04.08.25

C.H.A.N. - O.S.M.

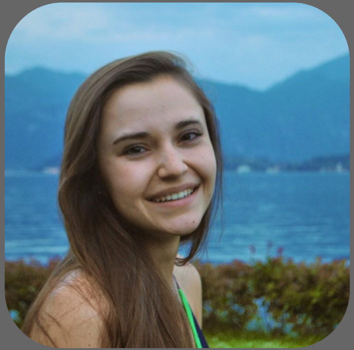
Climatic High-Altitude Navigator for Optical Signal Measurement

Final Presentation: Group 2

Michael “Zion” Franz · Jake “Dorf” Dorfman · Lily “Oculus” Sigg · Hector “Diesel” Parra · Sean “Shaggy” Rego

Meet The Team

Jacob Dorfman
Electrical Engineering (BS)
2025



Lily Sigg
Photonics Engineering (BS)
2025

Sean Rego
Electrical Engineering (BS)
2025

Hector Parra
Electrical Engineering (BS)
2025

Michael Franz
Electrical Engineering (BS)
2025

1. Motivation & Background
2. Goals & Objectives
3. Specs & Requirements
4. Hardware & Software
5. Testing

1. **Motivation & Background**
2. Goals & Objectives
3. Specs & Requirements
4. Hardware & Software
5. Testing

Problems & Our Solutions

Educational Problems

- **There are not enough high altitude STEM kits.**
  - Almost all kits are a collection of COTS parts sold as a package.
  - There are no integrated “plug ‘n play” kits available.

Ecological Problems

- **There is a disconnect between terrestrial and atmospheric fire models.**
  - Satellites in orbit cannot monitor one area for an extended period of time.
  - Satellites struggle to detect fire/smoke through cloud cover.
  - Satellites cannot determine what type of vegetation is burning.
- **Not every country can afford satellite wildfire monitoring.**
  - Fire-monitoring balloons could take the place of satellites.
  - Much cheaper to launch a myriad of balloons vs one satellite.

1. Motivation & Background
2. **Goals & Objectives**
3. Specs & Requirements
4. Hardware & Software
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Goals & Objectives

- **Basic Goals: Design a Balloon Payload that can….**
  - Measure atmospheric conditions such as temperature, humidity, and pressure.
  - Determine its velocity, altitude, and coordinates.
  - Transmit data to a receiver & record data that can be clearly interpreted.
  - Determine levels of and ratio between potassium and sodium in a flame using the spectrometer.

- **Advanced Goals:**
  - Create a base station that receives live data and displays it in a clear manner.
  - Design a GUI for graphically displaying data collected by the payload.
  - Determine the presence of green, unburnt vegetation from the data captured by the photodiode.

- **Stretch Goals:**
  - Reach an apogee of 100,000+ feet.
  - Recover the payload.
  - Obtain the absorbance spectra of burnt vegetation (carbon deposits) using both the spectrometer and photodiode.

1. Motivation & Background
2. Goals & Objectives
3. **Specs & Requirements**
4. Hardware & Software
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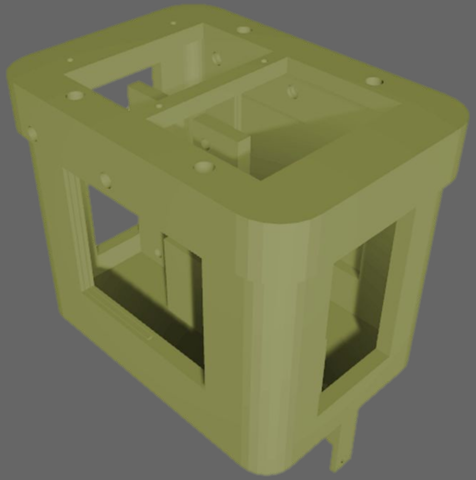
Engineering Requirements

Electrical Specifications		
Component	**Parameter**	**Specification**
Radio	Communication Range	100 feet
Anemometer	Measurement Range	5 – 25 mph
Temperature Sensor	Accuracy	+/– 10 °C
Humidity Sensor	Accuracy	+/– 10% RH
Pressure Sensor	Accuracy	+/– 10 mbar
Altimeter	Vertical Accuracy	+/– 2 meters
GNSS System	Horizontal Accuracy	+/– 10 meters
IMU	Bias Instability	6 deg/hr
Camera	Frames Per Second	24+ FPS
System	Power Consumption	< 10 W

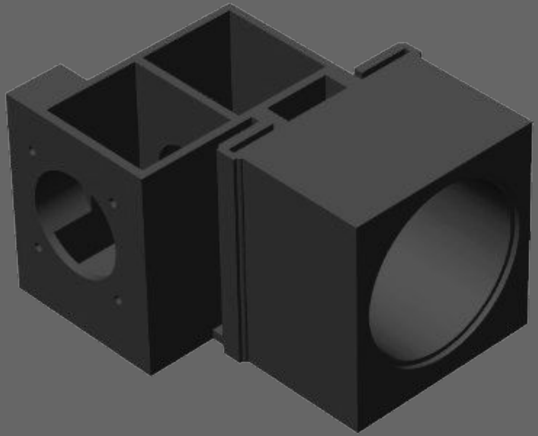
Optical Specifications		
	Parameter	**Specification**
Overall System	Detection Distance	1 foot
	Weight	< 2.5 kg
	NaCl Concentration	min 1 M
	KCl Concentration	min 1 M
Component	**Parameter**	**Specification**
CMOS	Wavelength Range	430 nm – 850 nm
	Accuracy	+/– 10 nm
Electrical System	Temperature Range	–50 °C – 30 °C
Housing	Size	10 x 10 x 10 cm
Light Source	Required Intensity	1000 mcd
Photodiode	Detection Distance	1 foot

Hardware Conceptualization

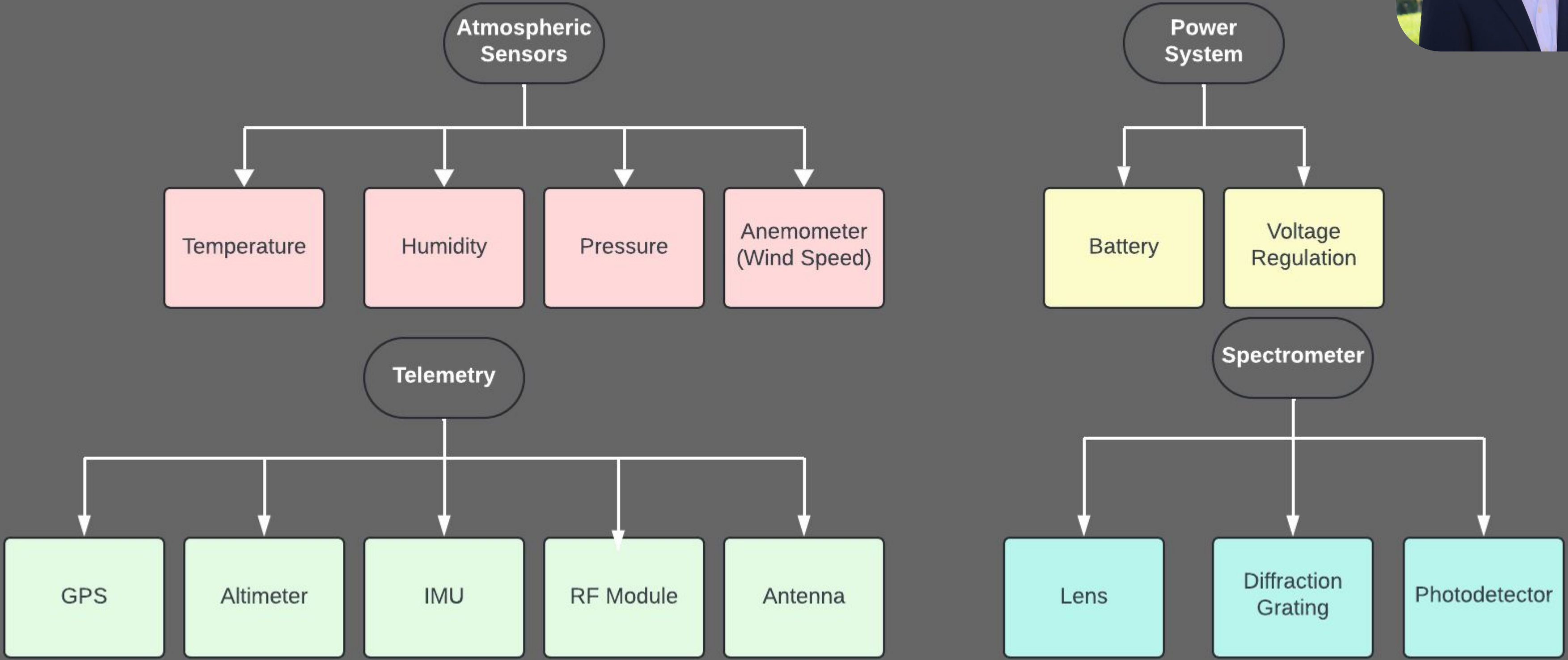
- **Payload**
  - 3D Printed box that holds electronics and battery
  - USB power port for Action Camera (Mounted on Outside)

