EECE 5554 Lab 1: Recording, Publishing, and Analyzing GPS Data

Brennan Cesar

February 7, 2026

1 Purpose

The purpose of this lab was to use a USB-based GNSS (GPS) receiver to collect latitude and longitude data, convert it to UTM coordinates, and publish this information using a custom ROS2 message. Three datasets were collected: stationary in an open area, stationary in an occluded area near buildings or trees, and while walking in a straight line. These were analyzed to quantify GPS positioning error and identify its sources.

2 Sources of GPS Error

GPS positioning is subject to several physical sources of error. Multipath occurs when GPS signals reflect off buildings, the ground, or trees before reaching the receiver, causing incorrect range measurements. Atmospheric delay from the ionosphere and troposphere slows the signal and introduces systematic range errors. Satellite geometry, captured by the Horizontal Dilution of Precision (HDOP), affects precision—poor satellite distribution in the sky leads to higher dilution of precision and larger position errors. Receiver noise from internal clock errors and electronic noise adds random error to each measurement. Finally, occlusion from buildings or trees blocks satellites from portions of the sky, reducing the number available for position computation.

3 Stationary Data Analysis

3.1 Open Sky Dataset

A total of 340 messages were recorded over approximately 5 minutes in an open area with clear sky visibility. The mean HDOP was 1.89.

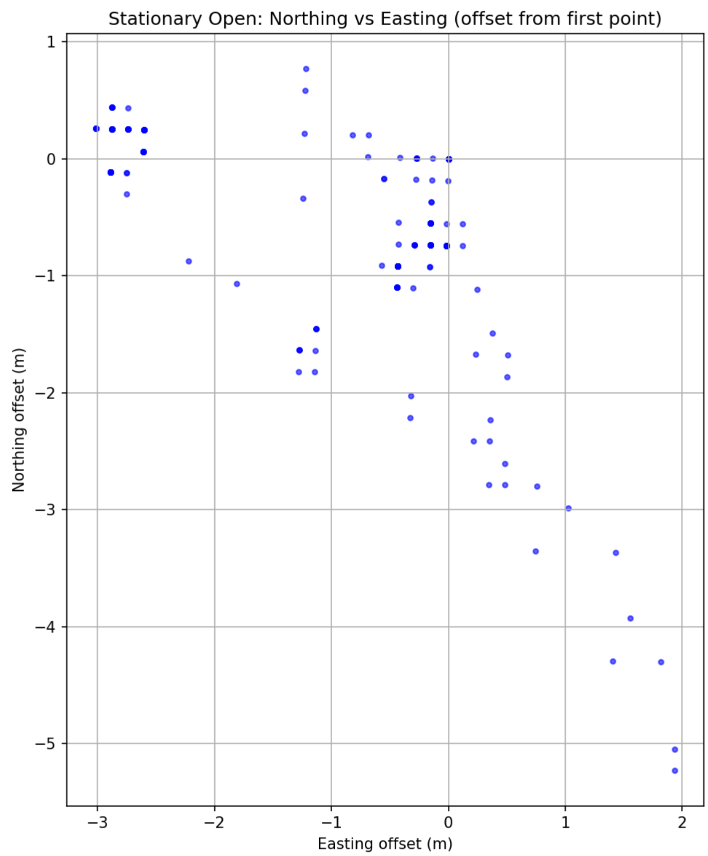

Figure 1: Stationary open: Northing vs. Easting scatterplot, offset from the first recorded point. The tight clustering indicates good receiver precision under open-sky conditions.

