Spectral Forest

ME 476C Section 02

Team: Tyler Lerew, Torrey King, & Derrick Doan

Project Description

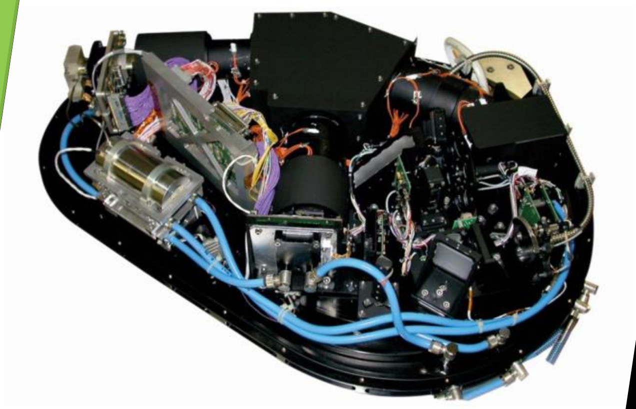
Build a robust spectrometer housing to record wavelengths of light reaching forest floor ranging from 350-1000 nm, it could help change the trajectory of forests research and conservation efforts.

Insights into plant health, leaf makeup and thickness, water concentrations in soil and in trees, temperature differences due to water conspiring up the tree, this data will be put into prediction models to analyze the forests' health

The unit will be placed in a specific understory position to continuously monitor a location. Later the device will be attached to a drone and can analyze the forest from above. The lab application is to view the optical and energy properties of semiconductors like energy transfer and light reflection and absorption

Use single aperture with fiber optics splitting cable to direct the light into the 3 special chips that are being used to decipher the light and collect the data

Sponsors: Alexander Shenkin (Assistant Research Professor) and Carlo da Cunha (Assistant Professor) - SICCS



Background & Benchmarking

The state of the art (SOTA) designs utilize spectrometers that capture spectral data ranging from 350-2500 nm. The 3 pre-existing models use remote sensing to study forest ecosystems through biophysical and biochemical variables.

Design 1: Airborne Prism Experiment (APEX) Imaging Spectrometer

- Attached to drone, hyperspectral data in 300 bands, spectral range pf 380-2500 nm and at a spatial ground resolution of 2-5 m

Design 2: ASD FieldSpec 4 Standard-Res Spectroradiometer

- Portable, handheld, spectral range of 350-2500 nm, interchangeable contact probes and mug lights

Design 3: NASA HyMap Sensor

- Four spectrometers in the interval of 450-2450 nm, 2 major atmospheric water absorption windows, on-board bright source calibration system

Customer and Engineering Requirements

- Design requirements
- One central aperture to allow light to enter the unit
- 3 chips are required for the full spectrum of light to be collected
- Aperture must feed all 3 chips
- Chips and lenses coving aperture must be perfectly perpendicular
- Electronics inside must be easily accessible
- Unit must be sealed to ensure it is waterproof
- Vents are required so no negative pressure differentials are created
- Operating temperature range is 0-50 C

Customer and Engineering Requirements Cont.

- Customer requirements
- Protect internal instruments
- Resilient to temperature fluctuations
- Protection against humidity and water entering the unit
- UV resistance
- Proper venting
- Compatible design to accommodate all electronic components with ease of install
- Integrated cable management
- Gimbal mounting system
- Integrate BFL44HS01 1-4 fiber optic bundle splitter
- As light and as small as possible
- Outside color should be white

Customer and Engineering Requirements Cont.

- Engineering requirements
- Long life
- Stable internal conditions
- High precision tolerances
- Waterproof
- Adaptive design
- Lightweight (>2lb)

QFD

- Customer needs with most weight: Durable, 1 central aperture, and sealed unit
- Ranked competing designs based off customer needs

System QFD

Project:	Spectral Forest
Date:	Fall 2023

Correlation Legend	
++	Strong positive
+	Moderate positive
-	Moderate negative
--	Strong negative

Legend	
A	APEX Imaging
B	ASD FieldSpec 4
C	NASA HyMap

		1	2	3	4	5
1	Long life					
2	Stable internal conditions	++				
3	High precision tolerances	+	+			
4	Waterproof	++	++	-		
5	Adaptive design	+	+	+	+	
6	Lightweight					