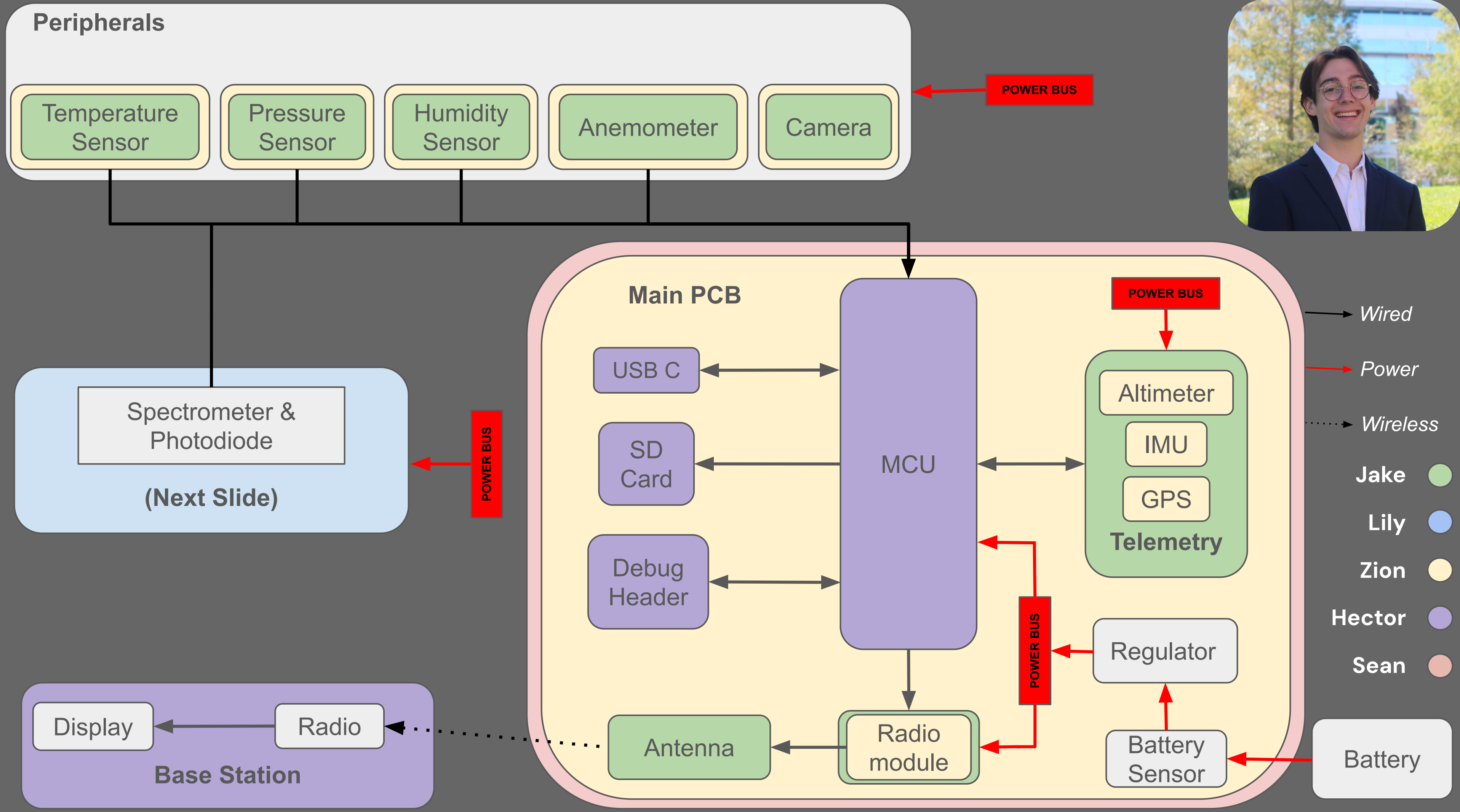


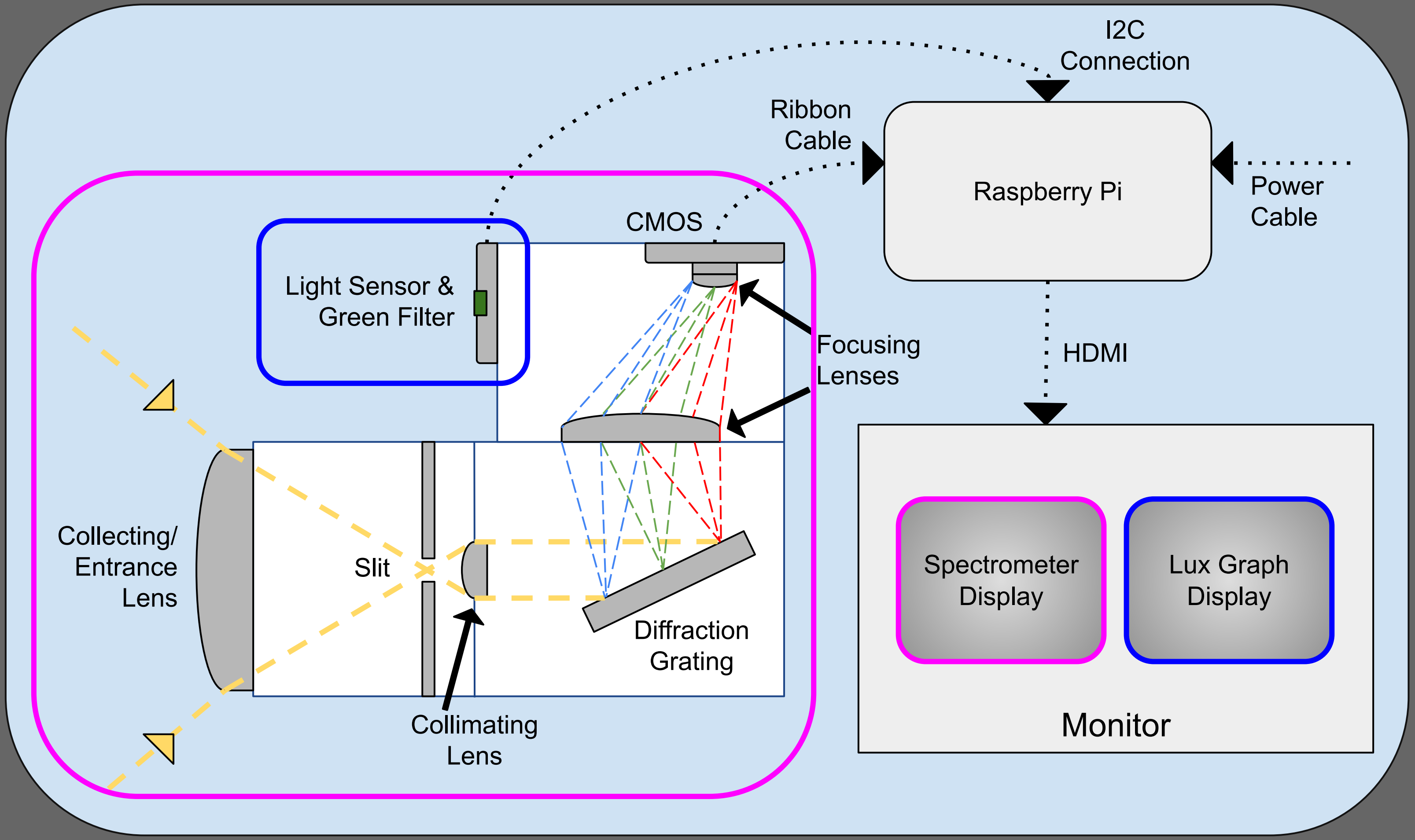
- **Optics**
  - Black 3D printed assembly to minimize contamination and house the lenses, slit, and diffraction grating
  - Configured to work with Arducam



Subsystems


Atmospheric Sensors
Temperature
Humidity
Pressure
Anemometer (Wind Speed)
Power System
Battery
Voltage Regulation
Telemetry
GPS
Altimeter
IMU
RF Module
Antenna
Spectrometer
Lens
Diffraction Grating
Photodetector


Peripherals
Temperature Sensor
Pressure Sensor
Humidity Sensor
Anemometer
Camera
POWER BUS
Spectrometer & Photodiode
(Next Slide)
POWER BUS
Main PCB
USB C
SD Card
Debug Header
MCU
POWER BUS
Altimeter
IMU
GPS
Telemetry
POWER BUS
Regulator
Antenna
Radio module
Battery Sensor
Battery
Display
Radio
Base Station
Wired
Power
Wireless
Jake
Lily
Zion
Hector
Sean


I2C
Connection
Ribbon
Cable
Raspberry Pi
Power
Cable
CMOS
Light Sensor &
Green Filter
Focusing
Lenses
HDMI
Collecting/
Entrance
Lens
Slit
Diffraction
Grating
Collimating
Lens
Spectrometer
Display
Lux Graph
Display
Monitor

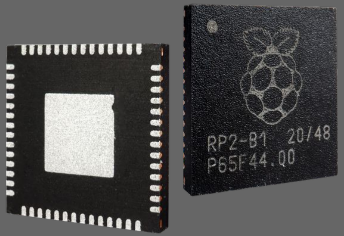
System Architecture

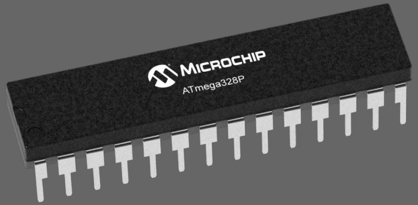
	Microcontroller	FPGA
Power Consumption	Preferred	Acceptable
Parallelization	Acceptable	Preferred
Peripheral Support	Preferred	Acceptable
Programmability	Preferred	Acceptable

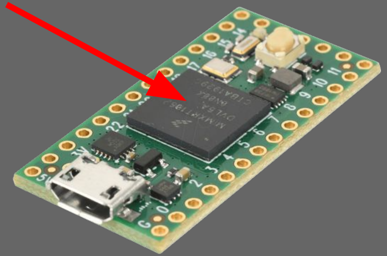
- We chose a microcontroller
  - Application does not need heavy computing power
  - Power consumption, peripheral support, and programmability are key to mission success.

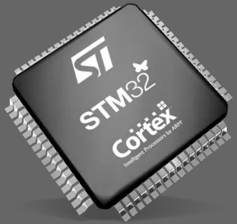
Microcontroller Selection

- Important Metrics:
  - Onboard Flash Size
  - Programmability (Arduino IDE)
  - Solderability (Pin Pitch)
  - Low Power Consumption
- Top Competitors:
  - RP2040
  - ESP32 (Wroom Series)
  - ATmega328P
  - i.MXRT1062
  - STM32F446









Microcontroller Selection

		RP2040	ESP32	ATmega328P	i.MX RT1062	STM32F446
2nd Highest	**CoreMark**	NA	994.26	NA	2314	608
	Dhrystone	NA	NA	0.0127	NA	225
Highest	**Flash Size (Onboard)**	0 kB	4 MB	32 kB	0	512 kB
2nd Highest	**RAM Size**	256 kB	520 kB	2 kB	1 MB	128 kB
Easiest (Tie)	**Programmability**	Medium	Easy	Easy	Medium	Difficult
Easiest (Tie)	**Solderability**	Medium	Easy	Easy	Difficult	Medium
3rd Lowest	**Power Consumed (mA/MHz)**	9.4	0.28	0.375	0.123	0.2
2nd Lowest	**Cost Per Unit ($)***	0.7	1.00 - 6.79	1.52 - 3.03	12.56 - 18.79	7.23 - 11.48

*Prices on Digikey as of 7/21/2024

Legend
1st Place
2nd Place
3rd Place
4th Place

Atmospheric Sensor Suite

Humidity Sensor Technology Selection

Technology	Accuracy	Resolution	Operating Range	Response Time	Cost
Capacitive	Great	Best	Best	Best	Great
Resistive	OK	Great	Great	Great	Best
Thermal	Good	Good	Good	Good	Good
Gravimetric	Best	OK	OK	OK	OK

Legend
1st Place
2nd Place
3rd Place
4th Place

Atmospheric Sensor Suite

Capacitive Humidity Sensor Selection

Sample->

Component	Accuracy	Resolution	Response Time	Power Consumption	Cost
HTU21D(F)	5% RH	0.04% RH	5 sec	450uA	FREE
HS3003	1.5% RH	0.01%RH	6 sec	24.4uA	$4.58
HTU31	2% RH	0.01% RH	3 sec	414uA	$4.76

