Autonomous System to Establish Reference Direction for Large Ground-Based Antennas

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Boresighting

- Aligning an antenna with a target
  - Tight accuracies
  - Slow process (2 days)
  - Labor intensive
  - Long distances between required measurements
  - Expensive equipment

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Our Solution

Our solution is a rover and gimbal base station system that utilizes RTK GPS, a Raspberry Pi, and an accelerometer. First, the gimbal is leveled by the accelerometer and RTK GPS is initiated. The gimbal and rover are set up approximately one-hundred meters from each other and lined up using a rifle scope. Once set up is complete, the RTK establishes the position and the gimbal rotates to an entered latitude, longitude, and azimuth.

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Key Success Measurements

Measure	Stretch Goal	Excellent Performance (A)	Good Performance (B)	Fair Performance (C)	Modeled Value	Current Measured Value
Time to set up device	5 min	15 min	20 min	30 min	5 min	4.5 – 11.5 min
Pointing Accuracy (North and Level)	N/A	.01 degrees rms	.02 degrees rms	.03 degrees rms	.02 degrees rms	-
Distance from base unit to user	N/A	30 meters	50 meters	100 meters	100 meters	100 meters
Total hardware cost	N/A	$1000	$1250	$2500	$968	$968

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Step by Step Process

- Set up base station
- Initiate GPS and leveling procedure
- Place mobile station
- Align gimbal with the mobile station
- Input GPS coordinates of the target

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Place Mobile Station

- Place mobile station about 100m from antenna
- Place in clearing
  - Avoid multipath
  - taller is better
- Turn on device
- Check that blue LED is on
- Automatically begins survey-in

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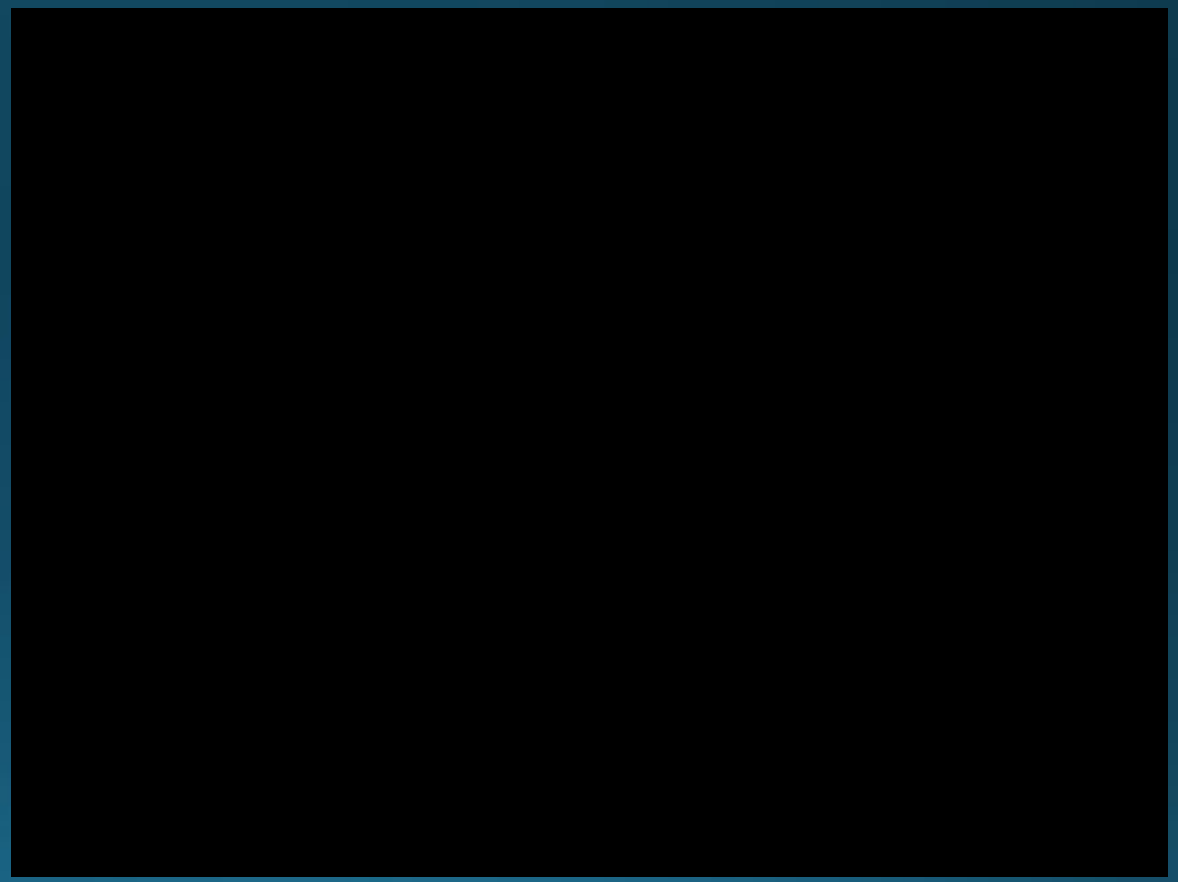
Rover Setup

