Positioning System

Team 5 - ECE 445

5 May 2025

Abstract

Problem

- Need a way to measure position in extreme environments
- Illinois Space Society attempting to be one of the first student teams to reach space

Solution

- Ground based radio network pings roaming object
- Perform trilateration with 3 unique 1D distances *"Like GPS without the satellites"*

Advantages

- Less reliance on GPS *(Potentially none)*
- Novel redundant tracking solution
- High theoretical tracking speeds *(Mach 5)*

Applications

- Warehouse automation
- Drones and autonomous vehicles
- Sports ball tracking
- Aerospace

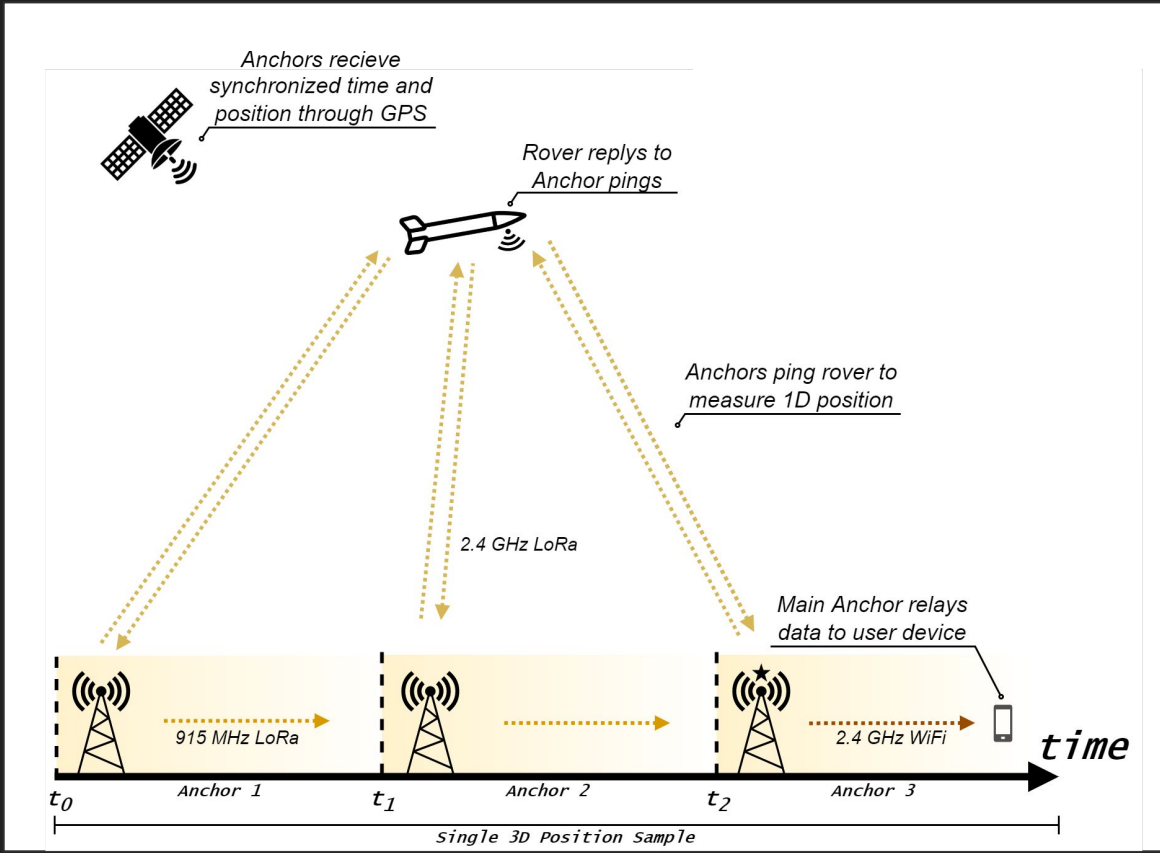
Concept Of Operations

High Level Requirement Summary

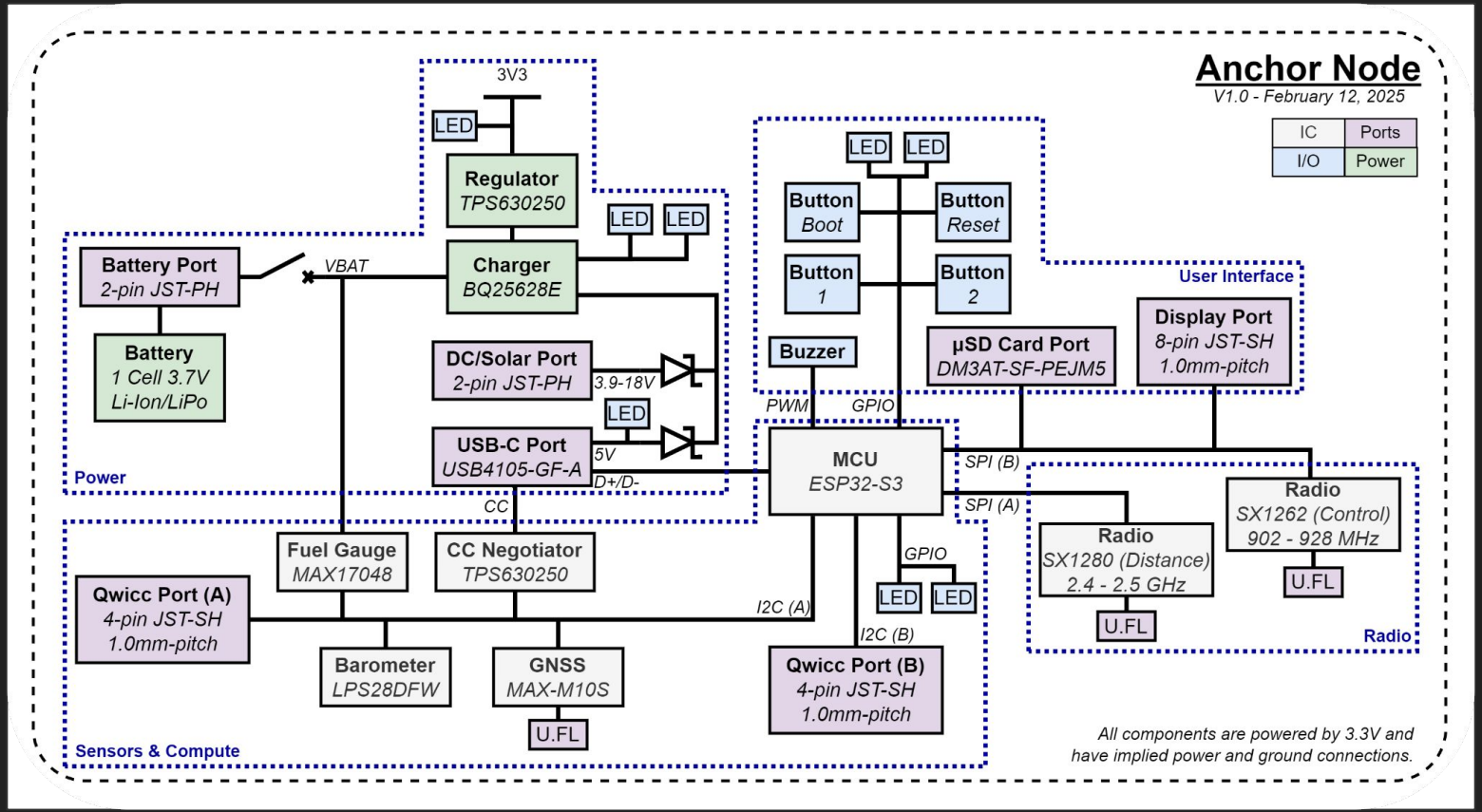
I. Perform trilateration of a Rover

II. Communicate between two Anchors

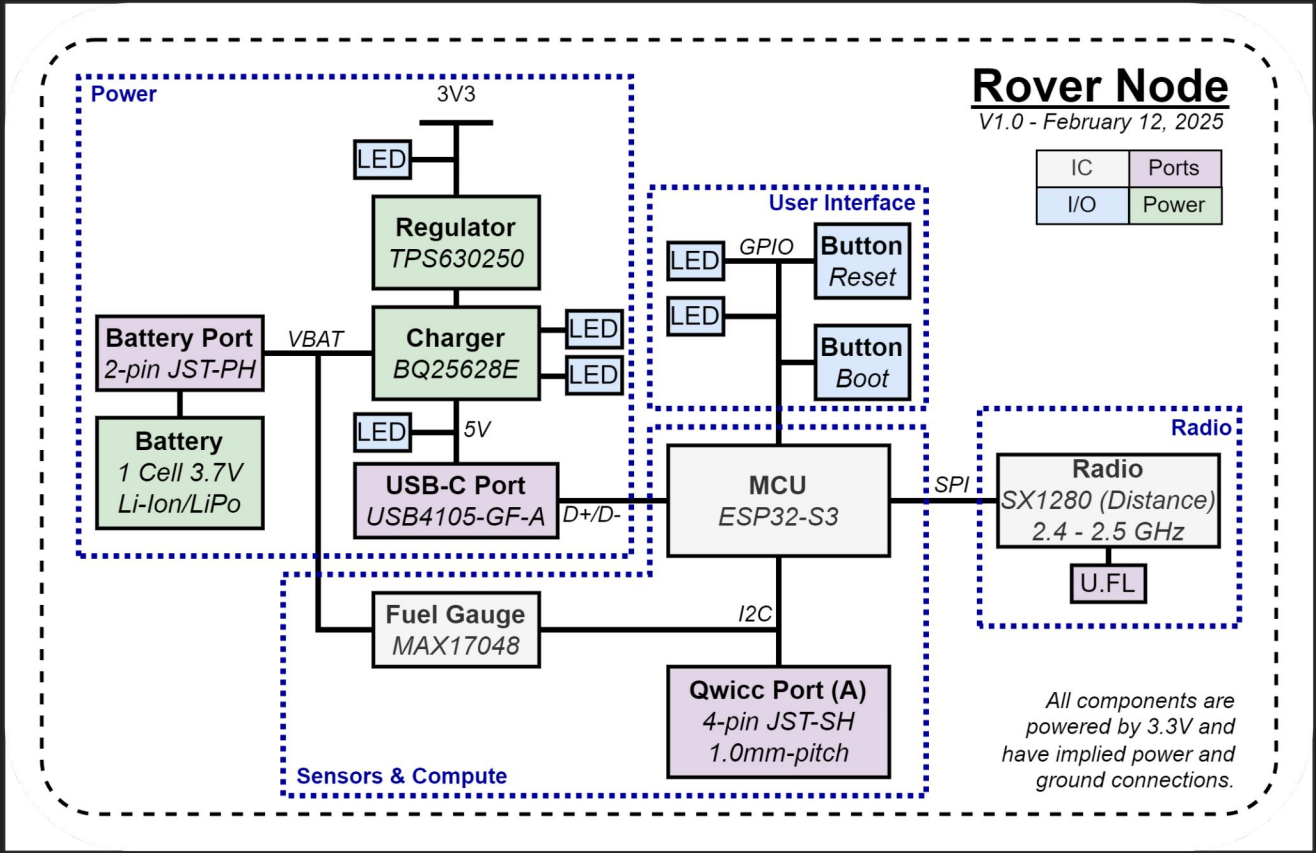
III. Publish data to a local WiFi webpage



Block Diagram: Anchor



Block Diagram: Rover



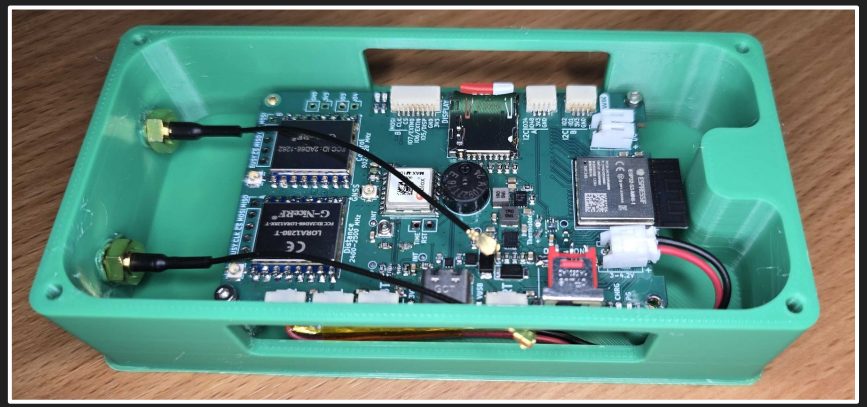
PCBs

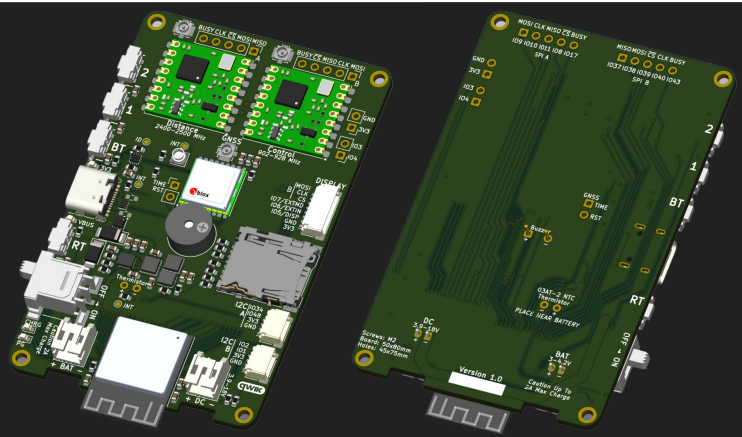
Anchor

- 4 Layer, 0603
- F.Cu populate only for easy assembly

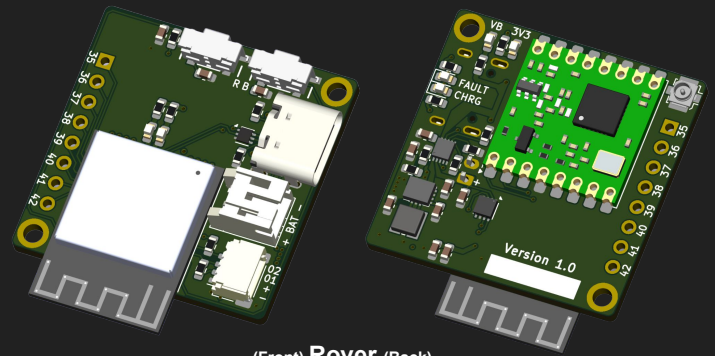
Rover

- 4 Layer, 0603
- Both sides populated for space savings





(Front) **Anchor** (Back)