Legend
1st Place
2nd Place
3rd Place
4th Place

Atmospheric Sensor Suite

Pressure Sensor Technology Selection

Technology	Accuracy	Resolution	Operating Range	Cost	Temperature Resistance
Mercury	Average	Average	Limited	Great	OK
Aneroid	Good	Average	Limited	Best	OK
Piezo (E/R)	Best	Great	Great	OK	Best
Capacitive	Great	Best	Best	Great	Great

Legend
1st Place
2nd Place
3rd Place
4th Place

Atmospheric Sensor Suite

Capacitive Pressure Sensor Selection

Component	Accuracy (Pa)	Resolution (Pa)	Pressure Range (mbar)	Cost ($)
ICP-10101	+/-1	0.01	30-1100	$3.67
MS560702BA01-50	+/-0.8	0.01	10-1200	N/A Bulk
MS580301BA01-00	+/-0.8	0.01	10-1200	FREE

Sample->

Legend
1st Place
2nd Place
3rd Place
4th Place

Atmospheric Sensor Suite

Anemometer Technology Selection

Cost is Crucial

Technology	Accuracy	Resolution	Response Time	Cost
Cup Type	Good	OK	Good	Best
Hot Wire	Good	Good	Best	OK
Sonic	Best	Great	Great	Bad
LiDAR	Great	Best	Great	Bad

Legend
1st Place
2nd Place
3rd Place
4th Place

Atmospheric Sensor Suite

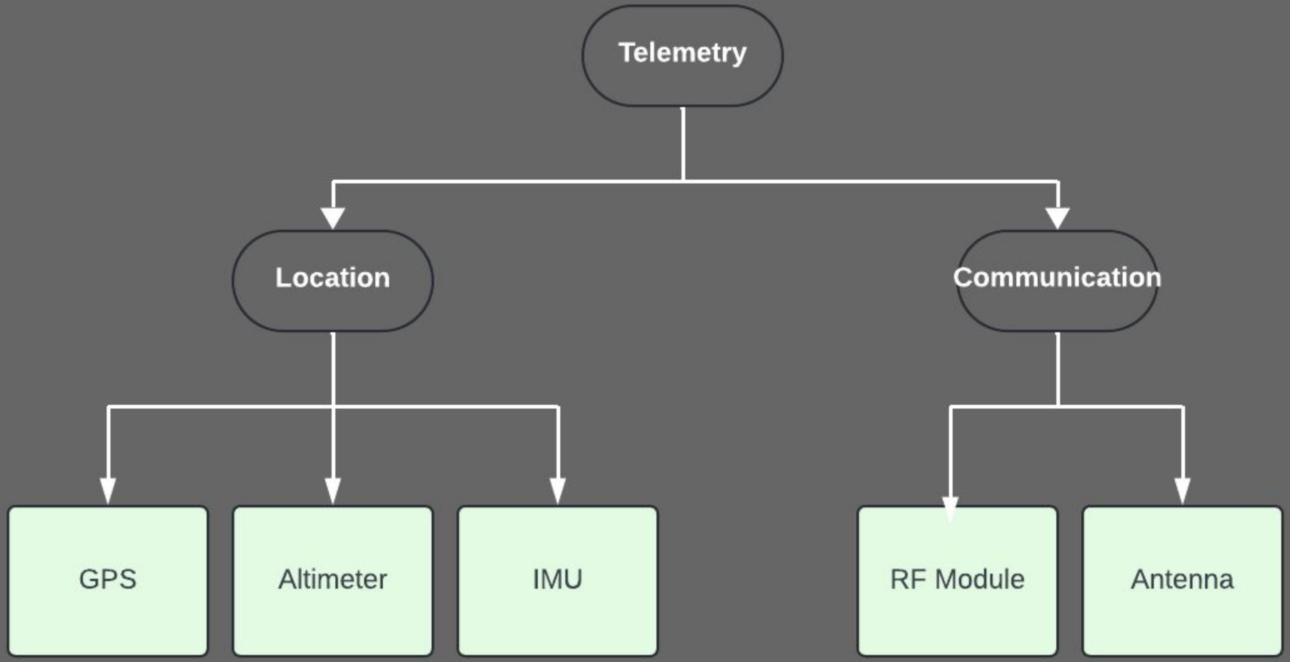
Anemometer Part Selection

Component	Accuracy	Size (in)	Operating Range (mph)	Cost
1733	+/- 0.3 mph	4.1x4	Up to 150	$44.95
Inspeed	+/- 1.0 mph	9x6x6	3 - 200	$69.00
NPN Pulse	+/- 0.2 mph	6.3x6.3	Up to 150	$19.80

Highest Operating Range

Legend
1st Place
2nd Place
3rd Place
4th Place

Telemetry Subsystem



Telemetry Subsystem

IMU Technology Choice

	FOG	MEMS
Bias Instability	Up to 0.0001°/hr.	Up to 0.1°/hr.
True North Positioning	Yes	No
Footprint	Large	Small
Weight	Heavy	Light
Cost (Vs competitor)	10X More	10X Less

Legend
1st Place
2nd Place
3rd Place
4th Place

- MEMS was the IMU technology choice for its small footprint, light weight, and drastically low cost (compared to at FOG).

Telemetry Subsystem

IMU Part Choice

Lowest Gyro Drift

Lowest Acc. Drift

Highest Acc. Update Rate

	ICM20948	BNO086	ISM330DHCX
Gyro Drift over Temperature (dps/°C)	+/- 0.05	N/A	+/- 0.005
Acc. Drift over Temperature (mili-g/°C)	0.8	N/A	0.1
Gyroscope Update Rate (Hz)	9000	1000	6667
Accelerometer Update Rate (Hz)	4500	500	6667
Cost Per Unit ($)*	8.64	16.85	9.60

Legend
1st Place
2nd Place
3rd Place
4th Place

Telemetry Subsystem

Altimeter Technology Selection

Technology	Range	Accuracy	Ease of Implementation	Cost
Barometric	Best	Okay	Best	Best
GPS	Great	Good	Great	Great
Radar	Okay	Great	Okay	Good
Laser	Good	Best	Good	Okay

Legend
1st Place
2nd Place
3rd Place
4th Place

Telemetry Subsystem

Altimeter Part Selection

Altimeter	Range	Operating Temp	Accuracy	Cost
MS5611-01B A03	30 – 110 kPa	-40 °F to 185° F	±0.150 kPa	$12
LPS28DFW	26 – 406 kPa	-40 °F to 185° F	±0.05 kPa	$16
MPL311A2	50 – 110 kPa	-40 °F to 185° F	±0.400 kPa	$10

Cost is Crucial

Legend
1st Place
2nd Place
3rd Place
4th Place

Telemetry Subsystem

GPS Technology Selection

	Accuracy	Service Area	Legality	Cost
GNSS	Best	Best	Best	Free
Cellular Network	Not Best	Not Best	Not Best	Based on plan

Legend
1st Place
2nd Place
3rd Place
4th Place

Telemetry Subsystem

GNSS Part Selection

	MAX-M10S	NEO-F10N	ZED-F9P	SAM M8-Q
Altitude Ceiling (m)	80,000	80,000	80,000	50,000
Positional Accuracy (m)	1.5	1	0.01	2.5
Velocity Accuracy (m/s)	0.5	0.5	0.5	0.05
Heading Accuracy (°)	0.3	0.3	0.3	0.3
I2C	Yes	No	Yes	Yes
Multiband	No	Yes	Yes	No
Antenna on Chip	No	No	No	Yes
Cost Per Unit ($)*	21.00	49.00	129.00 - 138.00	31.00

Legend
1st Place
2nd Place
3rd Place
4th Place

Important <-For Spatial Efficiency

Telemetry Subsystem

RF Module Technology Selection

Best for Long Range Communication

Framework	Data Access	Ease of Implementation	Cost
APRS	Best	Good	Best
LoRa	Good	Best	Good
Iridium	Worst	Worst	Worst

Legend
1st Place
2nd Place
3rd Place
4th Place

Telemetry Subsystem

Antenna Technology Selection

Antenna	Gain	Radiation Pattern	Ease of Implementation
Dipole	Okay	Best	Best
J pole	Great	Great	Great
Yagi	Best	Worst	Okay
Skew Planar	Worst	Good	Good
Iridium Satellite	Good	Okay	Worst

Legend
1st Place
2nd Place
3rd Place
4th Place

Power Supply

Battery Technology Choice

Small difference in energy and stability. Large save in cost. ->

Battery	Energy Density	Temperature Stability	Cost
Lithium Ion	Great	Great	Good
Lithium Polymer	Good	Good	Great
Lithium Iron Phosphate	Okay	Okay	Good
Alkaline	Worst	Worst	Best
Lithium Sulfur Dioxide	Best	Best	Worst

Legend
1st Place
2nd Place
3rd Place
4th Place

- Failure of this system means an almost certain loss of product
- Temperature & Capacity were the most important parameters

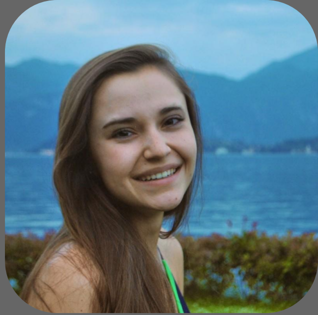
Power Supply

Voltage Regulator Part

Operation Mode	Supply Voltage (V)	Operating Temp. (C)	Current Draw (uA)	Cost (USD)
LT1242CS8	10-25	0-100	7	$9
LT1339CSW	12	0-70	14	$14
TSP62142	3-17	-40-125	17	$2

Legend
1st Place
2nd Place
3rd Place
4th Place

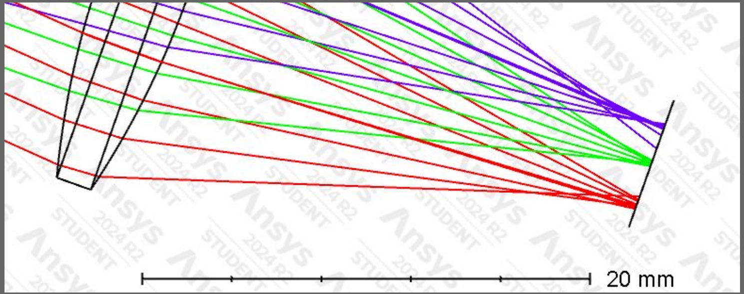
Spectrometer



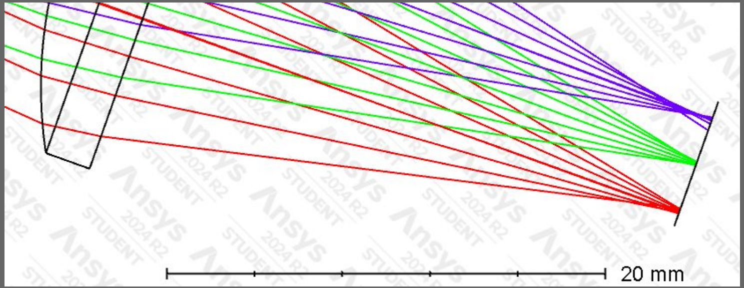
Lens Design Selection

Component	Average Cost	Wavelength Range (nm)	Applicability
Bi-Convex	$37	350 - 2200	moderate
Bi-Concave	$30	350 - 2200	low
Plano-Convex	$28	350 - 2200	high
Plano-Concave	$35	400 - 2200	low

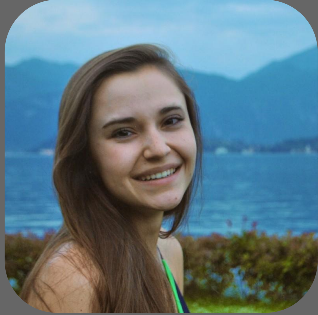
This option is the cheapest on average, within the preferred wavelength range, and as shown on the right, is more precise compared to the bi-convex lens.



