SNOW DEPTH INFORMATION AND MITIGATION BEFORE AVALANCHES

Spring Final Review (SFR)

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SPONSORS

:

Project Purpose and Objectives

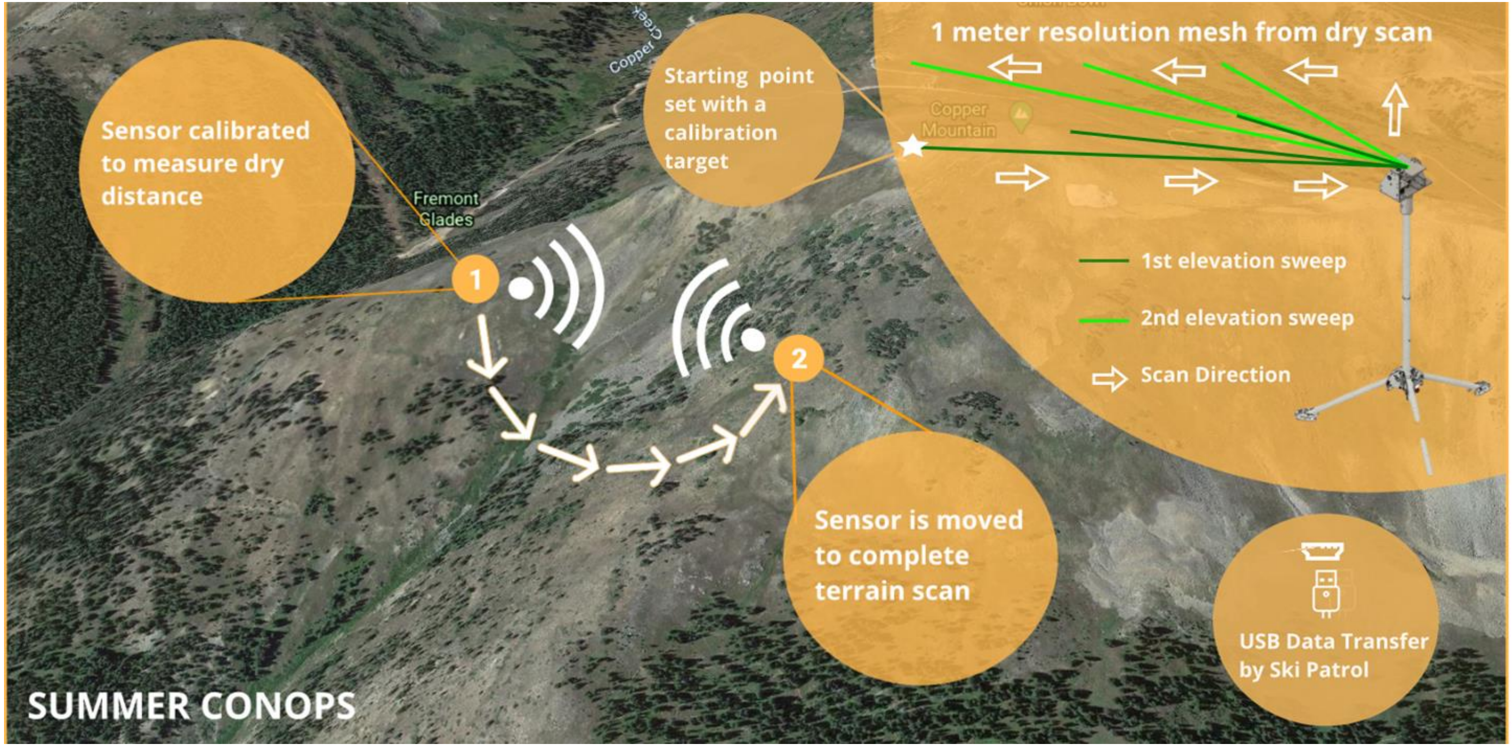
SIMBA

Project Purpose

The Problem: Avalanche Mitigation

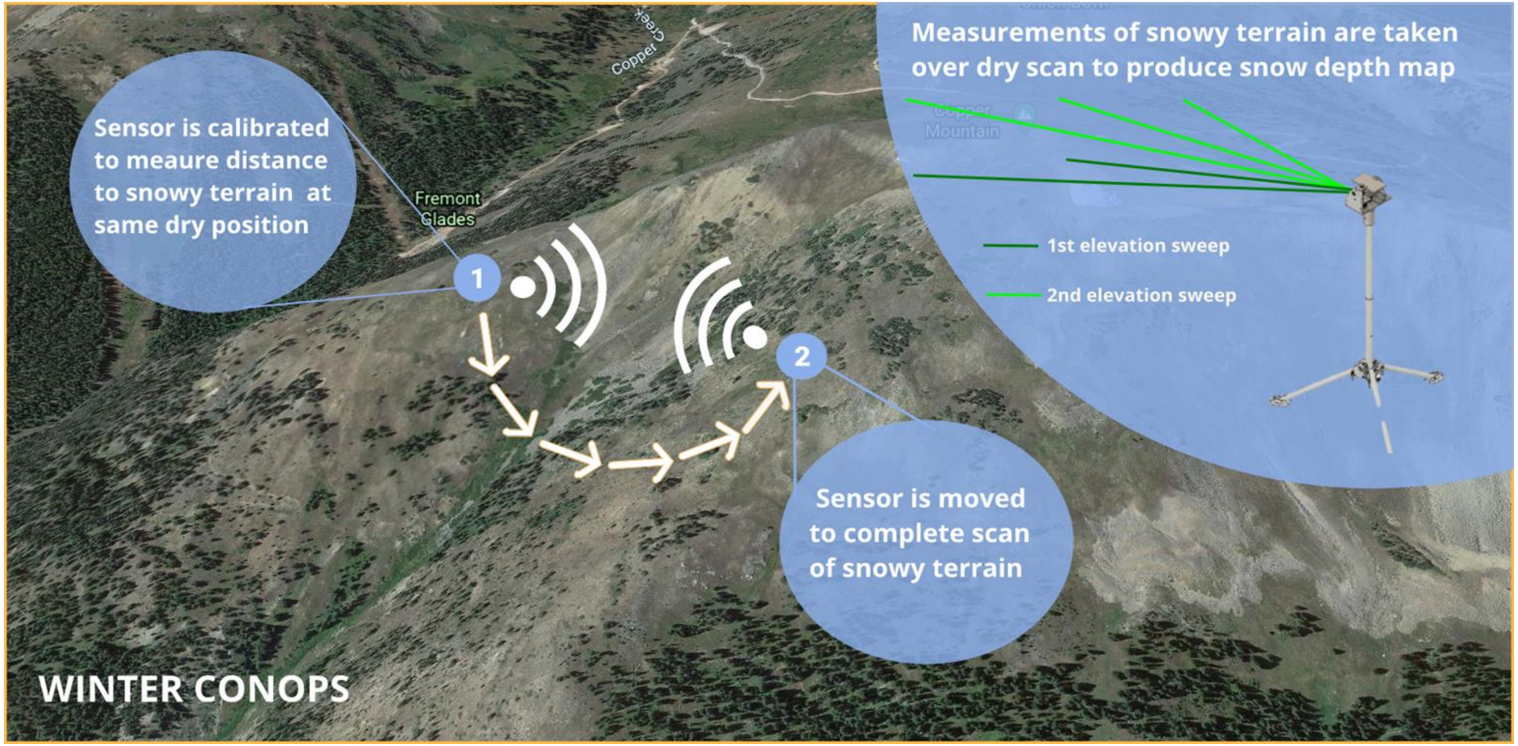
- Currently,
  - Ski patrol dig snow pits in avalanche prone areas to determine risk
    - Measure snow depth
    - Examine snow layers
  - Lack of snow depth data results in many pits needed to be dug
  - Dangerous, laborious, and time consuming
- Our system remotely measures snow depth
  - Snow pit locations will be more targeted
    - Reduces number of snow pits required
  - Reduces time and effort spent in avalanche prone areas
  - Reduces ski patrol risk exposure

CONOPS



1 meter resolution mesh from dry scan
Starting point set with a calibration target
Copper Creek
Copper Mountain
Sensor calibrated to measure dry distance
Fremont Glades
1
2
1st elevation sweep
2nd elevation sweep
Scan Direction
Sensor is moved to complete terrain scan
USB Data Transfer by Ski Patrol
SUMMER CONOPS

CONOPS


Measurements of snowy terrain are taken over dry scan to produce snow depth map
Copper Creek
Fremont Glades
Copper Mountain
Sensor is calibrated to meaure distance to snowy terrain at same dry position
1
2
1st elevation sweep
2nd elevation sweep
Sensor is moved to complete scan of snowy terrain
WINTER CONOPS

