Lab 2: Real Time Kinematic GNSS

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EECE5554

Group number: 5

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Introduction to RTK GNSS

Real-Time Kinematic (RTK) GNSS is a technique that enhances the precision of position data derived from satellite-based positioning systems. It uses measurements from the satellite systems, along with a fixed base station to provide real-time corrections, yielding centimetre-level accuracy.

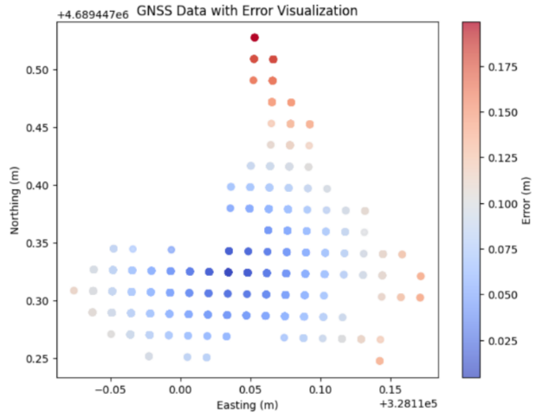
Differences Between RTK GNSS and Standalone GNSS

Feature	RTK GNSS	Standalone GNSS
Accuracy	Centimetre-level (1-2cm) accuracy	Meter-level accuracy(3-10m)
Correction Data	Uses base station corrections, real time corrections	No corrections, raw satellite data
Base Station requirements	Requires a fixed base station	Communicate directly with satellites, do not rely on base station
Error Sources	Reduced atmospheric & clock errors	High multipath & atmospheric errors
Fix Types	RTK Fix, RTK Float, DGPS Fix	Standard GNSS Fix
Cost	More expensive due to the additional hardware and complexity	Comparatively cheaper

Sources of Error in RTK GNSS

1. Multipath Effects - Signals bouncing off buildings cause interference.
2. Ionospheric and Tropospheric Delays - Atmospheric conditions delay signals.
3. Base-Rover Distance - Inaccuracies in the base station position can propagate to the rover.
4. Satellite Geometry - Poor satellite positioning increases error.
5. Fix Quality - RTK Fix mode is most precise, while Float has more uncertainty.

<u>**Stationary data on roof of Columbus parking garage**</u>



a. <u>Accuracy of RTK GNSS vs. Standalone GNSS</u>

RTK GNSS Accuracy:

Mean error: 0.2053 m
Max error: 0.2939 m

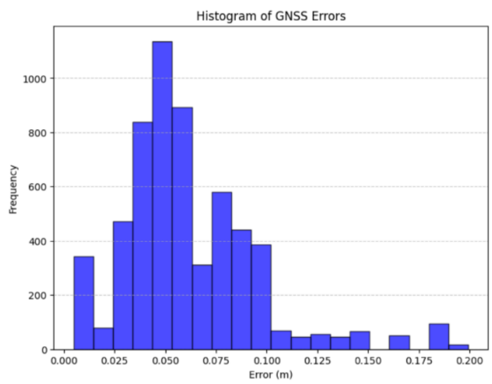
RTK GNSS is very precise with errors well below 1 meter. The clustering of points around the true position confirms the effectiveness of RTK corrections in reducing positional errors.

Standalone GNSS Accuracy (from Lab 1):

Mean error: 6.76 m
Error range: 5.5 m to 8 m

Standalone GNSS shows significantly larger errors due to the lack of real-time corrections

RTK GNSS is approximately 33 times more accurate than standalone GNSS in this scenario

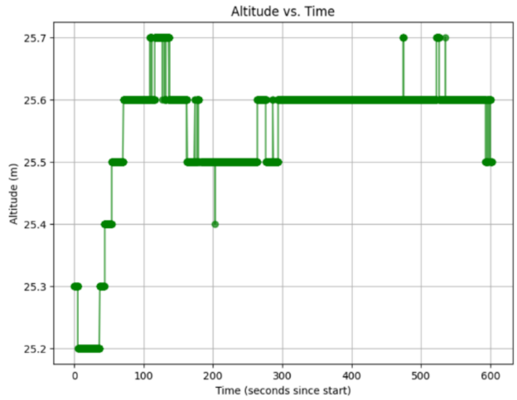


b. <u>Ranges and Shapes of Position in Easting and Northing</u>

The scatter plot shows a tight cluster of points around the true position, with deviations primarily within a radius of 0.3 meters. This indicates minimal fluctuation in position measurements.

