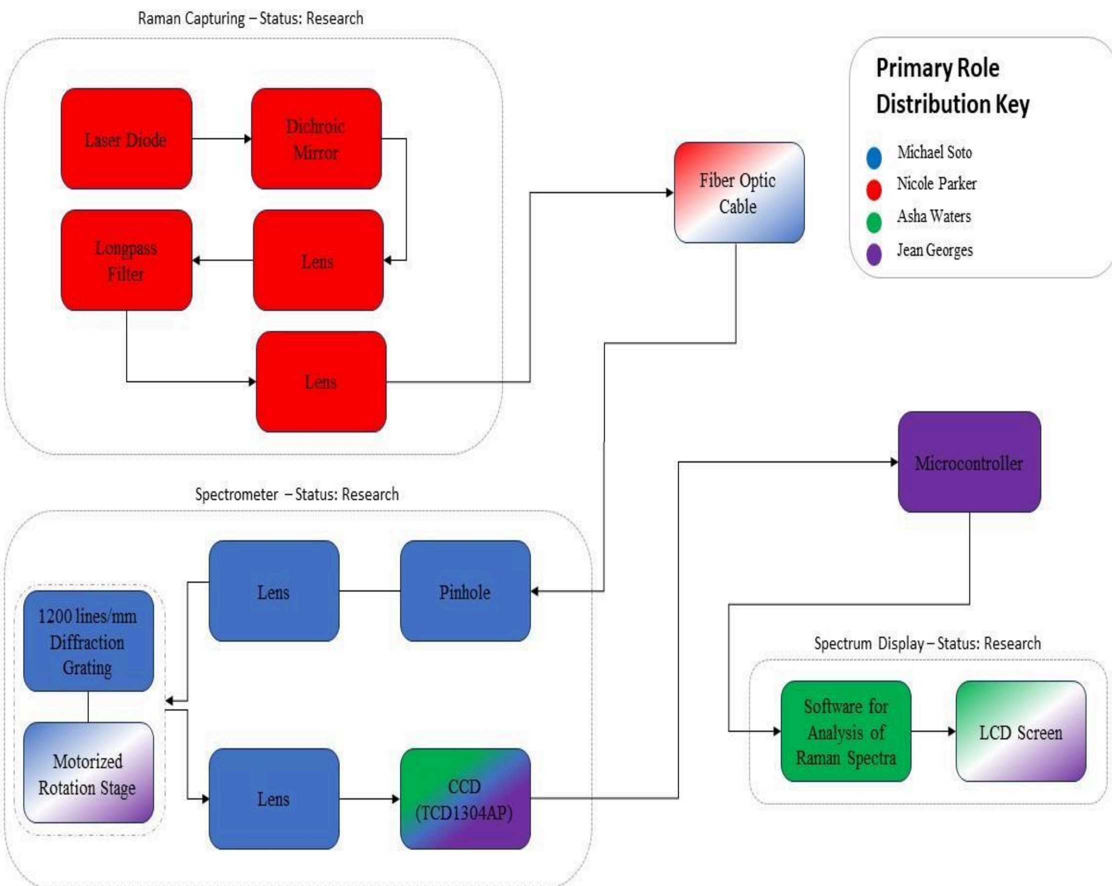

Figure 2.5 Hardware Block Diagram

2.6. Project Software Diagram

The implementation of the project necessitates the integration of software for the analysis of data acquired by the photodetectors. As depicted in Figure 2.6, a concise overview outlines the strategy for ascertaining the detection of GABA. The sensor generates data, which is subsequently transmitted to a detection algorithm. This algorithm employs statistical analysis to discern the presence or absence of GABA. Depending on the outcome, whether such illicit substances were detected or not, the result is then relayed to the LCD user interface display.