Functional Requirements

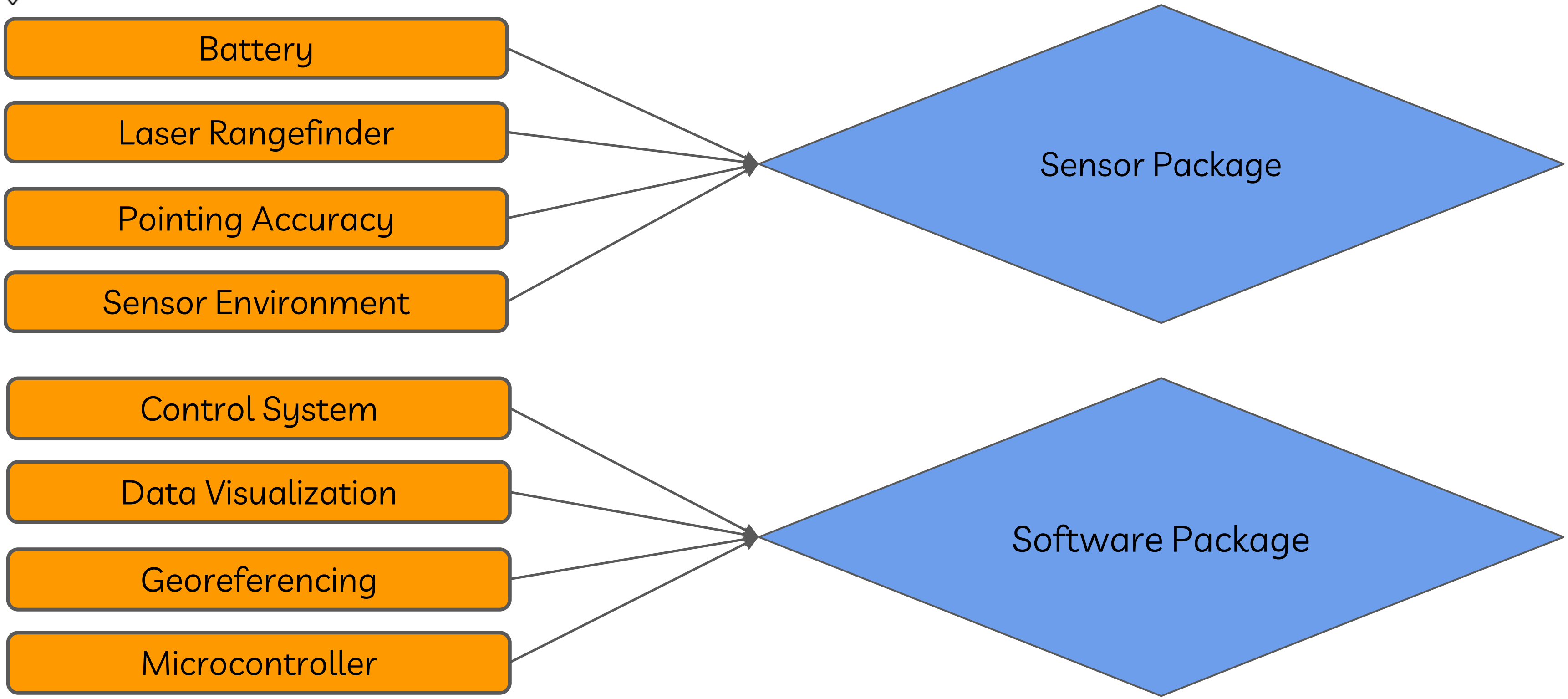
FR 1	The system shall **implement a snow depth detection system** to assist Copper Mountain ski patrol in avalanche mitigation
FR 2	The system shall be able to operate with acceptable endurance such that **data collection will occur in a reasonable amount of time**
FR 3	The system shall be able to **operate in the typical weather conditions** found on the top of Copper Mountain
FR 4	The system shall be able to **collect the required data, store the data, and transfer the data** to Copper Mountain ski patrol **through available interfaces** (Data Storage)
FR 5	The system shall **process the data collected and present snow depth data** to Copper Mountain ski patrol in the software found at their facilities
FR 6	The system shall **collect pointing data accurately** and then use that data **to control the sensor's pointing**

Levels of Success

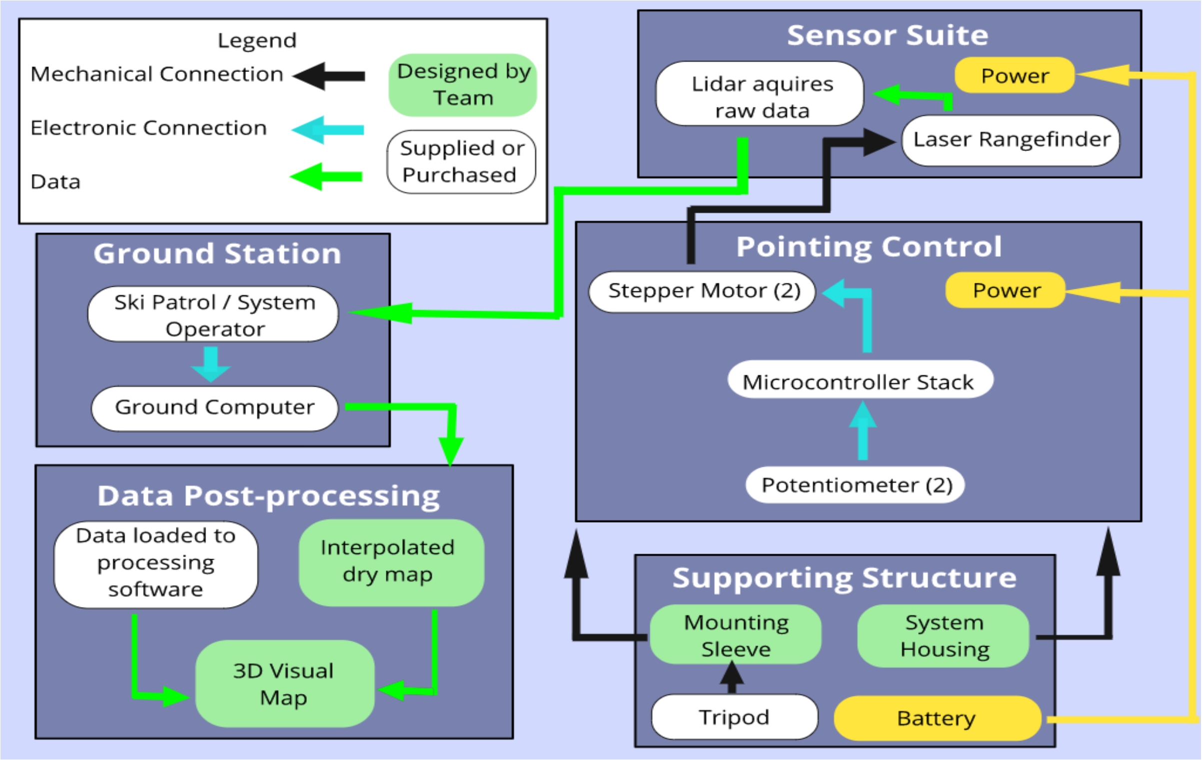
	Sensor Package	Software	Pointing Accuracy and Control	Output
1	Snow depth accurately measured within ±50 cm at 1 location at 400 m	Data of one distance measurement by sensor is saved	Laser pointing is able to be determined to 0.01 degrees. No feedback present. Motors ±1° of desired position	Compile data to form a plane to serve as origin for height measurements
2		Distance and attitude of each measurement is recorded for attitude control	Feedback is present allowing the motors to readjust as needed	Display snow depth calculated for one location
3	Snow depth accurately measured within **±15 cm** at 400m	**Distance, attitude, time & temperature of each measurement is recorded**	Motor initial move ±0.1° of desired position. Feedback allows for **±0.01°**	**Produce map displaying snow depth**
4	Snow depth accurately measured within ±10 cm at 400 m with 1 m spatial resolution		Motor initial move ±0.01° of desired position. Feedback allows for ±0.001°	Produce topographical snow depth map to within ±10 cm

