Equine Diagnostic Applications of Real-Time Kinematics Precision GPS systems

Seth Cox, Samriddhi Bhatia, Boyun Wang

General Background – Historical Context

1870's, Beginnings with MuyBridge

Used sequential photography to study equine gait.

1880's, Advancements by Marey

Developed Chronophotography, enhancing motion capture teqniques.

20th Century, From Observation to Technology

Transition to Video and digital sensors to enable precise and real time measurement.

21st Century, Modern Tecnology – GPS and IMUs

Integration of GPS and IMU sensors for detailed movement tracking to facilitate real time, high resolution data analysis.

General Background

GPS Effectiveness in Racehorse training

- Use of GPS to assess training load (J. K. Kingston et al., 2006)
- Use of GPS to measure running speeds (A. Lindner and A. Brand, 2020)

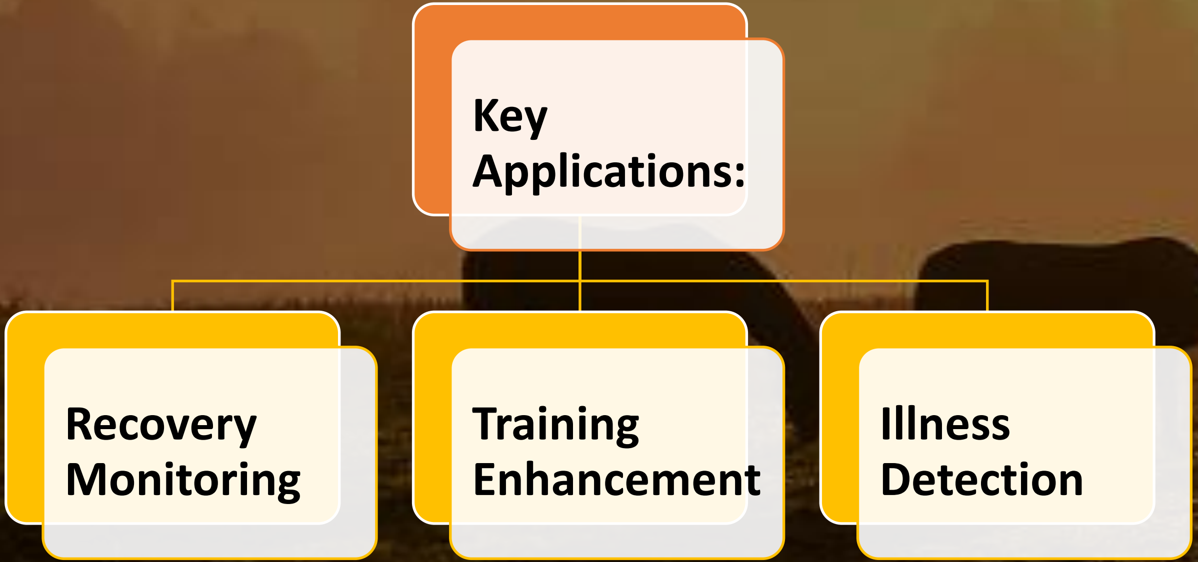
Role of IMUs in Equine Health monitoring

- Used for Lameness detection in trotting horses (Rhodin, M. et al., 2017)
- Used to investigate neuro muscular coordination during movement. (Barstow, A., Pfau, T., and Bolt, D.M., 2019)

Purpose

Hypothesis Exploration:

The combined utilization of high-precision GPS technology and Inertia Measurement Units (IMUs) can significantly enhance the monitoring and management of equine health and training by providing detailed insights into the movement patterns of horses over extended periods.



Applications

This is the application we aim to develop our unit for in this project.

1) Recovery Monitoring

- Collaboration with Veterinary Medicine: Partnership with the College of Veterinary Medicine to test the application of GPS in monitoring recovery phases.
- Purpose: To verify if GPS monitors can detect subtle changes in behavior and movement that indicate recovery progress or complications.
- Expected Outcome: Effective monitoring will enable timely adjustments to recovery plans, optimizing health outcomes and reducing recovery times.

Applications

These are future applications for which this device can be developed and tested for.

2) Training Enhancement:

- Purpose: To assess whether GPS and IMU data can improve training regimens by offering precise feedback on performance metrics such as speed, stamina, and gait consistency.
- Expected Outcome: Trainers can use these insights to customize training programs, potentially enhancing performance and reducing injury risks.

3) Illness Detection:

- Purpose: To explore the capability of GPS and IMU systems to identify early signs of illness or distress through anomalies in movement patterns.
- Expected Outcome: Early detection allows for quicker interventions, possibly improving prognosis and minimizing the impact of illnesses.

GPS RTK Background - How a GPS Works

GPS modules find their position via a process called trilateration. This is done by finding the range from multiple satellites to see where they intersect.

The GPS module determines the range by using the position of the satellite as well as the time the signal from the satellite was sent out via,

$$\rho_i = c\Delta t_i = \sqrt{\left(x - x_{\text{sat},i}\right)^2 + \left(y - y_{\text{sat},i}\right)^2 + \left(z - z_{\text{sat},i}\right)^2}$$

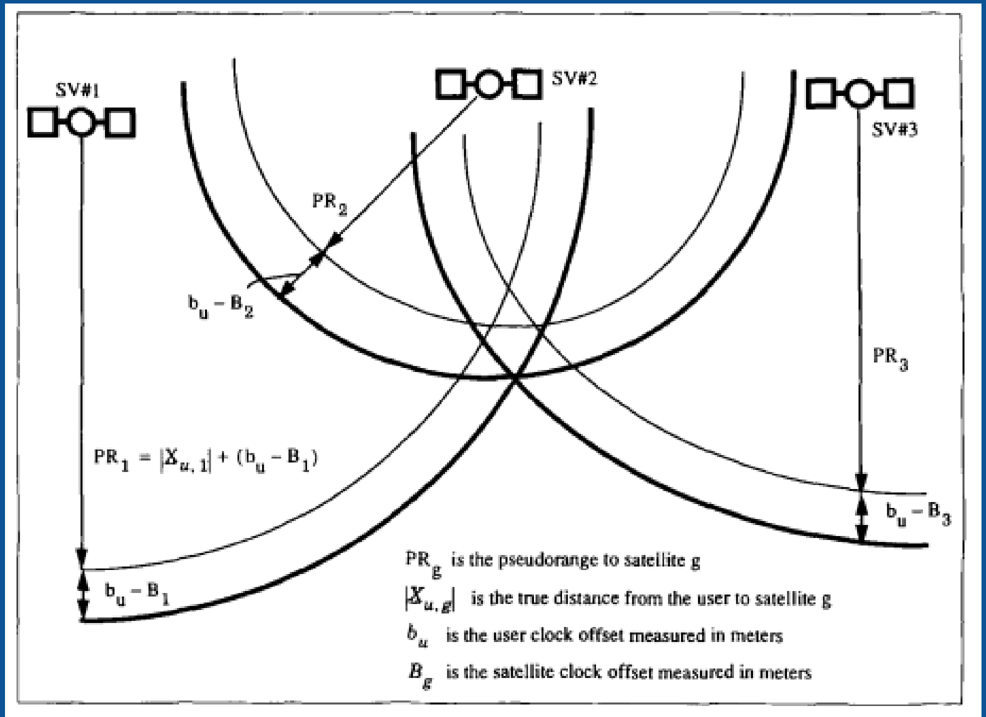


Image adapted from The Global Positioning System: Signals, Measurements, and Performance by Per K. Enge

GPS RTK Background - How a GPS Works

This assumes that the signal traveled in a straight line to the GPS module. In practice there are many sources of error affecting this measurement. This leads to the 'pseudorange'. Sources of error are

- Atmospheric effects, specifically refraction in the ionosphere and troposphere
- Clock offsets between the satellite and GPS module
- Errors in the Satellites Ephemeral data
- Selective Availability (Turned off in 2000)

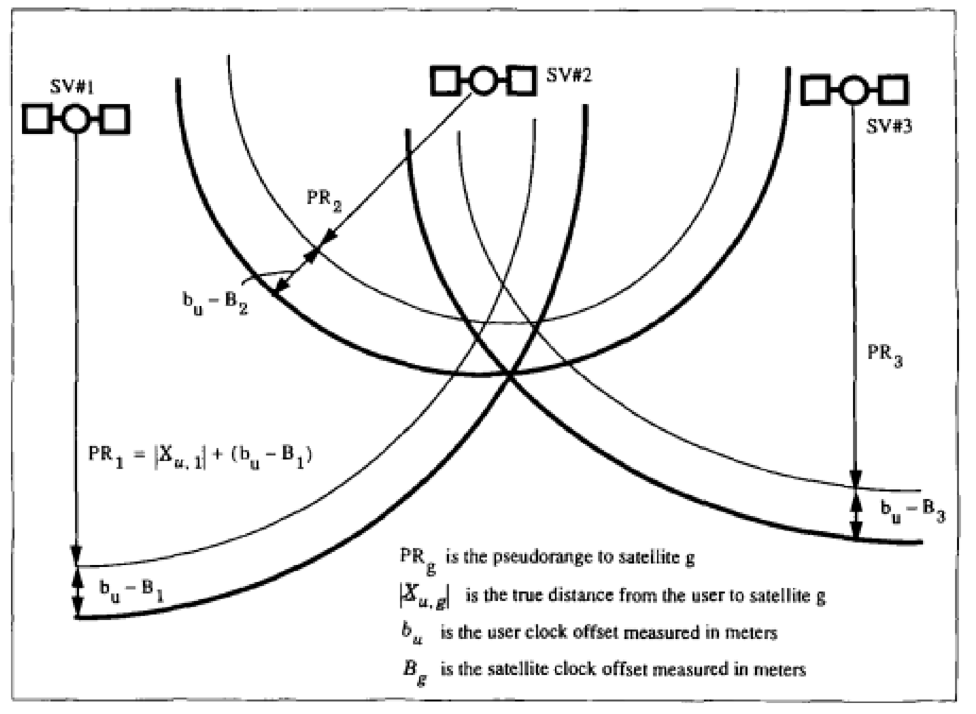


Image adapted from The Global Positioning System: Signals, Measurements, and Performance by Per K. Enge

GPS RTK Background – Intro to RTK

So how do we account for these errors? Real Time Kinematics (RTK) with ≈ 1cm accuracy.

RTK requires the use of two GPS modules

The Basic Steps to this process are:

1. The base station measures its pseudorange and the phase of the carrier signals, from this it can make estimates on the error the system is seeing since it already knows its position.
2. The base station sends this information, including its location and the phase of the carrier wave to the rover. This is done using the Radio Technical Commission for Maritime Services (RTCM) protocol
3. The rover then finds its pseudorange and uses the data the base station sent to it to find its relative position to the base station to high precision.