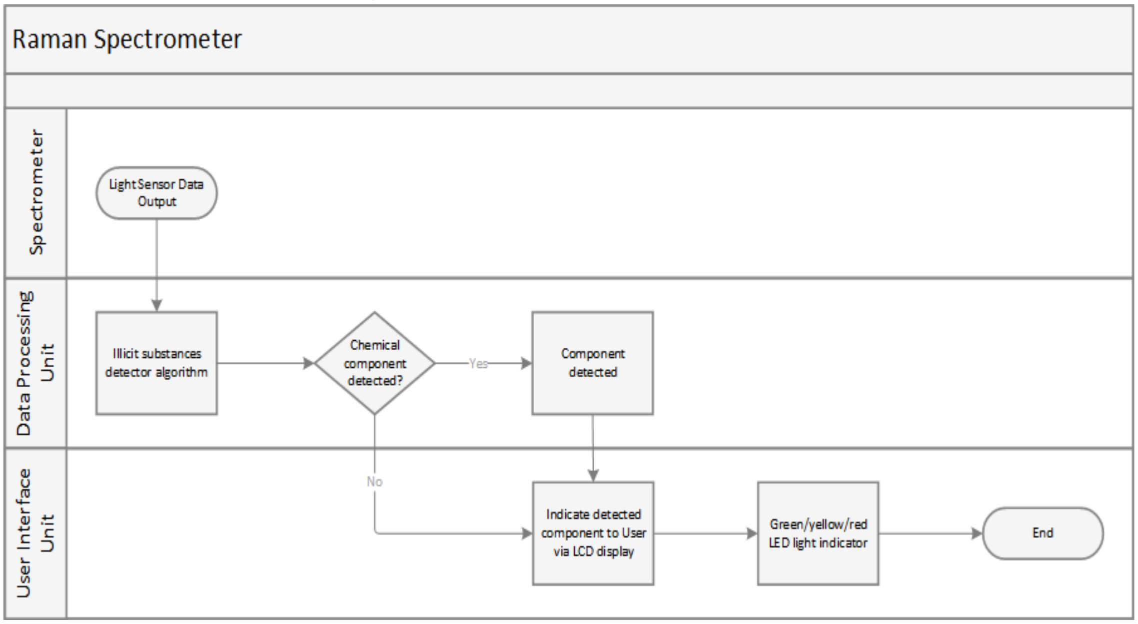

Figure 2.6 – Software Block Diagram

2.7. House of Quality

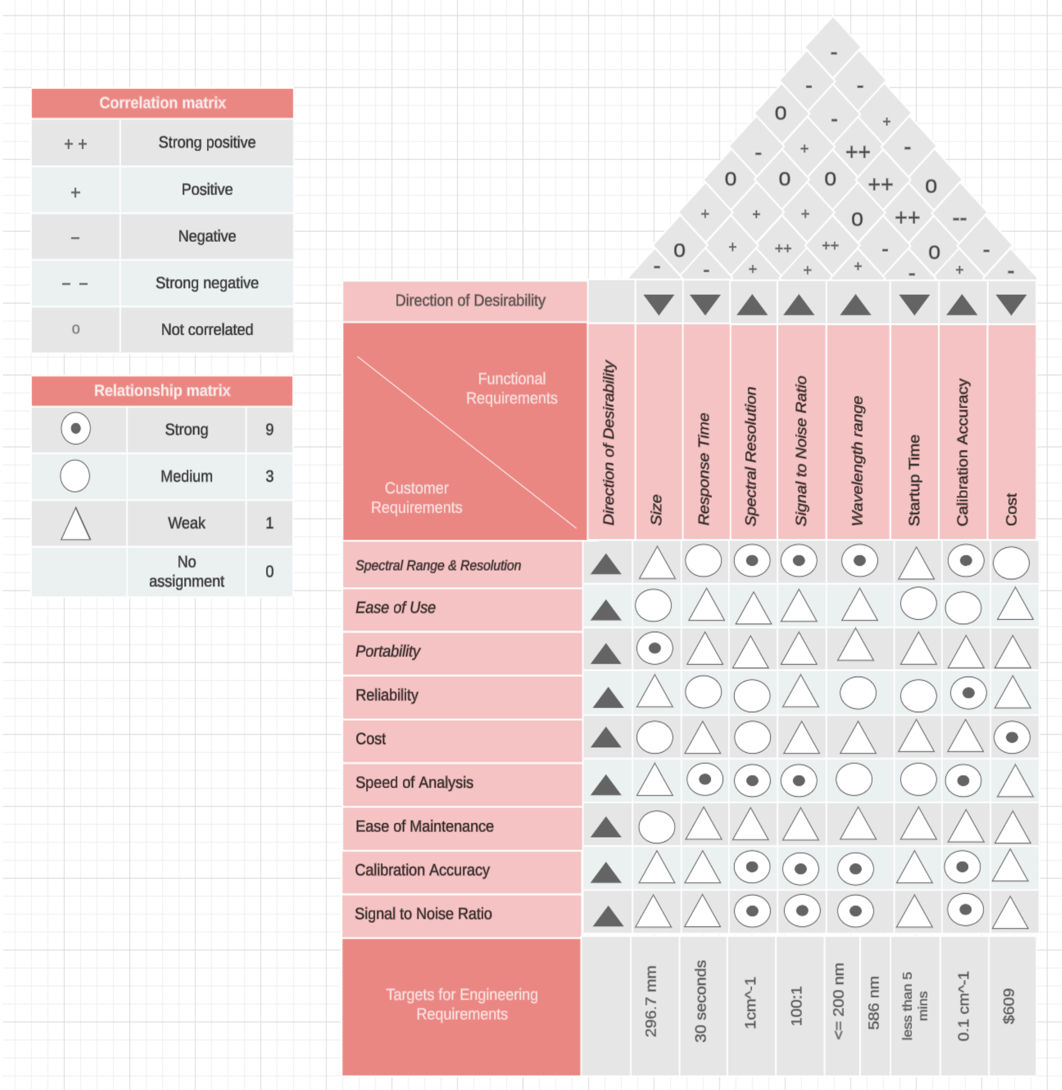

Figure 2.7 – House of Quality

2.8. Budget

Table 3 – Project Budget

Item	Quantity	Budget
Gamma-aminobutyric acid (GABA)	1	$10
532nm laser diode	1	$60
Dichroic Mirror	1	$75
Longpass filter	1	$185
15mm lens Ø12.7mm	2	$80
Lens	2	$80
Pinhole	1	$14
Photodiode (VTB4051H)	1	$20
LCD	1	$20
PCB + components	1	$50
Microcontroller	1	$15

2.9. Milestones

The creation of the following tables is to establish solid deadlines for our group throughout the upcoming two semesters. This initiative ensures collaborative efforts, fostering cohesion among team members in understanding task timelines. The RAID team has built a schedule to streamline our workflow which can be seen below:

Table 4 – Senior Design 1 Documentation Milestones

Task	Start Date	Anticipated End Date	Duration
Project Conceptualization	Fall	Spring	1 month
Formation of Group	01/08/2024	01/11/2024	3 days
Project Idea Finalization	01/05/2024	01/12/2024	1 week

Assign Roles of Project/ Research Tasks Associated	01/15/2024	02/02/2024	2 weeks
Divide and Conquer Report Writing (10-Page Milestone)	01/15/2024	02/02/2024	2.5 weeks