- Takes 20 seconds to set up rover
- Once powered, the rover automatically starts surveying-in and will send RTK correctional data to base station once they survey-in is finished



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North Finding

- RTK GPS system
- Located in both units
- Finds relative position between both units
  - Survey in
  - RTK fix
- Calculates north vector

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Interfacing and Testing

- Pi interacts with Ublox via Serial (NMEA protocol, mostly proprietary UBX)
- Survey-In, High Precision Position, RTK status, relative Position, Message Enable.
- Surveying in at Y
- Surveying in/Surveying targets at Park
- Timing variability

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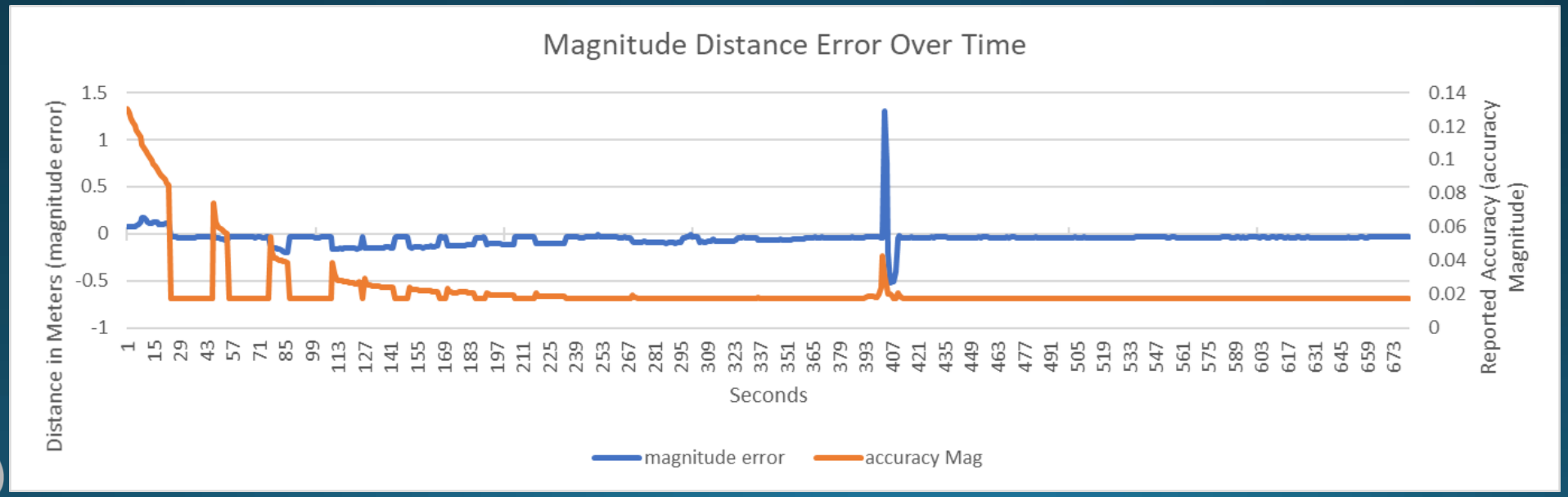
Testing and Validation

- Time: Variable but typically 2 minutes
- Determine location with centimeter accuracy
- 0.014° accuracy



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Testing and Validation

- RTK Solution measured accuracy: 2.6 cm
  - Predicted of 1.732 cm (in 3 Dimensions)
- Time to establish an RTK Fix: 1-5 minutes
  - Highly Variable (atmosphere, multipath, baseline length, satellite visibility)
- Survey-in Accuracy:
  - 1.4197m in 1 min
  - 1m in 13 mins,
  - .54m in 42 mins,
  - .55m in 97 mins (on Y mountain, bad multipath)
- No observable correlation between survey-in time and RTK fix time