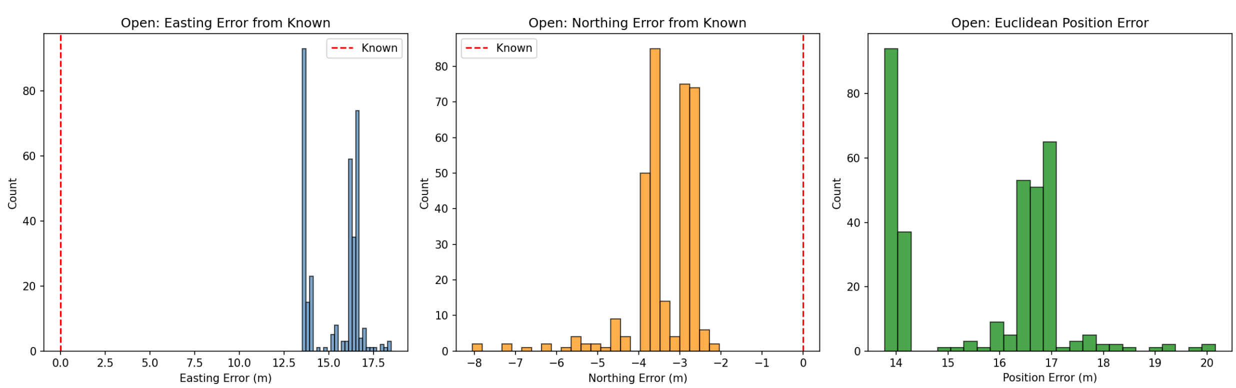

Figure 2: Stationary open: Histograms of easting error, northing error, and Euclidean position error from the known reference position.

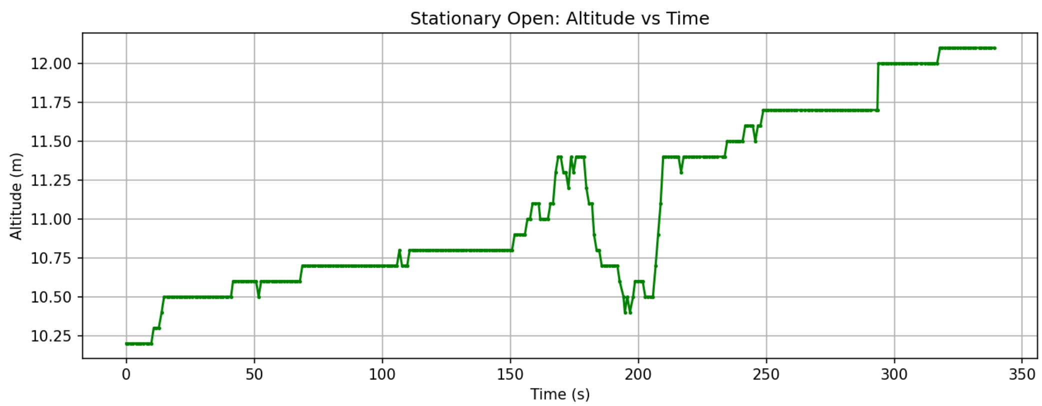

Figure 3: Stationary open: Altitude vs. time. Variations in reported altitude while stationary reflect vertical GPS error, which is typically larger than horizontal error.

3.1.1 Error Estimate

The position error was computed as the Euclidean distance between each measured UTM position and the known UTM position derived from cellphone maps:

$$\text{error} = \sqrt{(\Delta\text{easting})^2 + (\Delta\text{northing})^2} \tag{1}$$

The mean position error was 15.73 m with a standard deviation of 1.47 m and an RMS of 15.80 m. The dominant contribution was a systematic easting bias of 15.36 m, with only −3.35 m of northing bias. This consistent directional bias suggests that a portion of the measured error may be attributable to imprecision in determining the known coordinates. The actual GPS scatter, measured by the standard deviation of 1.47 m, indicates the receiver itself was quite consistent and well within the expected HDOP-based range.

3.1.2 HDOP Discussion

Civilian GPS typically has a base accuracy of approximately 2–5 m under ideal conditions. The expected position error is roughly HDOP $\times$ base accuracy. With a mean HDOP of 1.89, the expected error range is approximately 3.8–9.5 m. The measured mean error of 15.73 m exceeds this expectation, likely due to a combination of reference coordinate imprecision and real-world multipath effects. However, the receiver's precision (1.47 m standard deviation) falls well within the expected range, confirming reasonable GPS performance.

3.2 Occluded Dataset

A total of 333 messages were recorded over approximately 5 minutes near buildings or trees. The mean HDOP was 2.62, notably higher than the open-sky value of 1.89.