(Front) **Rover** (Back)

Mechanical Integration

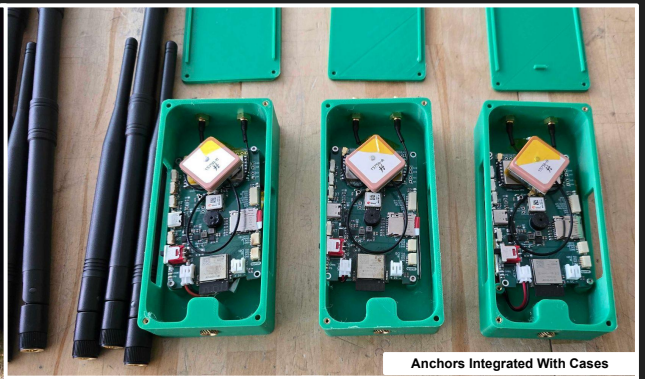
Case

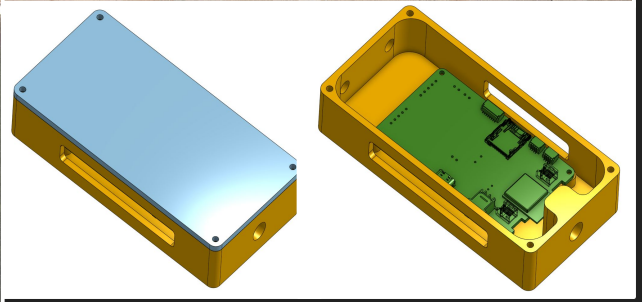
- Battery
- Anchor Node
- SMA to U.FL Adapters
- GPS Ceramic Patch Antenna
- 3/16" Thread for Tripod
- Full access to all ports

Tripods

- Easy field deployment
- Compact yet tall *(7 feet)*


Anchors Integrated With Tripods


Anchors Integrated With Cases



Design Changes

PCB

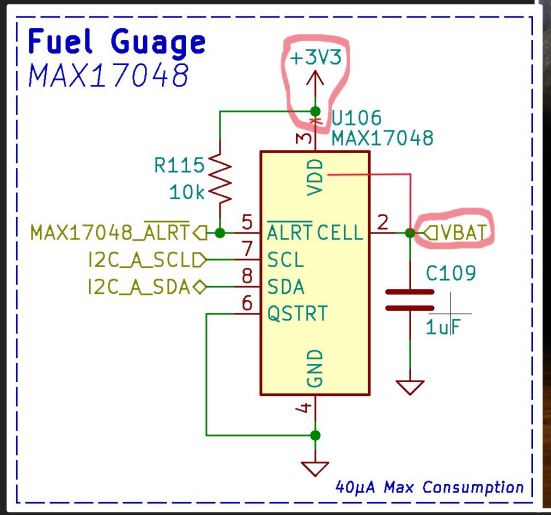
- Descoped USB-C PD negotiation chip *(Not needed)*
- Fuel gauge connected to 3.3V instead of VBAT *(Wrong)*

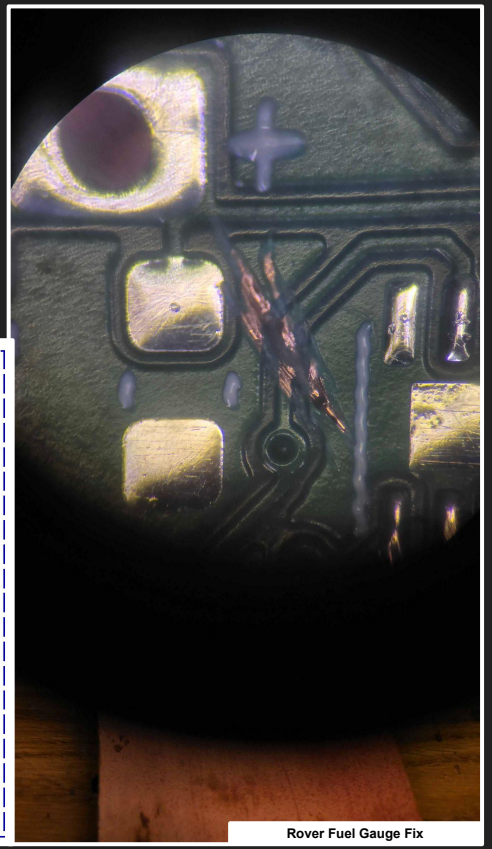
RF

- Switch to directional antennas for ranging

Software

- Went with Arduino framework
  (Faster development)

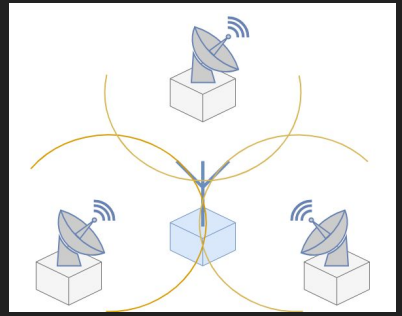



Rover Fuel Gauge Fix

Software Integration

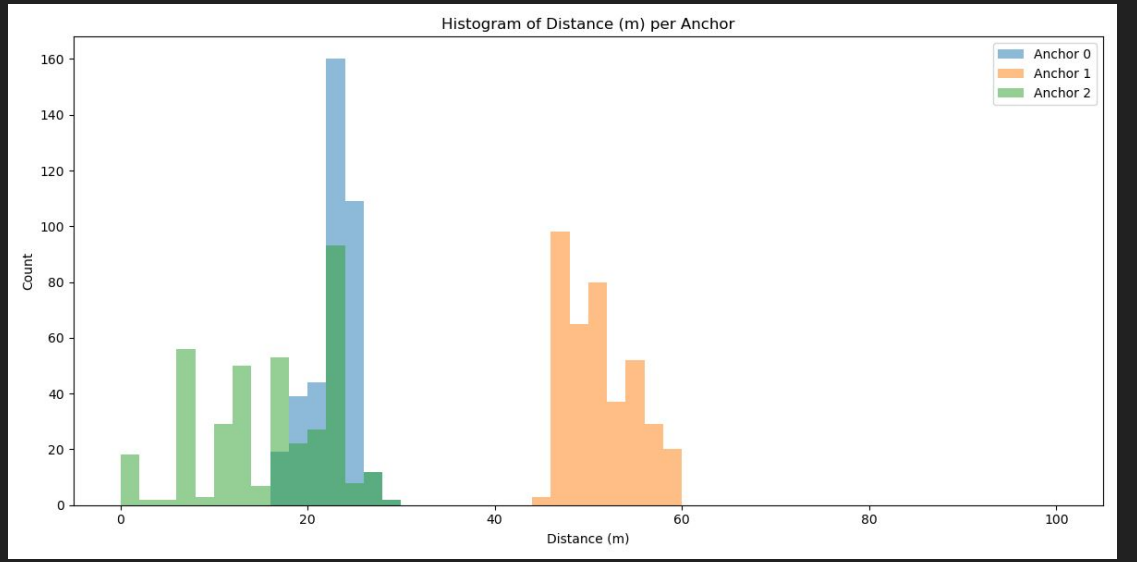
FreeRTOS:

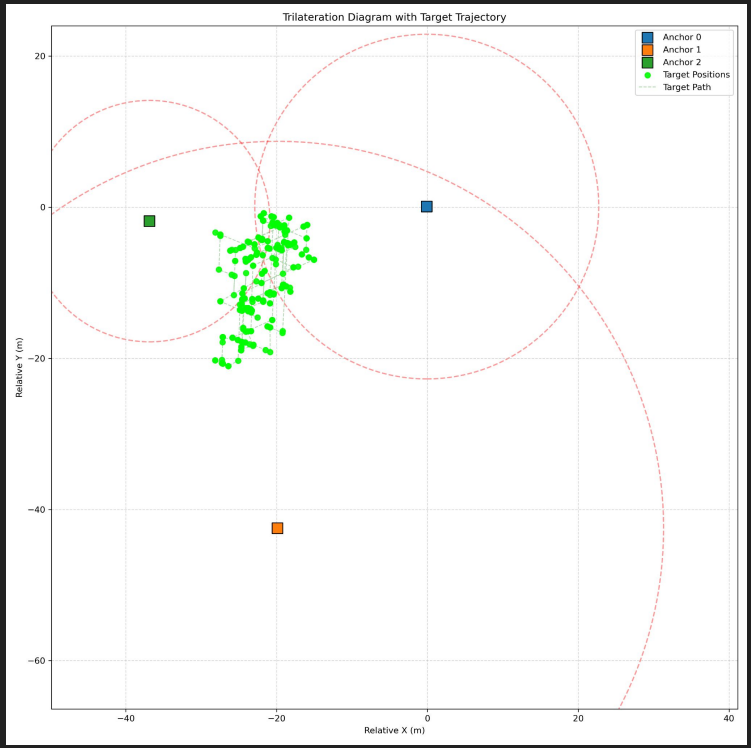
Real-Time Operating System enables our system to integrate complex tasks that meet our High Level Requirements:



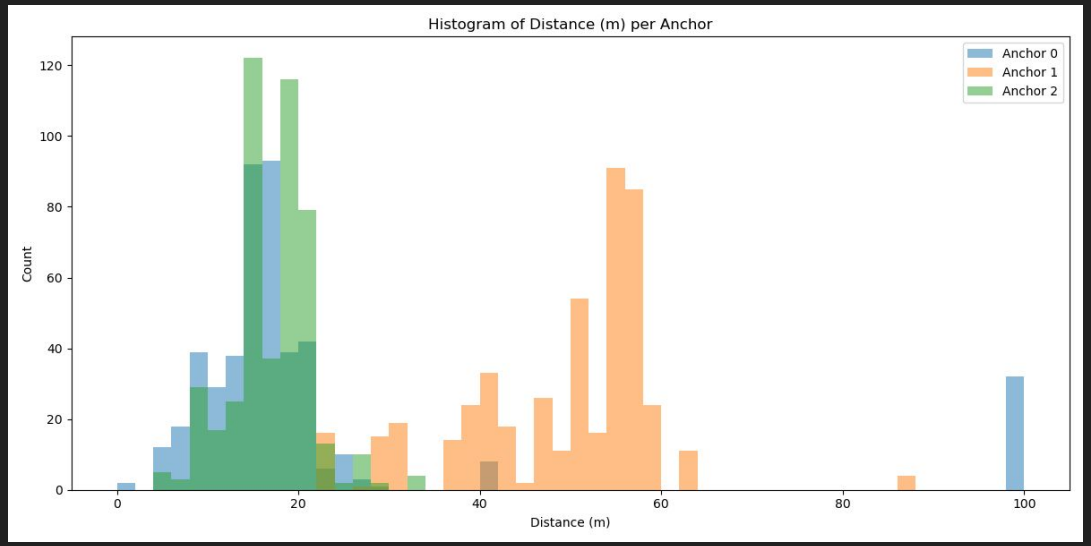
High Level Requirements	Software Implementation
I. Perform trilateration of a Rover	I. C++ application that performs filtering methods (kalman filter + outlier removal) on sensor readings and least squares to approximate Rover position
I. Communicate between two Anchors	I. Implement strict, millisecond-precise timing window for interference-free RF communication
I. Publish data to a local WiFi webpage	I. Wifi host application that broadcasts system status, sensor readings and calculations.

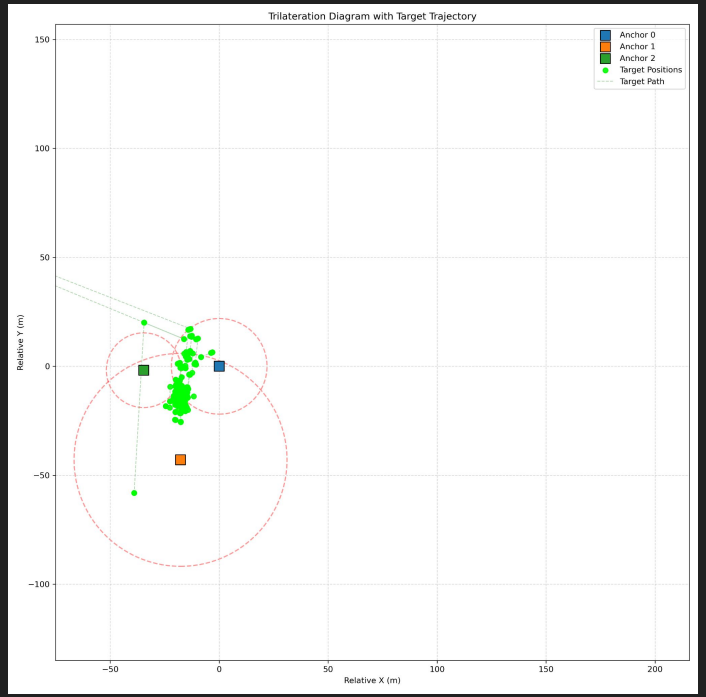
Field Testing





Field Testing (w/ Kalman Filter)