Bi-Convex



Plano-Convex



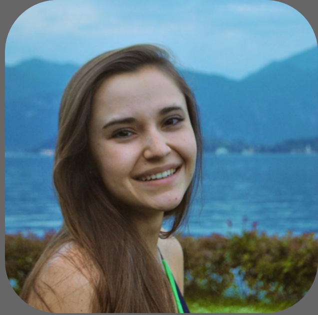
Spectrometer

Diffraction Grating Selection

Type	Spectral Range	Cost	Groove Density	Resolution	Stray Light
Ruled	Best in ultraviolet or specified singular wavelengths	~$15 (education-grade) ~$150 (industry-grade)	Best *below* 600 lines/mm	Single wavelength at blaze	More and presence of ghosts
Holographic	Best in ultraviolet into visible	~$150 (industry-grade)	Best *above* 600 lines/mm	Consistent across spectrum	Less and no ghosts

The resolution is generally better due to the photolithographic fabrication process, and the project specifications call for UV into VIS range.

Spectrometer

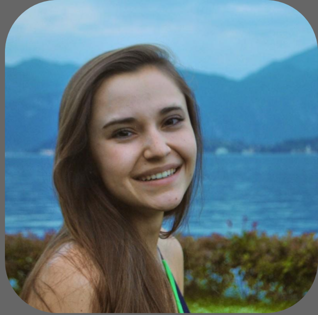


CMOS Detector Selection

Component	Wavelength Range (nm)	Peak Wavelength (nm)	Cost	Radiant Sensitive Area (mm^2)
Si Pin Photodiode	430 – 1100	800	$50	18.6
IR Photodiode (C10439-03)	190 – 1100	960	$907	100
InGaAs Photodiode	900 – 1700	1550	$100	6.45

Legend
1st Place
2nd Place
3rd Place
4th Place

The silicon option is not only the cheapest but also falls within the proper wavelength range. The range of wavelengths being detected are between 460nm and 768 nm, so the peak of 800nm falls the closest.



Ground Categorization

Chlorophyll Lux Detector Selection

Component	Wavelength Range (nm)	Max Lux Value	Cost
DF Robot Ambient Lux Sensor	380 - 750	200K	$9
AdaFruit VEML7700	500 - 900	120K	$5
HiLetGo	380 - 750	120K	$13

Legend
1st Place
2nd Place
3rd Place
4th Place

The AdaFruit VEML7700 is the cheapest and has detection in the green range that our filter is passing. It also comes with a built-in transimpedance amplifier.

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ESP32 IDE/Software Selection

IDE/Software	Language Complexity	Compatibility and Flexibility	External Support	Ease of Use
Arduino IDE (C/C++)	Good	Good	Best	Best
ESP-IDF (C/C++)	Good	Best	Good	Good
Simulink (MATLAB)	Bad	Worst	Bad	Bad
MicroPython (Python)	Best	Bad	Bad	Worst

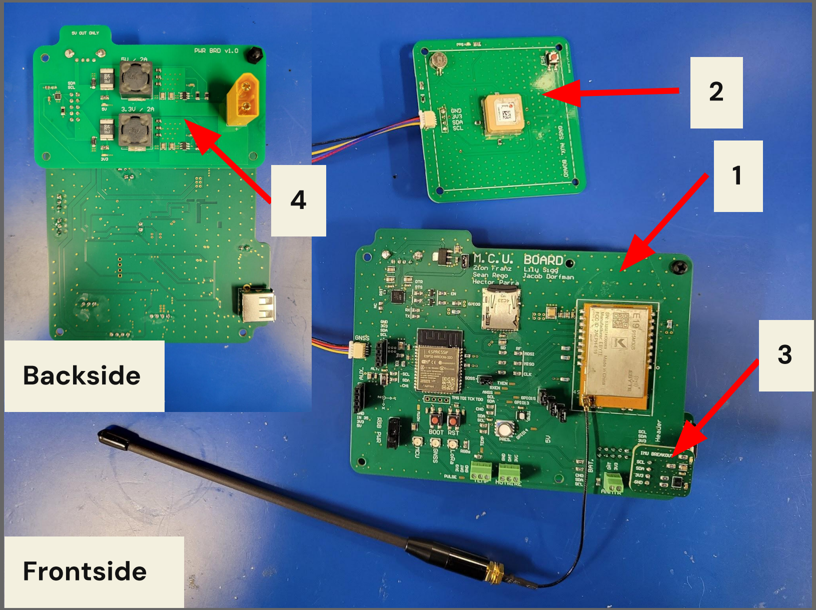
Data Processing/GUI Software Selection

Software	Capabilities	External Support	Ease of Use
C#	Best	Good	Worst
Python	Good	Best	Best
MATLAB	Bad	Bad	Good

The Balloon Payload System (B.P.S.)

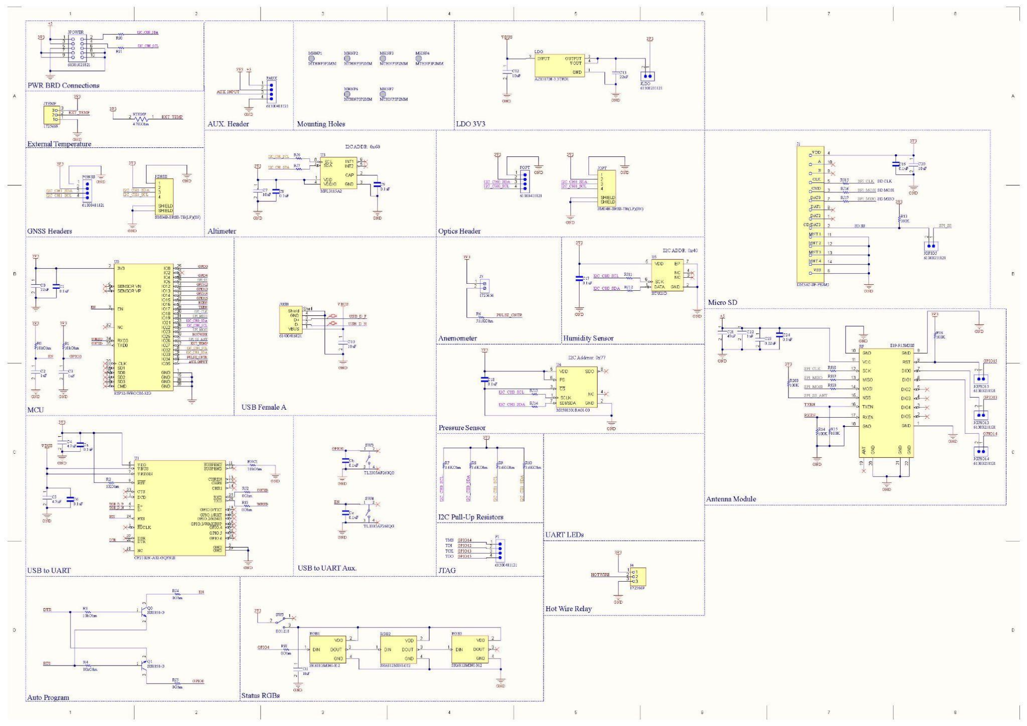
- Consists of Four Boards:
  - MCU Board (1)
  - GNSS Board (2)
  - IMU Board (Frontside MCU Board) (3)
  - Power Board (Backside MCU Board) (4)

- Provides a backbone for a variety of experiments.
  - Power & I2C supplied over auxiliary headers.
  - External temperature sensor support.
  - Rapid Deflation Device (RDD) support.



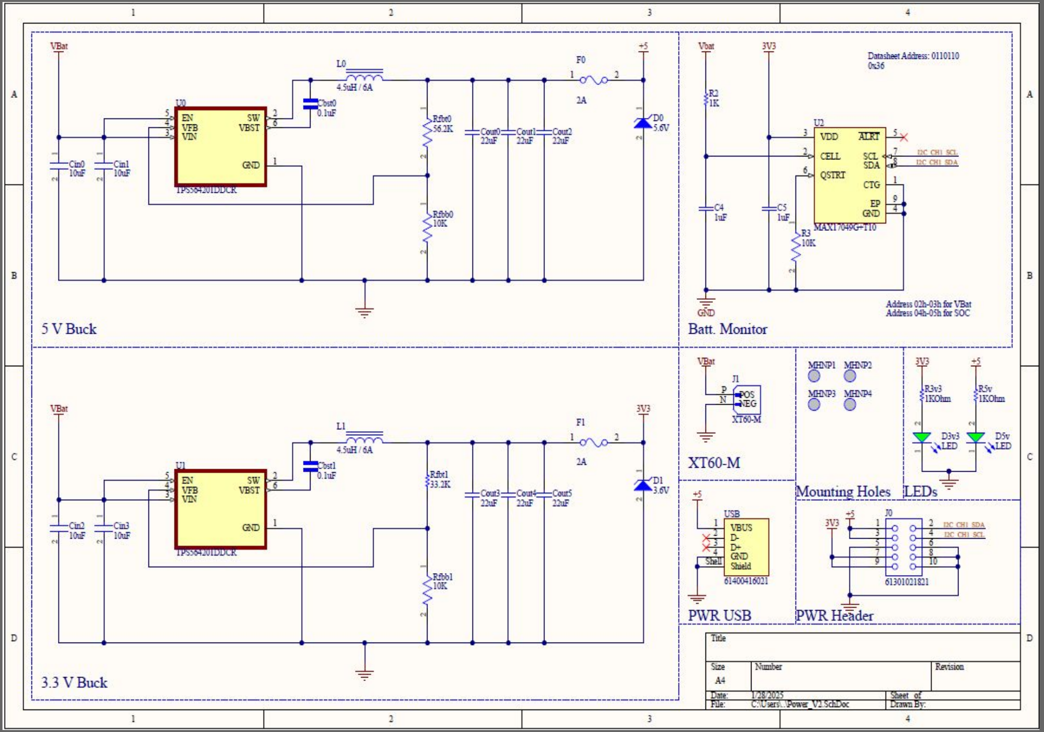
MCU Board Overall Schematic

- Contains all atmospheric & telemetry peripherals except:
  - GNSS
  - IMU
  - Anemometer
- GNSS module is on a seperate board due to its special ground plane and shielding requirements.
- IMU is mounted on a seperate board for ease of solderability due to high pin density.
- Anemometer interfaces via screw terminals.