Setup Base Station

- Setup Tripod
  - 5° of level
- Connect to power
- Turn on system
- Follow UI

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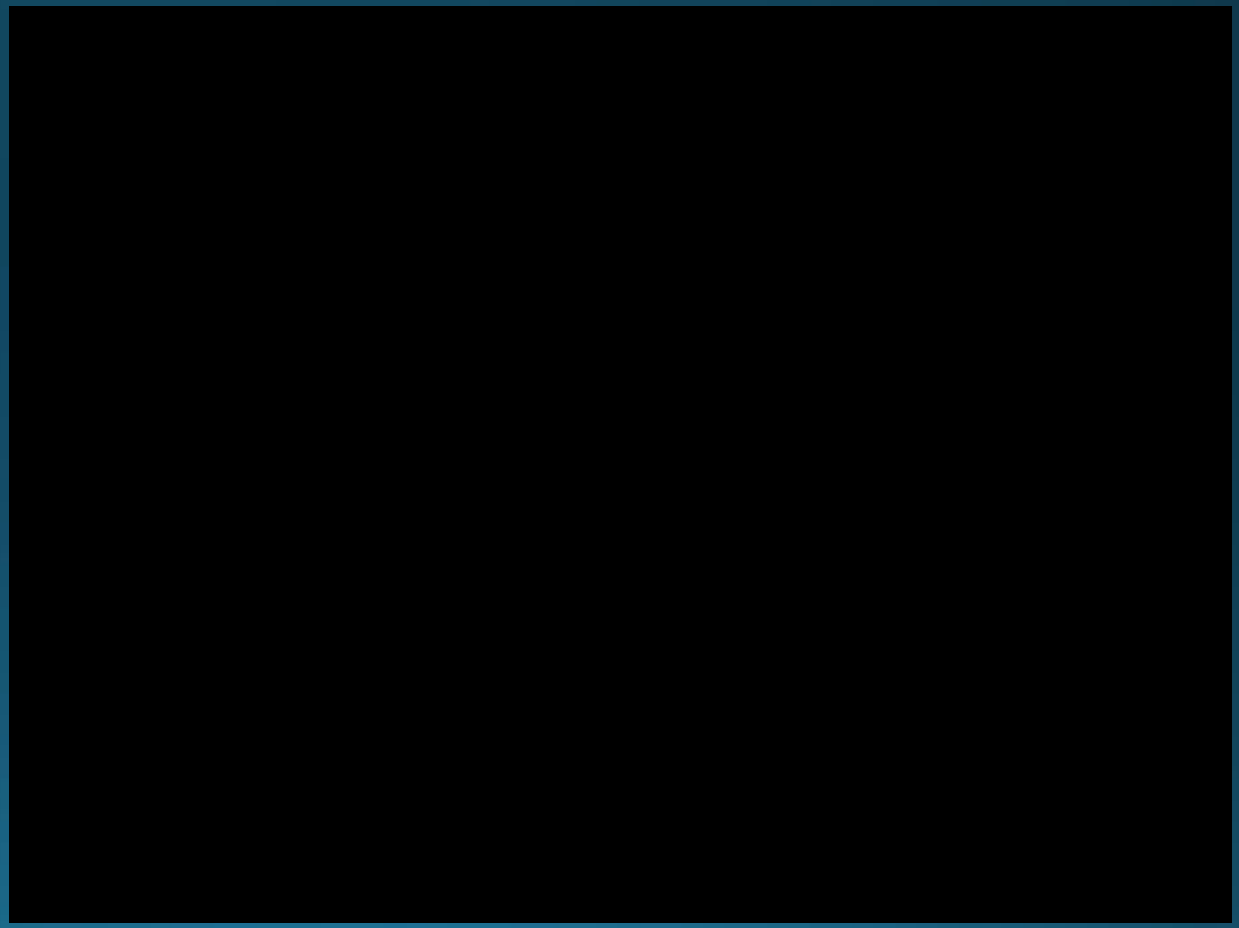
Base Station Setup

- Takes roughly 1 minute to set up base station



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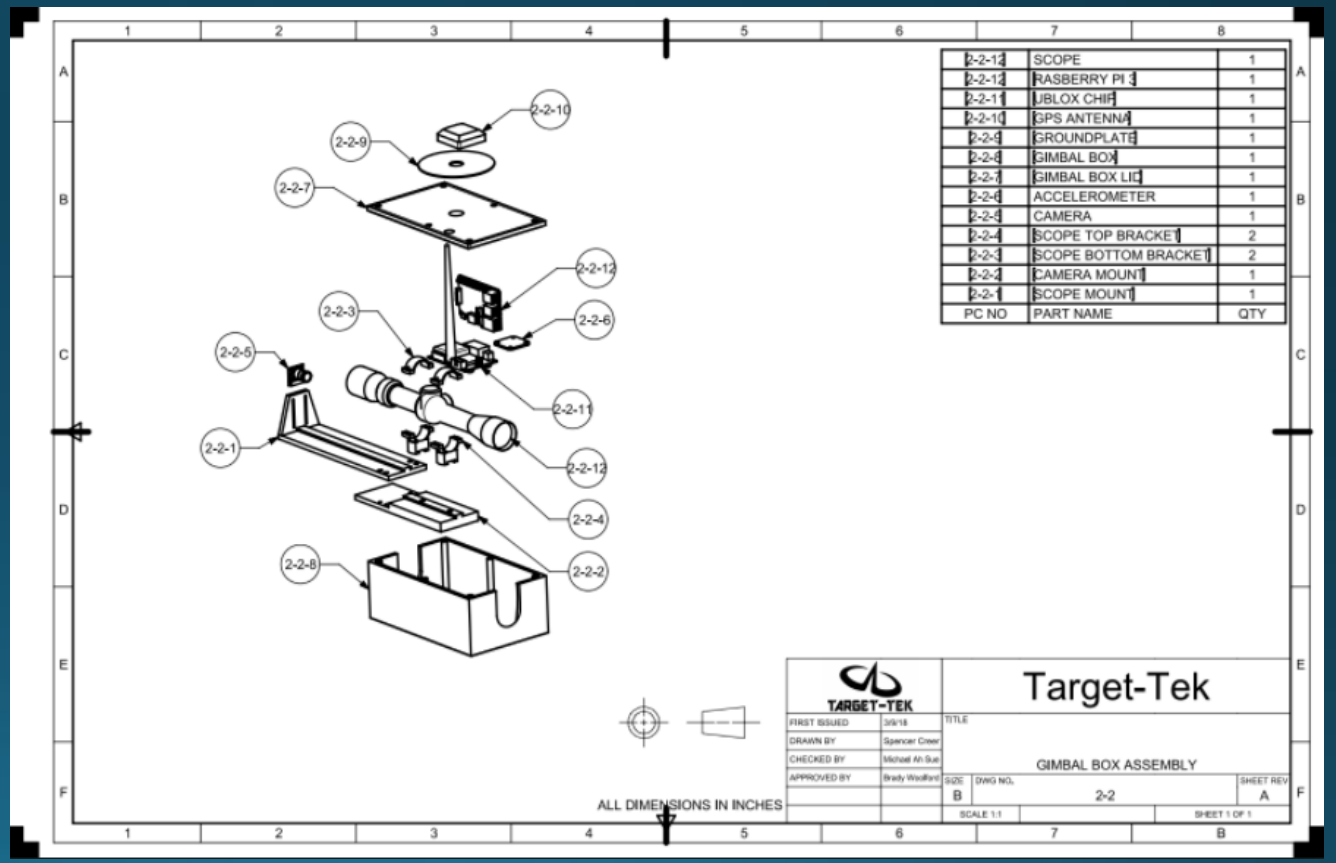
Align Gimbal and Mobile Station