Design Description

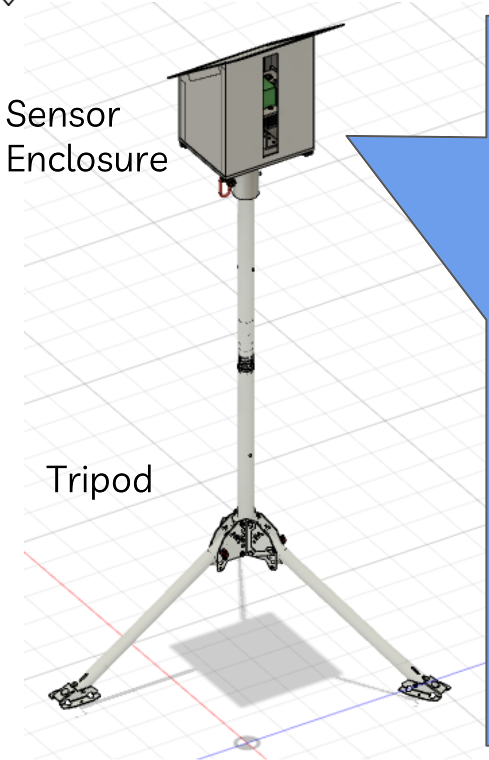
Critical Project Elements

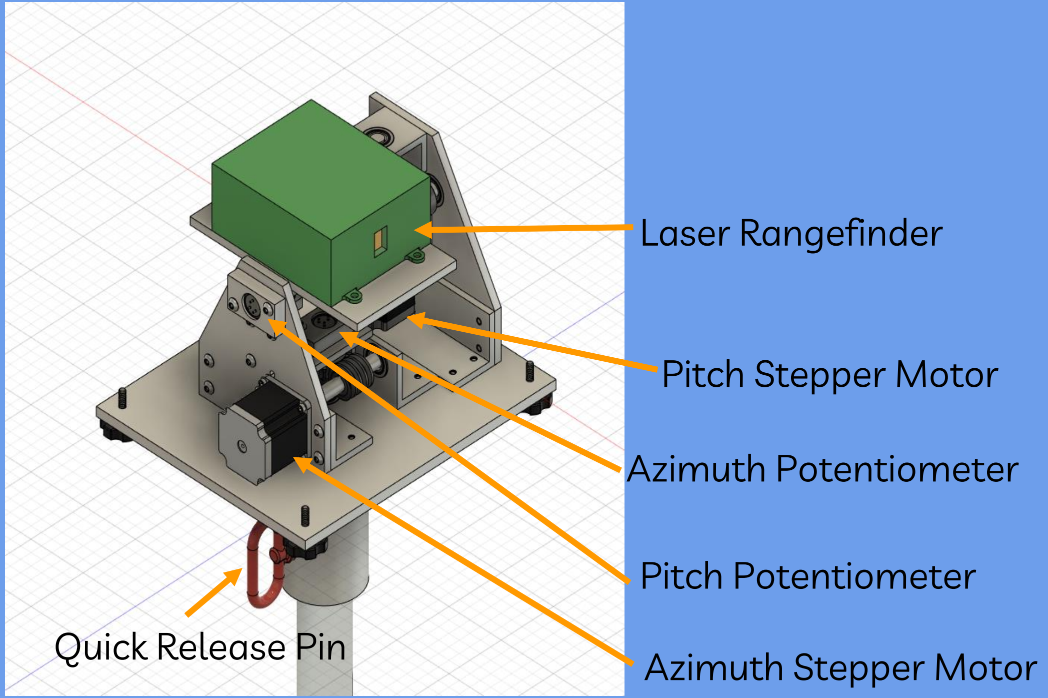


Functional Block Diagram

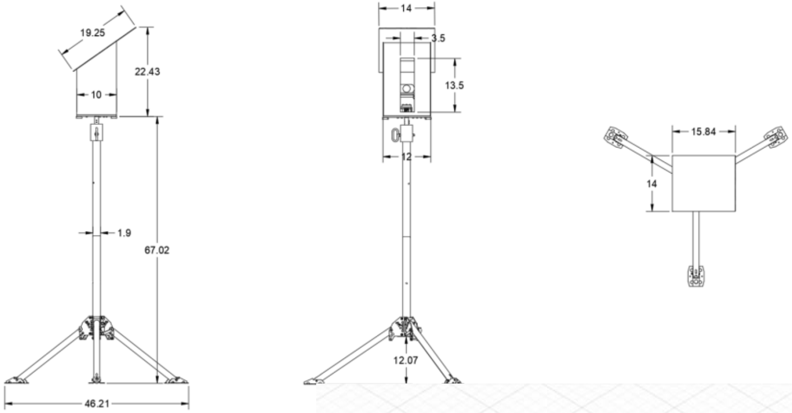


Final Design





Final Design



Test Overview

Completed Tests

- Laser Rangefinder Test
  - Range Test
  - Beamwidth Test
- ADC Noise Test
- Potentiometer Supply Voltage Stability Test
- Potentiometer Performance Test
- Whole System Test

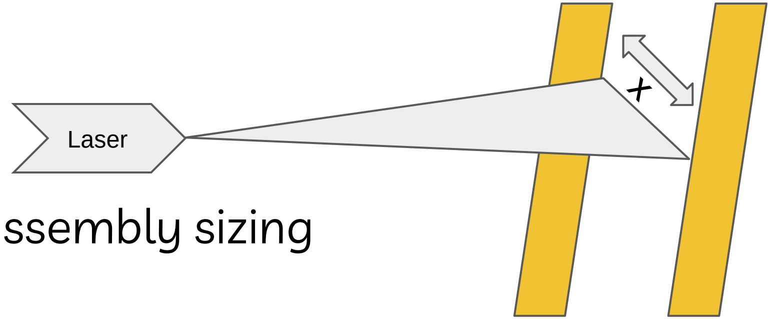
Significant Tests

Significance	**Test**
Characterization	• Laser Rangefinder Test • ADC Noise Test • Potentiometer Supply Voltage Stability Test
Model Validation	• Potentiometer Performance Test • Whole System Test

Laser Rangefinder

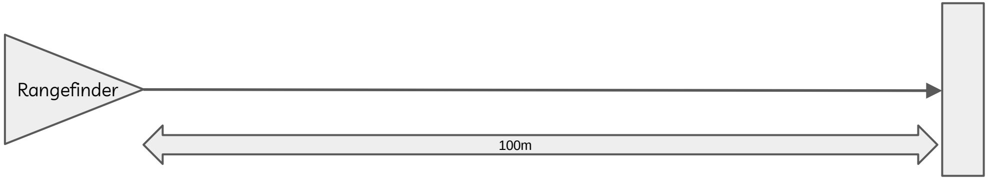
Test Purpose

1. Validate the accuracy of the rangefinder
2. Test rangefinder beamwidth for enclosure assembly sizing



Test Design

- Conducted at Manhattan Middle School track on the 100 meter straight
- A 2’x2’ piece of wood was used as a target



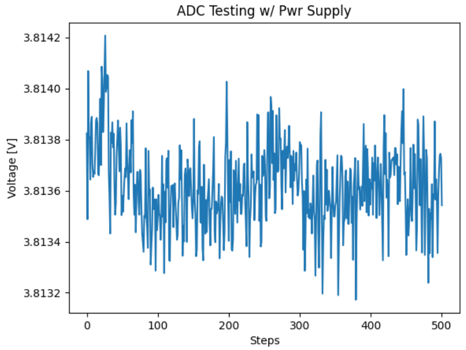
ADC Noise Test

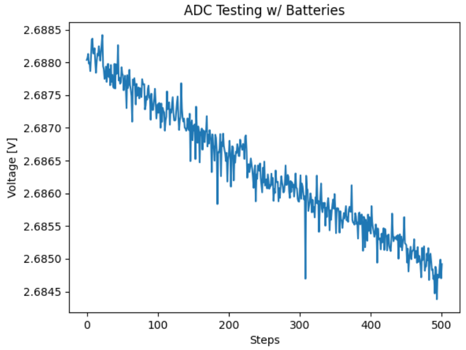
Test Purpose

- ADC noise decreases pointing accuracy. Determination of pointing error is required

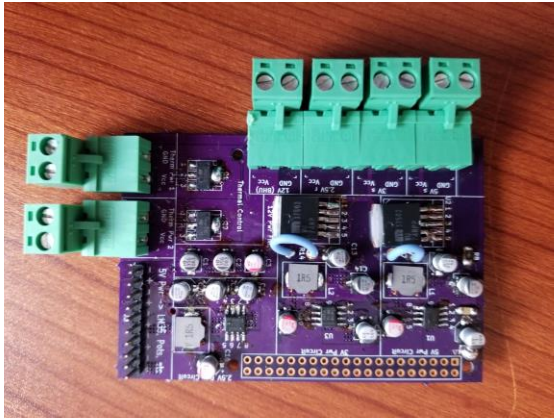
Test Design

- Steady voltage supply via batteries connected to ADC
- Oscilloscope measuring power supply and potentiometer output (2-channel)
- Code script:
  - Python - Control ADC and record voltage measurements
  - MATLAB - Determine ADC error and impact





Potentiometer Supply Voltage



Test Purpose
- ADC channel measurements are asynchronous
- Fluctuations in voltage supply can therefore result in potentiometer pointing noise

Test Design
- Examine voltage supply transient behavior with oscilloscope
  - Tune the 3 channel regulator with 6 low pass filters, 3 capacitor banks and regulator bypass to produce the cleanest signal
  - Determine average noise introduction from regulator
- Calculate power supply, regulator, potentiometer and ADC in static system

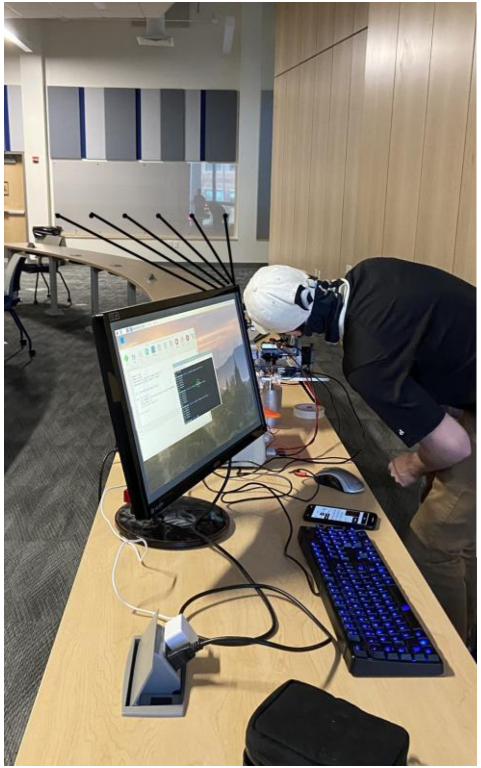
Potentiometer Performance Test

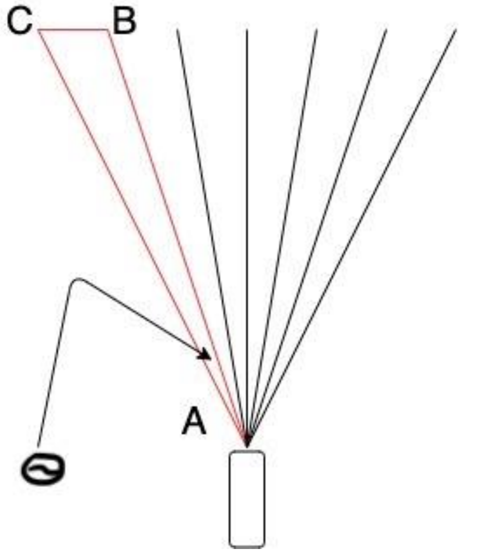
Test Purpose

- Largest component of system error
- This test characterizes potentiometer signal

Test Design

- Motor turns a step
- Triangle is physically measured to find turning angle
- Compare $\Delta V_{potentiometer}$ to θ





$$\theta = arccos(\frac{AC^2 + AB^2 - BC^2}{2 * AC * AB})$$

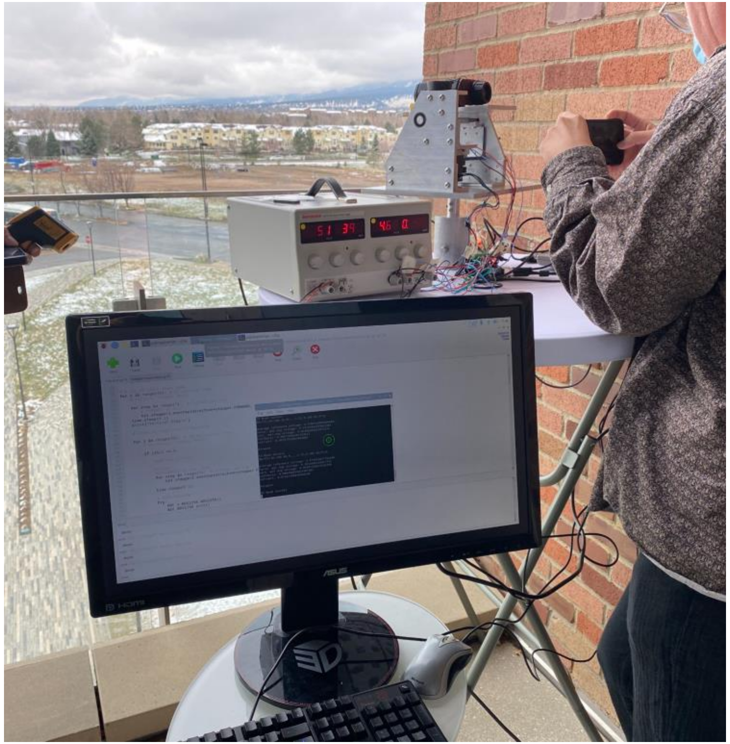
Whole System Test

Test Purpose

- Assess the accuracy of the whole system
- Use range and angle measurements along with location data to create a map