Calibration

Raw GPS Locations

Rover: 40.1149417, -88.2273388
Anchor 0: 40.1149197, -88.2275559
Anchor 1: 40.1152807, -88.2273501
Anchor 2: 40.1149406, -88.2271447

Ranging Distances to Rover

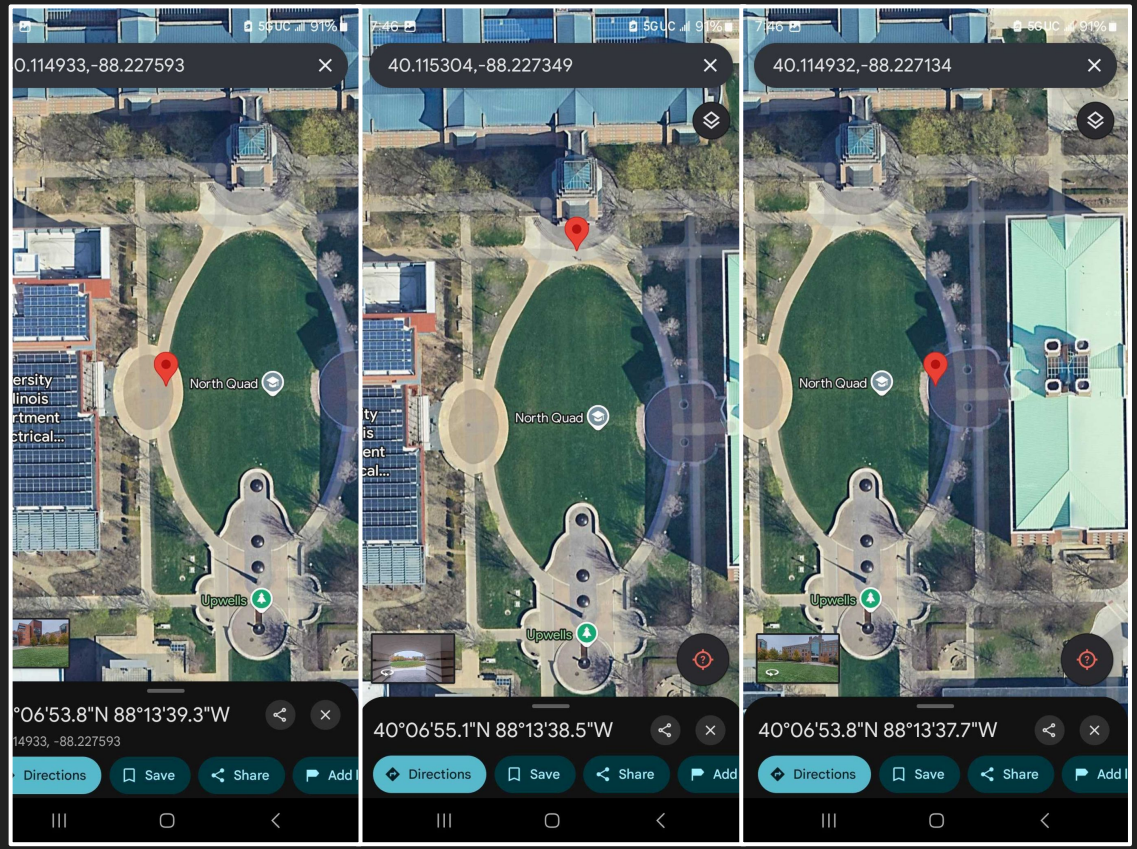
Anchor 0: 35.70m
Anchor 1: 88.36m
Anchor 2: 27.98m

GPS Distances to Rover (Map Pins)

Anchor 0: 18.54m
Anchor 1: 38.32m
Anchor 2: 16.23m

Difference Factor

Anchor 0: 1.925566
Anchor 1: 2.305845
Anchor 2: 1.723967



Requirement & Verification

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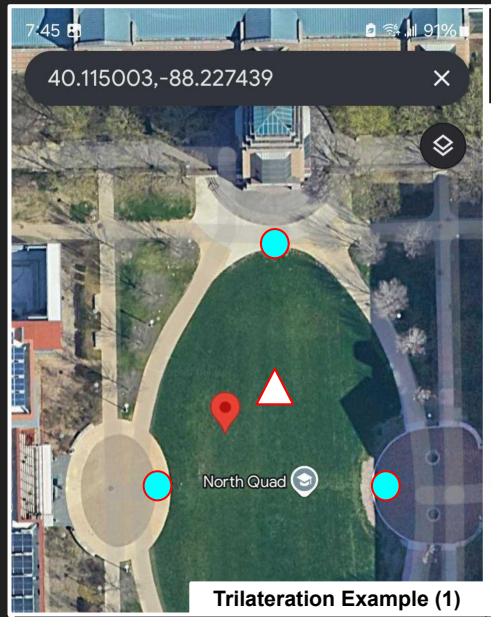
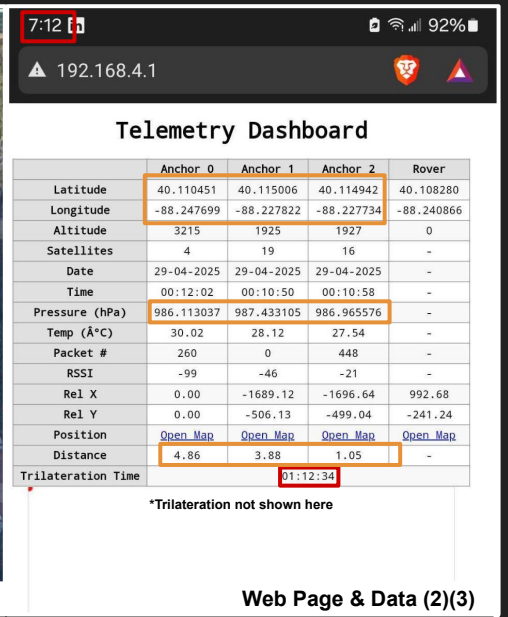
5 May 2025

High Level Requirements

1. Perform 3D trilateration of a Rover node at a minimum distance of 20 meters from at least one anchor node with a sample rate of at most 2 second. Sample rate is defined as the time period a position reading is resolved. ✅
2. Relay barometer, GNSS, and at minimum one other data point to another node in the network with a latency of less than 2 seconds. Latency is defined as the time from an initial sensor reading to reception by another member of the network. ✅
3. Publish position data to a local WiFi network in at most 5 seconds delay between receiving initial sensor or calculated data to receiving on WiFi. ✅



Trilateration Example (1)



Telemetry Dashboard

	Anchor 0	Anchor 1	Anchor 2	Rover
Latitude	40.110451	40.115006	40.114942	40.108280
Longitude	-88.247699	-88.227822	-88.227734	-88.240866
Altitude	3215	1925	1927	0
Satellites	4	19	16	-
Date	29-04-2025	29-04-2025	29-04-2025	-
Time	00:12:02	00:10:50	00:10:58	-
Pressure (hPa)	986.113037	987.433105	986.965576	-
Temp (Â°C)	30.02	28.12	27.54	-
Packet #	260	0	448	-
RSSI	-99	-46	-21	-
Rel X	0.00	-1689.12	-1696.64	992.68
Rel Y	0.00	-506.13	-499.04	-241.24
Position	Open Map	Open Map	Open Map	Open Map
Distance	4.86	3.88	1.05	-
Trilateration Time			01:12:34	