- Creates a reference location for the gimbal
- Manually established using a scope camera system



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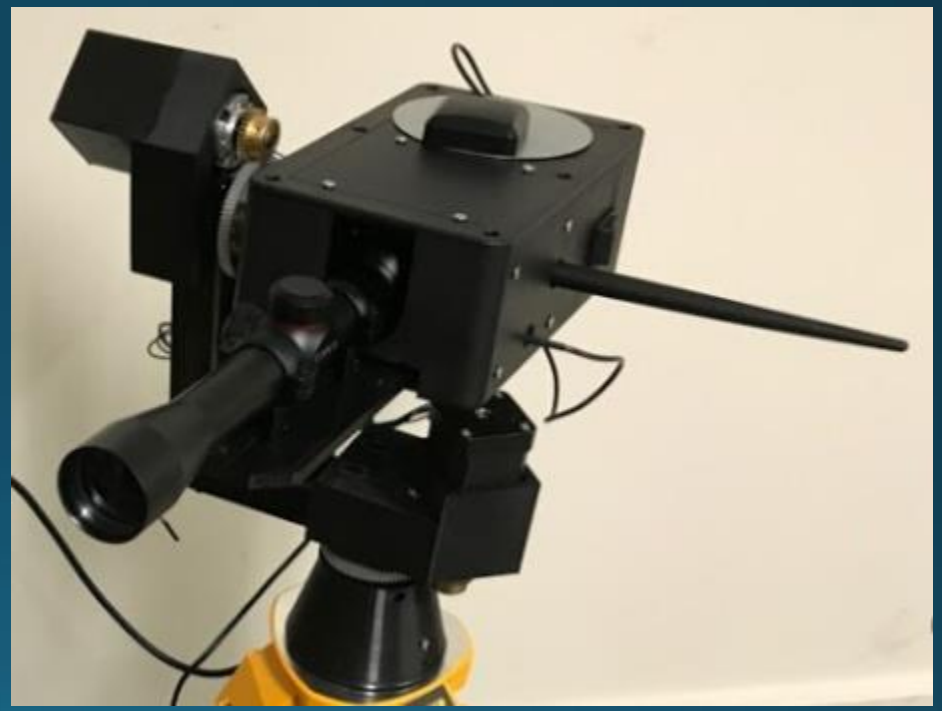
The Gimbal

- Allows alignment of the entire system and pointing at the final target
- Two axis of rotation
- Ramping function
- Encoders
- Accuracy: 0.002° per step
- Rotation Speed: 1 RPM



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Design and Testing

Average Step Size	.001840
Standard Deviation	.000056
Sample Size	31
Confidence Interval	2.04
Margin of Error	.000020
Upper Bound	.001861
Lower Bound	.001819
Max	.001982
Min	.001762
Range	.000220