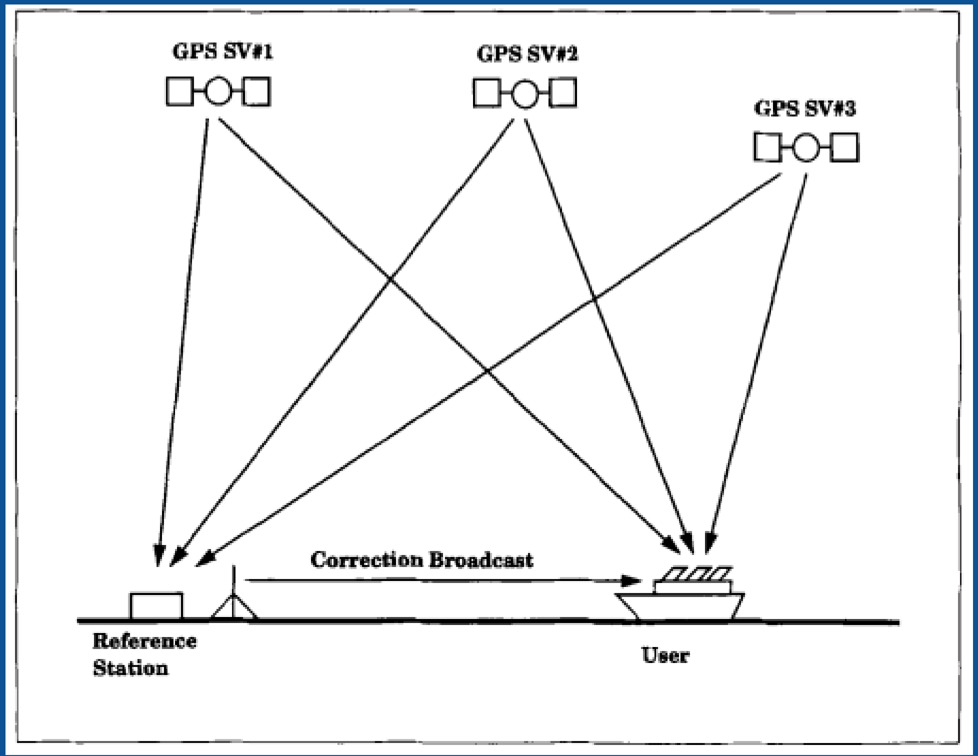


Image adapted from The Global Positioning System: Signals, Measurements, and Performance by Per K. Enge

GPS RTK Background - RTK Algorithm

To find the relative position of the rover from the base station, the rover must calculate the phase difference between the signals arriving there, and at the base station. This is done via process known as double difference processing. Mathematically this looks like,

$$\phi_{\text{base},i} = \frac{2\pi}{\lambda}\left[\rho_i - N_i\lambda + \epsilon_\phi + I_i - T_i + c\left(b_{\text{sat},i} - b_{\text{base}}\right)\right],$$

which finds the phase of the signal at the base station/rover. For double difference processing we need to find the phase difference between the base station and rover for 2 different signals and subtract them.

Variables in Equations:

λ - Wavelength

ϵ_ϕ - System Noise

I_i - Ionospheric Error

T_i - Tropospheric Error

c – Speed of Light

N_i - Integer Ambiguity

b – Clock Bias

GPS RTK Background - RTK Algorithm

This results in,

$$\Delta\Phi = \frac{2\pi}{\lambda}\left(\rho_{rec,1} - \rho_{base,1} - \rho_{rec,2} + \rho_{base,2} - \lambda\left(N_{rec,1} - N_{base,1} - N_{rec,2} + N_{base,2}\right)\right),$$

which resolves the issue to 4 integer ambiguities. Solve these and you have the relative position. This is what is known as RTK 'floating' mode.

Solving for these requires taking multiple sets of data and complex algorithms to solve. The time it takes for the rover to 'fix' is what denotes the quality of a device.

This process works on the assumption that the errors seen by the base station are the same as those experienced by the rover.

Variables in Equations:

λ - Wavelength

ϵ_ϕ - System Noise

I_i - Ionospheric Error

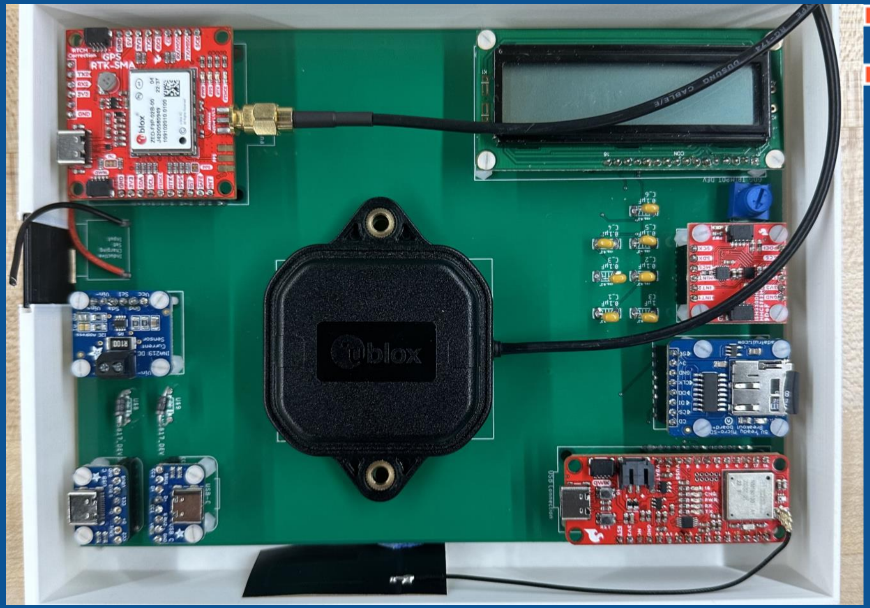
T_i - Tropospheric Error

c – Speed of Light

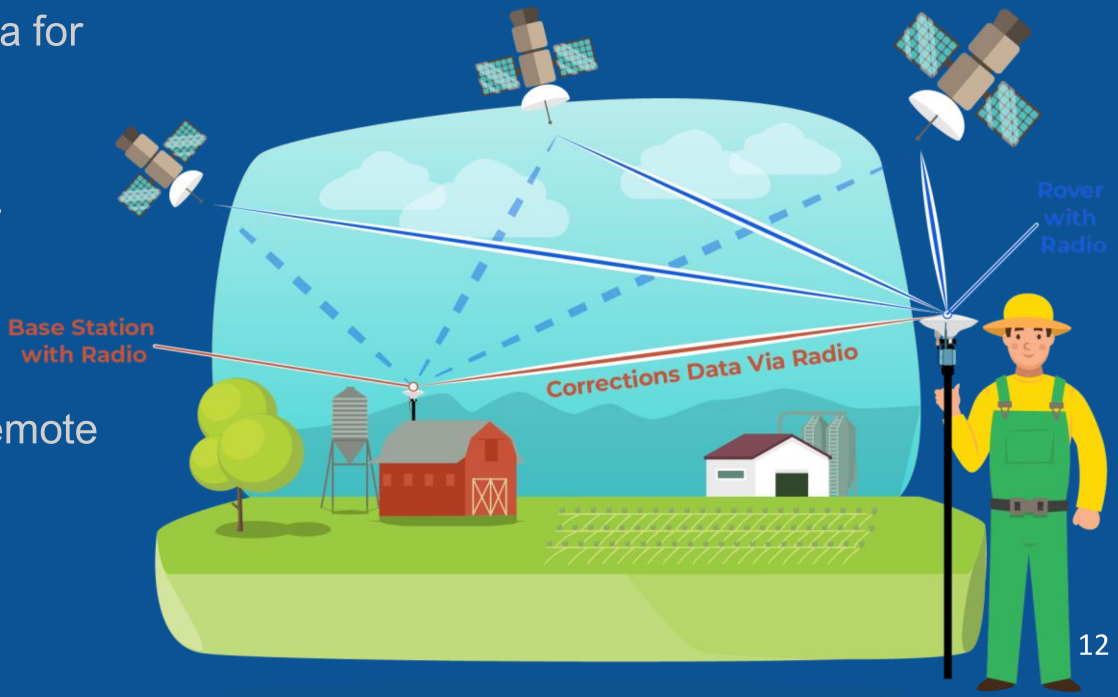
N_i - Integer Ambiguity

b – Clock Bias

Experimental Set-up



- System components: Two GPS-RTK-SMA Breakout boards by Sparkfun Electronics.
- Communication Setup : Each board is paired with LoRa Thing Plus - expLoRaBLE board, allowing communication over the radio antenna of 915 MHz.
- Antenna and Grounding plates: ANN-MB-00 GNSS multiband antenna for both L1 and L2 frequency bands along with grounding plates.
- Base Station Set-up and Data Collection : Data collection for up to 24 hours on the roof of Loomis for minimal disturbance. RTCM message transfer to GPS module on the rover
- Power and access : Base Station is powered by computer directly. Remote access to Base station's computer through Window's Remote Access Feature. Rover powered by a battery and charged via an inductive charging system.



Board Design

Base Station:

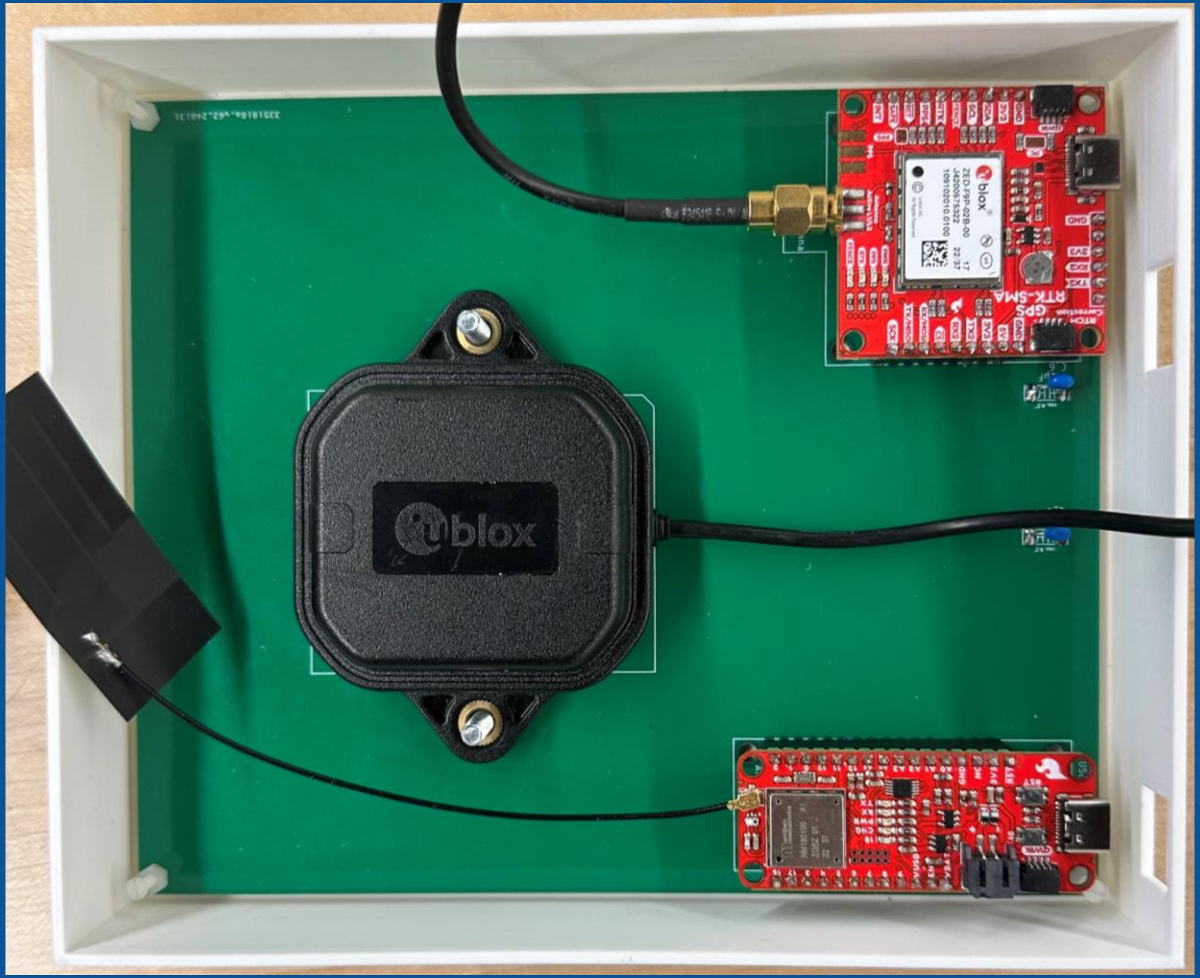
a) SparkFun GPS-RTK-SMA Breakout - ZED-F9P

b) SparkFun LoRa Thing Plus – explorable

Only necessary connection is I^2C between the ZED-F9P and LoRa Thing Plus.

Allows for connection to computer for access to U-Center.

Made to be powered indefinitely by computer.