	Customer Needs	Customer Weights	Technical Requirements: Long life	Stable internal conditions	High precision tolerances	Waterproof	Adaptive design	Lightweight	Customer Opinion Survey: 1 Poor	2	3 Acceptable	4	5 Excellent
1	Durable	5	9			9	3					AB	C
2	Vents ensure semi-constant conditions	4	3	9		9	1				B	A	C
3	1 central aperture	5		3	9	3	3					BC	A
4	Unit is sealed	5	9	3	9	9						AB	C
5	Ease of access	3		1		1	9				C		AB
6	Reliable	3	3	3	3	3	9	3			B	AC	
7	UV resistant	3										ABC	
8	Ambient operating range of 0-50 °C	3.5	3	9			9					AB	C
	Technical Requirement Units		Years	°F	in	N/A	N/A	lbs					
	Technical Requirement Targets		5	2 °F +/-	+/- 0.01			<2					
	Absolute Technical Importance		121.5	109.5	99	153	119.5	9					
	Relative Technical Importance		2	4	5	1	3	6					

A Literature Review Tyler

- [2] F. Süli, Electronic Enclosures, Housings and Packages, Woodhead Publishing, 2019, pp. 73-124.
  - Information about operating conditions, aesthetics, safety, internal fits, structural robustness, materials, maintenance. Will help us design a robust housing.
- **[3] F. Süli, Electronic Enclosures, Housings and Packages, Woodhead Publishing, 2019, pp. 415-473.**
  - Information about IP ratings (Ingress protection), condensation, corrosion, gaskets, and extreme conditions. Will help us over design so it will not fail in the field under extreme conditions.
- **[4] R. Cahuantzi and A. Buckley, "Geometric optimization of an accurate cosine correcting optic," Review of Scientific Instruments, vol. 88, no. 9, pp. 1-5, 2017.**
  - Insight about optimizing the cosine corrector so all the light comes into the chips in the correct orientation.
- **[5] K. J. Ranson, J. R. Irons and D. L. Williams, "Multispectral bidirectional reflectance of northern forest canopies with the advanced solid-state array spectroradiometer (ASAS)," Remote Sensing of Environment, vol. 47, no. 2, pp. 276-289, 1994.**
  - Aiding in the investigation of alternatives to the $500 splitter
- **[6] R. Jebens, W. Trimmer and J. Walker, "Micro actuators for aligning optical fibers," Sensors and Actuators, vol. 20, no. 1-2, pp. 65-73, 1989.**
  - Potential solution to misalignments during transit and data collection. More research is required to confirm if this is viable.
- **[7] "Understanding Fiber Optic Splitters and How They Work," TELHUA TELECOMMUNICATIONS CO., 2023. [Online]. Available: https://telhua.com/understanding-fiber-optic-splitters-and-how-they-work/.**
  - Aids in understanding how fiber optic splitters work so we can accurately design around it for optimal performance.
- **[1] NEMA, "NEMA Enclosure Types," NEMA, 2003.**
  - Rating for what environments electrical enclosures can safety be used in. We must match the rating to the conditions that our unit will be experiencing.

A Literature Review Torrey

- [8] D. Malacara and Z. Malacara-Hernandez, Handbook of Optical Design. CRC Press, 2017.
  - [object File][object File]
- [9] F. T. S. Yu and S. Yin, "Fiber Optic Sensors: Fundamentals and Applications," New York, NY: Wiley-Interscience, 2002.
  - This book explores the fundamentals of fiber optic sensors and their applications in different fields, including spectrometry.
- [10] V. Sprincean, A. Paladi, V. Andruh, A. Danici, P. Lozovanu and F. Paladi, "UAV-based Measuring Station for Monitoring and Computational Modeling of Environmental Factors," 2021 IEEE 8th International Workshop on Metrology for AeroSpace (MetroAeroSpace), Naples, Italy, 2021, pp. 80-85, doi: 10.1109/MetroAeroSpace51421.2021.9511706.
  - This paper covers the use of UAVs equipped with spectroscopic sensors for environmental monitoring, such as vegetation analysis or pollution detection.
- [11] B. Yang et al., “Research and application of UAV-based hyperspectral remote sensing for smart city construction,” Cognitive Robotics, vol. 2, pp. 255–266, 2022. doi:10.1016/j.cogr.2022.12.002
  - Hyperspectral imaging is a type of spectroscopy that captures a wide range of wavelengths. This paper looks at the applications of UAV-based hyperspectral imaging in separate but comparable fields to this project.
- [12] L. Deng et al., “UAV-based multispectral remote sensing for precision agriculture: A comparison between different cameras,” ISPRS Journal of Photogrammetry and Remote Sensing, vol. 146, pp. 124–136, Dec. 2018. doi:10.1016/j.isprsjprs.2018.09.008
  - A comparison between different cameras (Journal): An article covering topics in precision agriculture using UAVs and spectroscopic sensors to optimize crop management.
- [13] “1x4 Polarization-Maintaining Fiber Optic Splitters,” Thorlabs, Inc. - Your Source for Fiber Optics, Laser Diodes, Optical Instrumentation and Polarization Measurement & Control, https://www.thorlabs.com/newgrouppage9.cfm?objectgroup_id=15339 (accessed Sep. 12, 2023).
  - this was a proposed item to be used to be applied. Due to the cost and potential changes to chip type it might not be the best option.
- [14] “Cosine correctors,” Cosine Correctors | Ocean Insight, https://www.oceaninsight.com/products/sampling-accessories/free-space-optics/cosine-correctors/ (accessed Sep. 14, 2023).
  - ocean sight is a company that produces a variety of cosine correcting lenses which will be a necessary item in filtering light pre-fiberoptic and pre-chip. This is only a potential source to buy this item.