Test Design

- Conducted on roof of an apartment building and balcony of Aero building
- System scanned and collected 100 and 900 data points of grassy area



Test Results

Laser Rangefinder Test Results & Conclusion

Expected Results

1. A reading of 100m ± 4cm is expected by manufacturer specs at 100m range
2. Beamwidth is proprietary and is unknown

Test Results

- Track length is measured to be 100.07m with uncertainty of 0.5cm
- Laser Rangefinder measured 100.09m
- Laser Rangefinder **error of 2cm** with around 0.5cm uncertainty

Conclusion

- ± 2cm distance measurement validation **exceeded the expected** ± 4cm stated by the manufacturer
- Enclosure **widened to 3.5in** from 2.5in
- Satisfies **FR 1 & FR 3**

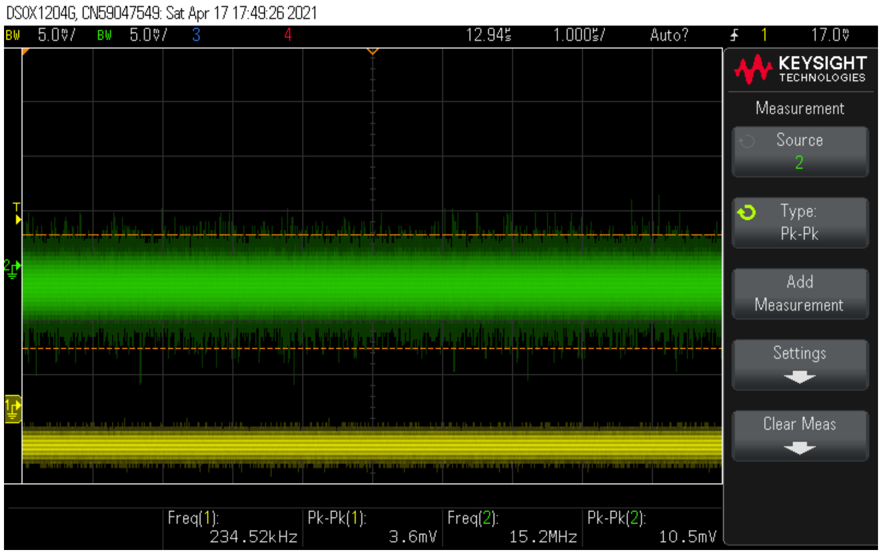
ADC Noise Results

Expected Results

- ~1mV and some attenuation
- 3uV bin sizes

Test Results: Battery Voltage

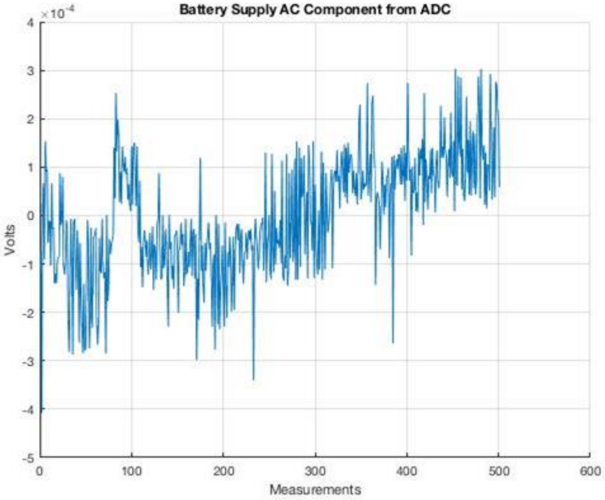
- Power supply AC noise: 29.5mV
- Oscilloscope limit reached (yellow)!
  - Noise threshold: 3.75mV
  - Lengthening probe writes add noise
- Measured battery AC noise (green)
  - 10.5mV? 5.6mV?

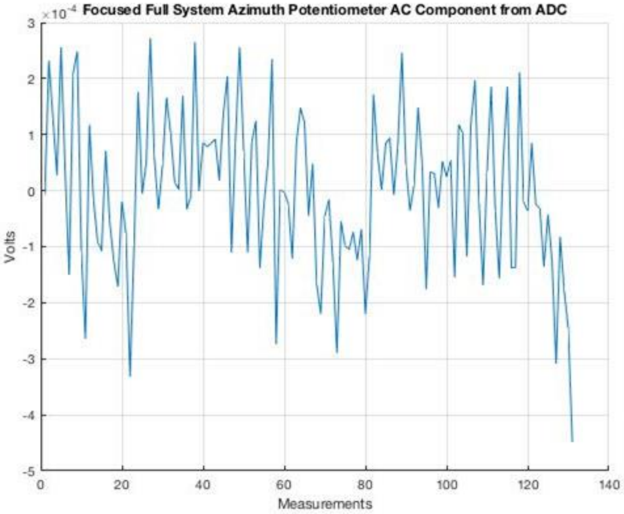


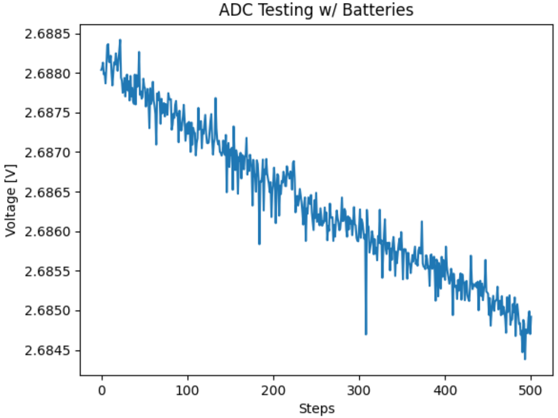
ADC Noise Results Continued

Test Results: ADC

- Assuming battery supply is constant
- Noise threshold ~710uV







ADC Noise Test Conclusion

Design Requirement Validation

- At least 0.34° of noise, 58 cm error
- Possibly ~0.054° of noise, 9.24 cm error

Testing Conclusion

- ADC noise is 61.6% of total error budget
- **Hardware exceeds subsystem accuracy budget**
- Possible improvements explored later

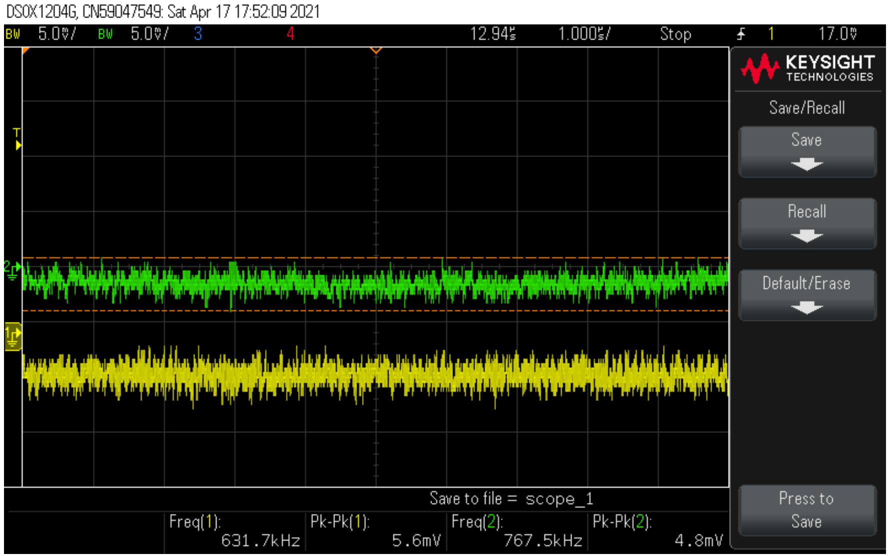
Voltage Supply Test Results

Expected Results

- 10 mV> pk. pk spikes from testing with first iteration
- 0.72°> of noise or 123 cm

Test Results

- Oscilloscope limit reached!
- Noise threshold: ~3.75mV
- Battery line (yellow): 5.6mV
- 5V supply (green): 4.8mV

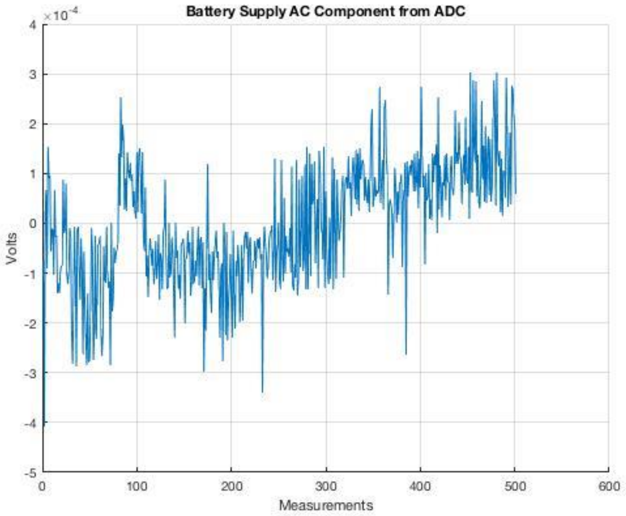


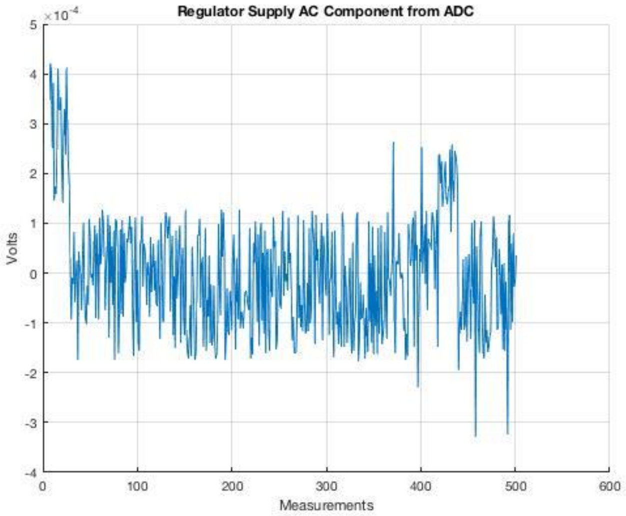
Objectives | Design | Testing | Results | Systems | Management

Voltage Supply Test Results Continued

ADC Results

- Battery line: ~710uV, 5V supply: ~750uV
- Instrument limited results





Voltage Supply Test Conclusion

Design Requirement Validation

- Oscilloscope limit: At least 0.34° of noise, 58 cm error
- ADC limit: Possibly ~0.054° of noise, 9.24 cm error
- True limit unknown

Testing Conclusion

- Results inconclusive
- ADC is the bottleneck. PCB noise is within ADC noise.