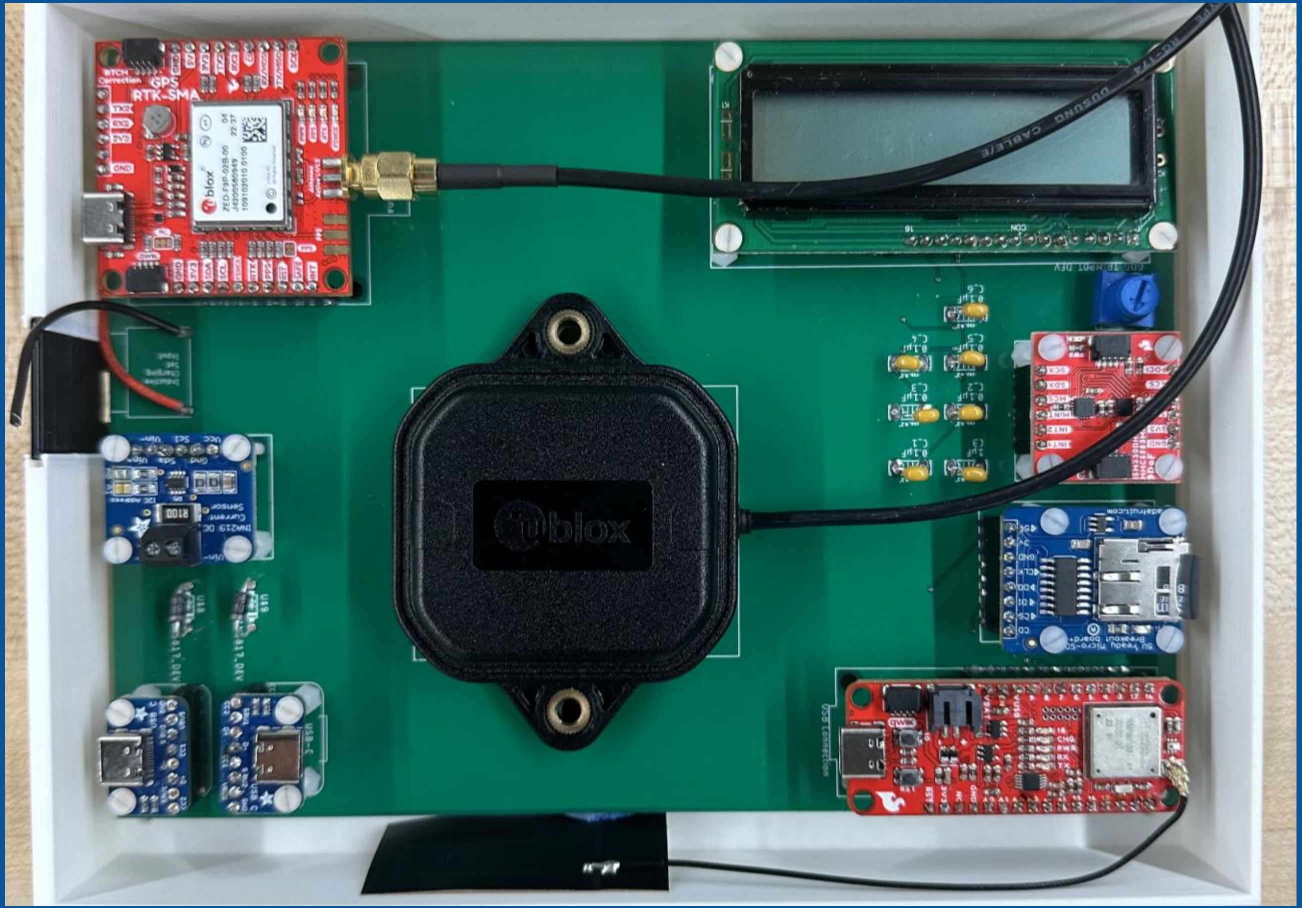
Board Design

Equine GPS Rover

a) SparkFun GPS-RTK-SMA Breakout - ZED-F9P
b) SparkFun LoRa Thing Plus – explorable
c) 6DoF IMU Breakout - BMI270
d) INA219 Current Sensor
e) Adafruit Micro-SD Breakout
f) LCD Screen
g) Inductive Charger

The rover is capable of radio communication which allows for wireless control and long data runs.

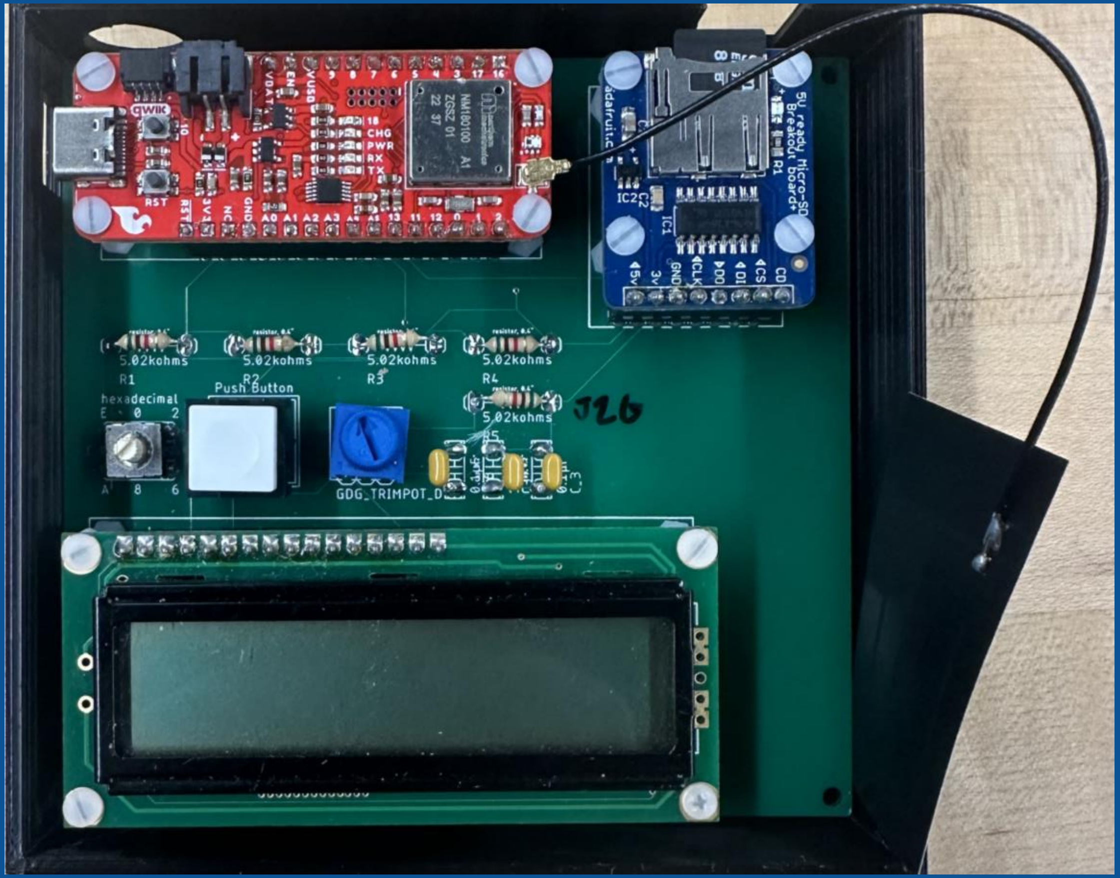
Not seen is a 10050mAh battery used for power.



Board Design

Receiving Board

a) SparkFun LoRa Thing Plus – explorable
b) Adafruit Micro-SD Breakout
c) LCD Screen
d) Inductive Charger
e) Button and Hexadecimal Rotary Switch



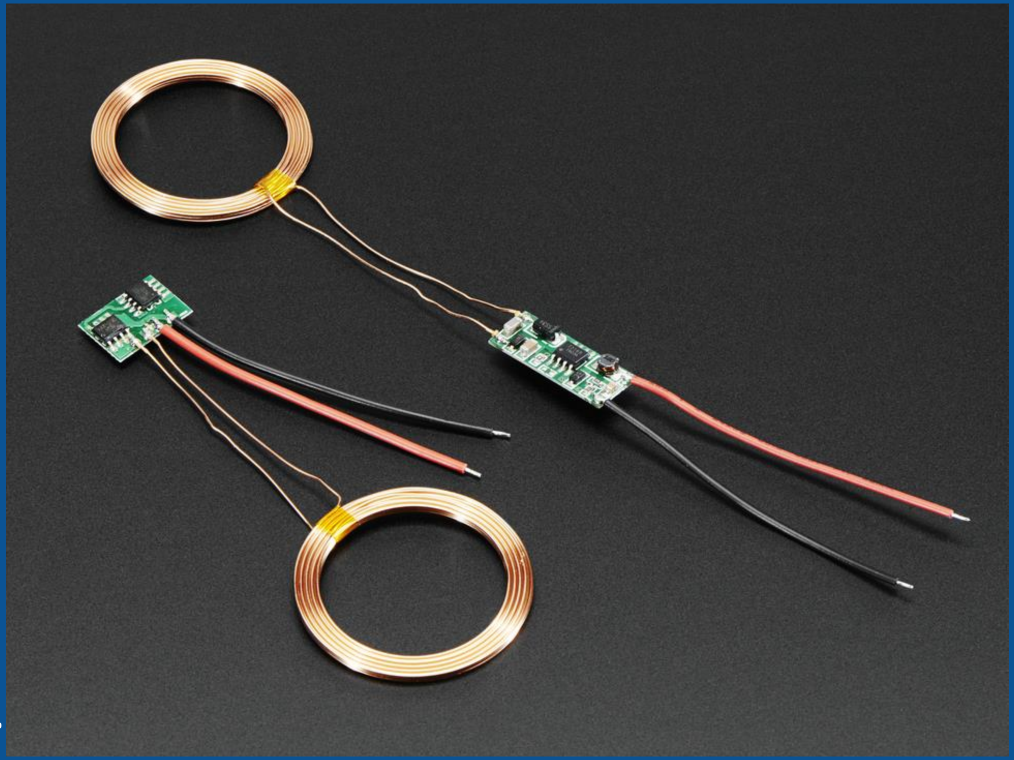
Receiving board can control the rover remotely and collect data without removing the rover from the horse.

Housing Design and Setup

Charging Choice: Inductive Charging

- Why We need to use Inductive Charging?
  1. Convenient
  2. Waterproof

- How it works?
  1. These chargers work by taking a power transformer and splitting it in half, an AC waveform is generated into one, and couples into the second coil.
  2. Any non-ferrous/non-conductive material (eg air, wood, leather, plastic, paper, glass) can be used between the two coils. The material doesn't affect the distance or efficiency.