The histogram reveals that most deviations are concentrated within plus or minus 0.1 m in both Easting and Northing.

The distribution resembles a Gaussian shape centered at (0,0), indicating random noise rather than systematic bias. The tight clustering and small deviations confirm that RTK GNSS provides highly reliable positional data in open environments.



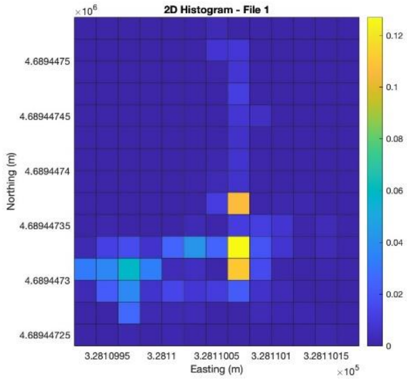
c. Comparison with Lab 1 Dataset

In Lab 1 (Standalone GNSS), the scatter plot showed a much larger spread (errors between 5.5 m and 8 m). The shape was irregular due to multipath effects and poor satellite geometry.

In contrast:

RTK GNSS data forms a compact cluster with minimal spread.

The histogram for RTK data is sharply peaked near zero error, while the standalone GNSS histogram had a broader spread with frequent large errors.



Moving Rover on the roof of Columbus parking garage

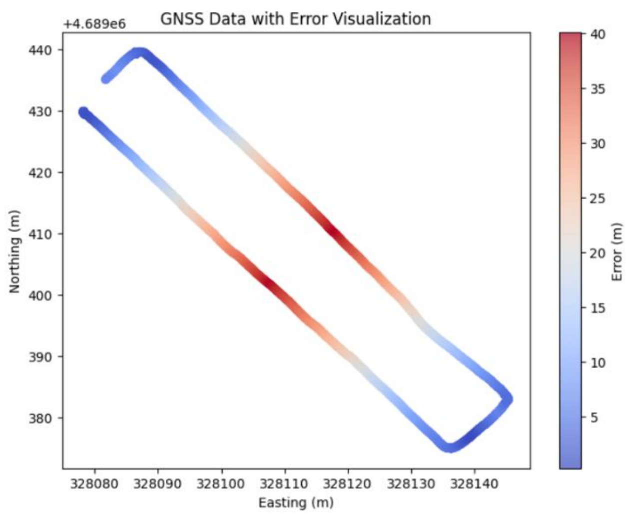
The plotted path forms a well-defined rectangular loop, indicating that the GNSS receiver successfully captured the intended movement pattern. The return to the starting point aligns closely with the initial position, suggesting good consistency in positional data.

The color gradient represents error values, ranging from approximately 5 meters (blue) to 40 meters (red).

Errors are lowest at certain corners (blue regions) and highest along specific segments of the path (red regions). This variability could be due to temporary degradation in RTK fix quality or environmental factors.

The error increases significantly along one side of the rectangle (red area), which might indicate a momentary loss of RTK fix or transition to RTK float mode.

In contrast, other sides of the rectangle show lower errors, likely corresponding to periods with a stable RTK fix.



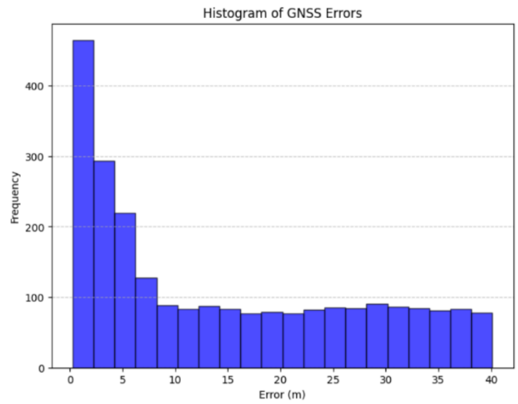
a. Accuracy of RTK GNSS vs. Standalone GNSS

RTK GNSS Accuracy:

The RMSE error for this dataset is 18.0428 meters, which is significantly higher than what is typically expected for RTK GNSS in open environments (sub-meter to decimeter-level accuracy).