Discuss Progress in Group Meeting (30-Page Milestone)	02/05/2024	03/21/2024	2.5 weeks
60-Page Milestone	02/05/2024	03/29/2024	3.5 weeks
Discuss Progress in Group Meeting (90-Page Milestone)	04/05/2024	04/14/2024	1.5 weeks
Final Document (120-Page Milestone)	04/01/2022	04/23/2024	2.5 week

Table 5 – Senior Design 1 Project Design Milestones

Task	**Start Date**	**Anticipated End Date**	**Duration**
Components Selection	01/24/2024	02/24/2024	1 month
Discuss Selections with Advisors	02/25/2024	03/02/2024	1 week
Components Finalization	03/03/2024	03/29/2024	3.5 weeks
Purchasing Components	03/30/2024	04/30/2024	1 month

Table 6 – Senior Design 2 Fabrication Milestones

Task	**Start Date**	**Anticipated End Date**	**Duration**
Motorized Rotation Stage	05/15/2024	05/22/2024	1 week
Raman Capturing Testing	05/15/2024	05/29/2024	2 weeks
Spectrometer Testing	05/15/2024	06/07/2024	3 weeks
System Integration	05/29/2024	06/26/2024	3.5 weeks

Mock Demo (to find and fix issues that arise)	07/03/2024	07/17/2024	2 weeks
Upload Final Documentation	TBD	TBD	TBD
Final Presentation	TBD	TBD	TBD

Declaration: We hereby declare that we have not copied more than 7 pages from the Large Language Model (LLM). We have utilized LLM for drafting, outlining, comparing, summarizing, and proofreading purposes.