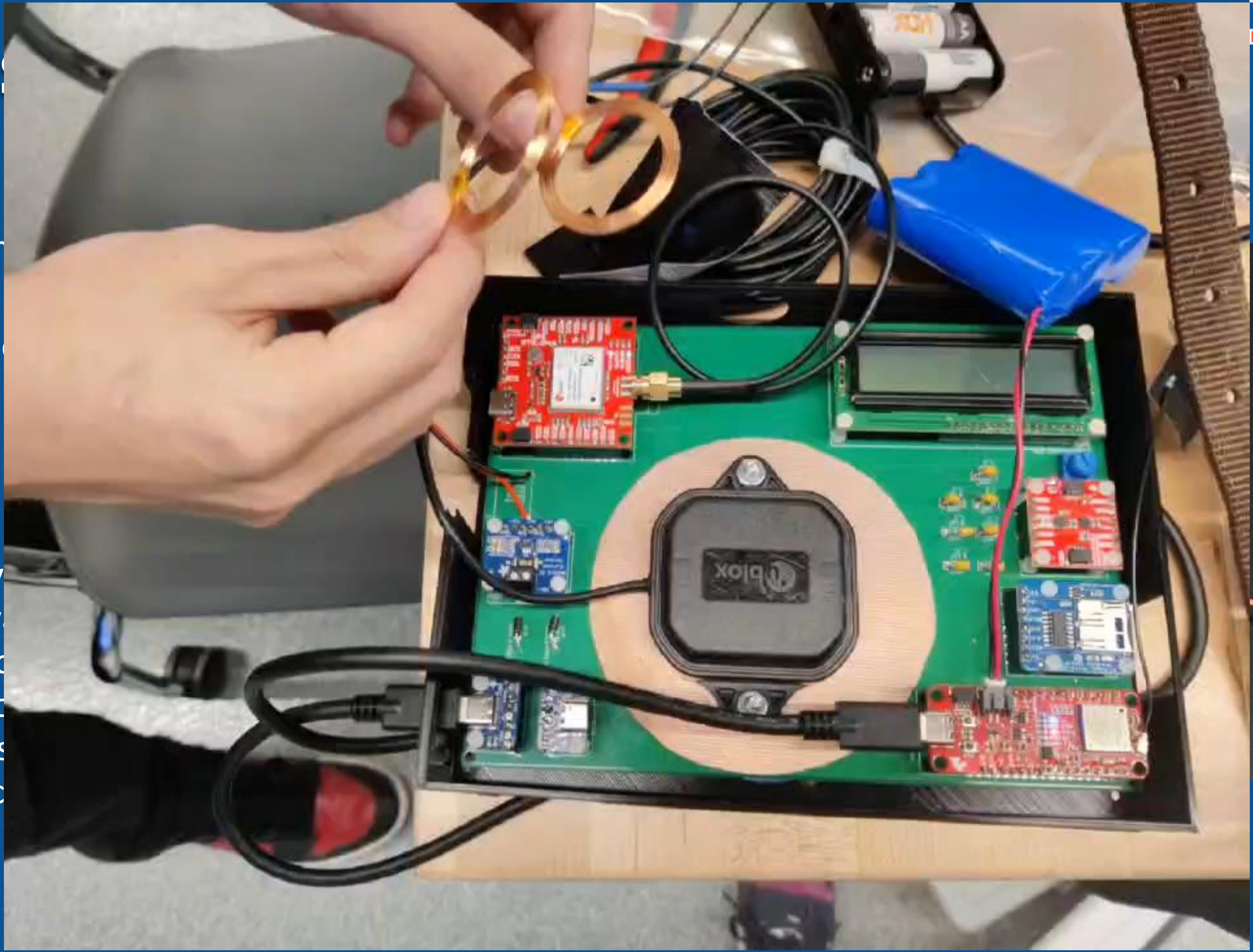


Housing Des

Charging Choice: Inductive Ch

- Why We need to use Induc
  1. Convenient
  2. Waterproof

- How it works?
  1. These chargers work by
  splitting it in half, an AC w
  couples into the second co
  2. Any non-ferrous/non-co
  leather, plastic, paper, glas
  The material doesn't affec



Housing Design and Setup

Equine GPS Rover

Components:

- PCB Board with Circuit

External Design:

- We chose to mount the PCB onto a surcingle which would go on the back of the horse.
- Waterproof and Fixing Choice
  Fixing case with zip ties on the surcingle, then use sealed waterproof bags to cover it.

Housing Design and Setup

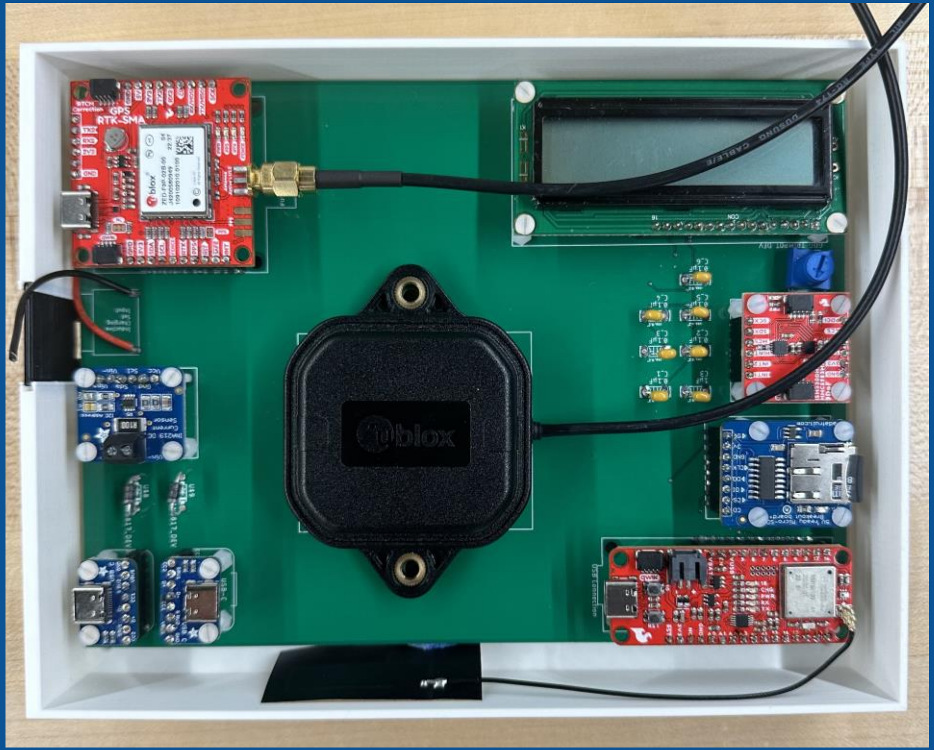
Equine GPS Rover

Sealed PCB Bag: A customized bag has waterproof, anti-corrosive, and mildew-proof functions, and the waterproof antenna also extends from one end.

3D Printed Case: Used for fixing PCB board and playing a reinforcing role.

Things to Consider:

1. Environmental factors
2. The comfort of the horse
3. The behavior of the horse



Housing Design and Setup

The reference Base Station:

- Assembly and power supply: Assemble the PCB circuit board powered by USB and connect it to the reference computer. We aim to build an analogous setup to the one provided by SparkFun's tutorial on building a DIY GNSS reference station.

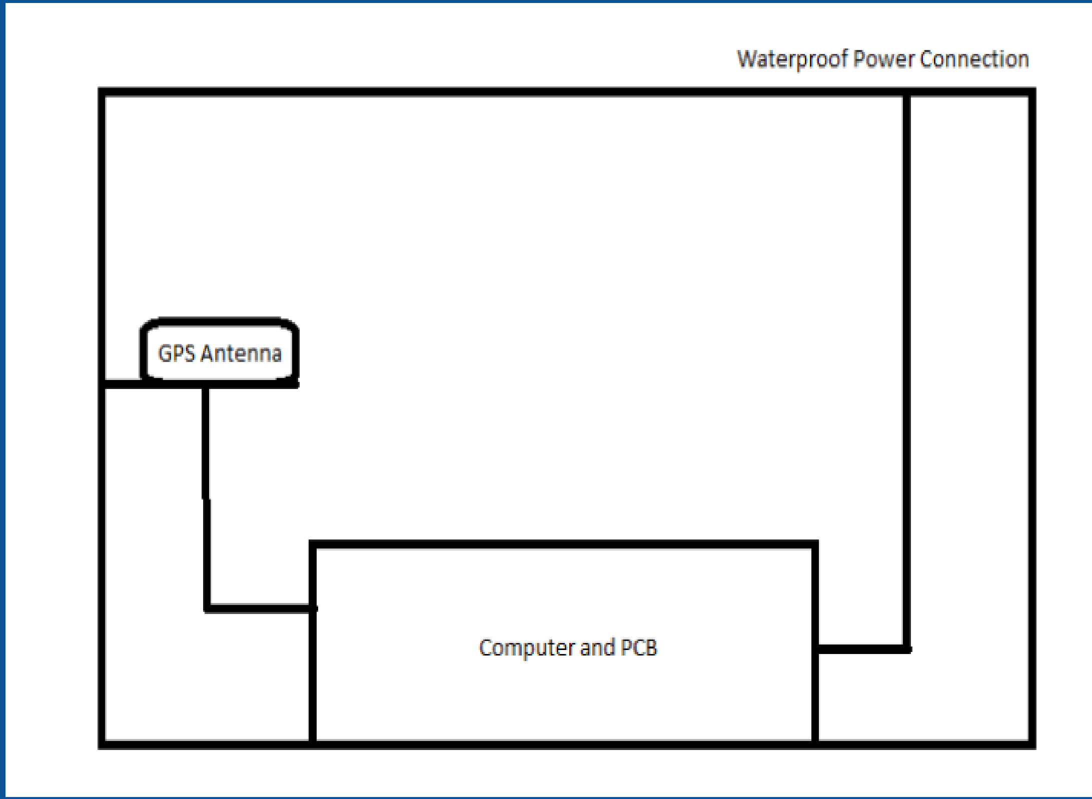
External shell:

- The system adopts a completely waterproof shell to ensure that the internal components are protected from weather conditions.

Problems:

Waterproof is not done well, which leads to the failure of waterproof cover in windy environment.

The receiving antenna is placed in an obstacle-free area to ensure the strength and integrity of the received signal.



Data Acquisition and Procedure

To acquire accuracy data, a few separate tests were done, each over a one-minute time interval which corresponds to approximately 60 data points.

Tests were done to gauge the accuracy with/without the steel grounding plate, and when the rover was moving.

For the stationary test, the rover system was placed a little over 1 meter from the base station and was not touched for the entire test.

For the moving test, one of us walks around in circles in the same spot each time approximately 1-2 meters from the base station.

Data Acquisition and Procedure

Accuracy data was collected using the built in horizontal and vertical accuracy functions of the GPS breakout board.

We tested the accuracy of the device while moving while walking around Loomis.

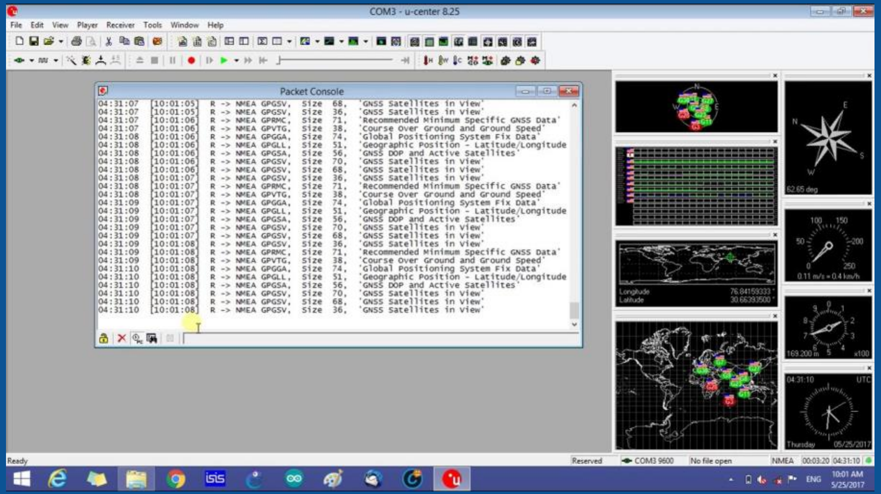
Lastly, we put the rover on the horse and conduct a field test.