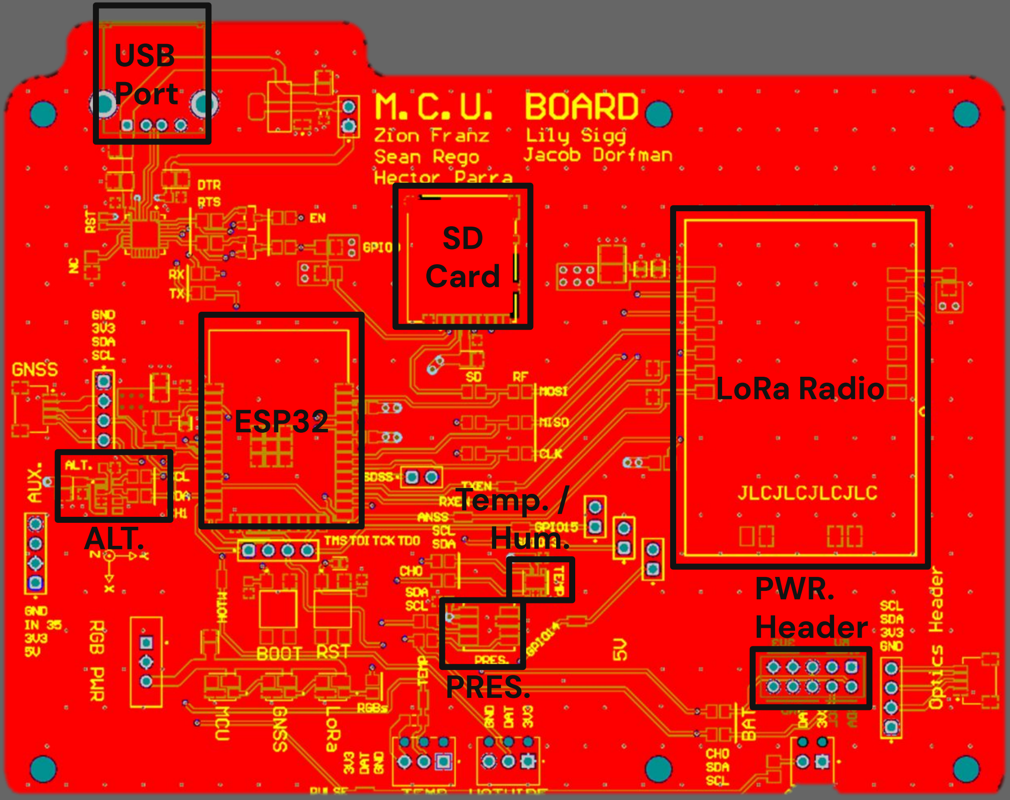


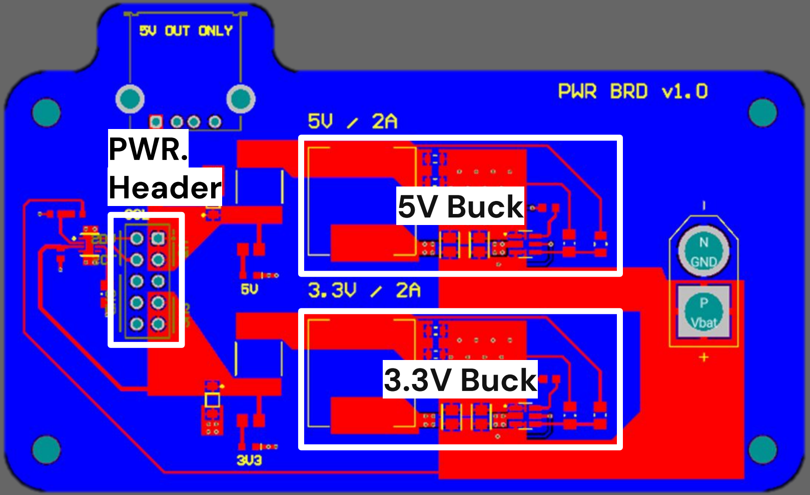
Power Board Schematic

- Buck Converter Topology
- 3.3 V & 5.0 V
- Low switching frequency (~500 KHz)
- Outputs protected via zener diodes & fuses
- 2 Cell Lipo Battery State of Charge monitor

