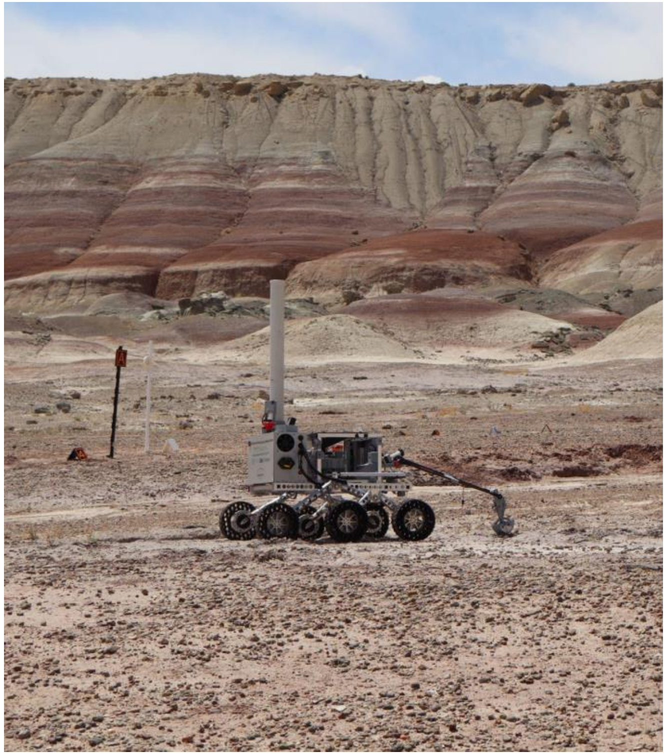
Final Design Review:
Raman Spectrometer for Soil Sample Classification

Senior Project Team: ECD 512
Sponsor: Avangrid
Client: Binghamton University Rover Team

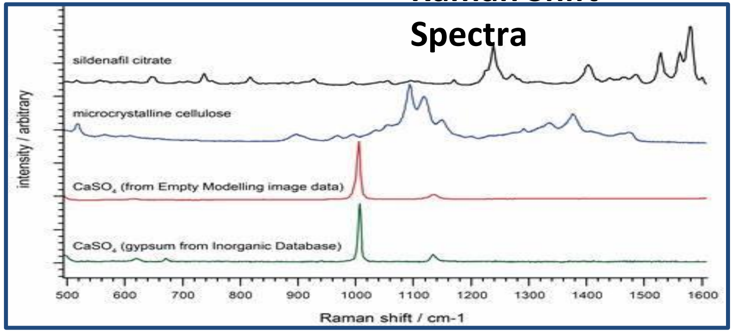
Agenda

- Raman Spectroscopy Basics
- System Concept
  - Project Overview
  - Engineering Standards
- Detailed Design Overview
- Project Details
  - Risks and Mitigations
  - Financial Summary
  - Timeline
  - Next Steps



Raman Spectroscopy Basics

Raman Shift Spectra



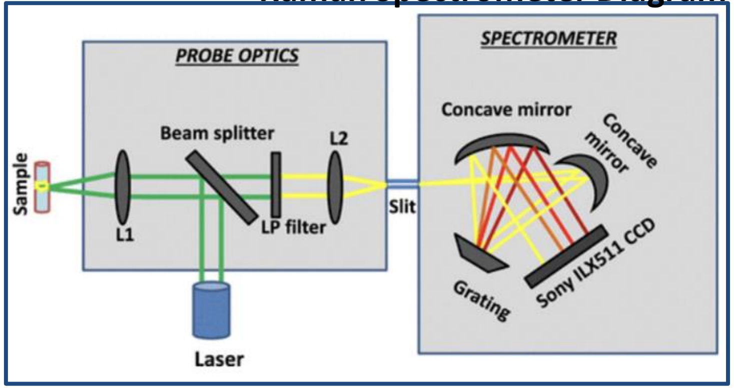
Purpose

- Identifies the chemical composition of materials by analyzing light scattered off a sample

How it Works

- A laser shines on the sample
- Most of the light reflects back unchanged, but a small portion changes due to molecular interactions
    - This is called **Raman scattering**
- Each molecule causes a unique pattern of light changes, allowing for material identification