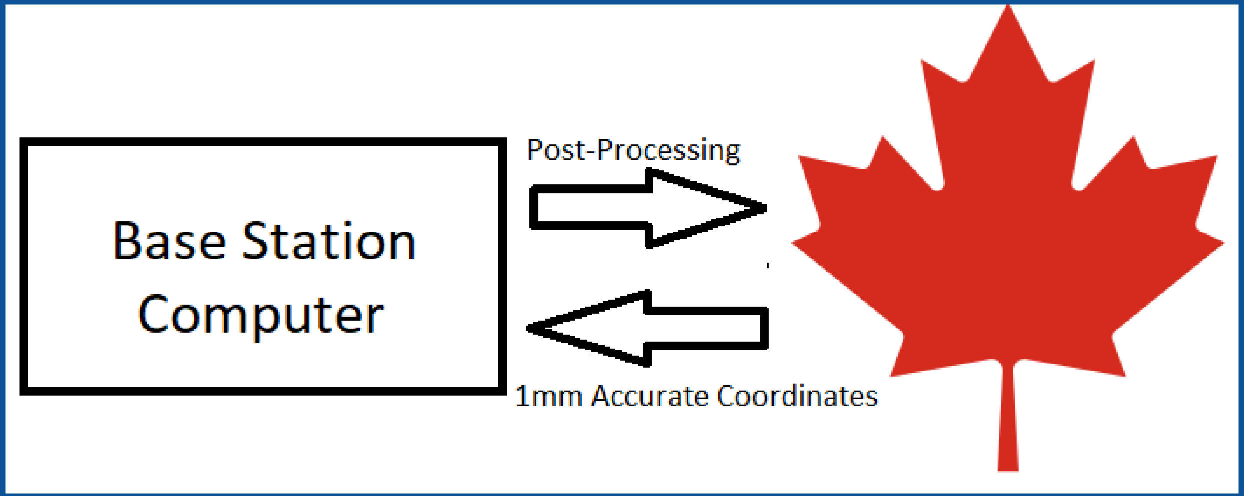
Data Acquisition and Procedure

GPS Data can also be acquired using the software U-Center.

This program lets us control all aspects of the GPS module inside the program instead of the code.

This program will be used to determine the coordinates of the antenna once the permanent base station is installed.

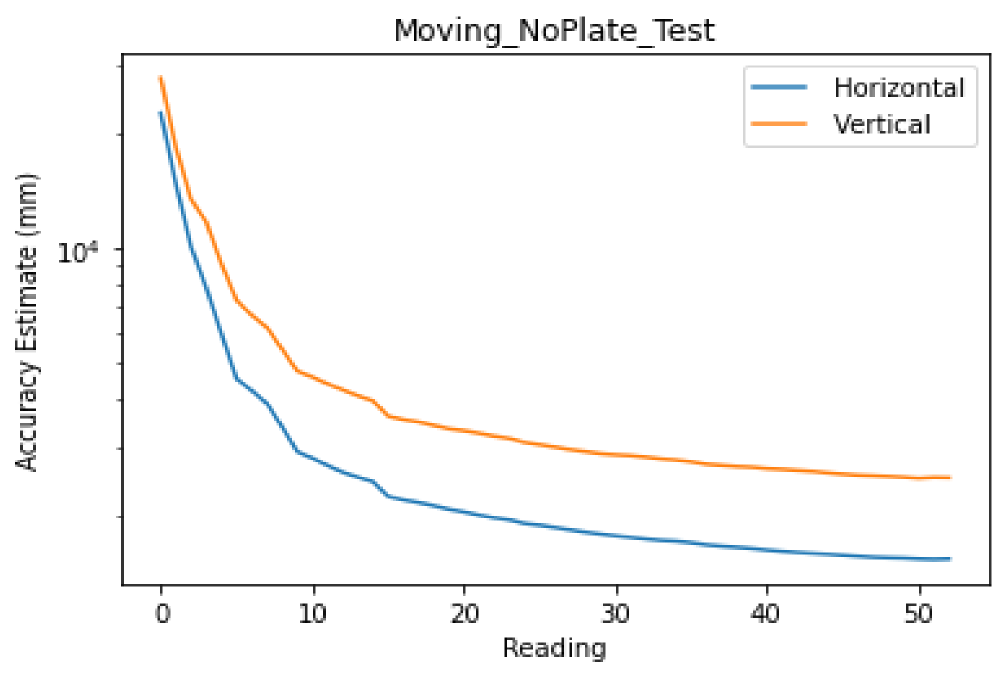


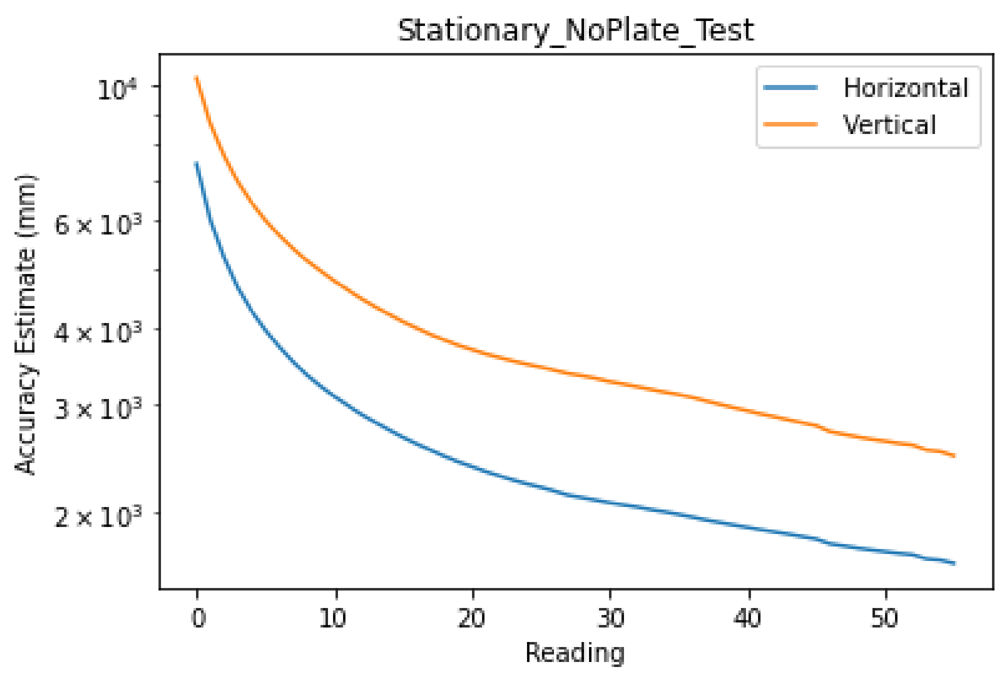


Results

Data from accuracy tests while stationary and moving, and with/without grounding plate.

These tests confirm the plate is necessary, device never comes close to a fix without it and accuracy is unacceptable to current goals.



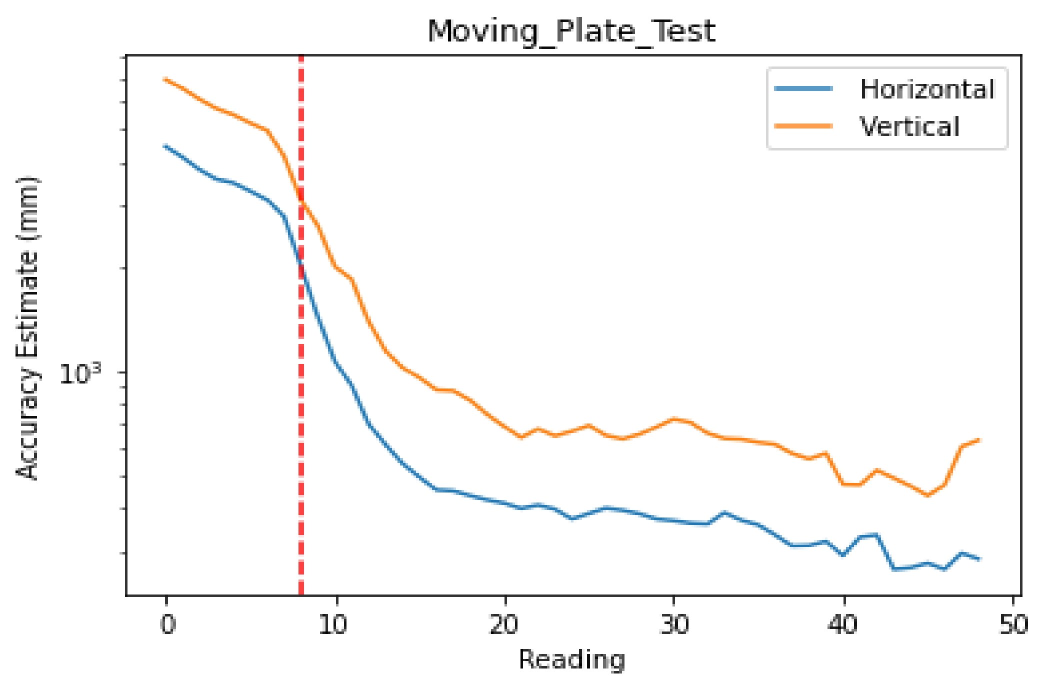


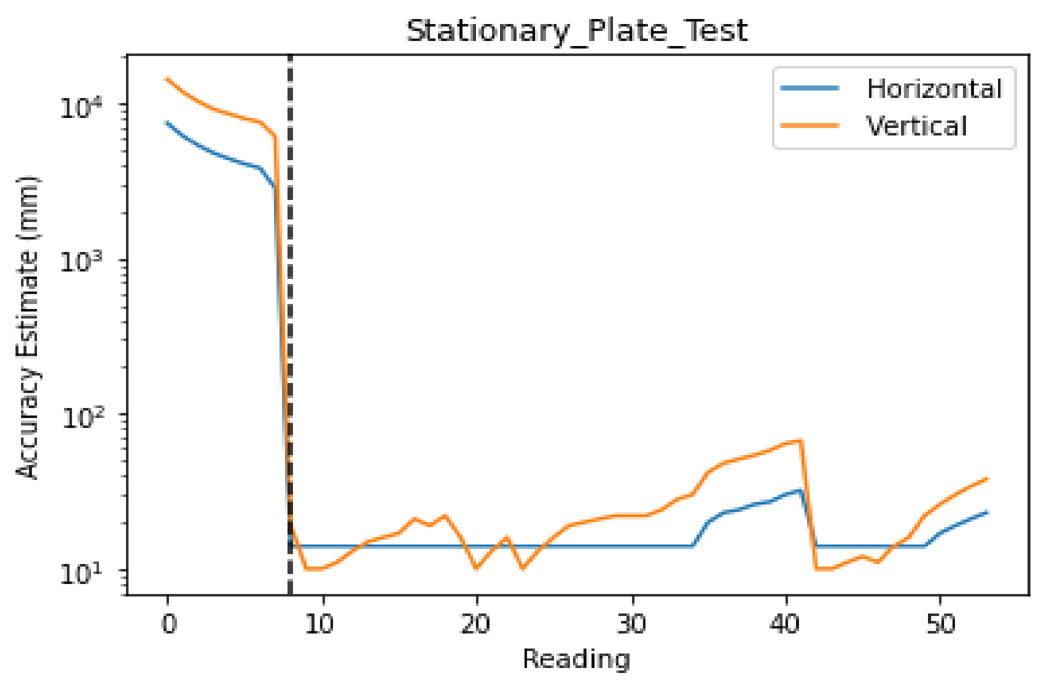
Results

Vertical accuracy is always at least slightly worse than horizontal, something to keep in mind.

Moving Data is also worse than stationary, important to consider with purpose of project.

Further tests need to be done to test the effects of moving on the accuracy, is there a maximum speed the device can move while fixed/fixing?