The scatter plot shows a systematic pattern of errors along the trajectory, with some sections exhibiting larger deviations (up to about 40 meters).

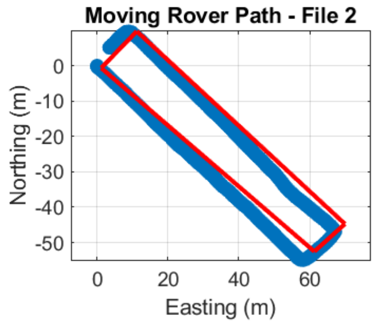
This suggests that the RTK fix quality may have degraded during portions of the test, potentially due to temporary loss of corrections or satellite visibility issues.



Standalone GNSS Accuracy (from Lab 1):

Errors for standalone GNSS in Lab 1 ranged between 5.5 meters and 8 meters, with a mean error of 6.76 meters.

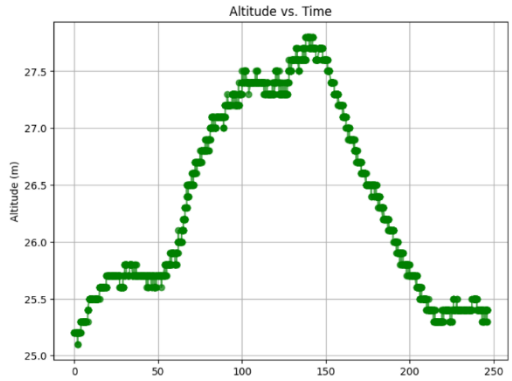
Although standalone GNSS errors are generally larger than those from RTK, the unexpectedly high RMSE for this RTK dataset indicates that the system did not maintain a "fixed" solution throughout the test.



In ideal conditions, RTK GNSS should outperform standalone GNSS by a large margin, achieving sub-meter accuracy. However, in this case, the RMSE error of **18.0428 meters** is worse than standalone GNSS performance from Lab 1.

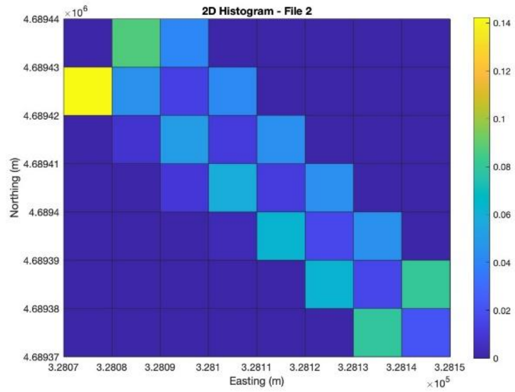
This discrepancy suggests that the RTK corrections were not consistently applied during the test, possibly due to:
Loss of RTK "fixed" status (falling back to "float" or standalone mode), environmental factors causing signal degradation, issues with base station communication or satellite geometry.

b. Ranges and Shapes of Position in Easting and Northing



The scatter plot shows a rectangular trajectory with systematic deviations along certain segments where most data points are concentrated along the edges of the rectangular trajectory, but there is noticeable spreading around these edges.
The positional data shows significant deviations from the expected trajectory, with errors likely caused by degraded RTK fix quality during portions of the test. While the overall shape of the trajectory is preserved, the large spread in Easting and Northing indicates inconsistent accuracy.