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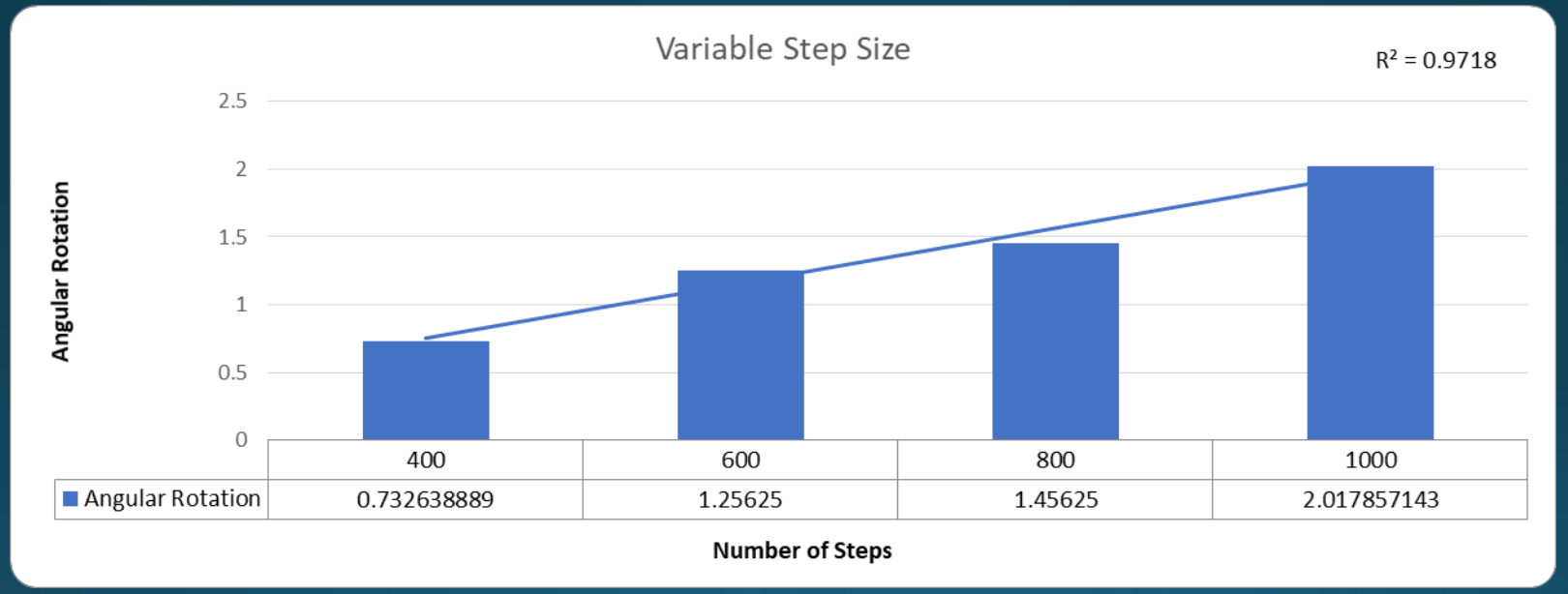
Additional Testing



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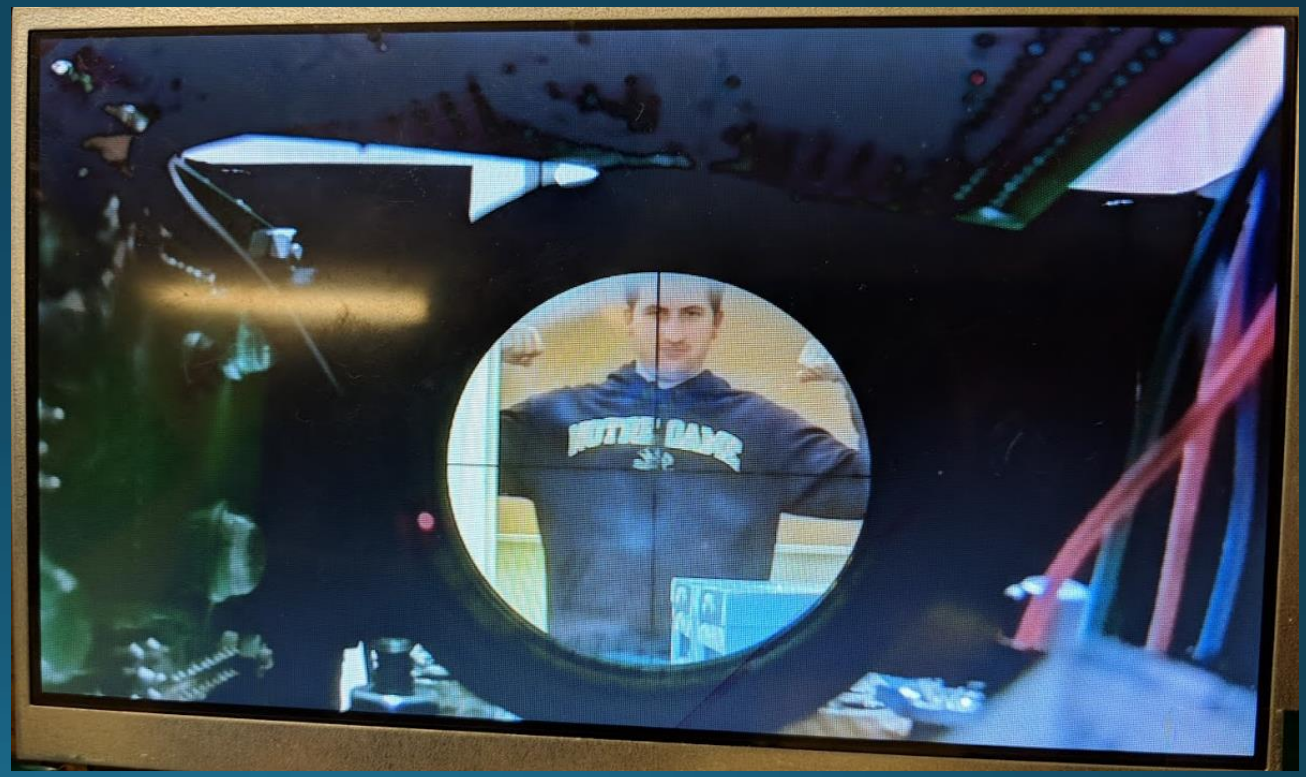
Manually Establishing The Baseline