*Trilateration not shown here

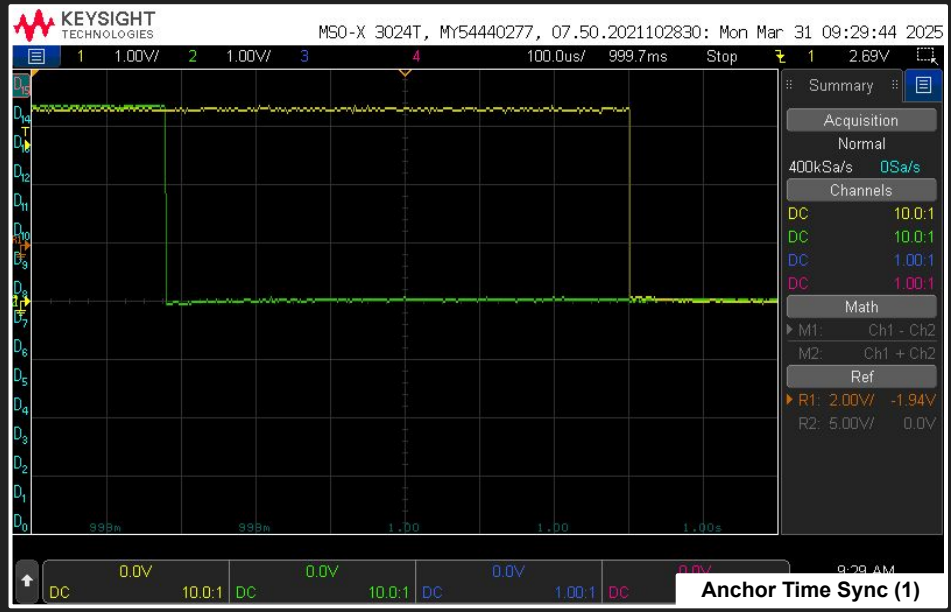
Web Page & Data (2)(3)

Key

- Anchor
- Rover Actual
- Rover Measured
- GNSS, Barometer, Distance
- Web Page Update Time

Anchor

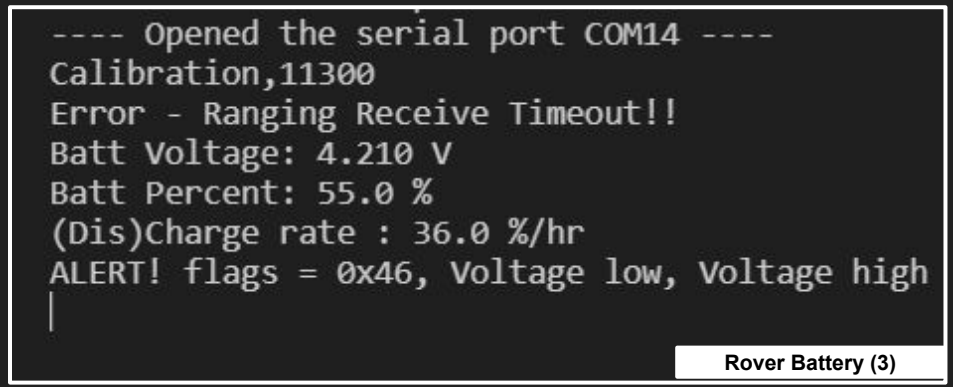
1. Anchor nodes must have synchronized time with less than 200 ms offset ✅ *(Image)*
2. Anchor must be able to receive GPS transmissions at least once every two seconds ✅ *(Previous Slide)*
3. Anchor must have at least two status LEDs and at least one I2C expansion port ✅ *(Live Demo Validation)*
4. Anchor must be able to operate from 4.2V battery ✅ *(Live Demo Validation)*
5. Anchor must be able to determine altitude from two or more means (GPS & Barometer) ✅ *(Previous Slide)*



(Only a 600 uS offset after losing GPS synchronization for ~15 minutes! to take measurement)

Rover

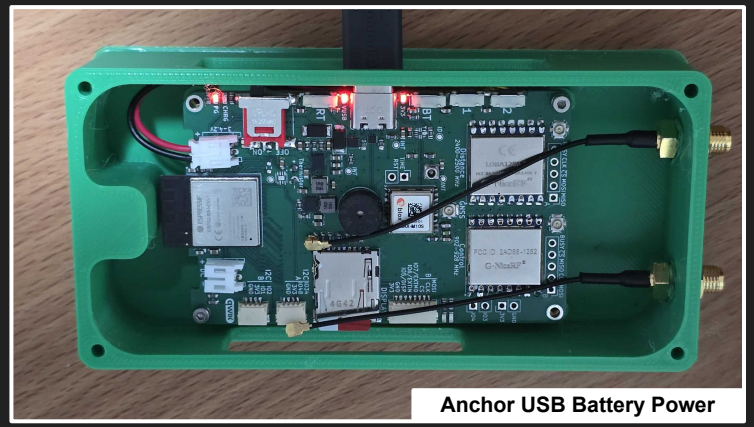
1. *Nodes must automatically respond to Anchor ping requests in less than 500µs. ✅ *(Live Demo Validation)*
2. Rover must have at least two status LEDs and at least one I2C expansion port ✅ *(Live Demo Validation)*
3. Rover must be able to operate from ~3.3V battery ✅ *(Live Demo Validation)*



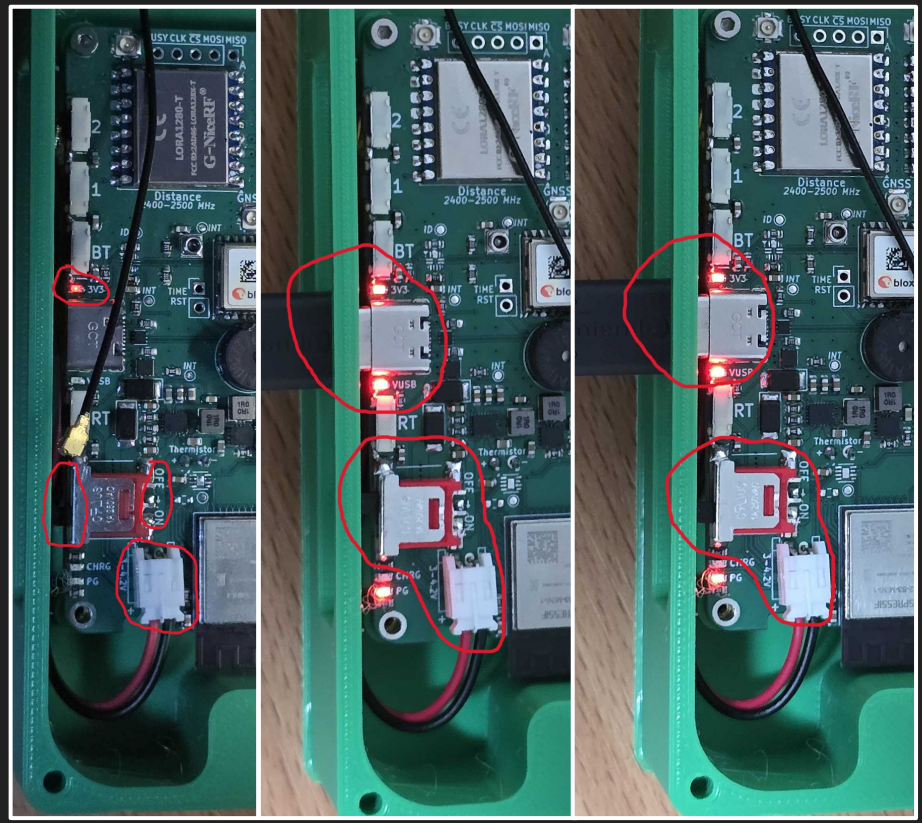
Rover Battery (3)