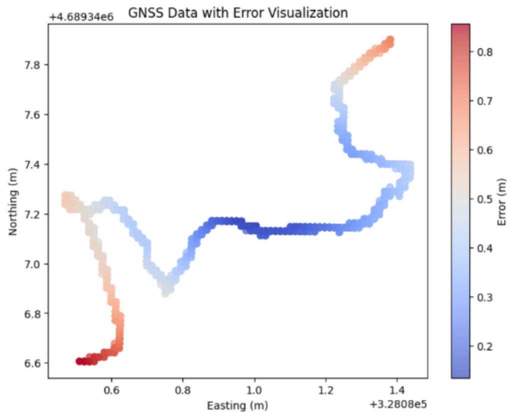
c. Comparison with Lab 1 Dataset



In Lab 1 (Standalone GNSS) the scatter plot showed a much larger spread and irregular patterns due to atmospheric effects and multipath interference and the errors were more uniformly distributed across the trajectory, reflecting the lack of real-time corrections.
In this dataset the trajectory is more structured and follows a rectangular path, indicating that RTK corrections were partially effective. However, the unexpectedly high RMSE error (~18 m) suggests that RTK performance was not optimal during this test.

Stationary data in occluded environment

a. Accuracy of RTK GNSS vs. Standalone GNSS

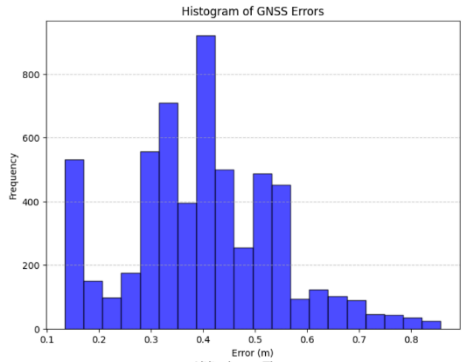


The errors observed here (ranging from 0.1 m to 0.8 m) demonstrate that RTK GNSS provides significantly better accuracy than standalone GNSS, even in an occluded environment. Standalone GNSS typically has errors ranging from 5 to 10 meters, whereas RTK GNSS achieved sub-meter accuracy for most measurements.

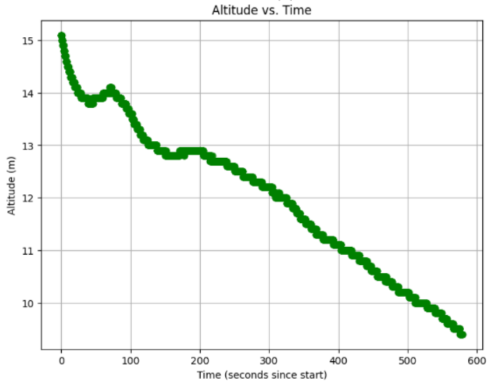
The error distribution indicates that RTK GNSS maintained relatively good accuracy despite the occlusion, with sub-meter errors dominating. The presence of outliers suggests occasional degradation in fix quality, likely due to multipath effects or intermittent satellite visibility.

b. Ranges and Shapes of Position in Easting and Northing

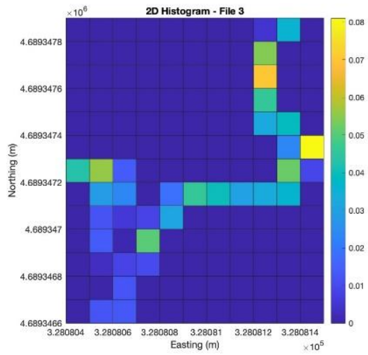
The histogram shows that most errors are concentrated between 0.3 m and 0.5 m, with the highest frequency around 0.4 m. A few outliers exist, with errors extending up to 0.8 m. The 2D histogram highlights the density of positional measurements in Easting and Northing coordinates. Most data points are concentrated within a small region, but there is noticeable spreading, particularly along one axis. The spreading indicates deviations from the true stationary position, likely caused by multipath effects and degraded satellite geometry due to occlusion.



Range: Easting deviations range from approximately 328080 m to 328140 m, indicating a spread of 60 meters. Northing deviations range from approximately 4689340 m to 4689375 m, indicating a spread of ~35 meters. The position data forms a dense cluster near the true position but exhibits spreading along one axis (likely due to poor satellite geometry or multipath effects).