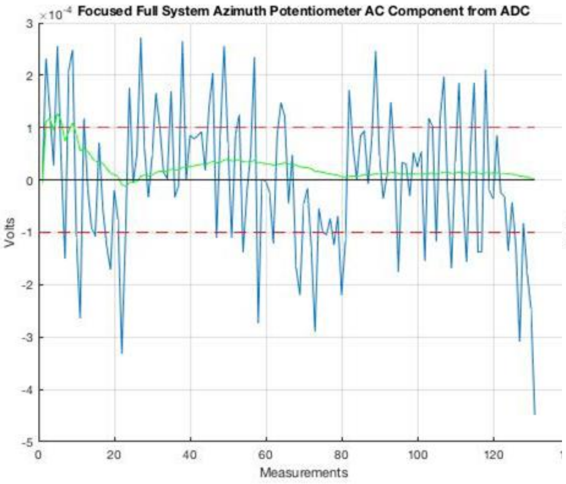
ADC-Regulator Potential Fix and Result

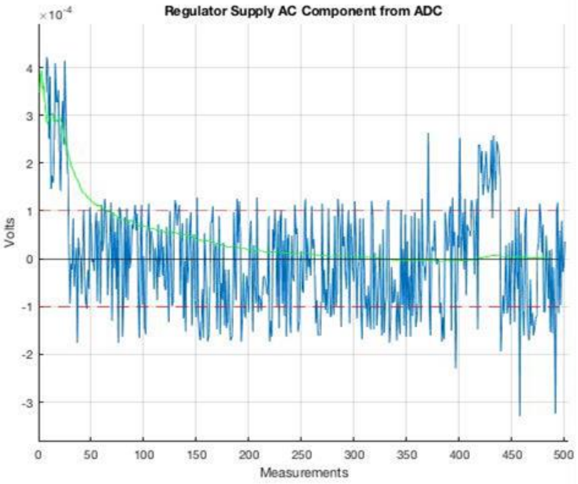
New ADC

- Same noise characteristic, 17.25 V max: 2.5cm error
- Worse noise characteristic, op-amp pot. amplifier circuit where G=f(Vmax, pk. pk)

Software Solution

- Averaging multiple samples
- ~150 samples
  - 200uV pk.pk
  - 2.5cm error
- No way to validate this method!

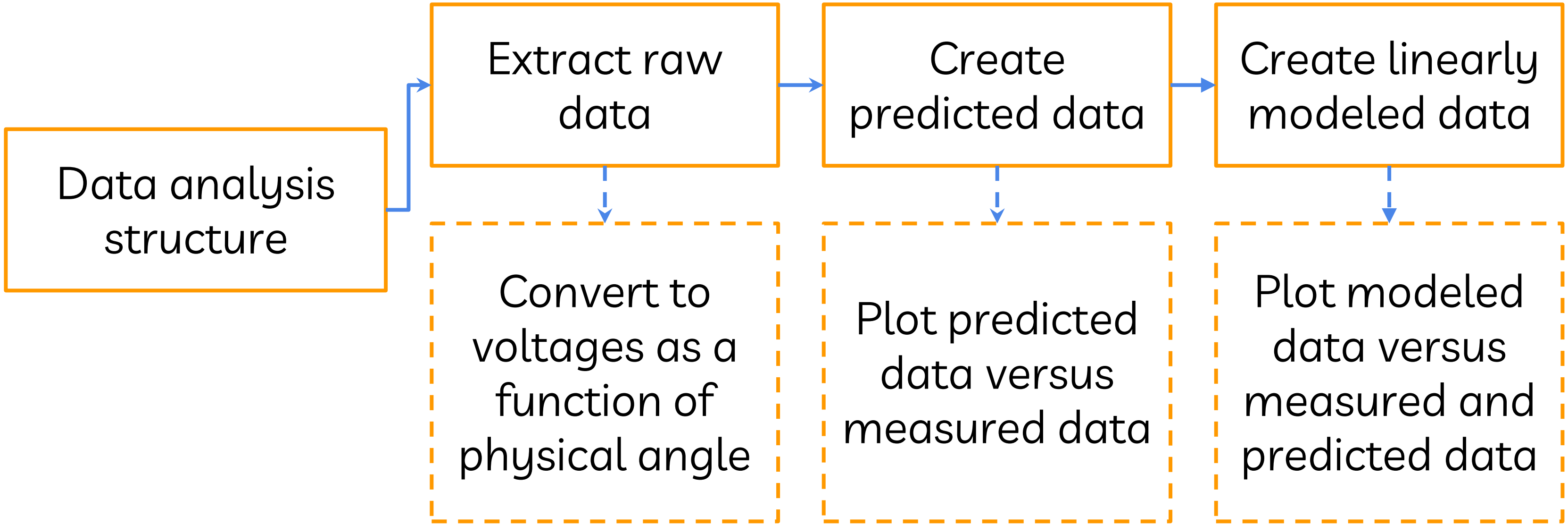




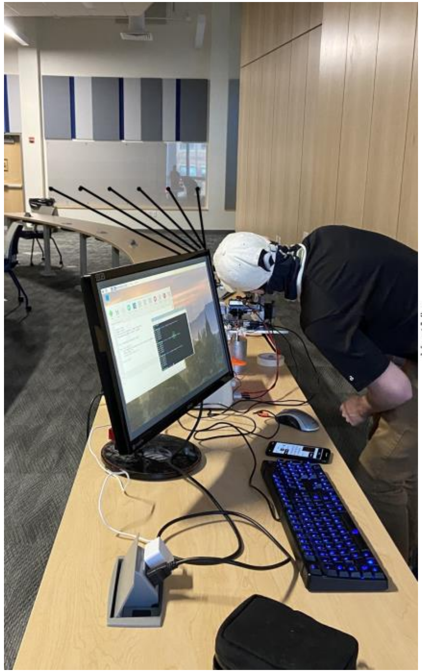
Potentiometer Performance Test Results

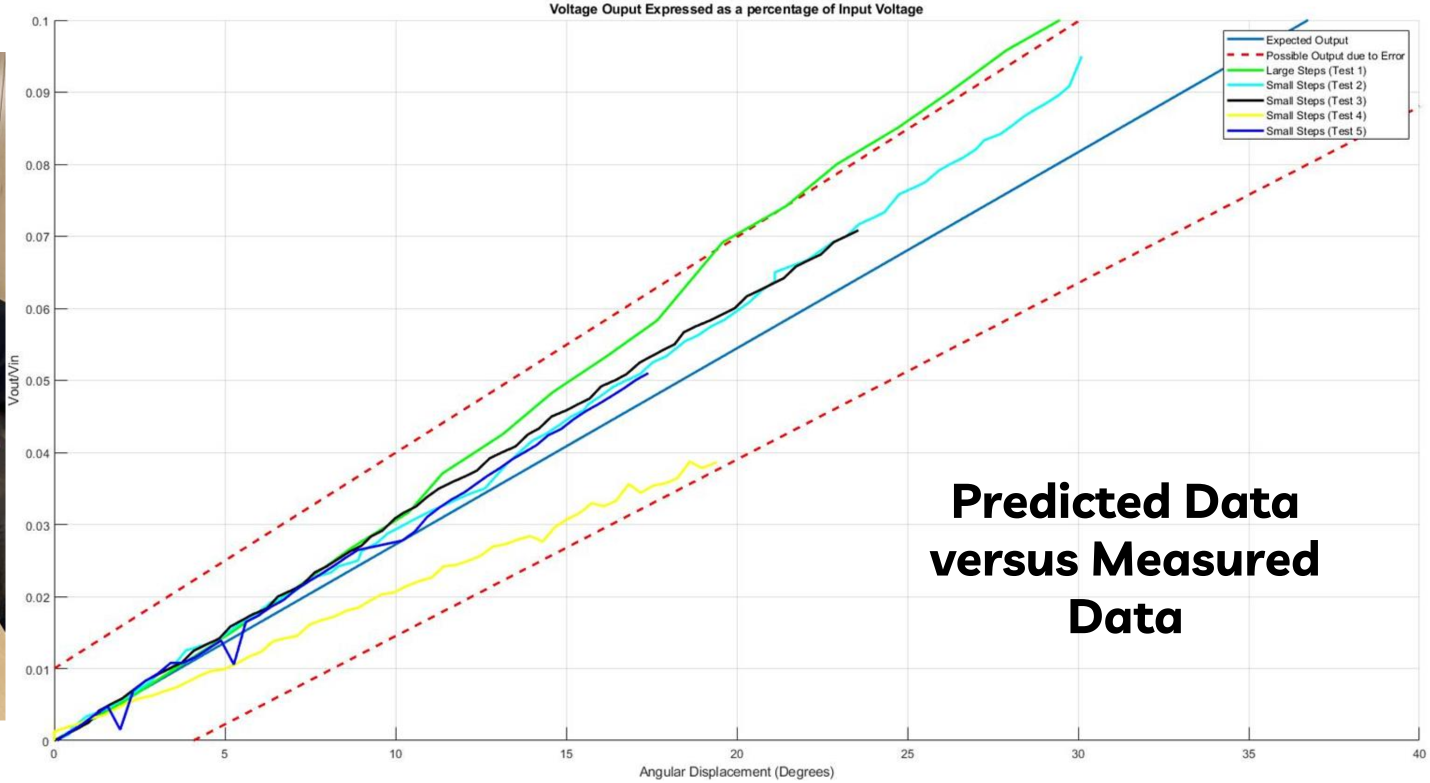
* All potentiometer data was analyzed using MATLAB