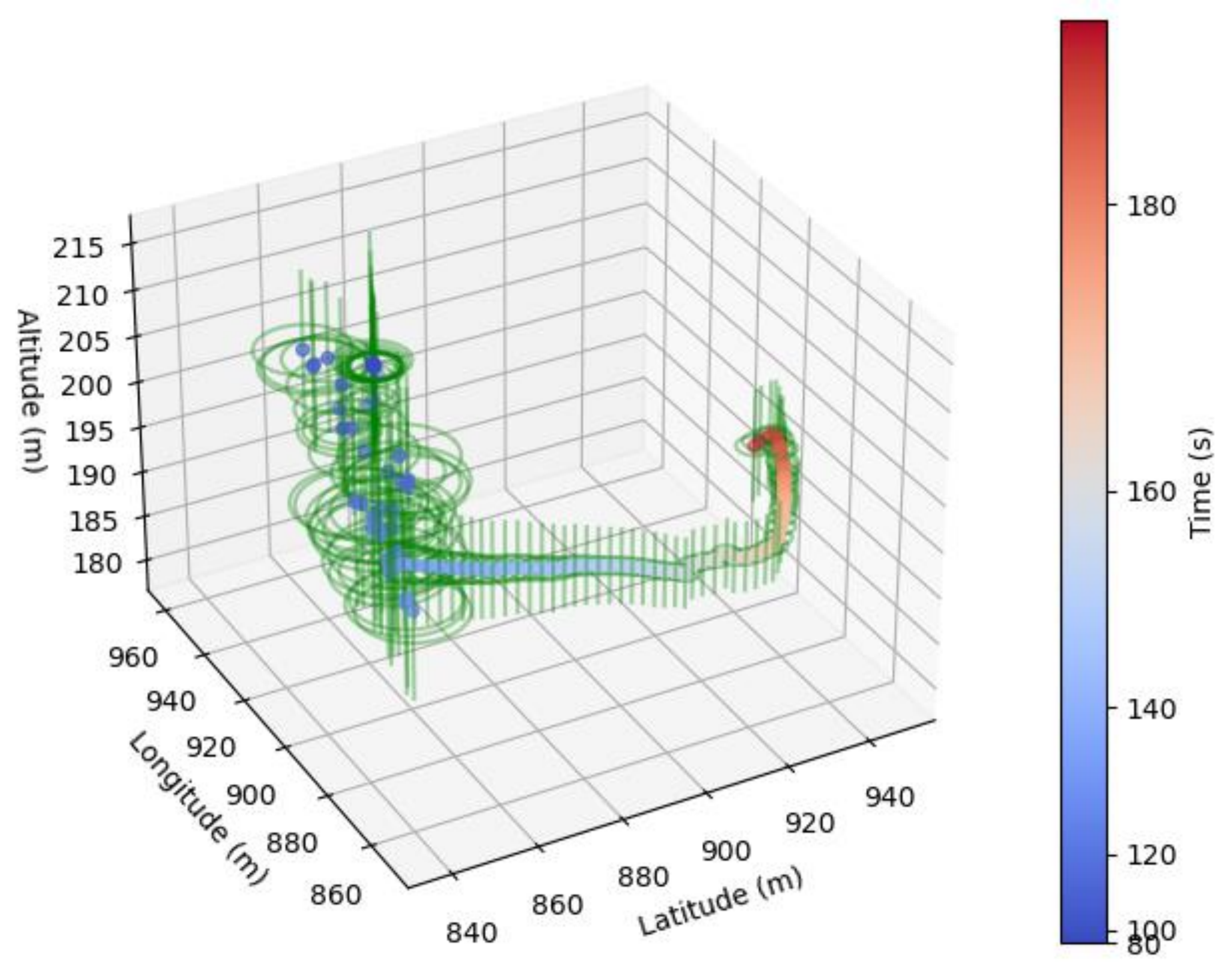


Results

Accuracy test done during a walk around Loomis.

Both horizontal and vertical accuracy ended at around 5m.

Base Station was not operational for this test.



Data Acquisition and Procedure

We affixed the device onto a surcingle placed upon the horse's back. Over a 10-minute trial, we had the horse to walk, run, and sit, while we recorded positional GPS data.

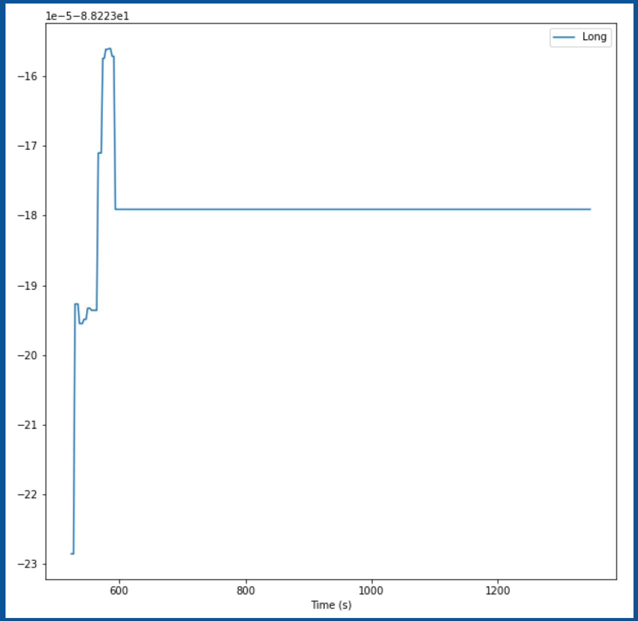
Results

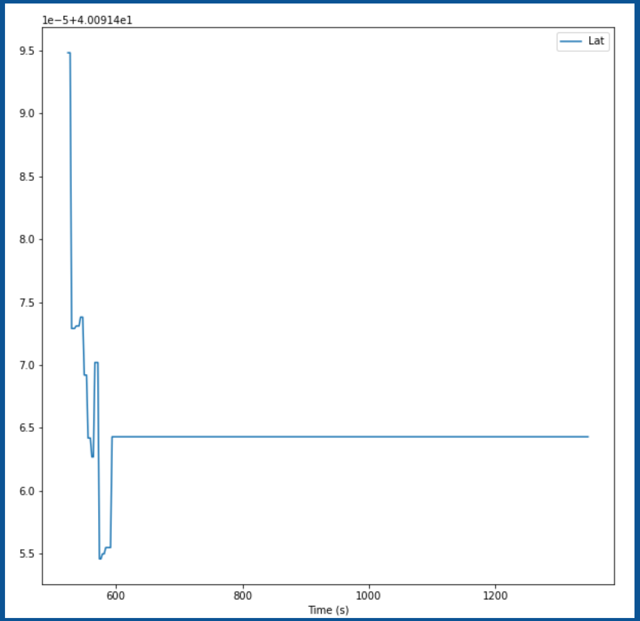
Or this test the horse stood still, walked, sprinted and eventually, laid down.

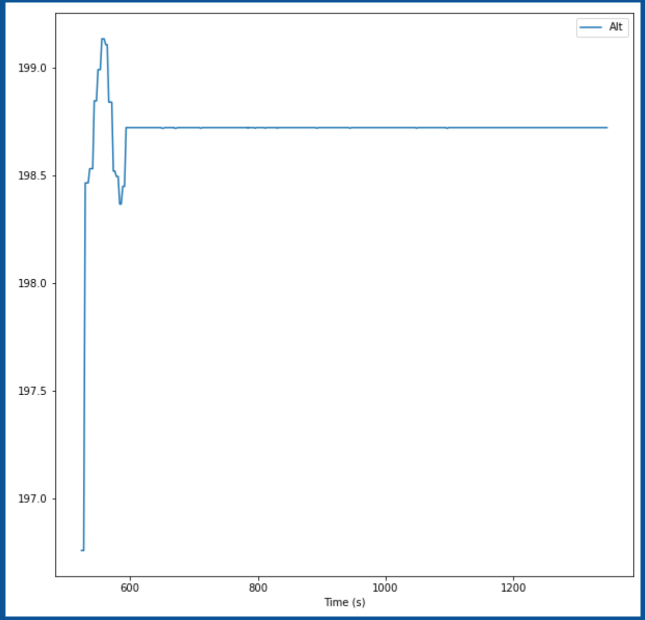
About 2 minutes into the test, the GPS module entered a ‘Time Only mode’. This restricts RTK connections and causes the GPS data to go constant.

This mode had been seen a few times during troubleshooting though no reliable cause or solution was seen.

Units in degrees Longitude/Latitude







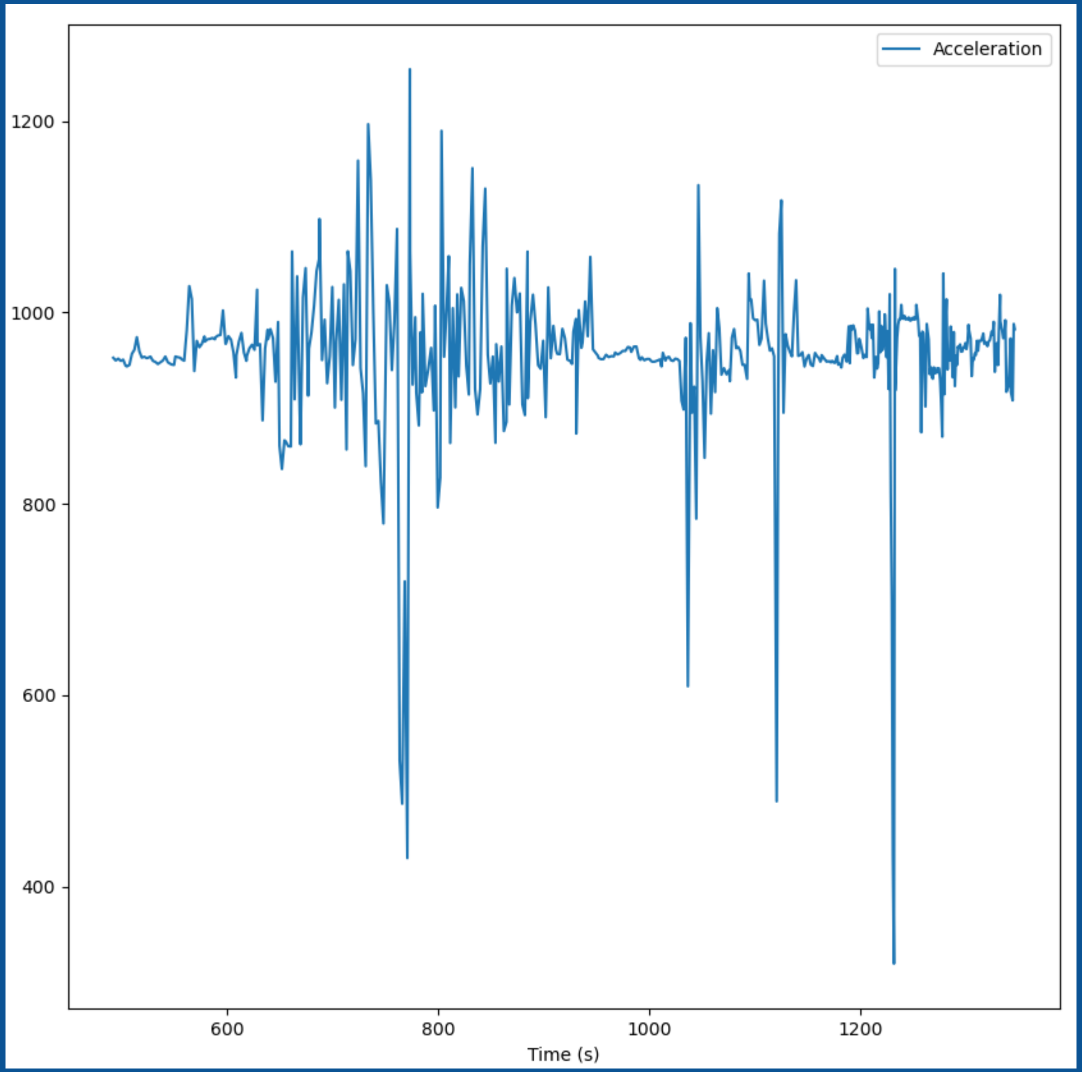
Units in Meters

Results

The IMU worked as desired, however.

From both acceleration and gyroscopic data, the points where the horse turned and laid down were clear.

While sharp changes in behavior can be seen, nothing can truly be said about nuanced behavior.



Units are in g's, but a calibration error caused the scale to be off.

Discussion

Current prototype's limitation in precision, accuracy and size hinder comprehensive behavior analysis and preemptive health issue detection.