- Keypad controls gimbal
- Visual display allows user to establish the baseline
- Scope is aligned with the U-blox antenna
- 1” X 1” target easily found at 100 Meters
- Accuracy: 0.01°



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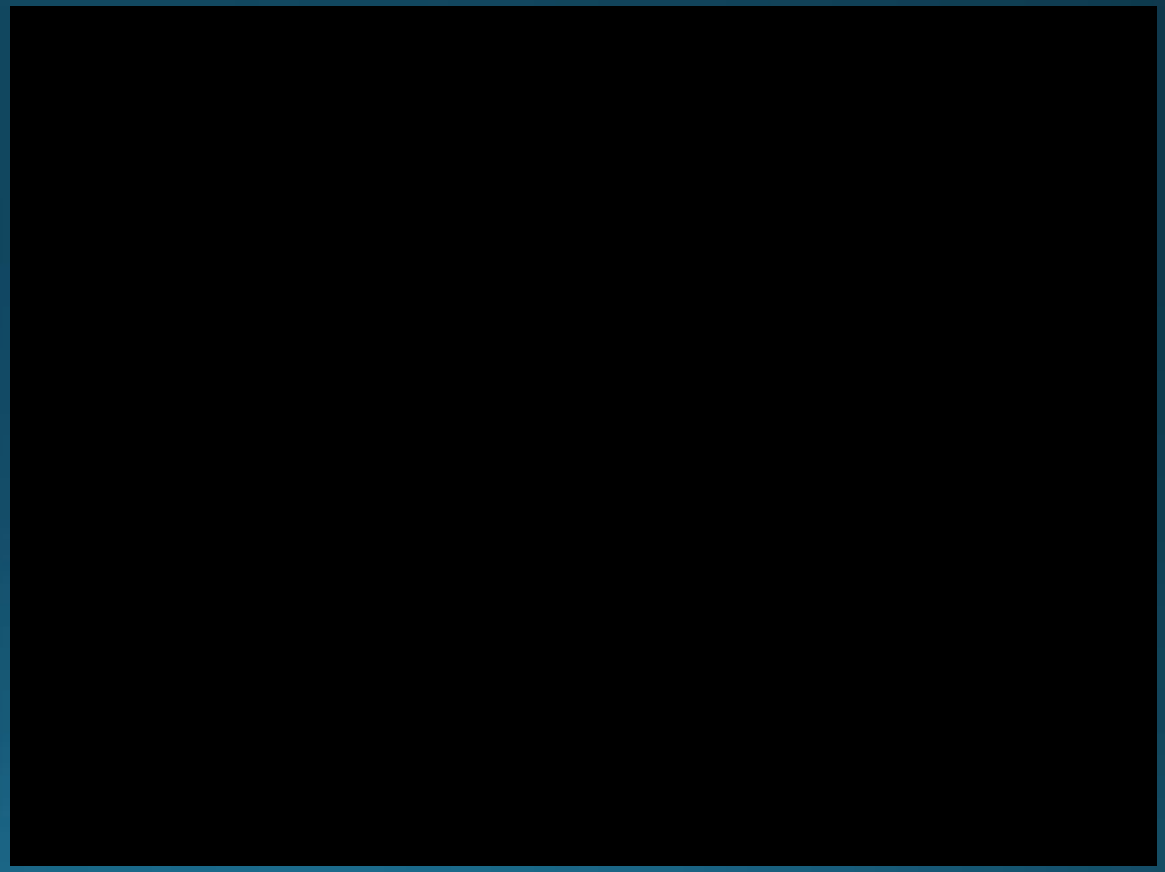
Baseline Setup

- Align orientation of gimbal with baseline
- This is accomplished by pointing the scope at the rover's GPS antenna
- Variable gimbal speed allows user to accurately point at rover