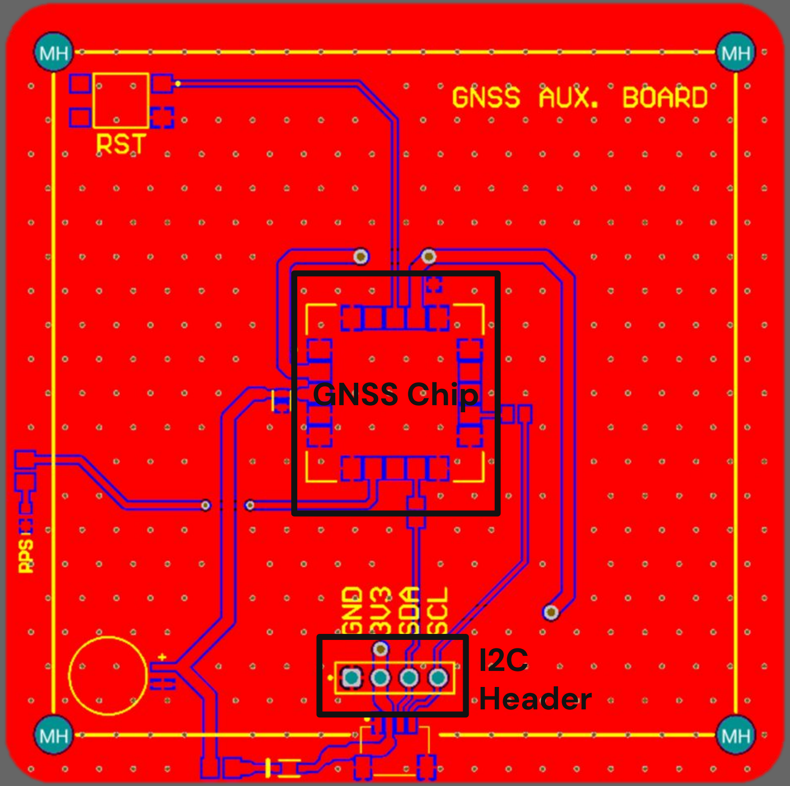


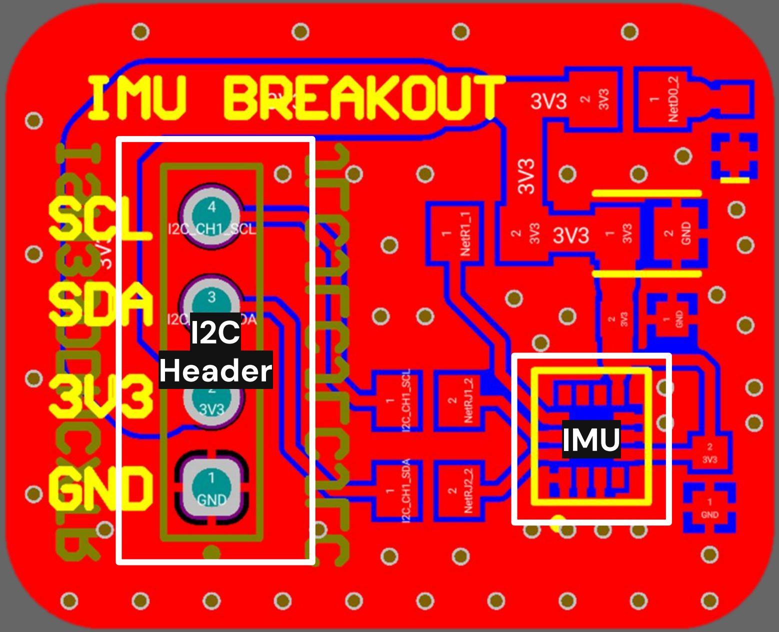
MCU & Power Boards



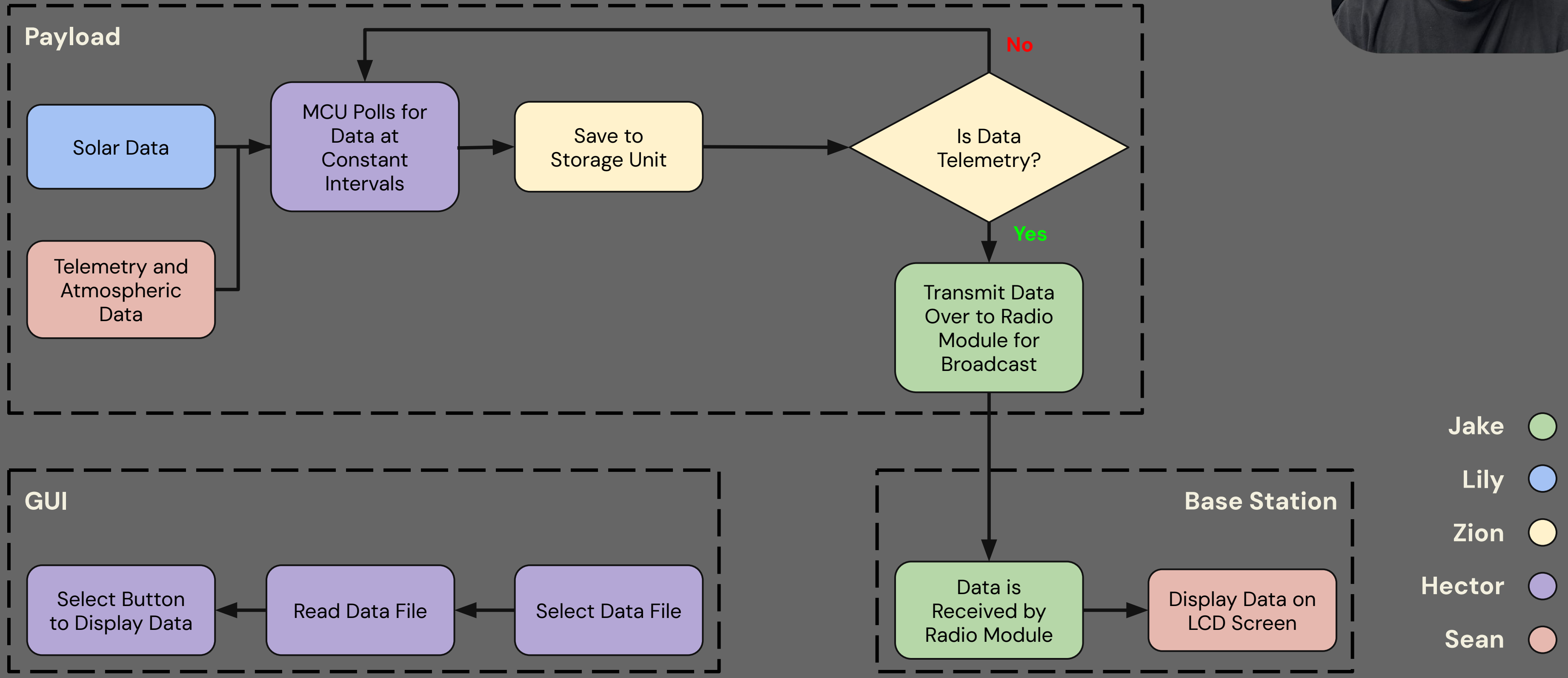


GNSS & IMU Boards





Software Diagram



Payload

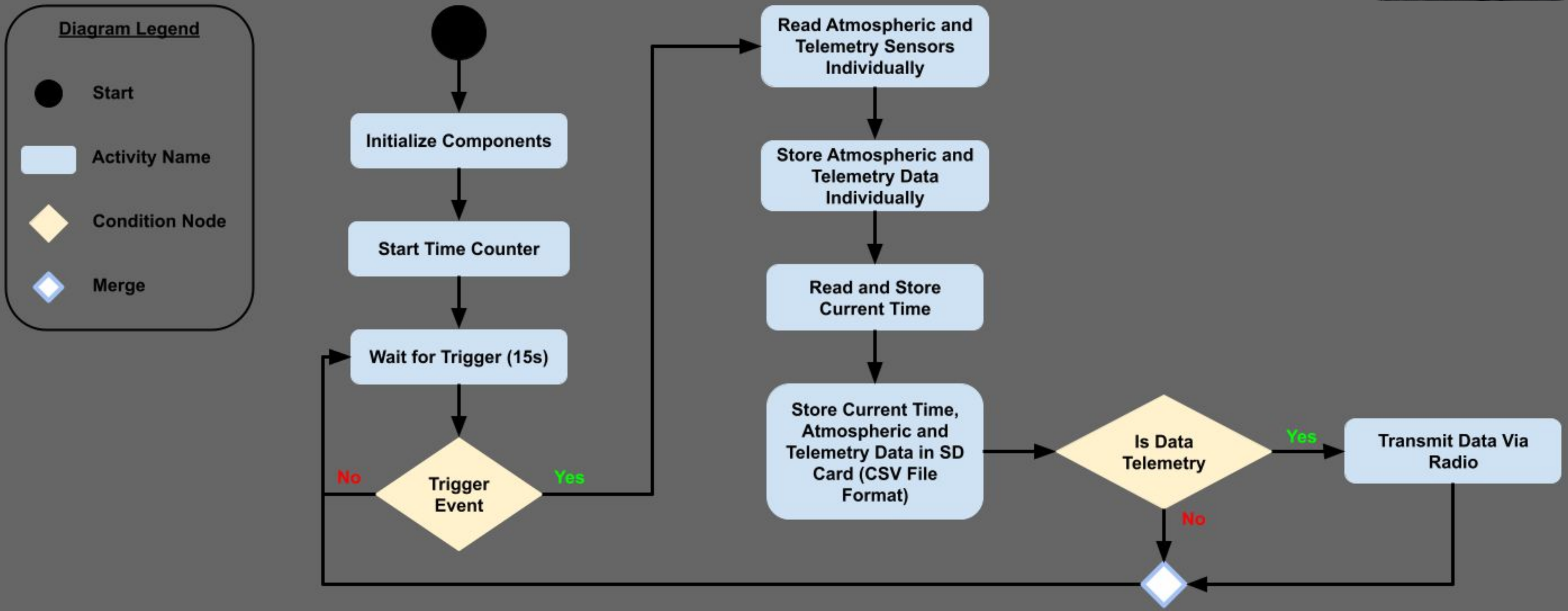
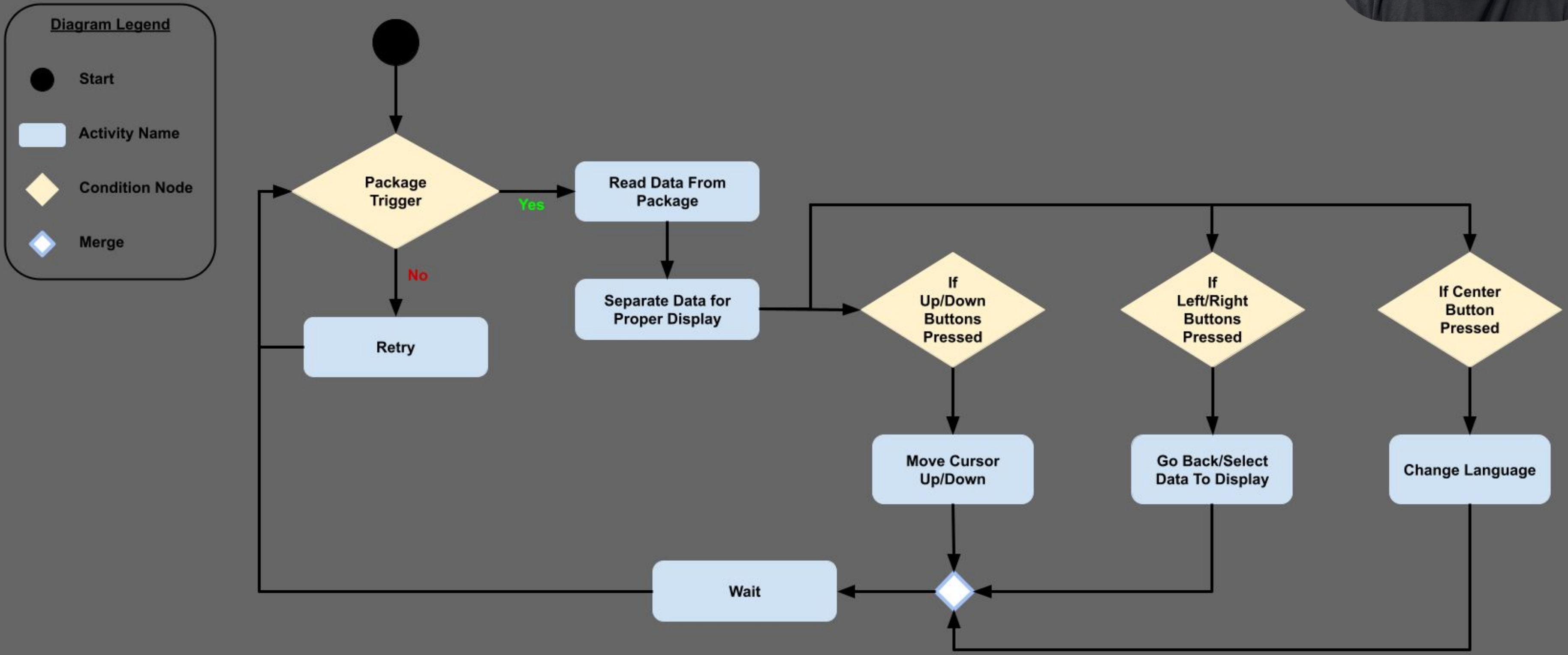


Diagram Legend
Start
Activity Name
Condition Node
Merge
Initialize Components
Start Time Counter
Wait for Trigger (15s)
Trigger Event
No
Yes
Read Atmospheric and Telemetry Sensors Individually
Store Atmospheric and Telemetry Data Individually
Read and Store Current Time
Store Current Time, Atmospheric and Telemetry Data in SD Card (CSV File Format)
Is Data Telemetry
Yes
No
Transmit Data Via Radio