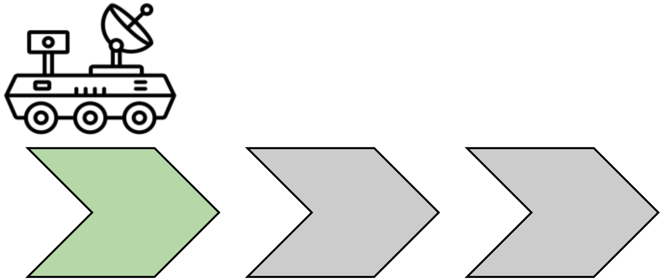
Raman Spectrometer Diagram



Components of a Raman Spectrometer:

- **Laser**: Provides the light source, using a 532nm or 785nm laser
- **Mirrors and Lenses**: Direct the laser and scattered light
- **Filters**: Remove unwanted light that isn't useful for analysis
- **Detector/Sensor**: Captures the scattered light and records data for analysis

System Concept



Project Summary

- Our project involves the design and development of a custom-made Raman Spectrometer for the Binghamton University Rover Team. This portable device will assist in the classification of soil samples by analyzing aqueous soil solutions for the status of life.
    - The spectrometer will utilize a 24V power source and standard electrical components
    - Display the resulting spectra graphically on a screen
    - It will be compact, self-contained, and capable of being mounted on the rover
    - A user guide and technical documentation included
    - While the Raman Spectrometer is intended for future Rover use, this project will be tested independently of the Rover

Use Case

- Designed for the Binghamton University Rover Team
- Suitable for use in the University Rover Challenge (URC) competition
- Science Mission Details
  - Teams must test soil samples for signs of life, and determine whether life is extant, extinct, or not present
  - All tests must be conducted by the rover during mission time

Specifications

Hardware:

- Device shall be powered using a 24V source
- Shall use standard electrical components
- Spectrometer shall be a self-contained unit
- Project shall include a user guide describing the device’s functionality with a bill of materials
- Device shall process samples contained in standard cuvettes

Software:

- A spectra shall be displayed graphically on a screen
- Device shall produce a Raman spectra suitable for status of life analysis of a selected aqueous solution

Stretch Goals

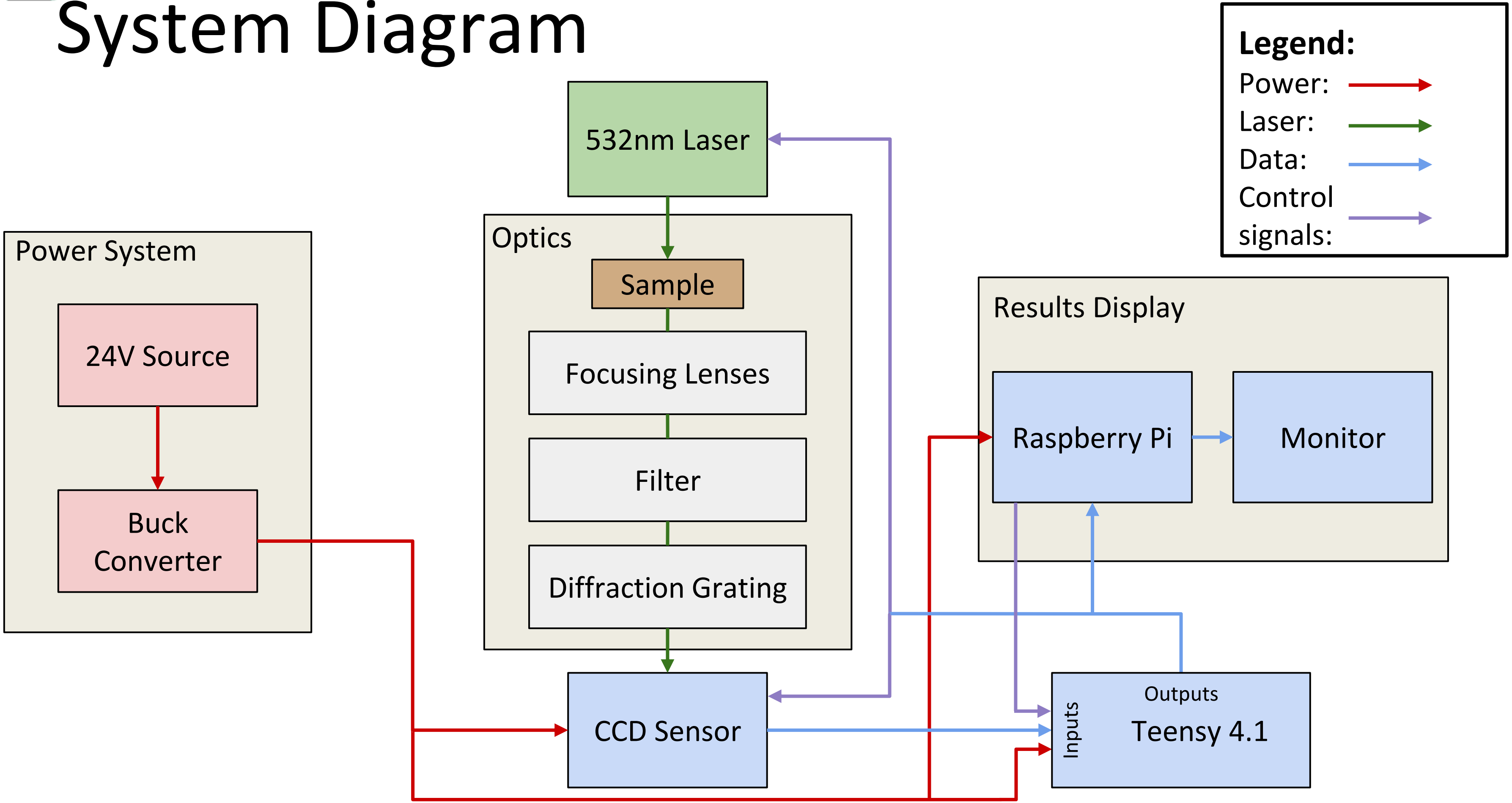
Hardware:

- Measurements should be no more than 300mm x 200mm x 100mm (LxWxH)
- Should be capable of integration onto the 2025 Rover
- Should draw no more than 1A from the 24V source
- Should weigh less than 2 kilograms

Software:

- Firmware should be written in C/C++
- Results display should include insight into the chemicals found in the solution through analysis of the spectra within 5-10 minutes

System Diagram



Alternate Designs

Laser:

- **Option 1:** 532nm Laser
- Option 2: 785nm Laser
- Trade-offs: cost, safety, resolution of spectra, fluorescence interference

Microcontroller:

- Option 1: Arduino Nano
- **Option 2:** Teensy 4.1
- Trade-offs: processor speed, amount of RAM, ease of use

Results Display:

- Option 1: Python GUI using Tkinter with graphs and analysis implemented on Raspberry Pi
- **Option 2:** Flutter GUI with graphs and analysis implemented on Raspberry Pi
- Trade-offs: ease of implementation, integration with Rover Team, professional appearance

CCD:

- Option 1: ILX551B CCD Linear Image Sensor
- **Option 2:** TCD1304DG CCD Linear Image Sensor
- Trade-offs: cost, precision, clock frequency, product availability

Engineering Standards

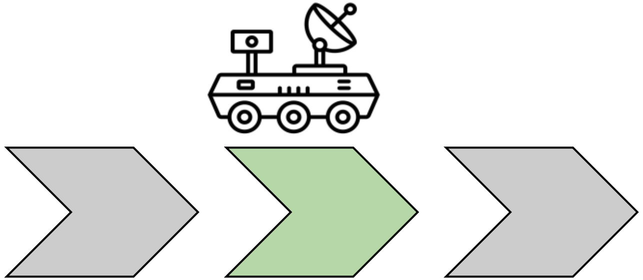
IEC 61010: Safety features to address issues such as fire and electrical shock.

IEEE 1100: Standards for grounding and powering the electronic.

ANSI Z136.1: The American National standard for laser safety.

IEC 60825: Ensures that laser products emitting radiation is in the wavelength of 180nm to 1mm.