A Literature Review Derrick

- [15] D. L. Sparks, E. Ben-dor, R. G. Taylor, and J. Hill, “Imaging Spectrometry for Soil Applications,” in Advances in Agronomy, vol. 97, Elsevier Science & Technology, 2008, pp. 321–392
  - incite on how spectrometers work and how they detect differences in soil
- [16]P. A. Tres, Designing Plastic Parts for Assembly., 9th ed. München: Hanser, 2021.sembly., 9th ed. München: Hanser, 2021.
- aides in the process of material selection, fasteners, hinges and techniques for assembling the model.
- [17] “Apex (Airborne Prism Experiment),” eoPortal, (accessed Sep. 18, 2023).
  - Remote sensing of forest biophysical variables using HyMap imaging spectrometer data (Paper) – demonstrates hyperspectral image data using HyMap sensor and linear predictive vegetation models.
- [18] “ASD fieldspec 4 Standard-Res Spectroradiometer,” Malvern Panalytical, (accessed Sep. 17, 2023).
  - Simulating imaging spectrometer data: 3D forest modeling based on LiDAR and in situ data (Paper) -information on key biophysical and biochemical variables, insight on photosynthetic processes, plant health, plant functional types, and species composition.
- [19] B. Koetz, F. Morsdorf, G. Sun, K. Ranson, and K. Itten, “Fusion of imaging spectrometer and LIDAR data over combined radiative transfer models for Forest Canopy Characterization,” Remote Sensing of Environment, (accessed Sep. 17, 2023).
  - Fusion of imaging spectrometer and LIDAR data over combined radiative transfer models for forest canopy characterization (Paper) - remote sensing signal of imaging spectrometry and large footprint LIDAR to derive comprehensive canopy characterization of forests.
- [20] J. Hill, C. Atzberger, and M. Schlerf, “Remote sensing of forest biophysical variables using HYMAP Imaging Spectrometer Data,” Remote Sensing of Environment, (accessed Sep. 17, 2023).
  - Malvern Panalytical (Online) – pre-existing design comparison, key applications, specifications, accessories (probes and lights).
- [21] F. D. Schneider et al., “Simulating Imaging Spectrometer Data: 3D Forest Modeling based on Lidar and in situ data,” Remote Sensing of Environment, (accessed Sep. 17, 2023).
  - eoPortal (Online)- pre-existing design comparison, specifications, sub-units/subsystems, figures showing process.