Base Station



GUI

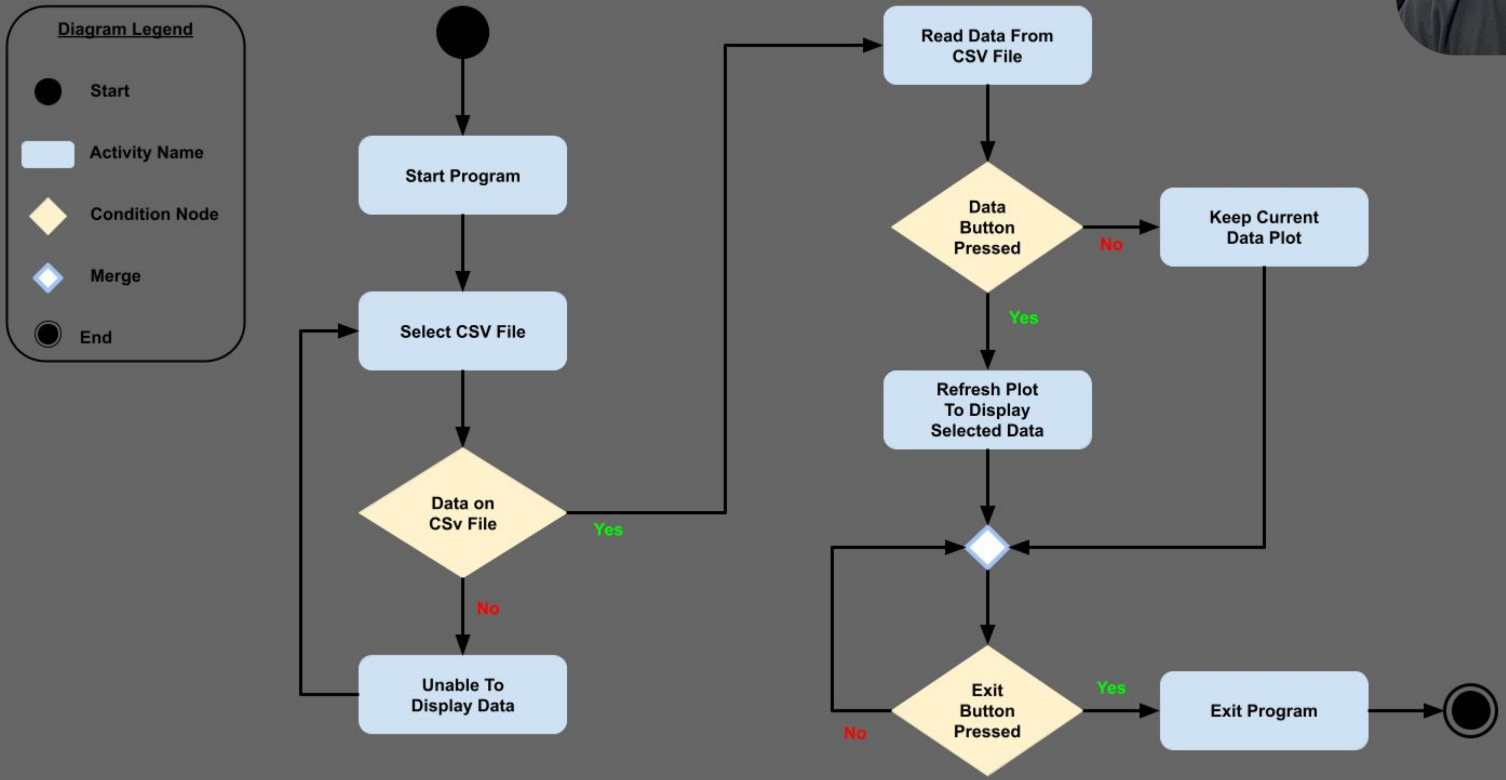


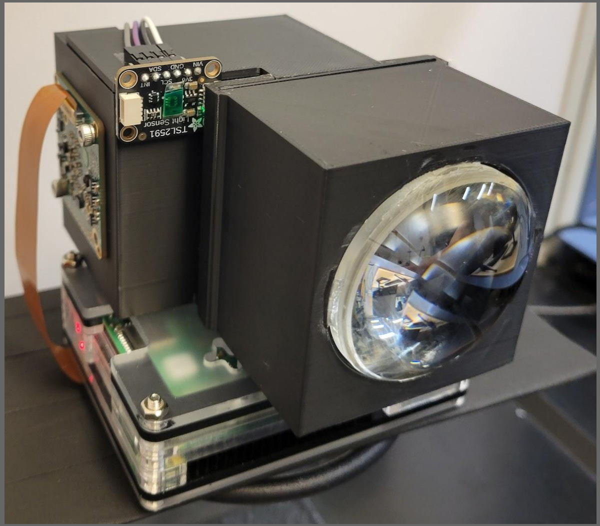
Diagram Legend
Start
Activity Name
Condition Node
Merge
End
Start Program
Select CSV File
Data on CSv File
Yes
No
Unable To Display Data
Read Data From CSV File
Data Button Pressed
No
Keep Current Data Plot
Yes
Refresh Plot To Display Selected Data
Exit Button Pressed
Yes
No
Exit Program

Mechanical Structure

- Several enclosure iterations were designed and 3D printed.
- One box encases the entire payload.
- The lid is held together to the enclosure by straps with rope attaching to the balloon.

Mechanical Structure

- An open polycarbonate box was constructed to hold the base station

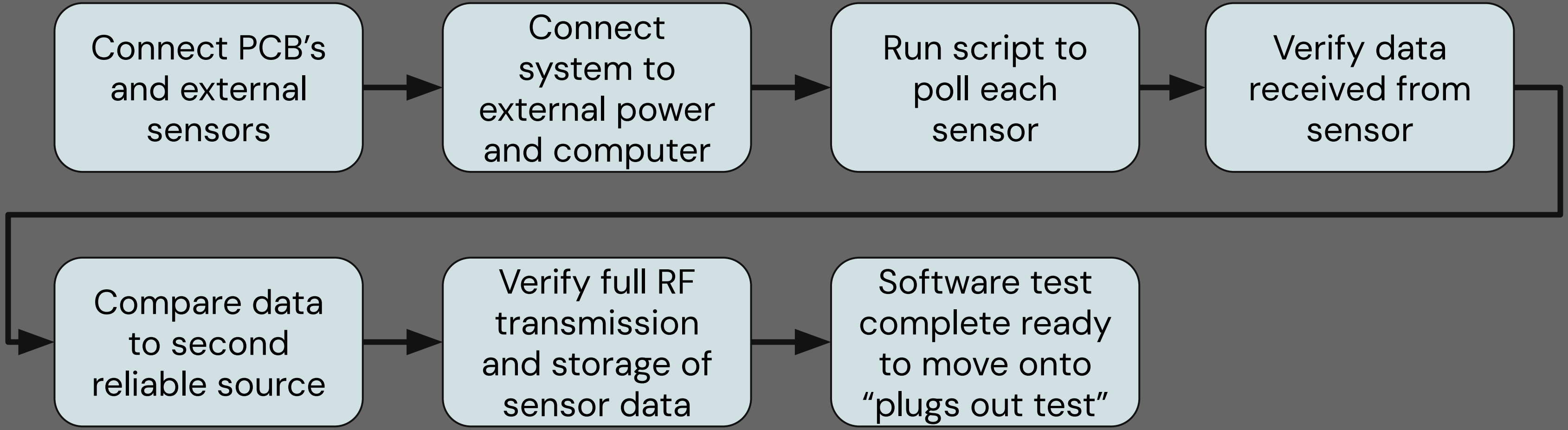


- A custom black box was fabricated to shield the spectrometer from unwanted ambient light.

Hardware Testing

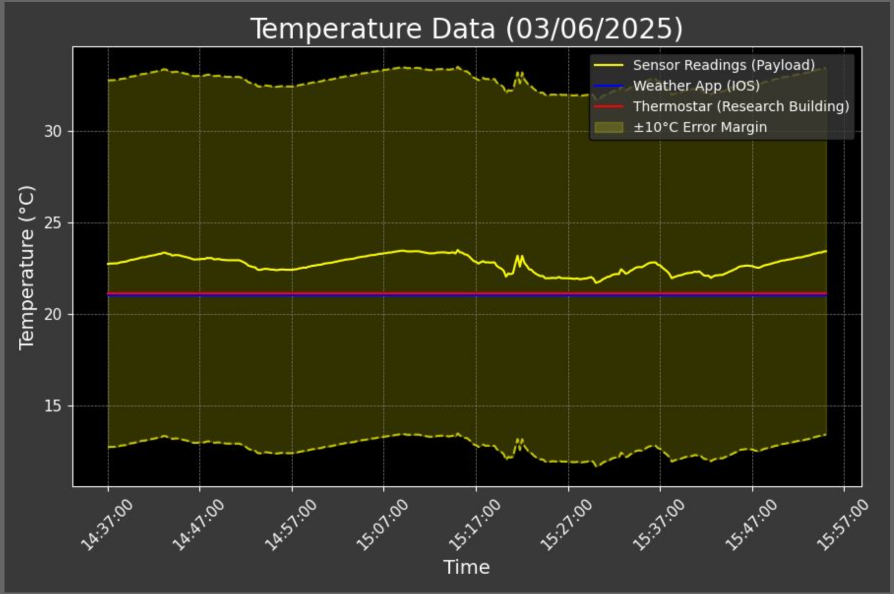
Connect PCB's and external sensors → Connect system to external power and computer → Verify correct voltage on each rail and sensor → Poll information from MCU to ensure SD card storage → Verify RF connection → Connect power board and batteries to system → Verify regulators and subsystem voltages → Hardware test complete ready to move onto "plugs out test"

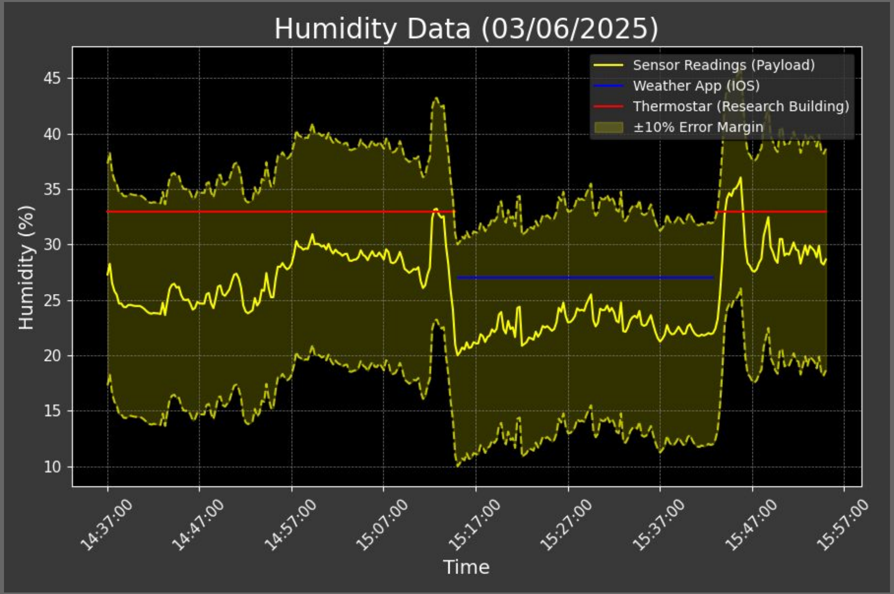
Software Testing



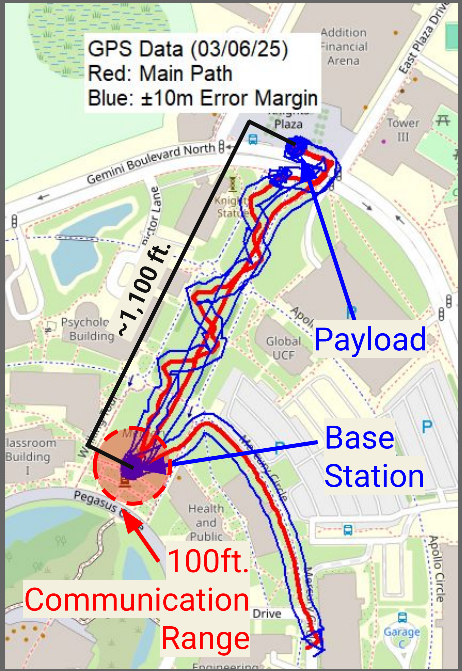
Testing

Payload Testing
(Temp. & Hum. Sensors)

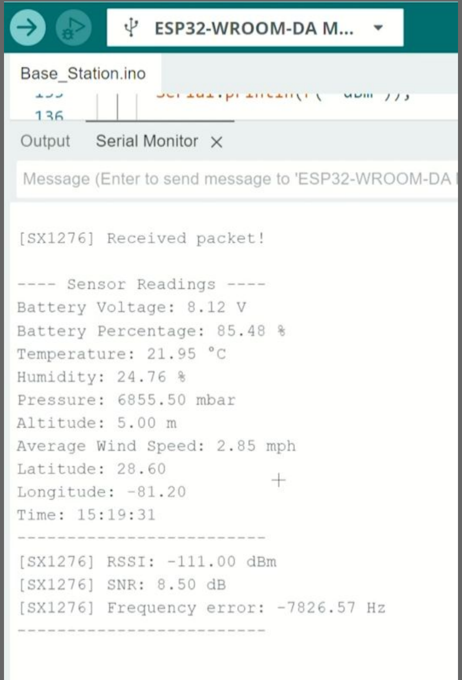




Payload Testing (GPS & RF)



Base Station Testing (RF & Data Logging)


ESP32-WROOM-DA M...