Detailed Design Overview



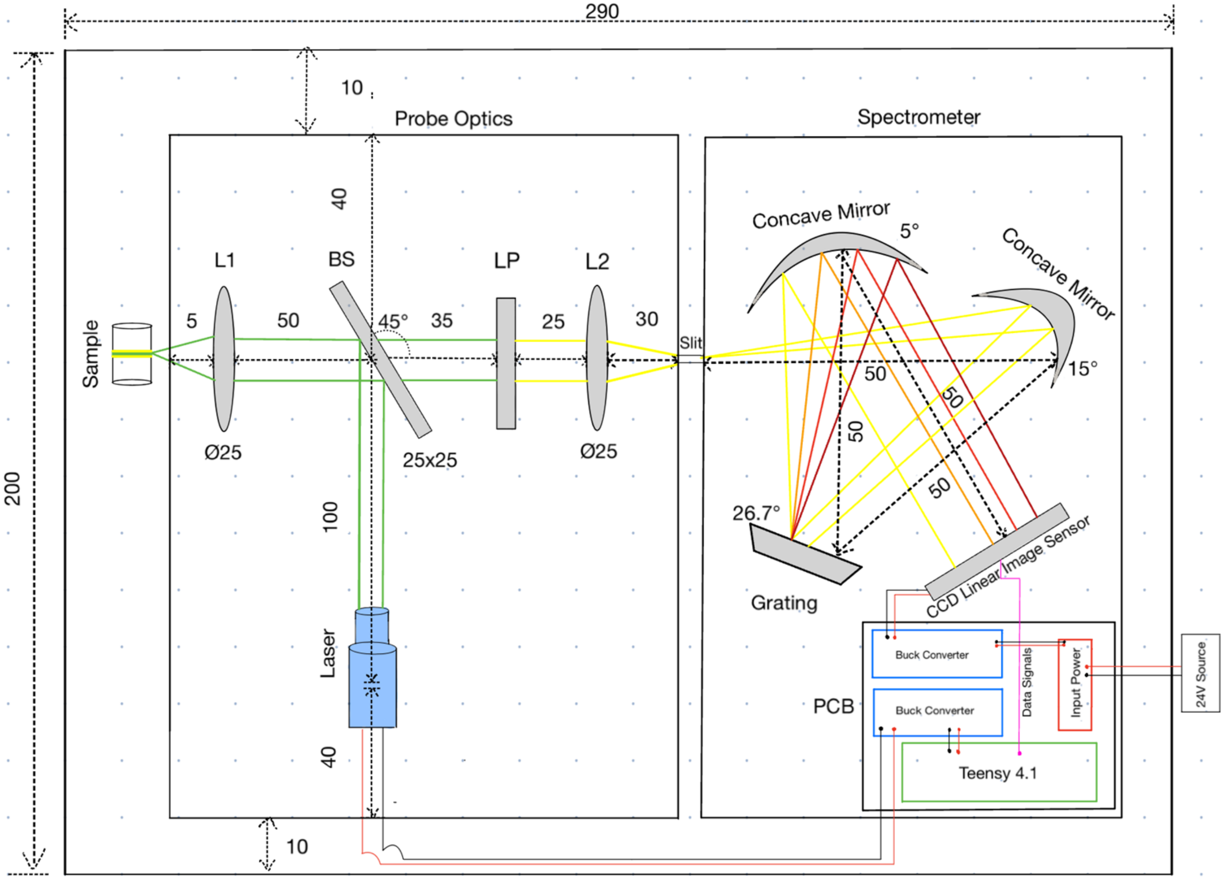
Enclosure

Requirements:

- “Spectrometer shall be a self-contained unit”
- “Measurements should be no more than 300mm x 200mm x 100mm (LxWxH)”
- “Should weigh less than 2 kilograms”

Implementation:

- 3D printed box with mounts for all optical and electrical components
- Grommets for wires and gasket between box and lid for dust-proofing



Laser

532 nm Solid-State Laser (JD 851)

- Serves as the excitation source to illuminate the sample and induce Raman scattering
- The inelastic scattering of light produces Raman signals, which reveal the sample's chemical composition

Why Use 532 nm?