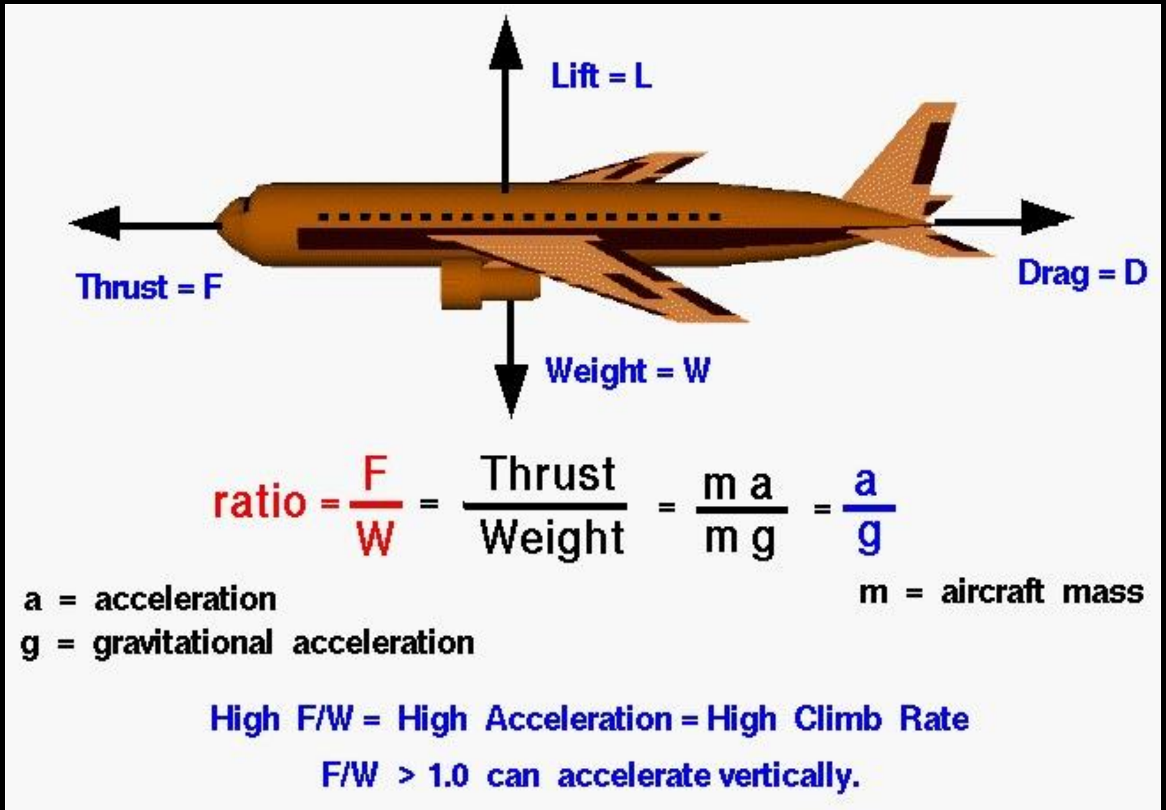
Mathematical Modelling Tyler

- Impact force and stress on housing if the unit is dropped, ensure no fracture to housing
  - Preliminary nylon housing mass estimate (101.6mm x 101.6 mm x 50.8mm): ~ 0.34 kg
  - Height of fall: 1.81 m
  - Height of bounce: 50.5 mm
  - Governing equation (Impact from a falling object): $F = \frac{mgh}{d}$
  - Stress equation: $\sigma = \frac{F}{A}$
  - **Total force: 120.4 N**
  - **Stress: 0.5 MPa**
  - **Ultimate Strength: 69 MPa**
- Can use this calculation later in the design process in FEA to ensure the unit is intact after a fall and design around this force to ensure internal components do not shift during impact

Mathematical Modelling Torrey

- Electronics heat disbursement and temperature increase
- Fourier's Law of Heat Conduction:
  - $Q = -k * A * \Delta T / \Delta x$
    - Defines heat transfer due to conduction through materials (internal environment to external environment).
- Newton's Law of Cooling:
  - Q = h * A * (T_surface - T_air)
    - Describes heat transfer due to convection with air through the proposed vents.
- Stefan-Boltzmann Law:
  - Q = ε * σ * A * (T_surface^4 - T_surroundings^4)
    - Represents heat radiation to/from the payload mostly being heat from electronics and sunlight.