- Code structure:



Potentiometer Performance Test Results

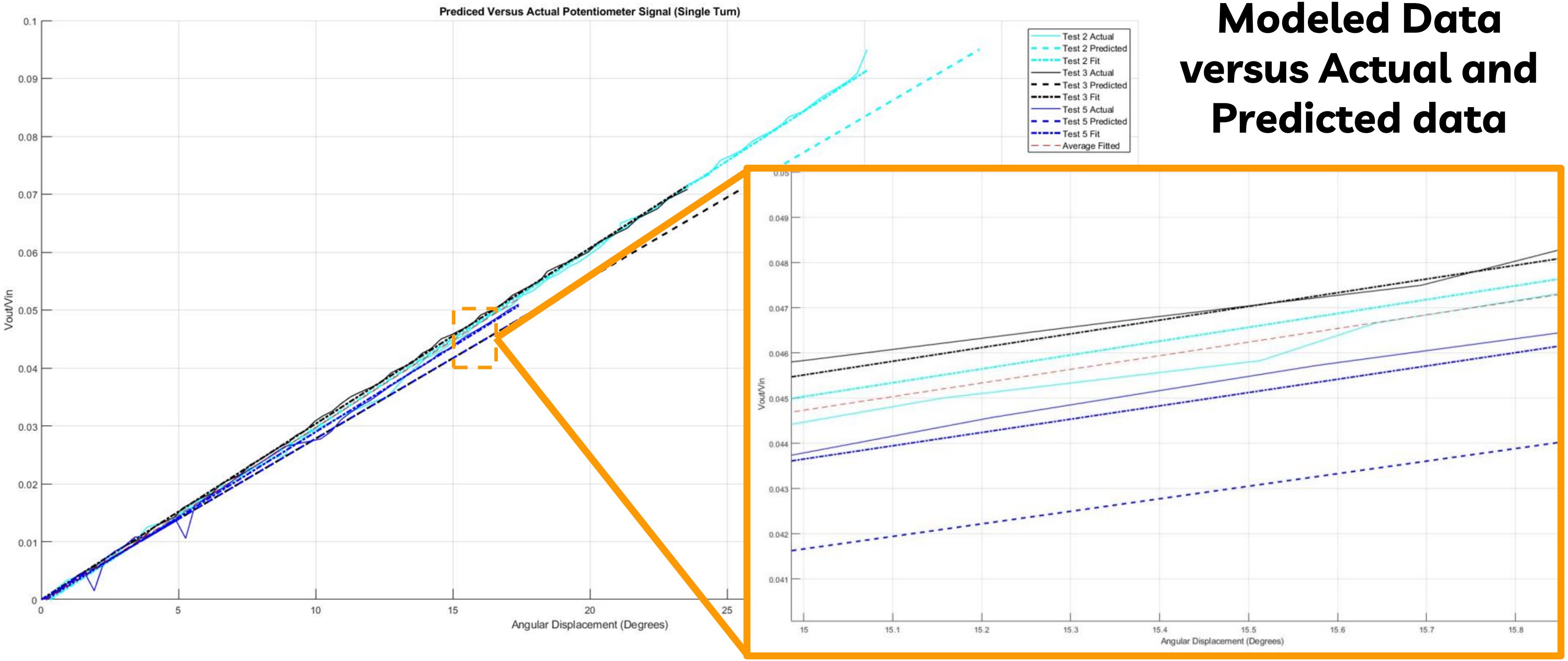




Predicted Data versus Measured Data

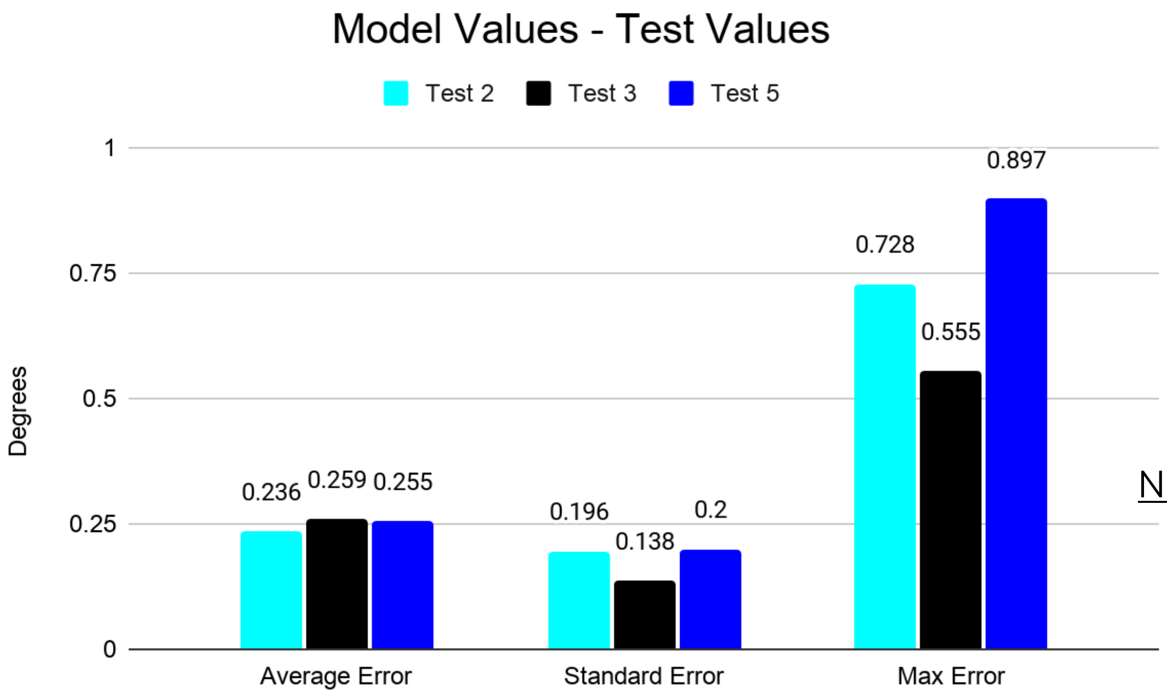
Objectives | Design | Testing | Results | Systems | Management

Potentiometer Performance Test Results



Modeled Data versus Actual and Predicted data

Potentiometer Performance Test Conclusion



Average error ~ 0.260° > Required Pointing error = 0.001°

Therefore this sensor <u>DOES NOT</u> meet level of success 1 for snow depth error.

*Note, signal output by power supply was not clean and as a result produced error within this test.

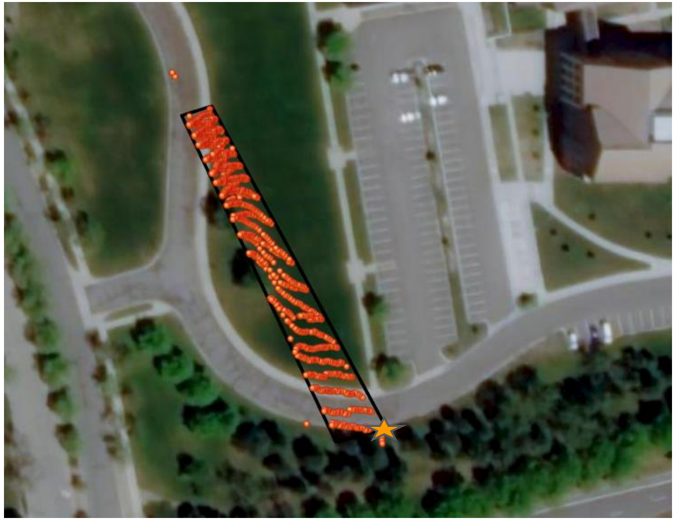
Whole System Test Results

Expected Results

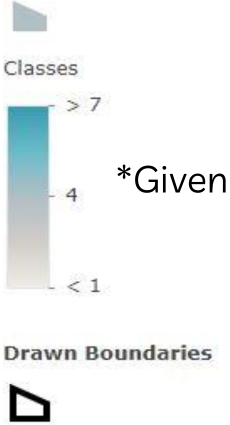
- Capture range and angle data
- Combine with known location to create contour of depths

Test Results

- Obstacles were able to be identified from data and map
- No snow accumulation to validate accuracy requirements