- **Higher energy photons:** Compared to longer wavelengths (e.g., 785 nm), 532 nm light provides more energy, resulting in stronger Raman signals
- **Ideal for many organic samples:** Works well for substances with low fluorescence interference
- **Compact and affordable solid-state laser:** Readily available, making it suitable for custom setups

How it Works

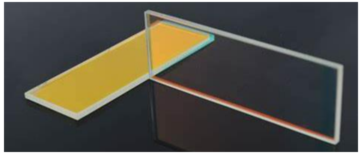
1. Laser beam is directed through optical components (e.g., lenses and mirrors)
2. The laser excites the sample, and inelastic scattering occurs
3. Raman-shifted light is separated from the Rayleigh scattering by a filter and analyzed through a diffraction grating and CCD detector

Pricing

- **Cost:** $15 (Laser pointer Store)

Optics

Microscope Slide (Beam Splitter)
- Reflects laser light while transmitting scattered Raman light
- Price: $9



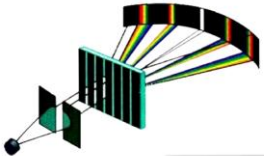
Bi-Convex Lens Ø1", f = 30.0 mm, Uncoated
- Focuses both the laser beam and scattered light into desired paths
- Price: $59

Longpass Filter, Colored-Glass Alternative, 2x2 in., 550 nm Cut-on
- Removes Rayleigh scattering, isolating only the Raman signal
- Price: $102

Ø1" Mounted Pinhole, 50 ± 3 µm Pinhole Diameter, Stainless Steel
- Controls the amount of light entering the spectrometer for better resolution
- Price: $79

Dielectric-Coated Concave Mirror, 400 - 750 nm, f = 50 mm
- Focuses light onto the diffraction grating and then the CCD
- Price: $160

Ruled Diffraction Grating, 25 x 25 mm, 500 nm, 26.7° Blaze, 1800 g/mm
- Disperses light into component wavelengths for spectral analysis
- Price: $139

Charge Coupling Device (CCD)

TCD1304DG CCD Linear Image Sensor

- Collects the spectra from the end of the optics array
- Data will be taken from device using Teensy and analyzed with the Raspberry Pi
- Clock Frequency: 0.8 - 4 MHz
- Spectra focused around 550 nm
- Similar sensitivity to other Raman Spectrometer designs
- Price: ~$38

Microcontroller

Teensy 4.1

- Used to toggle laser, collect data from CCD and send to Raspberry Pi for visualization and analysis
- Easily programmable with Arduino IDE
- ARM Cortex M7 Processor at 600 MHz
- 55 total I/O pins
- Can support 32 bit floating point numbers and 64 bit doubles
- Provided by the Rover team

Raspberry Pi

Raspberry Pi 4 Model B

- Using to collect data from Teensy and visualize it on our results display.
- Micro HDMI to allow communication with display
- Multiple USB ports for programming
- Anywhere from 1-8GB of RAM available
- Wifi and bluetooth capabilities
- Provided by the Rover team

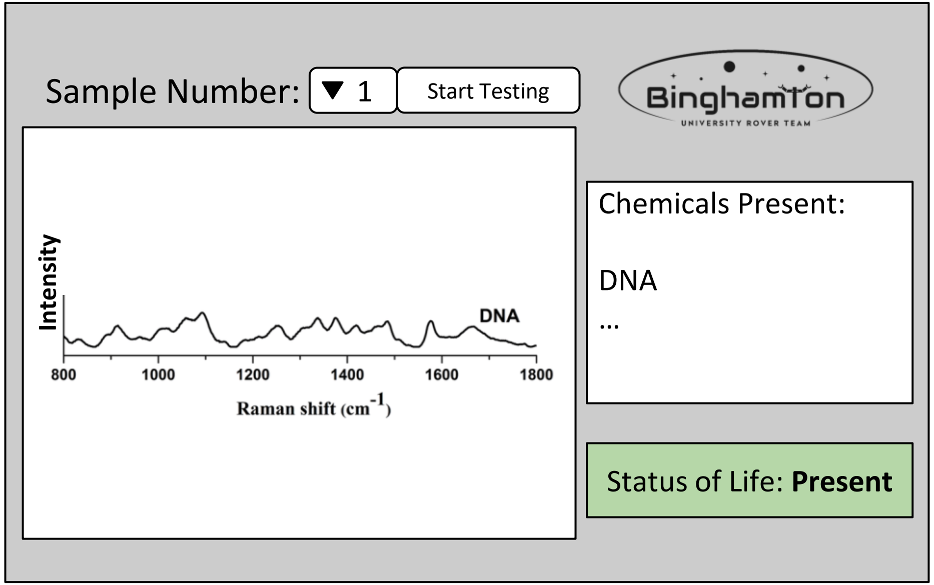
Results Display

Requirements:

- “A spectra shall be displayed graphically on a screen”
- “Results display should include insight into the chemicals found in the solution through analysis of the spectra within 5-10 minutes”

Implementation:

- GUI created with Flutter for easy-to-read user display
- Receive and send data from Teensy over USB
- Use Raspberry Pi connected to external monitor display



Voltage Converter

Requirements:

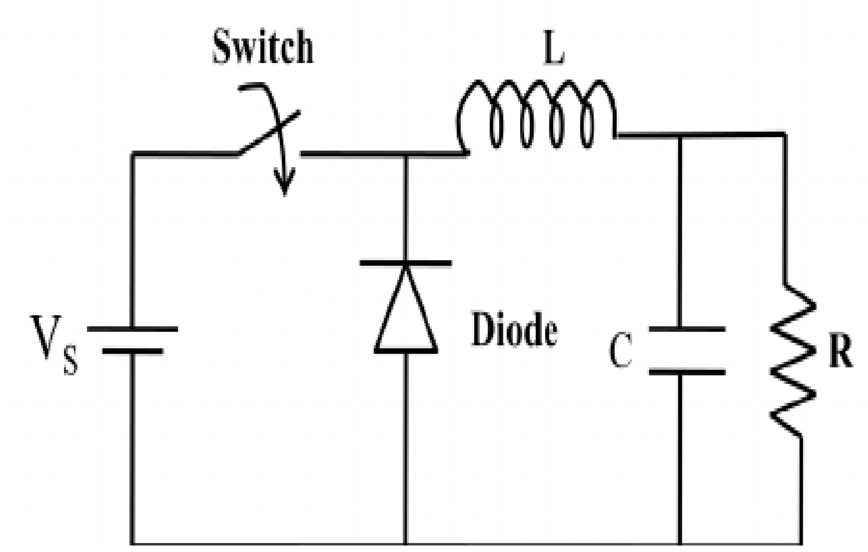
- “Device shall be powered using a 24V source”
- “Shall use standard electrical components”

Implementation:

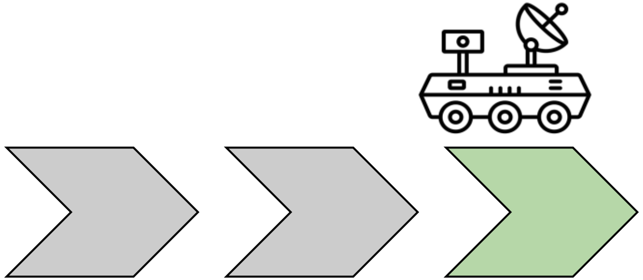
- The 24V source will be converted to lower voltages for the microcontroller, laser, and the CCD
- Using a buck converter for the efficiency, minimizing the energy lose during a power conversion

Price:

- ~$8 LM2596



Project Details



Potential Risks and Mitigation

Category	Risk	Mitigation
Parts Availability	- Difficulty in sourcing key components (e.g., laser, diffraction grating, CCD sensor) - Lead times may exceed the project timeline	- Identify and order critical components early - Maintain a list of alternative suppliers and compatible components
Lab Access	- Limited access to an optics table could slow integration	- Coordinate a shared calendar with the professor who manages the table - Request lab reservations ahead of time
Technical Challenges (Firmware & Optics)	- Difficulty in calibrating the laser and optical elements - Firmware development may encounter bugs that disrupt spectral analysis	- Start early prototyping and calibration sessions - Use open-source firmware libraries to speed up development - Conduct regular code reviews

Potential Risks and Mitigation

Category	Risk	Mitigation
Hard Deadlines & Scheduling Issues	- Tasks may take longer than expected due to unforeseen challenges. - Missing internal deadlines could impact final delivery.	- Use a Gantt chart with buffer periods for critical tasks. - Regularly update Dr. Summerville on progress. - Hold weekly team meetings to adjust workloads.
Budget Constraints	- Unforeseen expenses may exceed the $1500 budget. - High-quality equipment may cost more than expected.	- Prioritize high-cost components early. - Track expenses closely. - Reuse lab equipment or source parts from past projects. - Reserve funds for emergencies.