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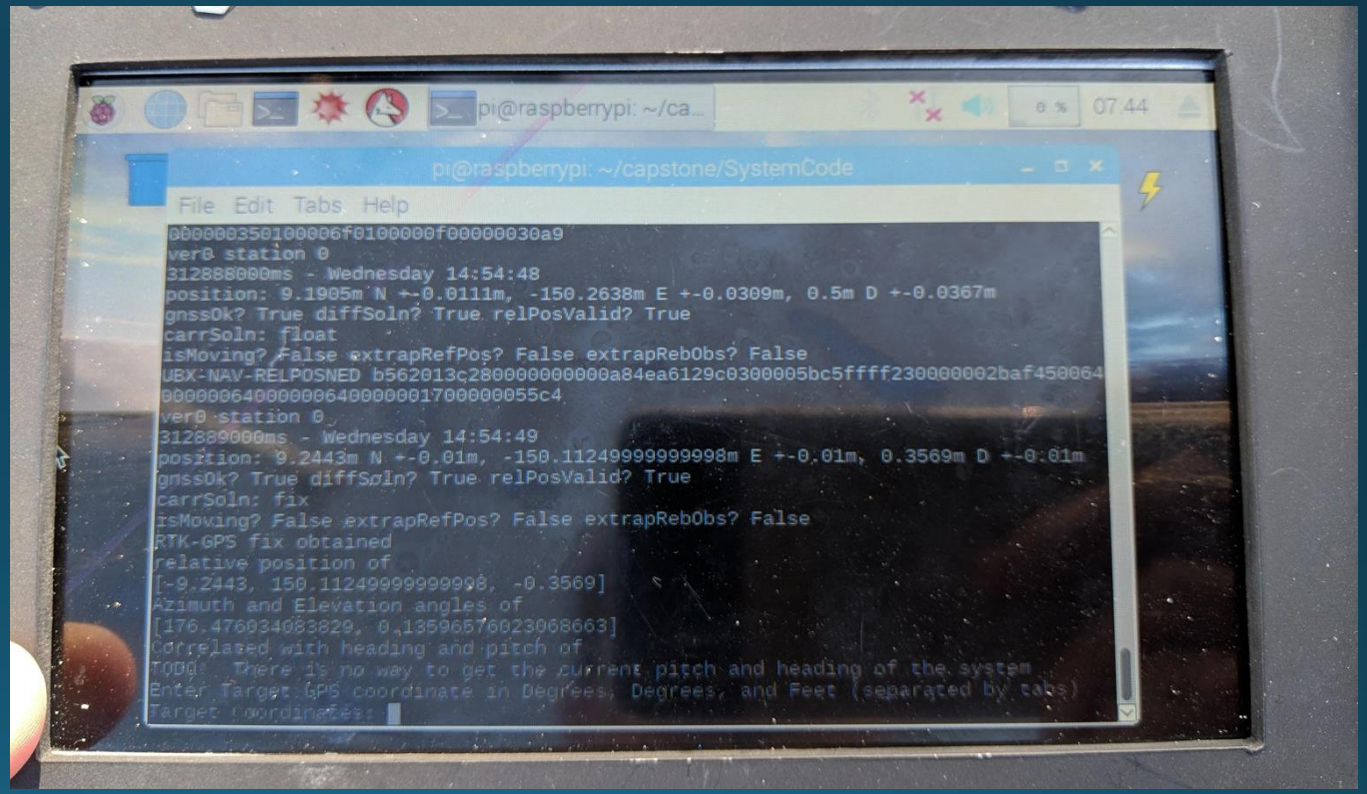
Input Pointing GPS Coordinates

- UI navigation and target GPS coordinates are entered via keypad on the handheld



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Level The Gimbal

- Triple-axis accelerometer
- The gimbal system pans in 45° intervals allowing the accelerometer to take readings at different locations
- Self-levels
- Rotates again to validate how level the system is

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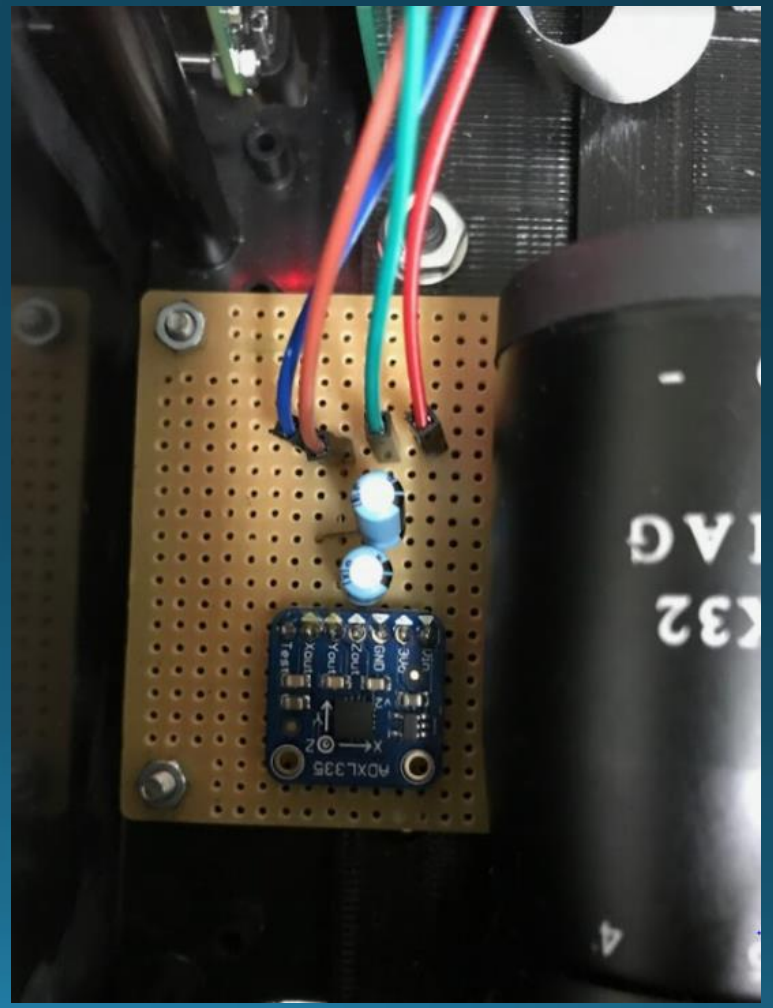
Testing and Validation