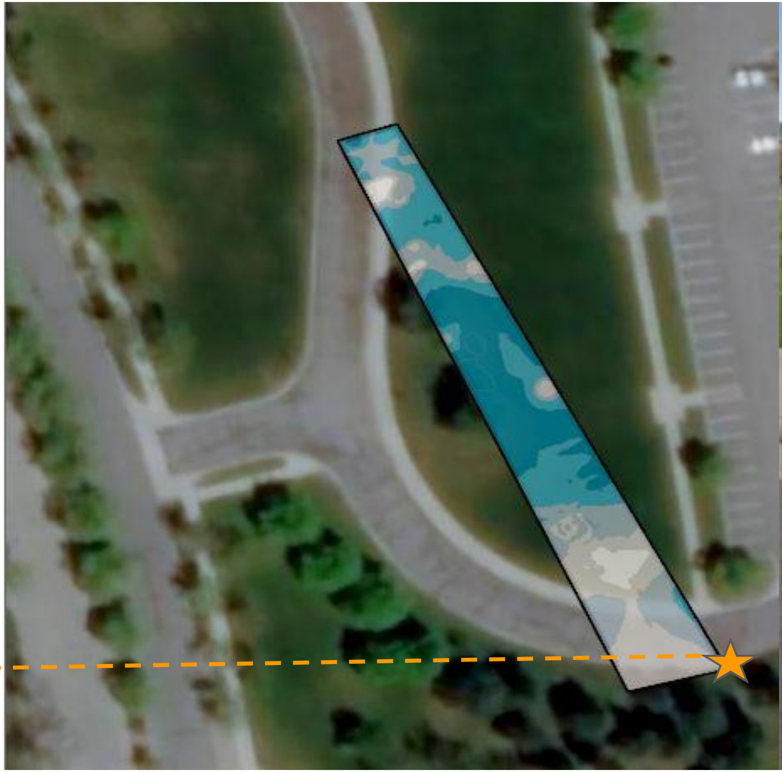


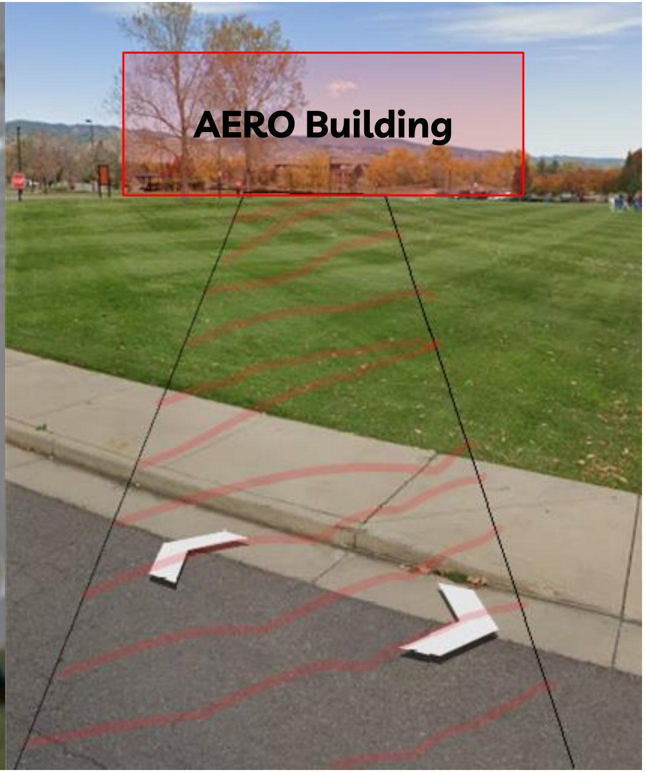
Whole System Test Conclusion



*Given in meters

* Heights are relative to initial start point.





Error Budget

Contributing Factor	Expected Error	Actual Error
Pointing Accuracy* (depth error of single scan)	• .001° • 0.35 cm depth error	• .26° • 89cm depth error
Laser Rangefinder (depth error of single scan)	• 4cm • 0.75 cm depth error	• 2cm • 0.36 cm depth error
TOTAL (depth error of combined wet and dry scan)	• 1.5 cm depth error	• 90-127 cm depth error†

*Potentiometer accuracy is dependent on ADC readings. The test was done with power supply that outputs variable voltages, leading to inaccurate readings.

†Total error was calculated assuming a slope angle of 10° and sensor platform angle of 3.3°-7.0°. The more perpendicular these two angles are to each other, the better the accuracy.

Verification & Validation Summary

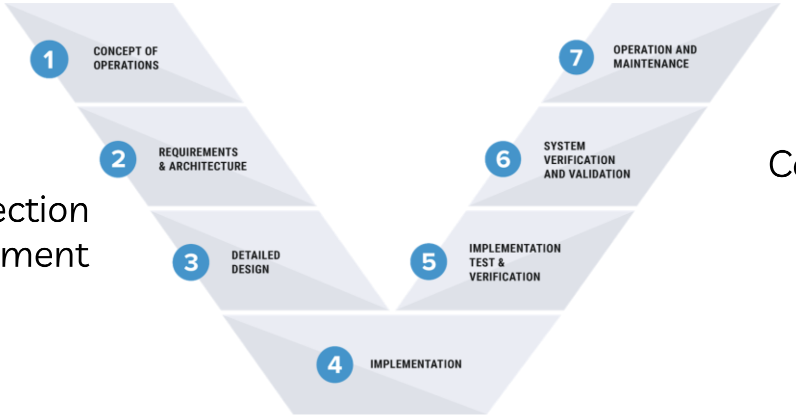
	Sensor Package	Software	Pointing Accuracy and Control	Output
1	Snow depth accurately measured within ±50 cm at 1 location at 400 m	Data of one distance measurement by sensor is saved	Laser pointing is able to be determined to 0.01 degrees. No feedback present. Motors ±1° of desired position	Compile data to form a plane to serve as origin for height measurements
2		Distance and attitude of each measurement is recorded for attitude control	Feedback is present allowing the motors to readjust as needed	Display snow depth calculated for one location
3	Snow depth accurately measured within **±15 cm** at 400m	**Distance, attitude, time & temperature of each measurement is recorded**	Motor initial move ±0.1° of desired position. Feedback allows for **±0.01°**	**Produce map displaying snow depth**
4	Snow depth accurately measured within ±10 cm at 400 m with 1 m spatial resolution		Motor initial move ±0.01° of desired position. Feedback allows for ±0.001°	Produce topographical snow depth map to within ±10 cm

Systems Engineering

Concept Development

Customer emphasis
- Safety
- Accuracy
- Resolution
- Mobility

Functional Objectives
- Snow depth detection
- In Alpine Environment
- Data:
  - Collection
  - Storage
  - Presentation



Trades
- Sensors
- Actuators
- Georeferencing method
- Processing software

Concepts Considered
- Mobile platform
- Stationary Platform
- Photogrammetry
- Ultrasonic Sensing
- LiDAR

Functional Requirements

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FR 2	The system shall be able to operate with acceptable endurance such that **data collection will occur in a reasonable amount of time**
FR 3	The system shall be able to **operate in the typical weather conditions** found on the top of Copper Mountain
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FR 5	The system shall **process the data collected and present snow depth data** to Copper Mountain ski patrol in the software found at their facilities
FR 6	The system shall **collect pointing data accurately** and then use that data **to control the sensor's pointing**

Driving Requirements

1. **FR 1**
    1. The sensor package shall be able to **measure snow depth** of the snowpack with an **accuracy of ±10 cm**
2. **Fr 2**
    1. System shall have sufficient endurance to survey a **dry area in up to 22 hours**
    2. System shall have sufficient endurance to survey a **wet area in up to 2 hours**
3. **FR 3**
4. **FR 4**
5. **FR 5**
    1. **A heat map shall be created** and overlaid onto a geophysical map with snow depth data
    2. The heat map shall have a **dry scan spatial resolution of 2 m^2**
    3. The heat map shall have a **wet scan spatial resolution of 6 m^2**
6. **FR 6**
    1. The system needs to be able to **sweep out 60° about its pitching axis**
    2. The system needs to be able to **sweep out 135° about its azimuth axis**
    3. The system shall have a **pointing accuracy on the order of 0.01°**

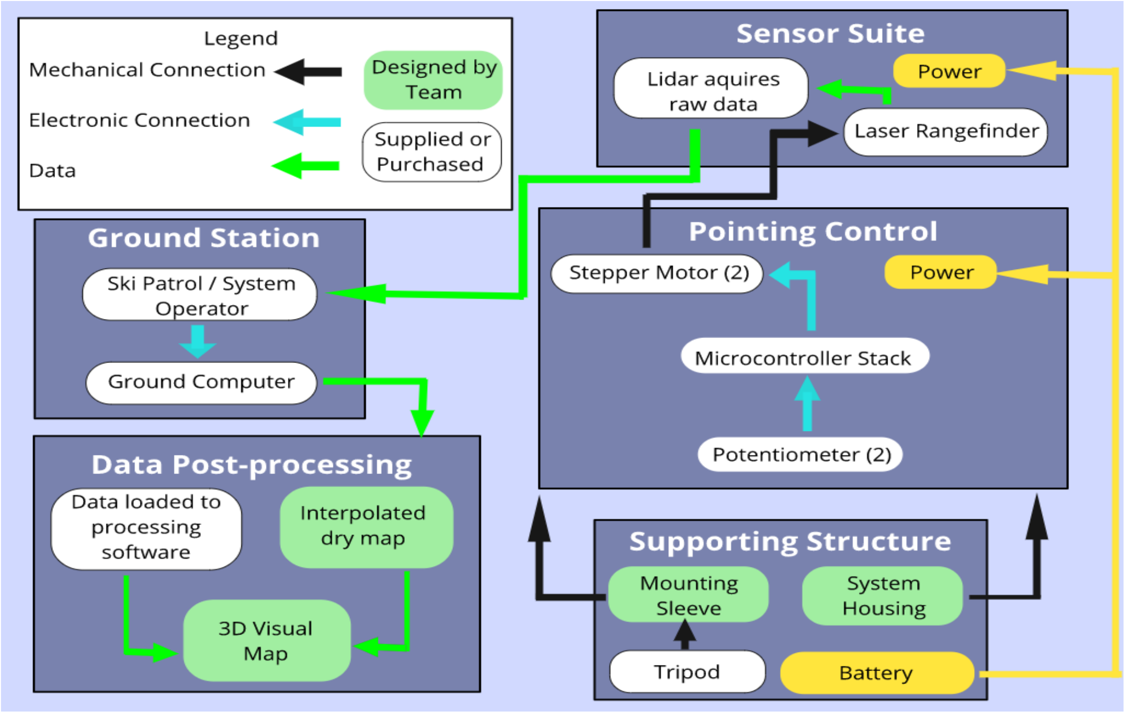
Interfaces

Power Regulation
PCB filters and regulates power

System Operation
Raspberry Pi controlled using ground computer

Attitude Determination & Control
Motors and rangefinder commanded
Angles and distance recorded

Post-Processing
Data uploaded to ArcGIS Online



Risks

CDR Predicted Risk	Mitigation	Encountered and Effect
Thermal Drift in Potentiometer	Thermal subsystem	Not encountered
Water Damage	Enclosure and raised components	Not encountered
Pi crash due to bugs	Alternate Pi, quickly replaceable	Testing delay & reconfiguration
Tripod Deflection	Additional guy wire available	Not encountered
Sensor error due to reflectivity	Rangefinder made for outdoor use	Not encountered
Potentiometer Backlash	Realign voltage every change of elevation in scan	Not encountered