Power

1. Voltage regulator must output 3.3V and supply 2A at maximum ✅ *(Live Demo & Image)*
2. Battery charger must be configurable with GPIO and resistors, or I2C ✅ *(Battery Charges)*
3. Battery charger must accept 1S 3.7V LiPo batteries and automatically switch between USB and battery power sources. ✅ *(Live Demo Validation)*



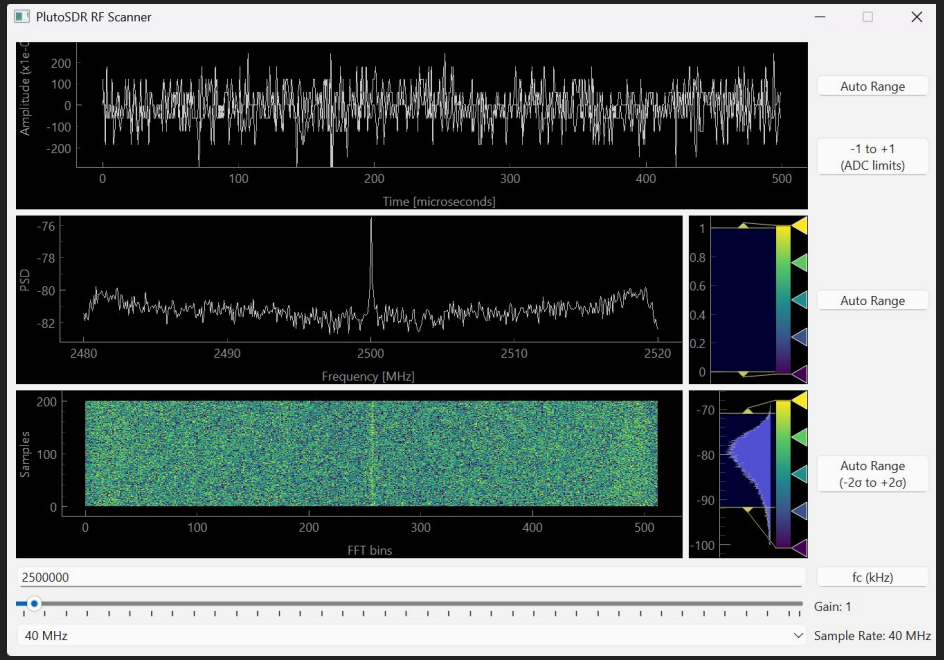
Anchor USB Battery Power



Radios

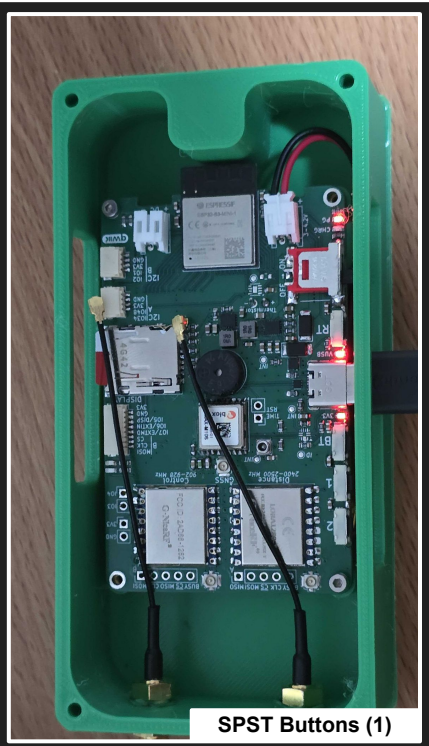
1. Radio systems must use separate frequency bands to avoid congestion ✅ *(Image)*
2. Radios must occupy ISM bands for license free operation ✅ *(Image)*
3. Radios must use SPI or I2C for communication with MCU✅ *(Live Demo Validation)*

SX1280 (Ranging)

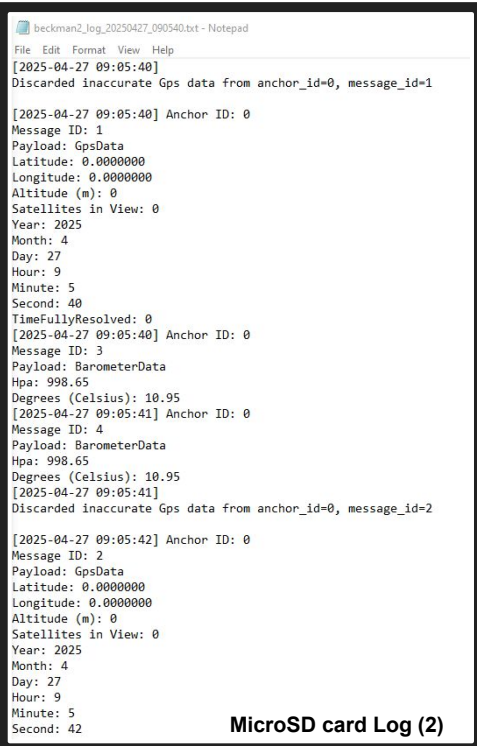


User Interface

1. MCU must have SPST buttons to enable programming ✅ *(Image)*
2. MicroSD card must interface with at most 32GB FAT32 cards over SPI ✅ *(Image)*