- Noise verified to ≤ 1 LSB
- 17-bit ADC
- Experimentally verified average offset from level of 0.012° over 10 trials



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Self-Calibration

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Full Test

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Cost

- Gimbal costs not included in final cost of the system
- Key Components
  - U-blox
  - Accelerometer
  - Simmons 3-9 power scope
  - 7” screen
  - Raspberry Pi
- Total Cost: $968

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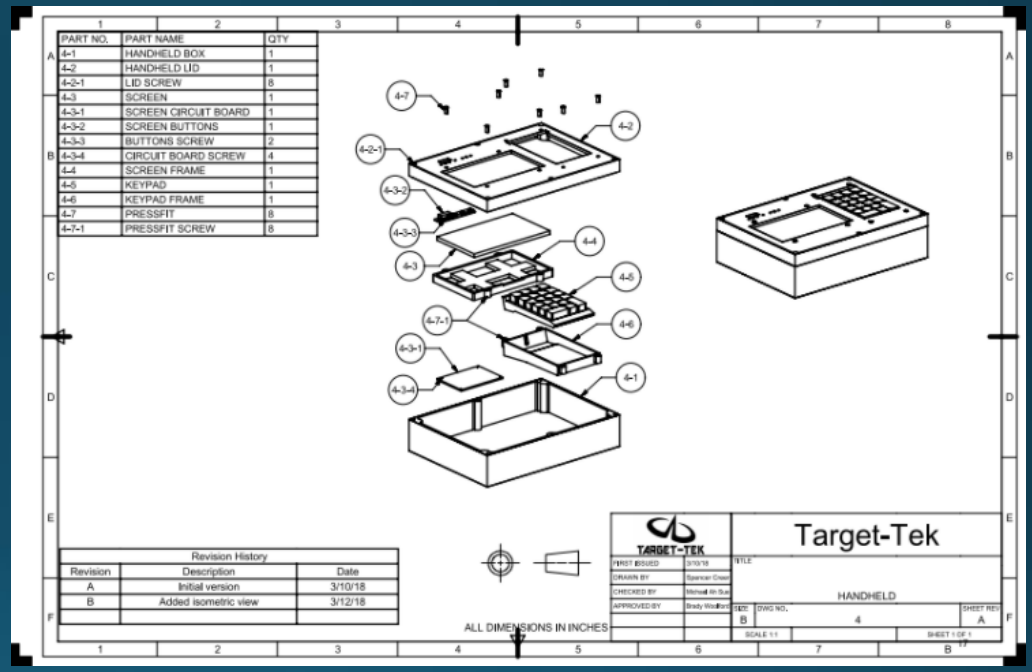
Bill of Materials (BOM)

Item	QTY	Cost	Subsystem
Accelerometer Eval Board	1	30.82	Base Station
Accelerometer	1	35	Base Station
Base Station Box	1	19	Base Station
Camera Module for Raspberry Pi 5 MP 1080 p	1	21.99	Base Line
Simmons 511039 3-9 x 32 mm Scope	1	38.5	Base Line
Encoder Wires (DF13-2630SF1571-26A9-300	20	18.2	Base Station
Press-Fit Threaded Stadoffs with Closed End	25	14.61	Base Station
U-blox C94-M8P-2	1	399	North Finding
Dewalt Tripods DW0737	2	95.98	Base Station / Rover
Voltage Regulators 945-1690-1-ND	1	3.39	Base Station
Rocker Switches EG1529-ND	2	3.1	Base Station / Rover
PT785-S Pan & Tilt System	1	349.99	Base Station
Raspberry Pi2 Model B	2	75.58	Base Station / North Finding
Rapsberry Pi 8 GB preloaded SD Card	2	21.7	Base Station / North Finding
Pololu Driver Boards	2	12	Base Station
Anker PowerCore 10000 Portable Battery	1	25.99	Rover
100:1 Planetary Gerabox Nema 17 Stepper Motors	2	106	Base Station
516-3594-ND Encoders	2	390	Base Station
HDMI 4 Pi 7" Screen	1	74.95	Base Station
22-Key Number Pad	1	17.99	Base Station
Plastic Case 8.85" X 4.44" X 2.48"	1	6.28	Rover
11.4" X 8.3" X 3.1" Plastic Box	1	26.82	Base Station
Mis. Cables	1	24.35	Base Station
3D printing parts*	1	22.99	Base Station
Hardware	1	10	All SubSystems
	Total:	1844.23	
	Total without gimbal:	968.04	

Deliverables

- Full system
- Design Package
  - Setup Procedure
  - Code
  - CAD models
  - Circuitry design
  - Testing and validation procedures and data
- Documented design process performed by the team



Recommendations

- Object recognition for establishing baseline
- Encoders
  - Self Leveling
- Additional Testing
- Replace 3D prints

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Results

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