Mathematical Modelling Derrick

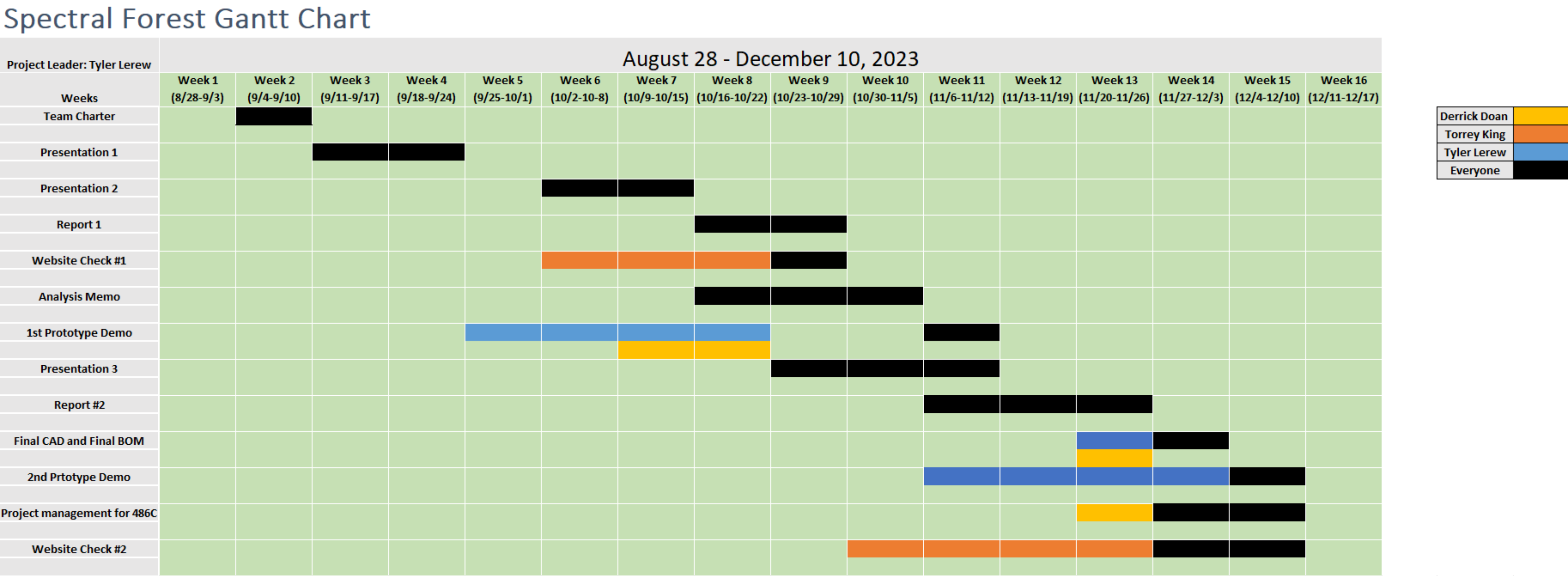


- Forces Applied When Flying
  - Mass estimate (m): Drone (2kg) + Design (.34kg) = 2.34 kg
  - Avg. Drone Speed (a): 45 mph = 20.13 m/s
  - Gravity (g): 9.8 m/s^2
  - Thrust (F): 47.1 kg-m/s or N-s
  - Weight (W): 22.93 kg-m/s^2 or N
  - Ratio (F/W): 2.05 = High Climb Rate
  - Measurements to be used when creating housing for system to resist movement from these forces (material, fasteners, hinges, etc.)

Schedule & Budget

- $500 for each ME and EE teams $1000 total, can be moved around
- Anticipated expenses:
  - Prototyping ($50), optical splitter ($500) we are looking into alternate routes, final product parts ($150-200)
- Total expenses to date: None
- Total balance: $500
- We will raise $50 ourselves, which is 10% of the allotted budget
  - Can use GoFundMe, restaurant fundraiser, or donate the funds ourselves
- Gantt chart on following slide
  - We are on schedule if not slightly behind schedule. Due to the EE team getting assigned this project less than a week ago

Gantt Chart


Spectral Forest Gantt Chart
Project Leader: Tyler Lerew
August 28 - December 10, 2023
Weeks
Week 1 (8/28-9/3)
Week 2 (9/4-9/10)
Week 3 (9/11-9/17)
Week 4 (9/18-9/24)
Week 5 (9/25-10/1)
Week 6 (10/2-10-8)
Week 7 (10/9-10/15)
Week 8 (10/16-10/22)
Week 9 (10/23-10/29)
Week 10 (10/30-11/5)
Week 11 (11/6-11/12)
Week 12 (11/13-11/19)
Week 13 (11/20-11/26)
Week 14 (11/27-12/3)
Week 15 (12/4-12/10)
Week 16 (12/11-12/17)
Team Charter
Presentation 1
Presentation 2
Report 1
Website Check #1
Analysis Memo
1st Prototype Demo
Presentation 3
Report #2
Final CAD and Final BOM
2nd Prtotype Demo
Project management for 486C
Website Check #2
Derrick Doan
Torrey King
Tyler Lerew
Everyone

Thank you!

Questions?