Base_Station.ino

Output Serial Monitor

Message (Enter to send message to 'ESP32-WROOM-DA

```
[SX1276] Received packet!

---- Sensor Readings ----
Battery Voltage: 8.12 V
Battery Percentage: 85.48 %
Temperature: 21.95 °C
Humidity: 24.76 %
Pressure: 6855.50 mbar
Altitude: 5.00 m
Average Wind Speed: 2.85 mph
Latitude: 28.60
Longitude: -81.20
Time: 15:19:31
-------------------------
[SX1276] RSSI: -111.00 dBm
[SX1276] SNR: 8.50 dB
[SX1276] Frequency error: -7826.57 Hz
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```

Plugs Out Test / Performance Evaluation

- Demonstrate all systems and operational procedures in as near a flight configuration as is practical and to verify their capability in a simulated launch

- During this test, showcased in our SD1 Mini Demo, we verify all subsystems and power work together to gather, transmit and store data in a full system level launch simulation test.

Component	**Parameter**	**Specification**	**Tested Range**
Radio	Communication Range	100 feet	1000 feet
Anemometer	Measurement Range	5 – 25 mph	25 mph
Temperature Sensor	Accuracy	+/- 10 °C	< 10 °C
Humidity Sensor	Accuracy	+/- 10% RH	< 10% RH
Pressure Sensor	Accuracy	+/- 10 mbar	< 10 mbar
Altimeter	Vertical Accuracy	+/- 2 meters	< 2 meters
GNSS System	Horizontal Accuracy	+/- 10 meters	< 10 meters
IMU	Bias Instability	6 deg/hr	< 6 deg/hr

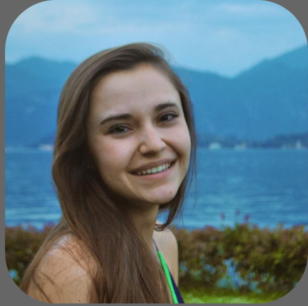
Successes and Challenges

SUCCESSES

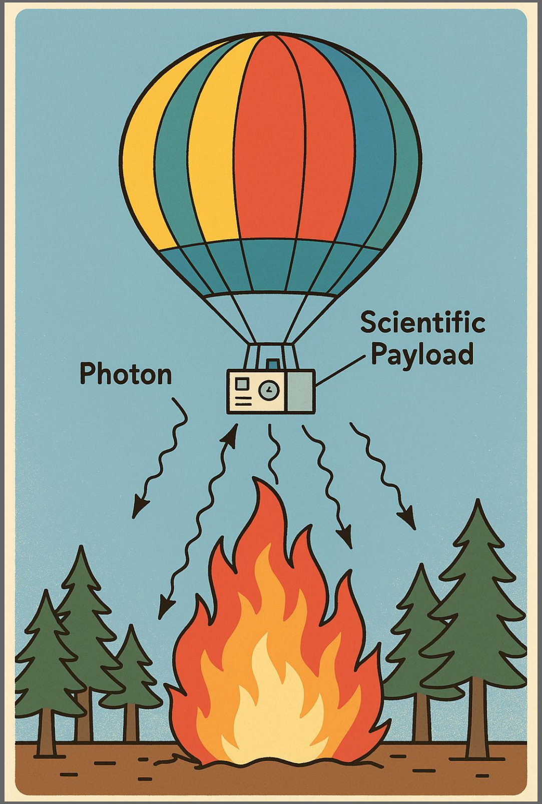
- Achieved an on ground communication range of approximately 1000 feet
- Full systems test complete
- Data interacts interacts and displays on GUI

CHALLENGES

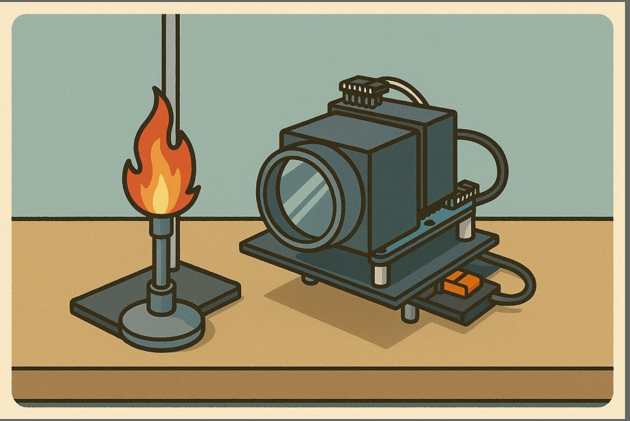
- Difficulties familiarizing ourselves with the equipment and verifying data
- Cooked RF Module during soldering
- Error in PCB text resulting in some confusion



Application to Lab Setting



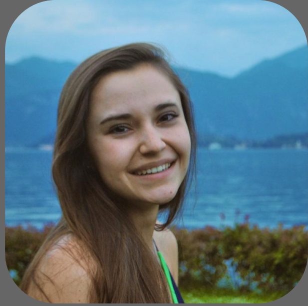
The left image is how our project could be theoretically used in the field. The spectrometer remotely senses flames and determines the ratio of Na to K. The photodiode picks up only green wavelengths to find unburnt areas.



The right image is how our project was tested in the lab. A burner was lit at a set distance and NaCl and KCl were placed in the flame. A monitor displayed a window for the live spectrum and a window for the live lux measurements.

The table on the right shows the conversions from lab setting to actual setting. The minimum mcd we aimed to achieve was 1000.

Compound	Avg Distance	Lux Detected	mcd
NaCl	1.5 ft	7	1463
	150 ft	0.0007	1463
KCl	1 ft	11	1021
	100 ft	0.0011	1021

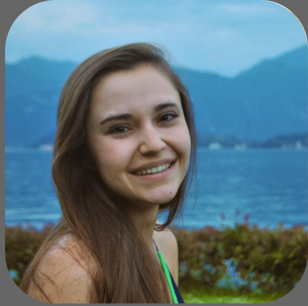


Optical Testing

1. Simulation is run in Zemax
2. Components are aligned on an optical table
3. Collimated halogen lamp is used to prove the concept
4. 3D component holder is designed in CAD & printed
5. Spectrometer is tested with Na & K flame
6. Lux sensor is tested with colored sheets and a flashlight
7. Testing cont' with varying conditions and values
8. Revisions made as needed

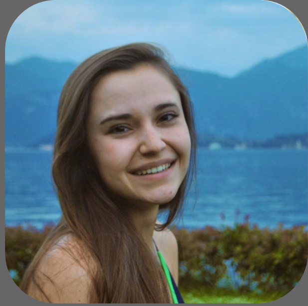
Spectrometer Testing Video: https://youtu.be/Wj1T_9L3c5A
Lux Sensor Testing Video: https://youtu.be/_VsJzEhout0

Spectrometer Results



Test Type	Concentration + Ratio of Salts	Flame Temp. (F*)	Result (Timestamp)	Accuracy (Na: 590 nm K: 404 & 766 nm)	Distance from Flame to Front Lens
NaCl	10 M	1300	0:53	+ 0.7 nm	1.5 feet away
	1 M	1300	1:43	+ 1.5 nm	1.5 feet away
	0.1 M	1300	2:57	+ 0.5 nm	1.5 feet away
	0.01 M	1300	3:37	- 2 nm	1.5 feet away
KCl	10 M	1300	1:19	+ 9 nm & - 20 nm	1.5 feet away
	1 M	1300	2:17	+ 10 nm & - 20 nm	1 foot away
	0.1 M	1300	3:22	+ 10 nm & - 20 nm	1 foot away
	0.01 M	1300	3:45	Unidentifiable	0.5 feet away
NaCl + KCl	3:1	1300	4:33	Na: + 2 nm K: + 11 nm & - 24 nm	1 foot away
	2:1	1300	4:12	Na: + 2 nm K: + 11 nm & - 24 nm	1 foot away
	1:1	1300	3:54	Na: + 2 nm K: + 11 nm & - 24 nm	1 foot away
	1:2	1300	4:44	Na: + 2 nm K: + 11 nm & - 24 nm	1 foot away
	1:3	1300	5:03	Na: + 2 nm K: + 11 nm & - 24 nm	1 foot away

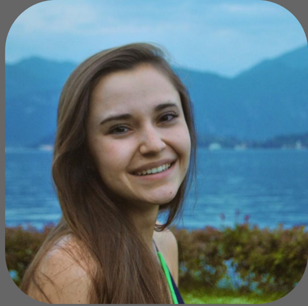
After these tests, the diffraction grating was shifted to increase accuracy and the spectrometer software was improved to resolve the potassium lines and increase accuracy.



Lux Sensor Results

Distance (from surface to sensor)	Test Color	Peak Lux		Results	
		Res = HIGH	Res = MAX	Res = HIGH	Res = MAX
6 inches	Black	0.5	0.4	0:12	0:37
	Red	1.25	1		
	Blue	1.5	1.2		
	Green	2.2	1.8		
12 inches	Black	0.34	0.25	1:03	1:43
	Red	0.62	0.35		
	Blue	0.75	0.46		
	Green	0.96	0.69		
18 inches	Black	0.25	0.2	2:09	2:43
	Red	0.37	0.24		
	Blue	0.43	0.3		
	Green	0.55	0.39		
24 inches	Black	0.22	0.18	3:06	3:35
	Red	0.26	0.2		
	Blue	0.28	0.21		
	Green	0.33	0.25		

Green reflection showed the highest lux measurement in each test variation due to the green filter over the sensor. This indicates the higher the lux detected, the more green there is on the ground.

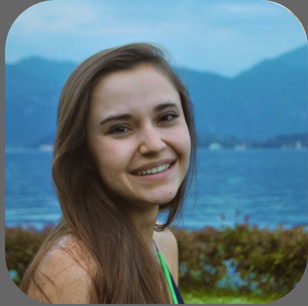


Performance Evaluation

- Using NaCl and KCl mixed in DI water, the spectrometer successfully fulfilled the specifications. The only unsuccessful parameter was the detection distance of potassium: the spectra was readable 0.5 ft but unresolvable at 1 ft.
- Using four different colors of cardboard and a broadband LED flashlight, the testing of reflection at varying distances was successful. The green resulted in a higher lux, meaning the green wavelengths are primarily detected.

Optical Specifications			
	Parameter	**Specification**	**Tested Range**
Overall System	Detection Distance	1 foot	0.5 – 1.5 feet
	NaCl Concentration	min 1 M	0.01 – 10 M
	KCl Concentration	min 1 M	0.1 M – 10 M
Component	**Parameter**	**Specification**	**Tested Range**
CMOS	Wavelength Range	430 nm – 850 nm	430 nm – 850 nm
	Accuracy	+/- 10 nm	+/- 2 – 15 nm
Photodiode	Detection Distance	1 foot	6 – 24 inches

Successes and Challenges



SUCCESSES

- Resolving a full visible spectrum
- Collecting adequate light
- Stable optical containment
- Concept is generally proved

CHALLENGES

- Wavelength accuracy decreases going into the IR region
- Diffraction grating is slightly scratched and oxidized, meaning fuzzy lines
- Accuracy of tree prediction is unknown for densely wooded areas

Thank You