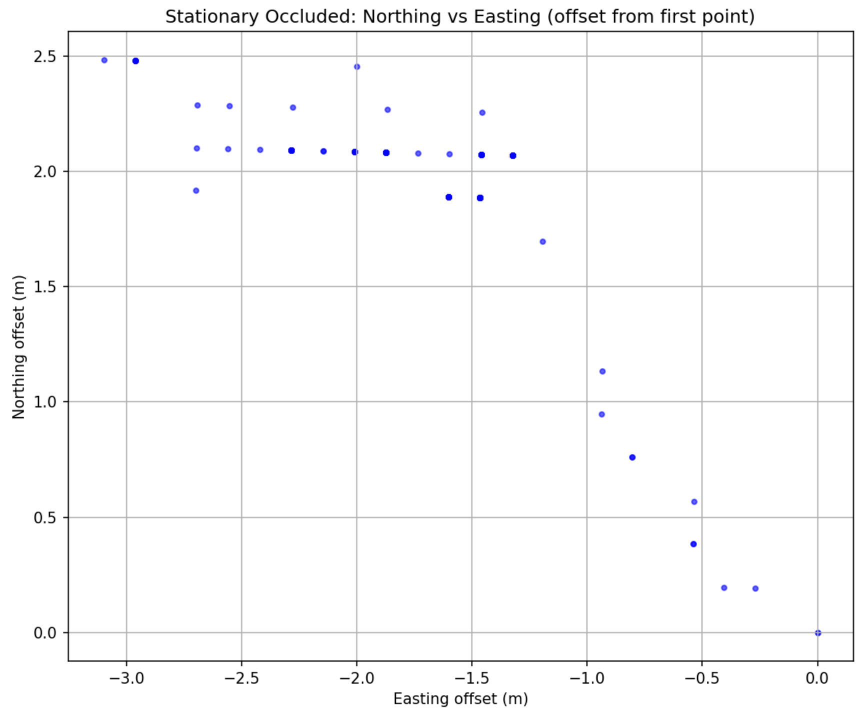

Figure 4: Stationary occluded: Northing vs. Easting scatterplot, offset from the first recorded point.

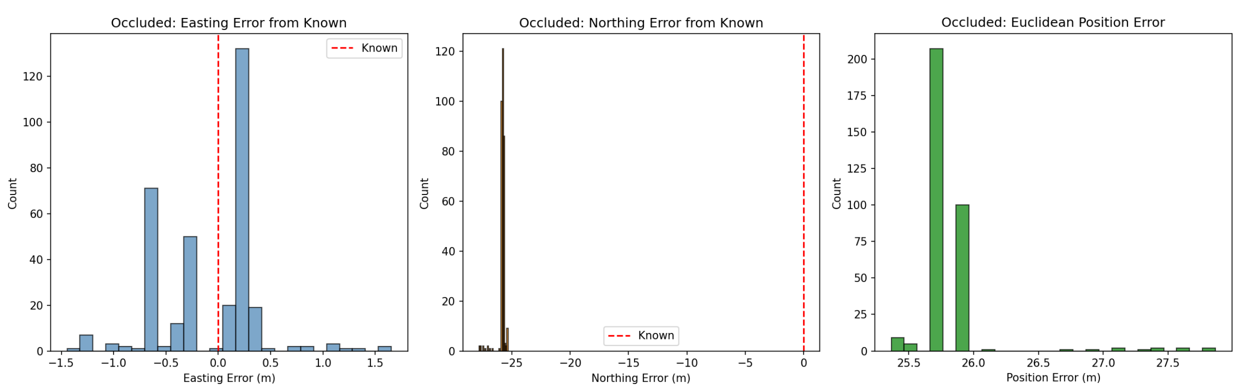

Figure 5: Stationary occluded: Histograms of easting error, northing error, and Euclidean position error from the known reference position.