Future Test

- Mode Stability and Velocity
- Distance and Accuracy

Design Modifications and Data Collection

- Improve Radio Antenna range
- Address Base Station Reliability

Rover Design Challenges

- Size and weight reduction.
- Durability against natural behavior (Eg. Rolling)

Outlook

Future tests for Feasibility

- **System Reliability:**
  Address issues with GPS reliability and potential unmonitored field challenges.
- **Data Collection and Analysis:**
  Consider collecting extensive data over multiple hours to use machine learning for trend analysis and anomaly detection.
- **Multiple Devices:**
  Consider collecting data from multiple GPS and IMU sensors placed on different parts of the horse to detect nuanced behavior.

Questions?

Acknowledgements:

Prof. George Gollin & Prof. Yuk Tung Liu

SparkFun Electronics

Prof. Annette Marie McCoy

References

[1] Anders Herlin, Emma Brunberg, Jan Hultgren, Niclas Högberg, Anna Rydberg, and Anna Skarin. Animal welfare implications of digital tools for monitoring and management of cattle and sheep on pasture. *Animals (Basel)*, 11(3), March 2021.

[2] Per K. Enge. The global positioning system: Signals, measurements, and performance. *International Journal of Wireless Information Networks*, 1(2):83–105, Apr 1994.

[3] Mauricio Andrada. Real-time kinetics (rtk), Sep 2020.

[4] Yanming Feng and Jinling Wang. GPS RTK performance characteristics and analysis. *Positioning*, 01No.13:8, 2008.

[5] BA Hampson, JM Morton, PC Mills, MG Trotter, DW Lamb, and CC Pollitt. Monitoring distances travelled by horses using GPS tracking collars. *Australian Veterinary Journal*, 88(5):176–181, April 2010.

[6] J K Kingston, G M Soppet, C W Rogers, and E C Firth. Use of a global positioning and heart rate monitoring system to assess training load in a group of thoroughbred racehorses. *Equine Vet J Suppl*, (36):106–109, August 2006.

[7] Arno Lindner and Anna Brand. Global positioning system–determined and stopwatch-determined running speeds of horses differ. *Journal of Equine Veterinary Science*, 84:102871, 2020.

[8] Rolf Moe-Nilssen and Jorunn Helbostad. Interstride trunk acceleration variability but not step width variability can differentiate between fit and frail older adults. *Gait posture*, 21:164–70, 02 2005.

[9] Thilo Pfau, Thomas H. Witte, and Alan M. Wilson. A method for deriving displacement data during cyclical movement using an inertial sensor. *Journal of Experimental Biology*, 208(13):2503–2514, July 2005.

[10] u-blox. *ZED-F9P-02B High precision GNSS module*, 2023. Rev. 3.

[11] Jan Gromeš. RadioLib. https://github.com/jgromes/RadioLib, 2023. [Online; accessed 9-Sep-2023].

[12] Shenzhen XinLisheng Hardware Electronics Co., Ltd. *2G 3G 4G LTE full band FPC Internal Antenna*, 2023.

[13] adafruit. *Inductive Charging Set - 5V @ 500mA max*, 2023.

[14] digiKey. *1593PTBU*, 2023.

[15] Made-in-China. *Custom ESD Logo Printed 2-Side Sealing Anti-Static Vacuum Clear Plastic Bag for PCB Packaging*, 2023.

[16] NATE. *How to Build a DIY GNSS Reference Station*, 2023.

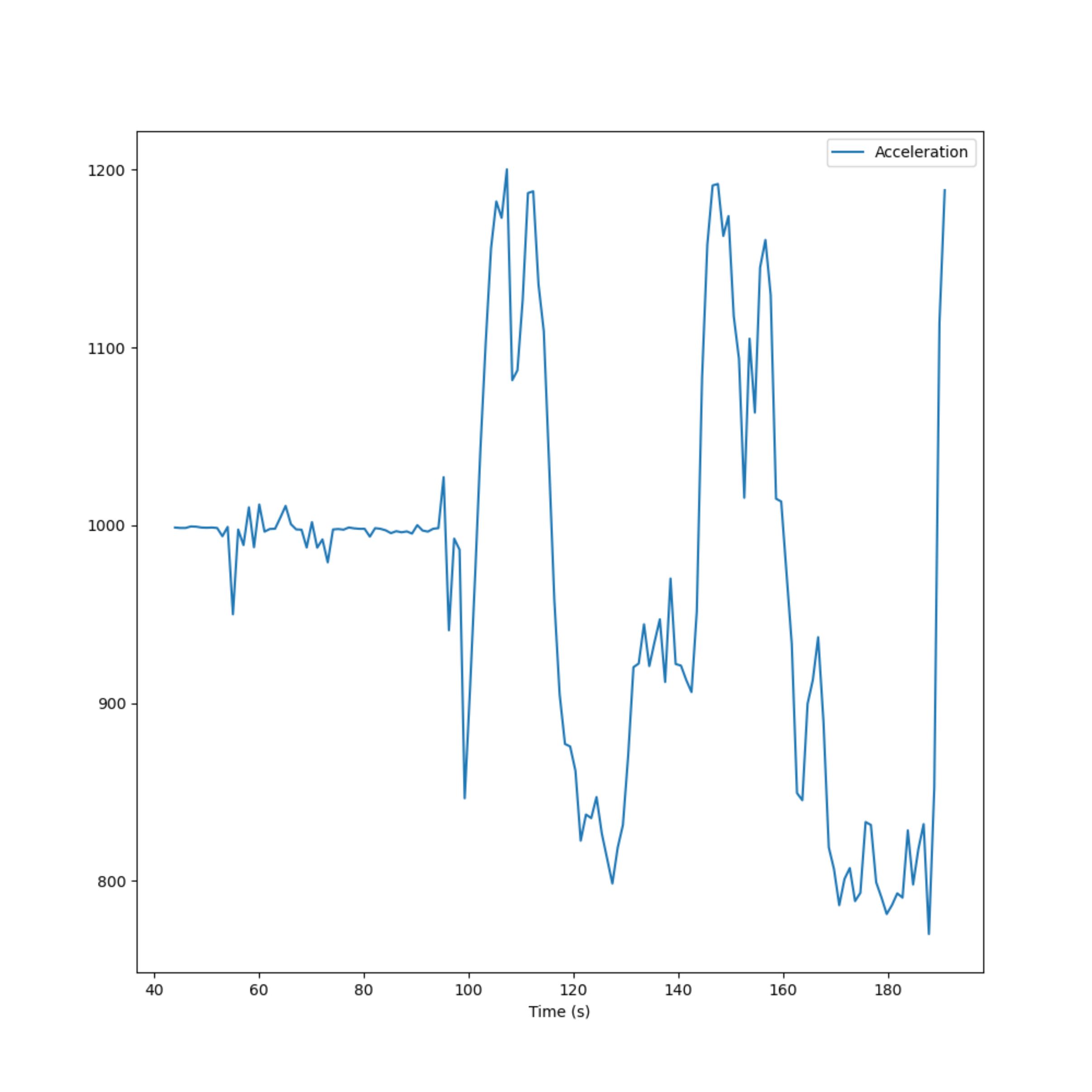
[17] Gistear. *915MHz LoRa Antenna Omni 5dbi Gain SMA Male for ESP32 LoRa OLED Board + 15cm IPEX Extension Cable 2 Pcs*, 2023.

18. Coastal Equine. (2020, April 28). Why do horses roll? Coastal Equine Services. https://www.coastalequineservices.com/post/why-do-horses-roll

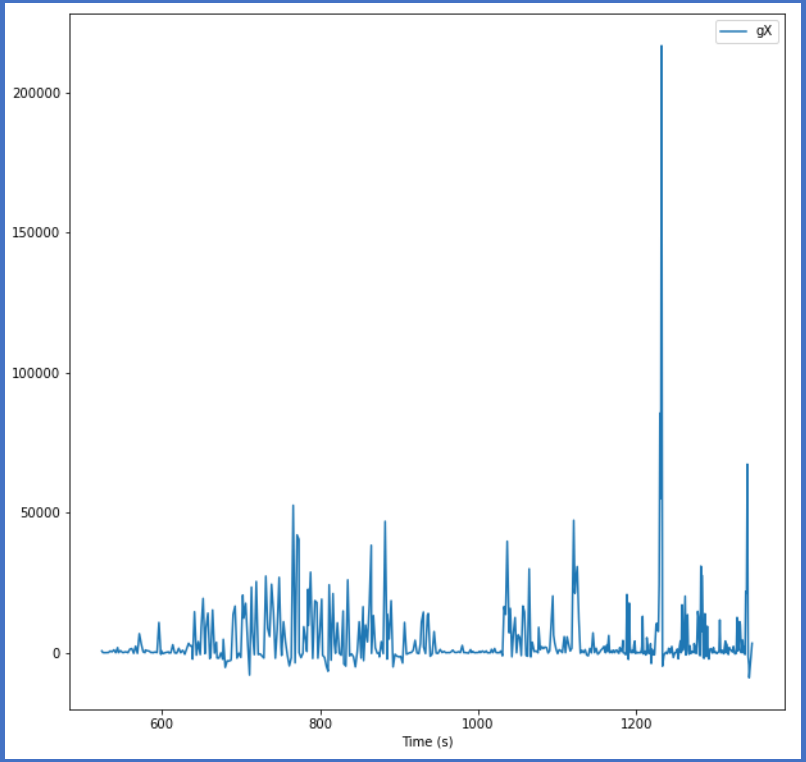
Extra Slide

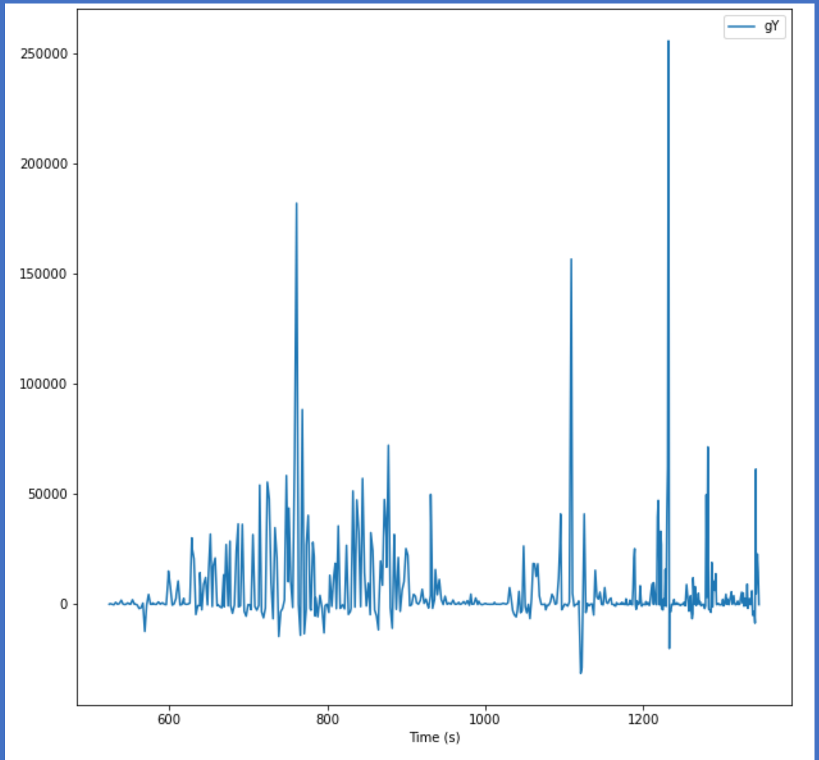
Acceleration plot for walk around Loomis Test

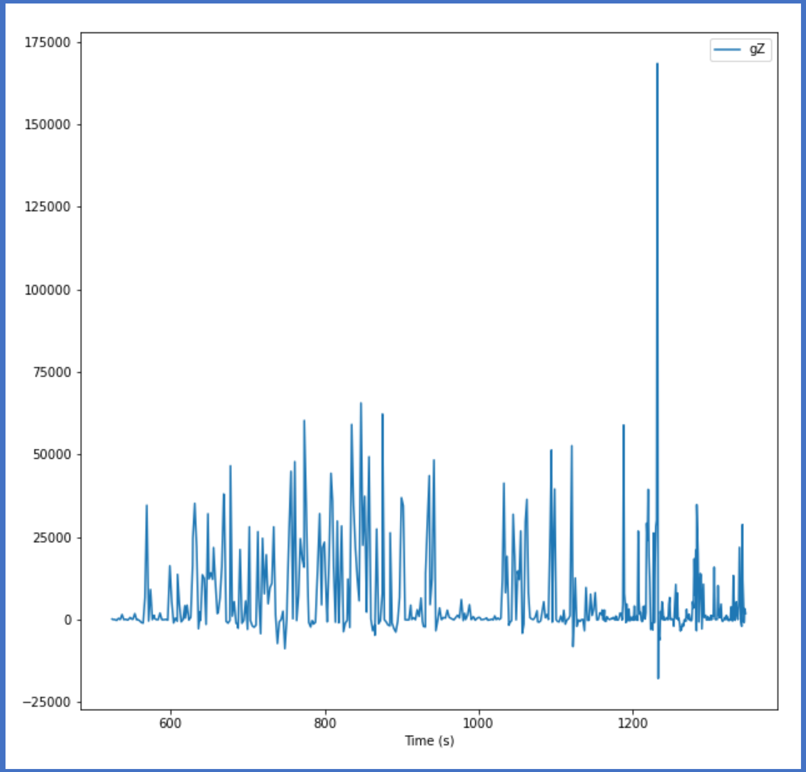
Units are in g's, but a calibration error caused the scale to be off.