Bill of Materials

Item	Manufacturer	Part_Number	Description	Qty	Cost/Unit	Subtotal
1	Mikikit	091158BRB2PONF	Cuvettes	1	$ 1.19	$ 11.89
2	SanDisk	SDSQUA4-032G-GN6MT	MicroSD card for Rasp Pi	1	$ 6.39	$ 12.77
3	TalentCell	LF8011	Talentcell 24V 6Ah LiFePO4 Battery Pack LF8011, 25.6V 153.6Wh Deep Cycle Rechargeable Lithium Iron Phosphate Batteries	1	$ 42.99	$ 42.99
4	Aitrip	LM2596	5 Pack LM2596 DC to DC Buck Converter 3.0-40V to 1.5-35V Power Supply Step Down Module	1	$ 1.60	$ 7.99
5	Laser Pointer Store	JD-851	532nm green laser 30 mW	1	$ 14.90	$ 14.90
6	Newport	20CGA-550	Longpass Filter, Colored-Glass Alternative, 2x2 in., 550 nm Cut-on	1	$ 102.00	$ 102.00
7	Thorlabs	CM127-050-E02	Ø1/2" Dielectric-Coated Concave Mirror, 400 - 750 nm, f = 50 mm	1	$ 65.63	$ 65.63
8	Thorlabs	CM254-050-E0	Ø1" Dielectric-Coated Concave Mirror, 400 - 750 nm, f = 50 mm	1	$ 93.55	$ 93.55
9	Newport	33009FL01-290	Ruled Diffraction Grating, 25 x 25 mm, 500 nm, 26.7° Blaze, 1800 g/mm	1	$ 139.00	$ 139.00
10	Thorlabs	LB1757	N-BK7 Bi-Convex Lens, Ø1", f = 30.0 mm, Uncoated	2	$ 29.36	$ 58.72
11	McKesson	70-101PMCK	McKesson Premium Microscope Slides, Plain, Float Glass, Beveled Edges, 25 mm x 75 mm x 1 mm, 72 Count	1	$ 0.13	$ 9.40
12	Thorlabs	P50K	Ø1" Mounted Pinhole, 50 ± 3 µm Pinhole Diameter, Stainless Steel	1	$ 78.62	$ 78.62
13	Toshiba	TCD1304DG(8Z,K)	CCD LINEAR IMAGE SENSOR	1	$ 37.90	$ 37.90
14	Kxable	KXU2A-Mic-2F	Micro-usb cable	1	$ 2.65	$ 5.29

Financial Summary

Optics and Filters

- **Longpass Filter (550 nm)**: Cost: **$102.00**
- **Concave Mirrors**: Total Cost: **$159.19**
- **Diffraction Grating**: Cost: **$139.00**
- **Bi-Convex Lenses**: Total Cost: **$58.72**
- **50µm Entrance Slit:** Cost: **$78.62**

Subtotal for Optics and Filters: **$537.53**

Laser Source:

- **532 nm Green Laser (30 mW):** Cost: **$14.90**

Subtotal for Laser Source: **$14.90**

Sample Handling:

- **Cuvettes**: Cost: **$11.89**
- **Microscope Slides**: Cost: **$9.40**

Subtotal for Laser and Sample Handling: **$21.29**

Power and Storage Components:

- **Battery Pack (24V, 6Ah LiFePO4)**: Cost: **$42.99**
- **Buck Converter**: Cost: **$7.99**
- **MicroSD Card (32GB)**: Cost: **$12.77**
- **CCD Linear image Sensor:** Cost: **$37.90**
- **Micro-USB Cable:** Cost: **$5.29**