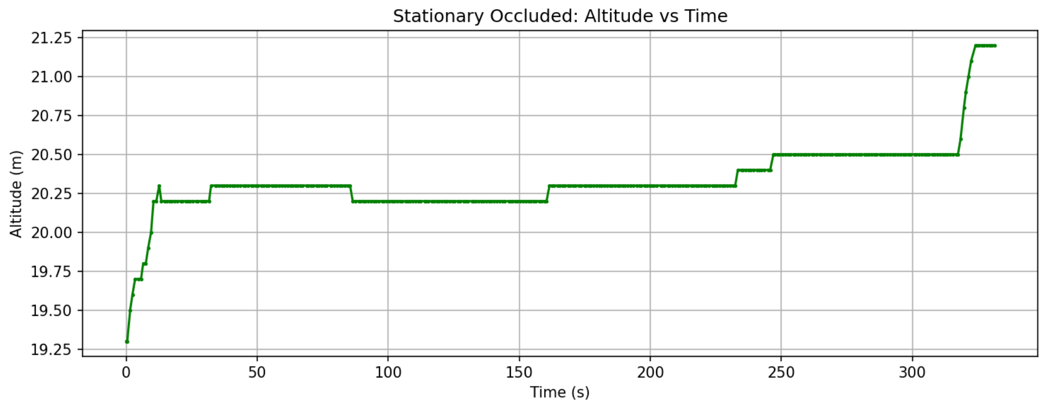

Figure 6: Stationary occluded: Altitude vs. time.

3.2.1 Error Estimate

The mean position error was 25.84 m with a standard deviation of only 0.31 m and an RMS of 25.84 m. The error was dominated by a large northing bias of −25.83 m, with nearly zero easting bias (−0.10 m). This pattern is consistent with the receiver being locked onto a consistent but geometrically biased set of satellites due to occlusion from nearby structures.

3.2.2 HDOP Discussion

With a mean HDOP of 2.62, the expected error range is approximately 5.2–13.1 m. The measured error of 25.84 m exceeds this estimate. The very low standard deviation of 0.31 m indicates the receiver was highly precise but systematically offset, likely due to multipath reflections from nearby buildings introducing a consistent bias. Some of the offset may also be due to imprecision in precisely tracking the reference coordinates.

4 Walking Data Analysis

A total of 221 messages were recorded while walking in approximately a straight line for 200–300 m. The mean HDOP was 2.17.

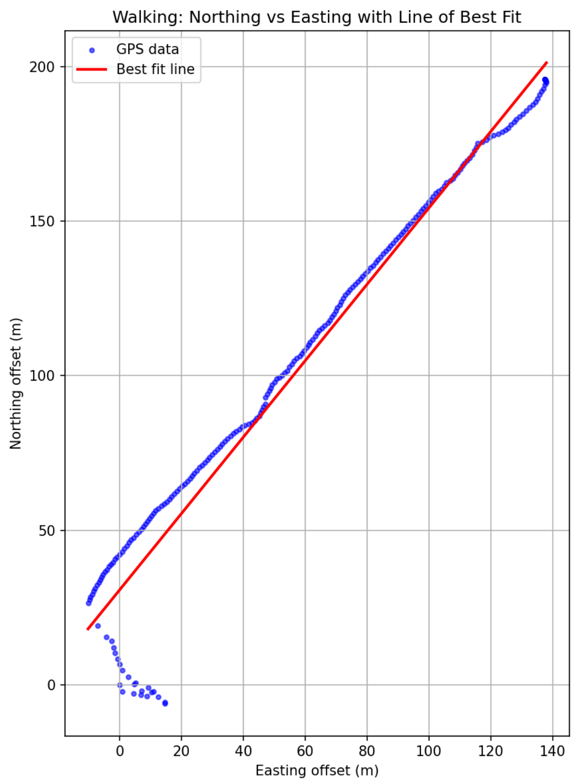

Figure 7: Walking: Northing vs. Easting scatterplot with line of best fit (red). The best-fit slope of 1.2351 corresponds to a heading of approximately 51° (northeast).