The altitude plot shows a gradual decrease over time, dropping from approximately 15 m to 10 m. The changes are smooth and consistent, with no abrupt jumps or noise suggesting that the GNSS receiver maintained consistent vertical positioning accuracy, even under occluded conditions.

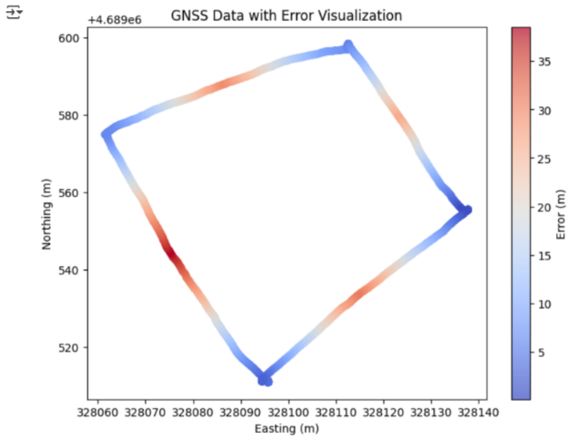


c. Comparison with Lab 1 Dataset

In Lab 1 (Standalone GNSS): Errors were larger (5 to 10 meters) and more uniformly distributed du e to the lack of real-time corrections. The histogram likely showed a broader spread with less clustering near the true position. While in this dataset errors are smaller (0.1 to 0.8 meters) and more tightly clustered around the true position. The histogram shows a clear peak near 0.4 meters, reflecting better accuracy compared to standalone GNSS. The histogram for this dataset is narrower and more structured than that from Lab 1, highlighting the superior performance of RTK GNSS over standalone GNSS.

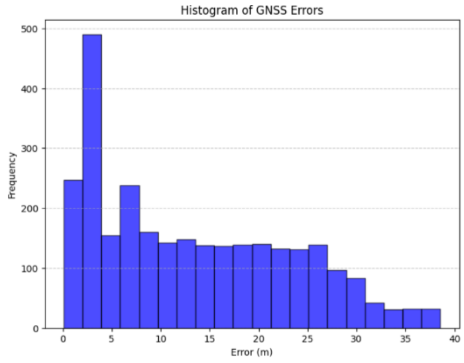
Moving Rover in occluded environment

a. Accuracy of RTK GNSS vs. Standalone GNSS



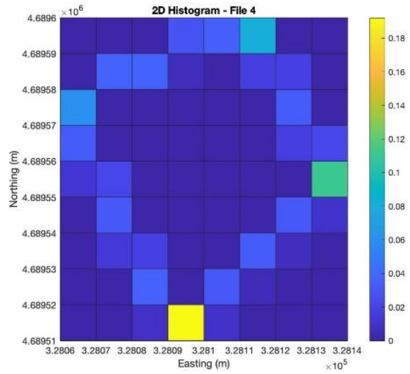
The trajectory forms a closed rectangular loop, but there are significant deviations along certain segments. Errors range from 5 meters to 35 meters, as shown by the color gradient, with red regions indicating the largest errors.
The large errors of 16.6513 meters are consistent with the GNSS fix quality being "5" (float mode), which is known to result in meter-level errors rather than centimetre-level accuracy.

Float mode occurs when the receiver cannot resolve integer ambiguities in satellite signals, often due to poor satellite visibility caused by occlusion, multipath effects (signals bouncing off nearby surfaces), weak communication with the RTK base station. The red regions along the trajectory indicate periods where the fix quality degraded further, leading to larger positional errors. The high RMSE is primarily due to the fix quality remaining in float mode ("5") throughout the test. This prevented the system from achieving the sub-meter accuracy expected from RTK GNSS.