Subtotal for Power and Storage: **$106.94**

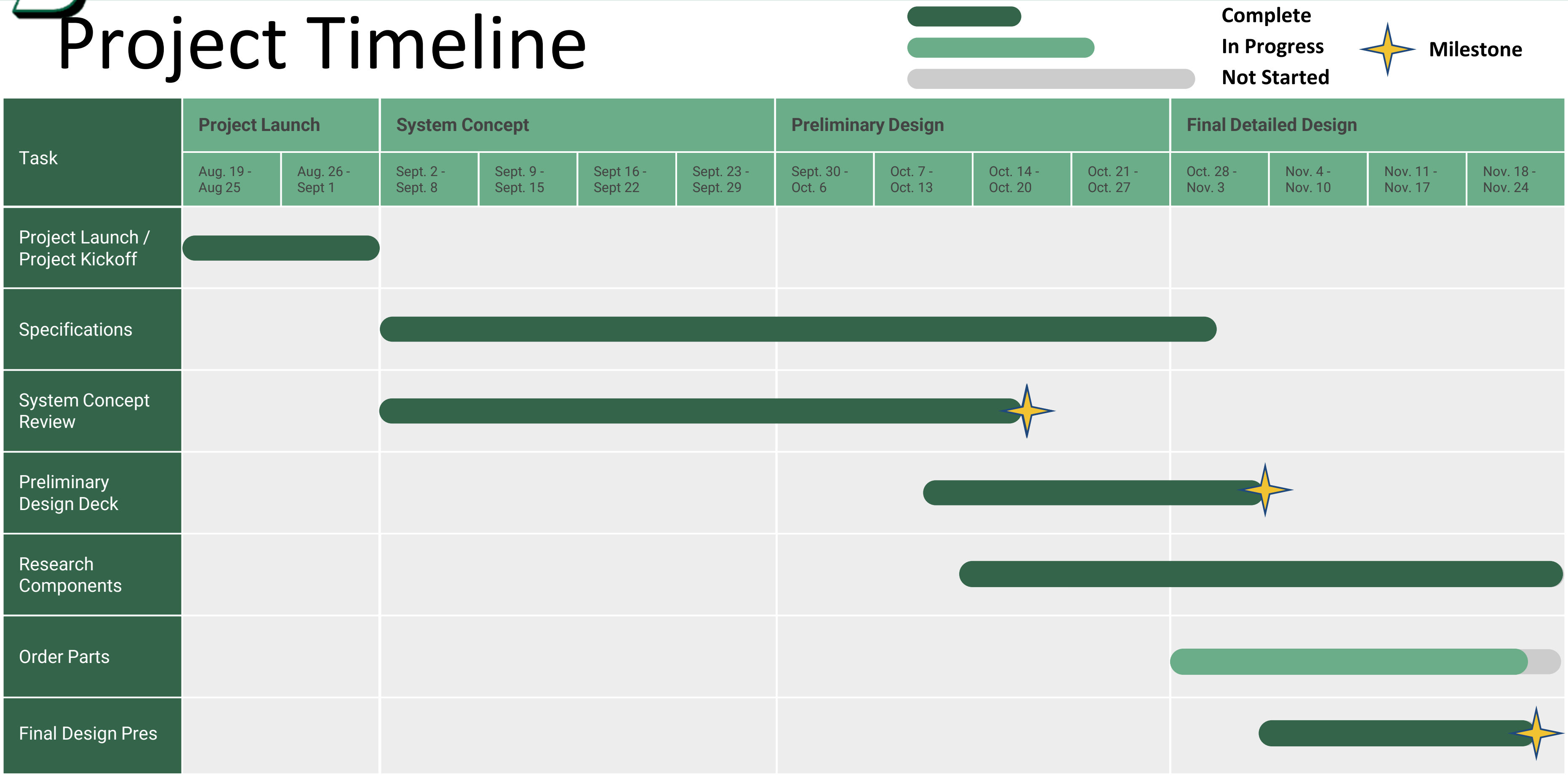
Total Cost: $694.00

Budget:$1500

Budget Analysis

- **Major Expenses**: Optical components are the primary cost drivers, representing 77% of the budget. This emphasis reflects the precision required for spectral analysis. Shipping is free other than one component.
- **Cost-Effectiveness**: Through strategic sourcing, we balanced high-quality optics with cost-effective electronic components, maximizing our budget’s impact.
- **Project Scope Alignment**: The chosen parts align with our project’s technical goals and field requirements, ensuring portability, durability, and accuracy for use in variable outdoor conditions.

Project Timeline



Project Timeline

Complete
In Progress
Not Started
Milestone

Next Steps

This semester:

- Finish prototypes of individual components
- Begin integrations

Next semester:

- Integrations testing
- Troubleshooting
- Final design

Questions?