Challenges and Lessons Learned

Challenges	**Lessons Learned**
Delays of Shipping Orders	- Increase lead times for ordered items - Local suppliers as off-ramps
Minimal In-Person Interaction	- CAD & MBSE for virtual coordination - Clear communication of manufacturing needs - Increase time required for testing
Difficulty verifying/calibrating components	- Calibration proved difficult - System uncertainty compounds

Project Management

Approaches and Results

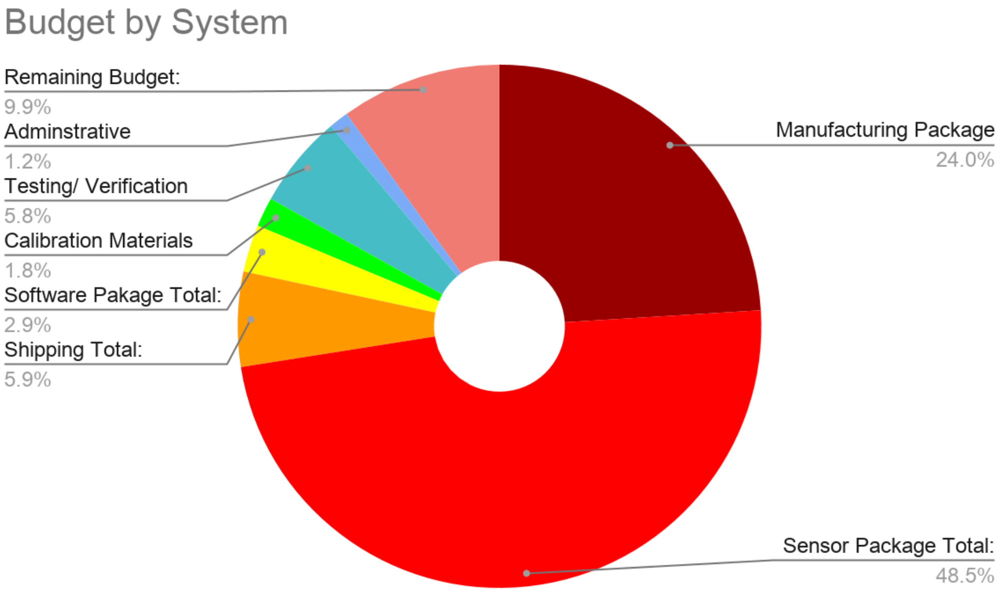
	Fall	Spring
Approach	• Group divided into subsystems • Tasks assigned to subsystems • Subsystems divided into sub-teams • Agendas made for the week	• Agendas made for the week including internal deadlines • Biweekly subsystem updates from team leads • Clickup used more to meet manufacturing and testing deadlines
Results	• Subsystems and sub-teams reassigned after project descoping • Existing subsystems tasks completed given time frame after descoping • Team project understanding not where it should have been	• Biweekly updates led to better understanding of project progress • Manufacturing completed 2 weeks ahead of schedule

Challenges and Lessons Learned

Challenges	**Lessons Learned**
Testing Challenges due to COVID • Team availability	• Assign specific testing days a week ahead • Gather team availability via When2meet
Leadership structure	• Effective communication between sub-team leads and PM
Team meetings and project progress updates over Zoom	• Setting agenda for every meeting • Having team leads summarize testing results every meeting

Planned vs. Actual Budget

Budget at CDR

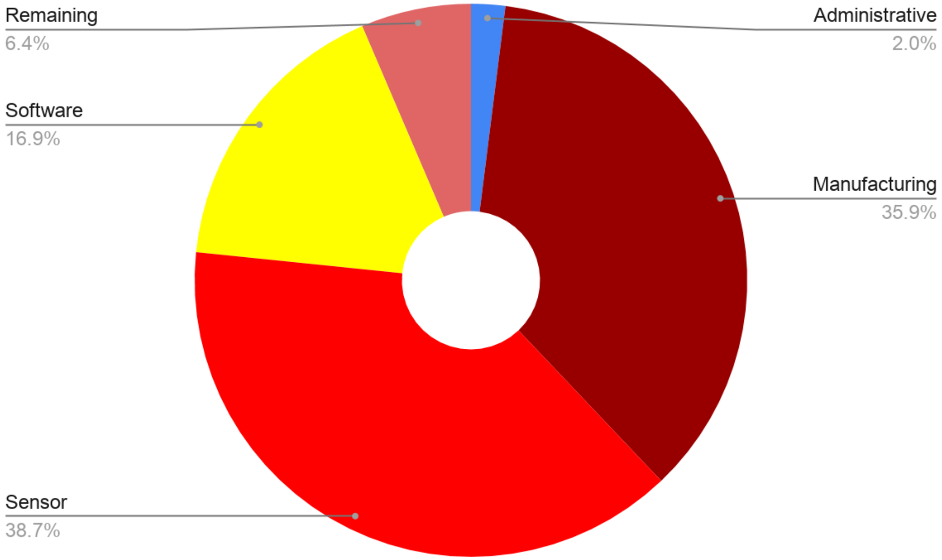


Manufacturing Package Total:	$1,201.25
Sensor Package Total:	$2,423.94
Shipping Total:	$286.73
Software Package Total:	$145.66
Calibration Materials	$90.83
Testing/ Verification Equipment	$288.74
Administrative	$60
Total w/ Margin:	$4,497.14
Remaining Budget:	$502.86

* 5% Margin applied to total to account for any costs not considered

Planned vs. Actual Budget

Final Budget



Manufacturing Package Total:	$1,795.56
Sensor Package Total:	$1,93594
Software Package Total:	$846.72
Administrative	$99.87
Total w/ Margin:	$4,677.90
Remaining Budget:	$322.10

Planned vs. Actual Budget

Comparison and major differences:

Budget at CDR

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Testing/ Verification Equipment	$288.74
Administrative	$60
Total w/ Margin:	$4,497.14
Remaining Budget:	$502.86

Final Budget

Manufacturing Package Total:	$1,795.56
Sensor Package Total:	$1,935.94
Software Package Total:	$846.72
Administrative	$99.87
Total w/ Margin:	$4,677.90
Remaining Budget:	$322.10

- Software package increase
- Manufacturing increase
- Sensor package decrease

Industry Cost

Based off the Timesheets, approximately 1009 hours were completed in the spring and 655.5 hours were completed in the fall . Since October 25th, a **total of 1704.5 hours** were logged across 12 team members.

Assuming an entry level salary of $65,000 for 2080 hours labor per person results in $31.25/hour. The **total direct labor cost would be $53,265.63** for this project with an additional **$4,677.90 for materials.**

With an **overhead rate of 200%** the cost for labor would come out to **$106,531.26**.

The **total industry cost** would come out to **$164,474.79**.

Backup Slides

ADC Noise Results: Bench Top Supply

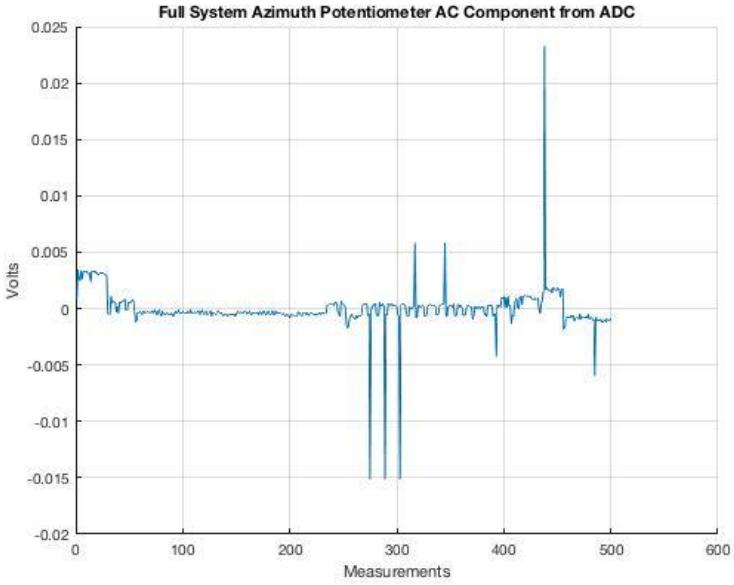
Expected Results

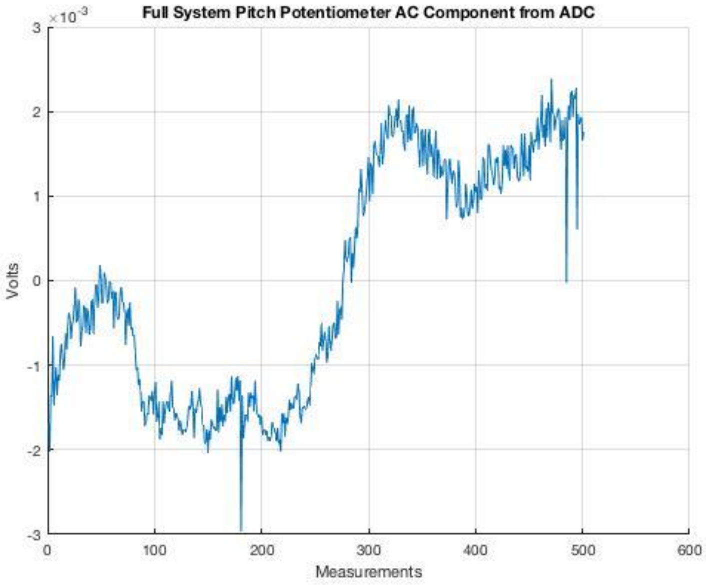
- Realistically, no noise from batteries, ADC ~1mV

Test Results: Bench Power Supply

- Power supply
  - 33.26 kHz
  - 70.0 mV peaks

Static Potentiometer Tests





Azimuth pk. pk: 38mV

Pitch pk. pk: 5.5mV