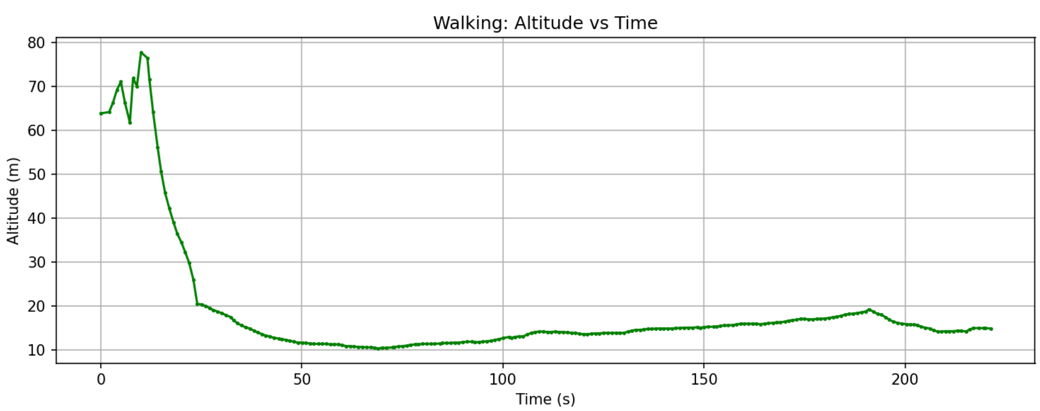

Figure 8: Walking: Altitude vs. time. The variation in altitude during the walk reflects both changes in terrain and vertical GPS error.

4.1 Error from Line of Best Fit

Assuming a perfectly straight walking path, a least-squares line was fit to the UTM easting and northing data, and the perpendicular distance from each point to that line was computed.

The mean deviation from the best-fit line was 5.29 m, with a standard deviation of 6.39 m, an RMS of 8.29 m, and a maximum deviation of 34.59 m. The relatively large maximum error and high standard deviation suggest there were some significant outlier points, possibly from momentary signal degradation or multipath effects during movement.

5 Comparison: Stationary vs. Moving Error

5.1 Changing Estimated Error Values

The stationary datasets showed very tight clustering, with standard deviations of 1.47 m (open) and 0.31 m (occluded). The walking data exhibited a mean deviation from the best-fit line of 5.29 m with a standard deviation of 6.39 m, which is significantly more scattered than either stationary dataset. The moving data shows roughly 3–4 times more spread than the stationary open data.

When the GPS receiver is stationary, it can effectively average multiple position fixes over time, smoothing out random noise and producing a very tight cluster of points. When moving, each fix occurs at a different true location, so the receiver cannot benefit from this temporal averaging; every measurement includes the full instantaneous error. Additionally, while walking, the receiver antenna changes orientation, the human body can partially block satellite signals, and the receiver may need to continuously reacquire satellites as geometry changes. The walking data also includes the assumption that the path was perfectly straight, which it almost certainly was not. Any natural curvature in the actual walking path appears as additional "error" relative to the best-fit line.

5.2 Likely Sources of Error

For the stationary datasets, the primary error sources are multipath reflections (especially in the occluded environment near buildings), atmospheric delay, satellite geometry (captured by HDOP), and receiver noise. The occluded dataset had a higher HDOP of 2.62 compared to the open dataset's 1.89, indicating poorer satellite distribution. The very low standard deviation of 0.31 m in the occluded data despite higher HDOP suggests the receiver was locked onto a consistent but biased set of satellites.

For the walking dataset, additional error sources include the human body intermittently blocking satellite signals, changes in antenna orientation, and the physical impossibility of walking in a mathematically perfect straight line. The large maximum deviation of 34.59 m suggests there may have been moments of particularly poor reception during the walk.

6 Summary of Results

Metric	Open	Occluded	Walking
Number of points	340	333	221
Mean HDOP	1.89	2.62	2.17
Mean error (m)	15.73	25.84	5.29
Std deviation (m)	1.47	0.31	6.39
RMS error (m)	15.80	25.84	8.29
Max error (m)	20.16	27.87	34.59

Table 1: Summary of GPS error statistics across all three datasets. Stationary errors are Euclidean distance from the known position; walking error is perpendicular distance from the line of best fit.