Extra Slide







Gyroscope data for horse test

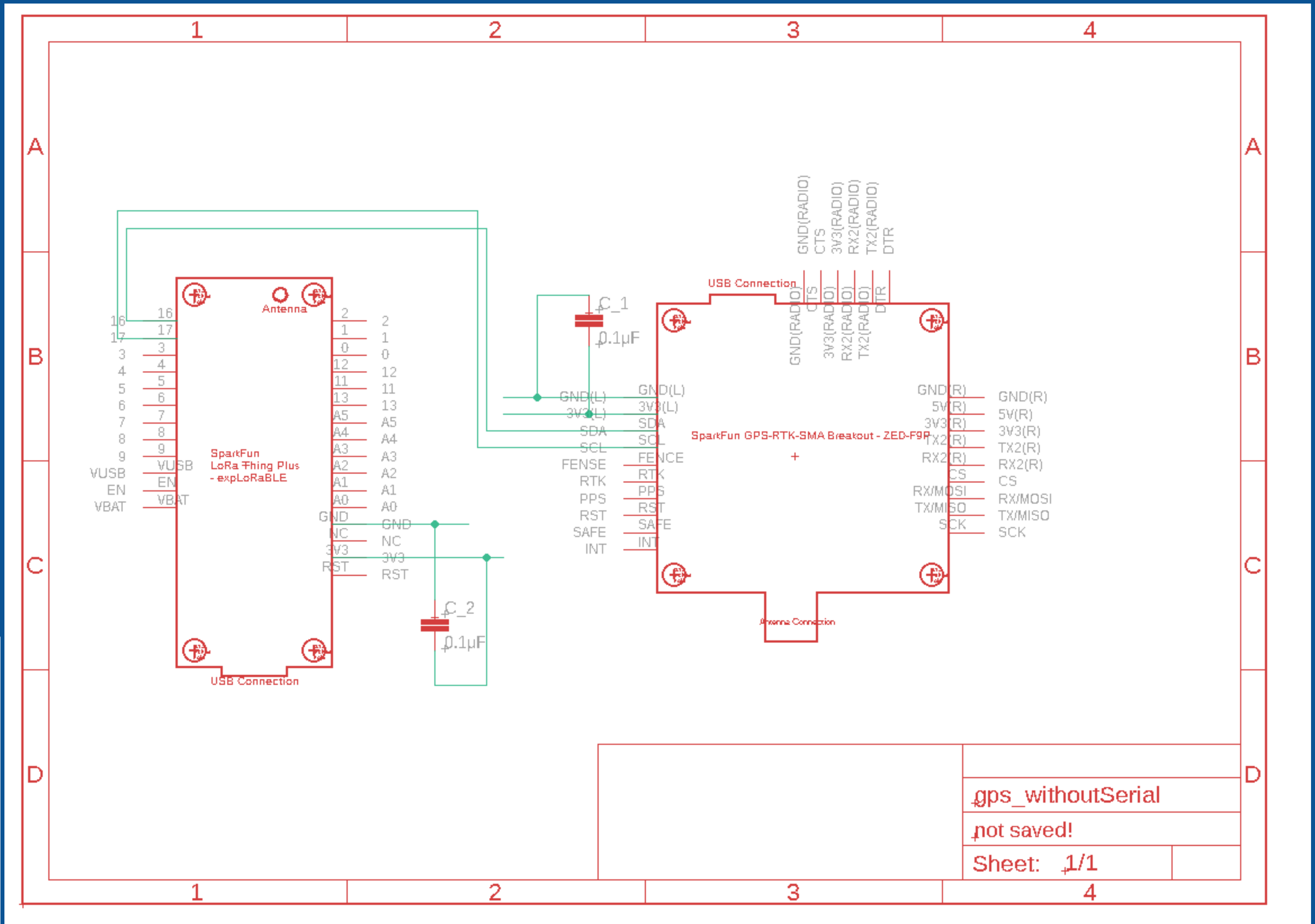
Units are in degrees per second

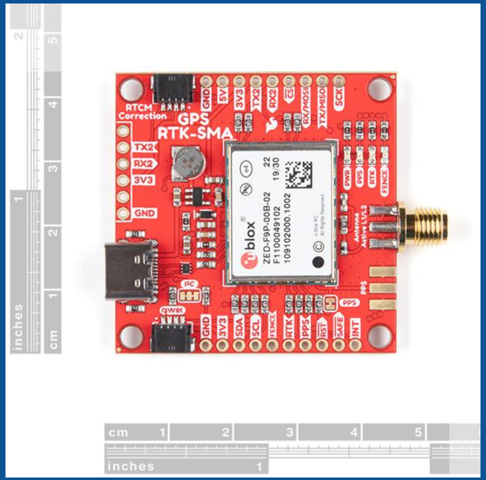
Extra Slide

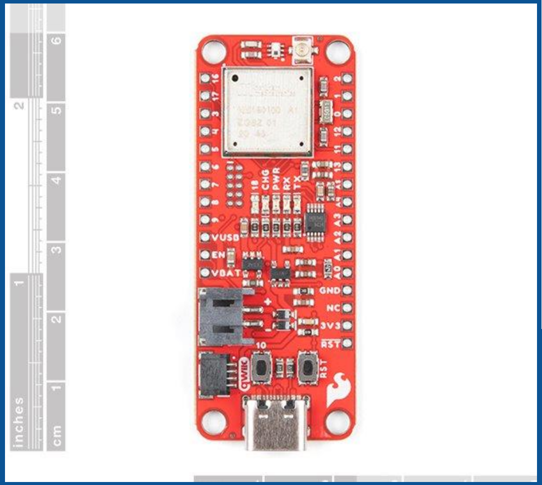
Base Station PCB Design:

1. Components:
   a. SparkFun GPS-RTK-SMA Breakout - ZED-F9P (Qwiic)
   b. SparkFun LoRa Thing Plus – expLoRaBLE

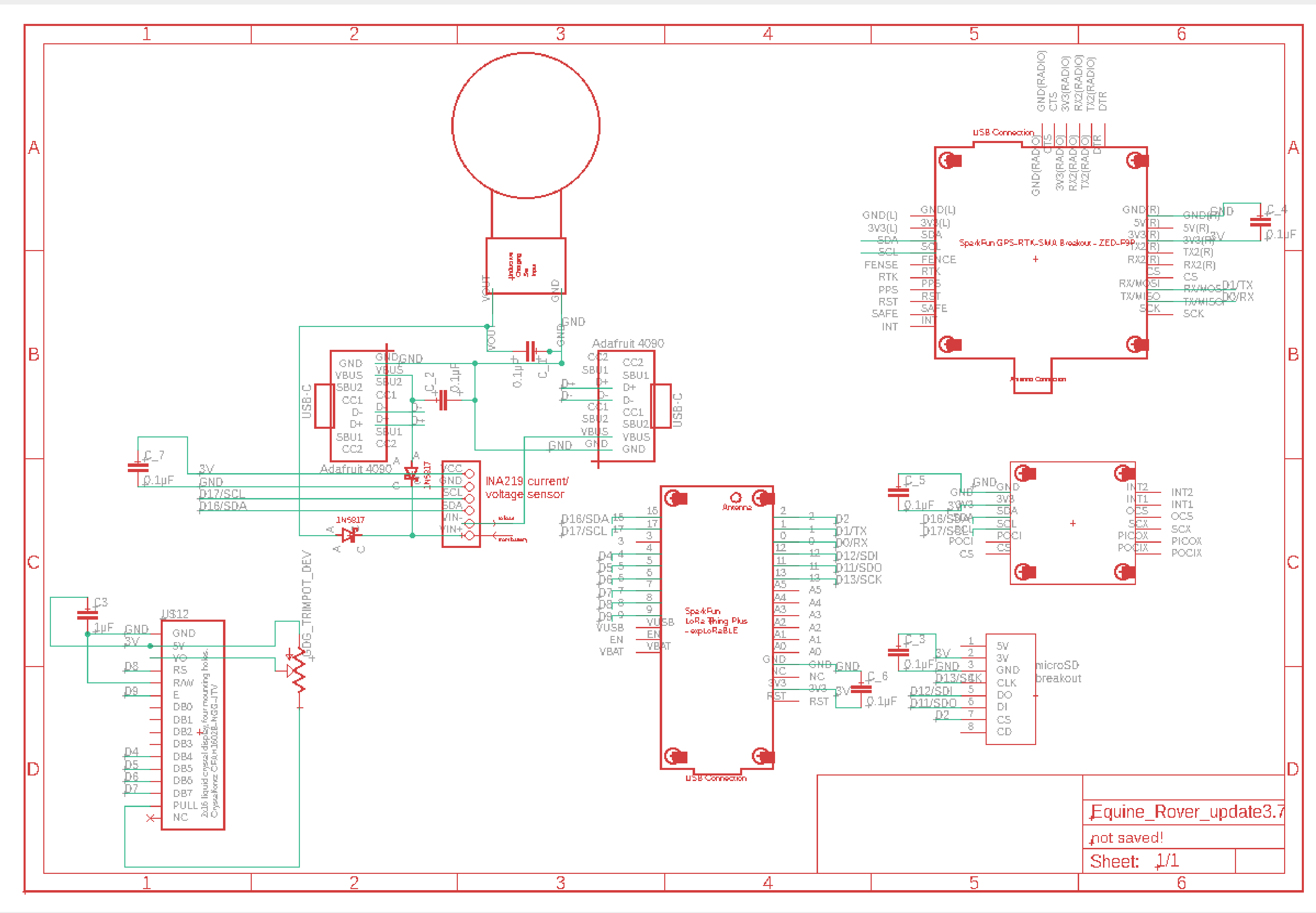
2. Connection:
   a. General I^2C







Extra Slide



Connection:
a. General I^2C
b. Serial Connection
c. USB Power Connection
d. Battery Directly Connection

Extra Slide

Receiving Board Design:

- Components:
  a. SparkFun LoRa Thing Plus – expLoRaBLE
  b. Inductive Charging Set - 5V @ 500mA max: Input Part
  c. Push Button
  d. Hexadecimal Rotary Switch
  e. MicroSD Breakout

- Connection:
  a. General I2C
  b. Charge for Inductive Charging Coil
  c. LCD connection
  d. Push button connected to the GND (with resistance)
  e. Rotary connection (with resistance):