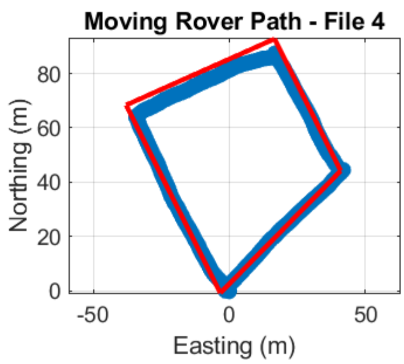
b. <u>Ranges and Shapes of Position in Easting and Northing</u>

The 2D histogram shows a clear rectangular pattern corresponding to the trajectory, but there is noticeable spreading along the edges. Certain areas have higher densities (darker blue), while others show more dispersion.



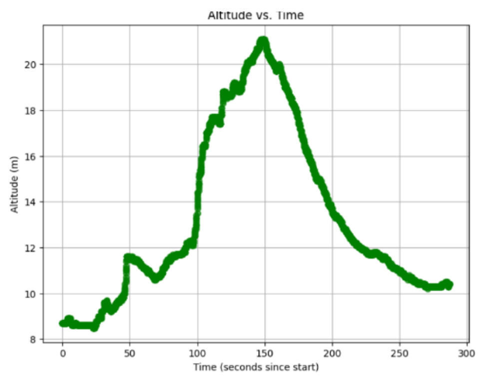
The spreading along the edges reflects deviations in Easting and Northing coordinates caused due to positional drift caused by float mode.

The higher density in some areas suggests that errors were more consistent in those segments, while other areas experienced larger deviations due to environmental factors like multipath interference or poor satellite geometry. Easting deviations range from approximately 328060 m to 328140 m, indicating a spread of 80 meters.
Northing deviations range from approximately 4689520 m to 4689600 m, indicating a spread of 80 meters.
The altitude plot shows a gradual increase followed by a decrease, forming a peak at approximately 20 meters. There are small fluctuations throughout, but no abrupt jumps or noise.



c. <u>Comparison with Lab 1 Dataset</u>

In Lab 1 (Standalone GNSS) errors were larger and more uniformly distributed due to the lack of real-time corrections. The histogram likely showed broader spreading without clear patterns or clustering.
In this dataset errors are smaller overall but still significant due to float mode. The histogram shows a structured rectangular pattern corresponding to the trajectory, reflecting partial effectiveness of RTK corrections even in float mode.



d. <u>Quantitative comparisons of moving data in open and occluded cases:</u>

Open environment:

- RMSE: 18.0428 meters
- Error range: around 5 to 40 meters
- Trajectory: Well-defined rectangular loop

Occluded environment:

- RMSE: 16.6513 meters
- Error range: 5 to 35 meters
- Trajectory: Rectangular loop with significant deviations

The similar RMSE values suggest that both environments faced challenges in maintaining RTK accuracy. However, the open environment showed slightly larger maximum errors (40m vs 35m).

GNSS fix quality correlation:
In the occluded case, the fix quality was consistently "5" (float mode), explaining the meter-level errors. For the open case, the high errors suggest periods of degraded fix quality, likely transitions between fixed and float modes.

e. Stationary data comparison in open and occluded cases:

Open environment:

- Mean error: 0.2053 m
- Max error: 0.2939 m
- Error distribution: Tightly clustered within ±0.1 m in Easting and Northing

Occluded environment:

- Error range: 0.1 m to 0.8 m
- Most errors concentrated between 0.3 m and 0.5 m
- Highest frequency around 0.4 m

The open environment clearly outperformed the occluded one, with sub-meter accuracy throughout. The occluded environment, while still achieving sub-meter accuracy, showed larger and more variable errors.

GNSS fix quality correlation:
The superior performance in the open environment suggests consistent high-quality fixes (likely "fixed" mode). The occluded environment's larger errors indicate occasional degradation in fix quality, possibly due to multipath effects and reduced satellite visibility, though it still maintained better accuracy than standalone GNSS.

References:

Modified RTK-GNSS for Challenging Environments - PMC

What is GNSS RTK positioning?

GNSS vs. RTK: Understanding the Difference and Choosing the Right Technology for Precision Mapping - Misc - Emlid Community Forum

What's the difference between FLOAT and FIXED? – Strictly Surveying – Discussion Forums for Land Surveyors