SPST Buttons (1)



beckman2_log_20250427_090540.txt - Notepad

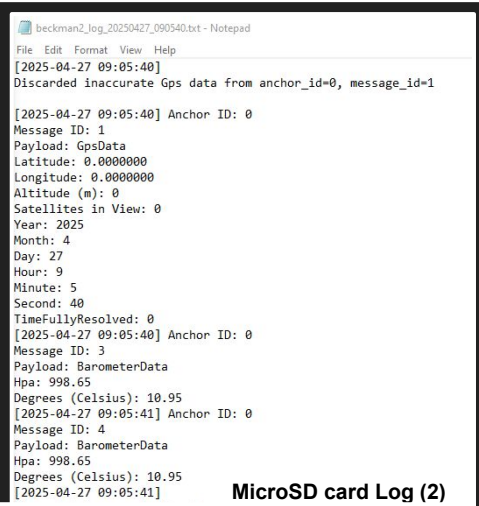
File Edit Format View Help

```
[2025-04-27 09:05:40]
Discarded inaccurate Gps data from anchor_id=0, message_id=1

[2025-04-27 09:05:40] Anchor ID: 0
Message ID: 1
Payload: GpsData
Latitude: 0.0000000
Longitude: 0.0000000
Altitude (m): 0
Satellites in View: 0
Year: 2025
Month: 4
Day: 27
Hour: 9
Minute: 5
Second: 40
TimeFullyResolved: 0
[2025-04-27 09:05:40] Anchor ID: 0
Message ID: 3
Payload: BarometerData
Hpa: 998.65
Degrees (Celsius): 10.95
[2025-04-27 09:05:41] Anchor ID: 0
Message ID: 4
Payload: BarometerData
Hpa: 998.65
Degrees (Celsius): 10.95
[2025-04-27 09:05:41]
Discarded inaccurate Gps data from anchor_id=0, message_id=2

[2025-04-27 09:05:42] Anchor ID: 0
Message ID: 2
Payload: GpsData
Latitude: 0.0000000
Longitude: 0.0000000
Altitude (m): 0
Satellites in View: 0
Year: 2025
Month: 4
Day: 27
Hour: 9
Minute: 5
Second: 42
```

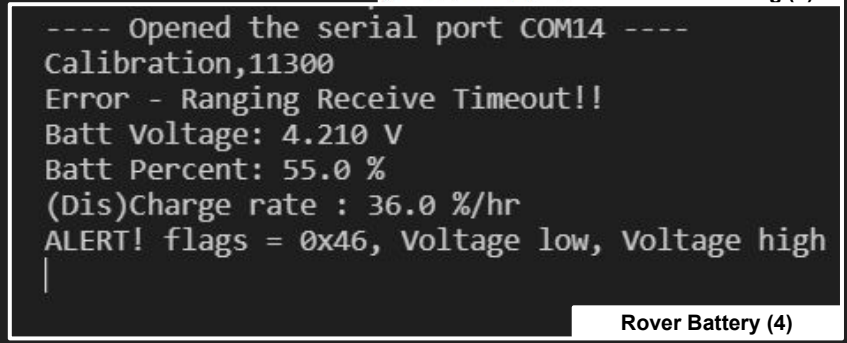
MicroSD card Log (2)

Sensors & Compute

1. All sensors must communicate over at least one of the following protocols – SPI, I2C, PWM – and draw 3.3V. ✅ *(Previous Slide - High Level)*
2. Barometer must output a resolution of at least 1 meter ✅ *(Previous Slides - High Level)*
3. GPS module must output 1 Hz time pulse and position within 3 meters ✅ *(Previous Slides - High Level & Anchor)*
4. Fuel gauge must read cell voltage and communicate over at least one of the following protocols – SPI, I2C, PWM ✅ *(Image)*
5. *MCU have a clock speed greater than 100 MHz and communicate over all of the following protocols – SPI, I2C, PWM – to interface with all modules. ✅ *(High Level Requirements Already Met)*



MicroSD card Log (2)



Rover Battery (4)

Future Work

Conclusion

5 May 2025

Summary

Success

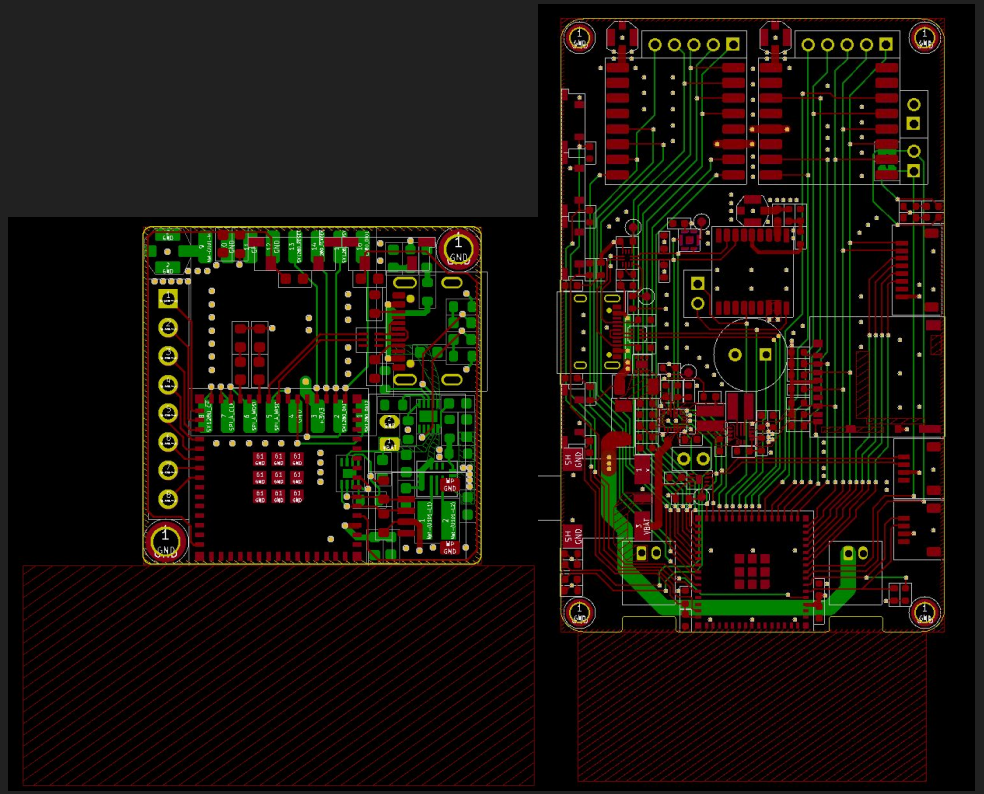
- Good trilateration minimum viable product
- Efficient timeline management (Early PCBs)
- Hardware test platform for future projects

Challenges

- Soldering ESP32-S3 with QFN pads
- Buttons being too fragile
- RTOS telemetry and logging queue
- Noise in distance readings
- Lower RSSI only on Anchor 0

Fun Facts

- Only one board design and assembly run
- Total cost ~$650 *(Dev board included)*
- 20 files and +3,000 lines of software
  (Estimating 10,000 lines from testing)



Future Work

Software

- Kalman filter & outlier detection
- User programmability through web page

PCB

- Find more durable SPST buttons
- Fix USB-C and Anchor battery monitor
- Explore better impedance matching

Mechanical

- Reprint cases to be stronger
- Add rubber lid to case ports

Testing

- Integrated flight testing on vehicles
- Longer range testing above 1 km

(And much more…!)

GPS Time Sync Testing

Questions / Comments

Thank You