References

[1] NEMA, "NEMA Enclosure Types," NEMA, 2003.

[2] F. Süli, Electronic Enclosures, Housings and Packages, Woodhead Publishing, 2019, pp. 73-124.

[3] F. Süli, Electronic Enclosures, Housings and Packages, Woodhead Publishing, 2019, pp. 415-473.

[4] R. Cahuantzi and A. Buckley, "Geometric optimization of an accurate cosine correcting optic," Review of Scientific Instruments, vol. 88, no. 9, pp. 1-5, 2017.

[5] K. J. Ranson, J. R. Irons and D. L. Williams, "Multispectral bidirectional reflectance of northern forest canopies with the advanced solid-state array spectroradiometer (ASAS)," Remote Sensing of Environment, vol. 47, no. 2, pp. 276-289, 1994.

[6] R. Jebens, W. Trimmer and J. Walker, "Micro actuators for aligning optical fibers," Sensors and Actuators, vol. 20, no. 1-2, pp. 65-73, 1989.

[7] "Understanding Fiber Optic Splitters and How They Work," TELHUA TELECOMMUNICATIONS CO., 2023. [Online]. Available: https://telhua.com/understanding-fiber-optic-splitters-and-how-they-work/.

References

[8] D. Malacara and Z. Malacara-Hernandez, Handbook of Optical Design. CRC Press, 2017.

[9] F. T. S. Yu and S. Yin, "Fiber Optic Sensors: Fundamentals and Applications," New York, NY: Wiley-Interscience, 2002.

[10] V. Sprincean, A. Paladi, V. Andruh, A. Danici, P. Lozovanu and F. Paladi, "UAV-based Measuring Station for Monitoring and Computational Modeling of Environmental Factors," *2021 IEEE 8th International Workshop on Metrology for AeroSpace (MetroAeroSpace)*, Naples, Italy, 2021, pp. 80-85, doi: 10.1109/MetroAeroSpace51421.2021.9511706.

[11] B. Yang *et al.*, "Research and application of UAV-based hyperspectral remote sensing for smart city construction," *Cognitive Robotics*, vol. 2, pp. 255–266, 2022. doi:10.1016/j.cogr.2022.12.002

[12] L. Deng *et al.*, "UAV-based multispectral remote sensing for precision agriculture: A comparison between different cameras," *ISPRS Journal of Photogrammetry and Remote Sensing*, vol. 146, pp. 124–136, Dec. 2018. doi:10.1016/j.isprsjprs.2018.09.008

[13] "1x4 Polarization-Maintaining Fiber Optic Splitters," Thorlabs, Inc. - Your Source for Fiber Optics, Laser Diodes, Optical Instrumentation and Polarization Measurement & Control, https://www.thorlabs.com/newgrouppage9.cfm?objectgroup_id=15339 (accessed Sep. 12, 2023).

[14] "Cosine correctors," Cosine Correctors | Ocean Insight, https://www.oceaninsight.com/products/sampling-accessories/free-space-optics/cosine-correctors/ (accessed Sep. 14, 2023).

[14] "Cosine correctors," Cosine Correctors | Ocean Insight, https://www.oceaninsight.com/products/sampling-accessories/free-space-optics/cosine-correctors/ (accessed Sep. 14, 2023).

References

[15] D. L. Sparks, E. Ben-dor, R. G. Taylor, and J. Hill, “Imaging Spectrometry for Soil Applications,” in *Advances in Agronomy*, vol. 97, Elsevier Science & Technology, 2008, pp. 321-392

[16] P. A. Tres, Designing Plastic Parts for Assembly., 9th ed. München: Hanser, 2021.

[17] “Apex (Airborne Prism Experiment),” eoPortal, (accessed Sep. 18, 2023).

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[19] B. Koetz, F. Morsdorf, G. Sun, K. Ranson, and K. Itten, “Fusion of imaging spectrometer and LIDAR data over combined radiative transfer models for Forest Canopy Characterization,” Remote Sensing of Environment, (accessed Sep. 17, 2023).

[20] J. Hill, C. Atzberger, and M. Schlerf, “Remote sensing of forest biophysical variables using HYMAP Imaging Spectrometer Data,” Remote Sensing of Environment, (accessed Sep. 17, 2023).

[21] F. D. Schneider et al., “Simulating Imaging Spectrometer Data: 3D Forest Modeling based on Lidar and in situ data,” Remote Sensing of Environment, (accessed Sep. 17, 2023).