EECE 5554 Robotics Sensing and Navigation

Lab 1: GPS

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Abstract

This report investigates the accuracy of GPS data under two conditions: stationary and dynamic motion. A GPS driver was developed using ROS to collect data from a BU-353N USB GPS Receiver. Data was collected while the device remained stationary for 10 minutes and while it moved along a straight-line path. Error estimates were calculated for both conditions. The stationary data exhibited increasing errors over time, with an average error of 7.37 meters. In contrast, the dynamic condition showed significantly lower errors, averaging 0.68 meters. These findings suggest that GPS accuracy improves during motion, with reduced error bounds compared to stationary use.

Methods

GPS Driver. A driver to collect and process data from a *BU-353N USB GPS Receiver* was developed to work in conjunction with ROS. The driver reads data streams from a serial port where the GPS device is connected to. Since the data comes in various formats (GPGGA, GPGSA, GPRMC, GPGSV), the driver was designed to parse GPGGA data only. After reading the parsed data, the driver publishes the relevant fields of the data as well as a header to a ROS topic. The relevant fields include latitude, longitude, altitude, UTM easting, northing, zone, and letter. Note that the respective conversion for latitude and longitude from DDDmm.mm to decimal degrees is done prior to a UTM conversion to obtain the easting, northing, zone, and letter.

Data Collection. Data was collected under two conditions: stationary, and dynamic (linear motion).

- **Stationary Condition:** the GPS device was positioned at a fixed location. Data was recorded continuously over a 10-minute period without any movement.
- **Dynamic Condition:** the GPS device was used while moving along a straight-line, two-way trajectory. Data was collected as the device moved back and forth along this path.

Both datasets were taken after a GPS fix, and in an open field to reduce the likelihood of signals bouncing off nearby structures.

Error Calculation. The errors for both conditions were estimated by calculating the distance between each sample and the ground truth. Then, this distances were averaged to obtain a final estimation of the errors.

In the stationary condition, the following equation was employed to calculate the error:

$$SE_{avg} = \frac{\sum_{i=1}^{k} \sqrt{\left(e_{2,i} - e_{1,i}\right)^2 + \left(n_{2,i} - n_{1,i}\right)^2}}{k}$$

Where, SE_{avg} is the mean stationary error, e is the UTM easting, n is the UTM northing, and k is the number of samples.

For the dynamic condition, each sample's estimated error was calculated by finding the closest distance from each sample point to a line describing the actual trajectory:

$$DE_{avg} = \frac{\sum_{i=1}^{k} \frac{|a * e_i + b * n_i + c|}{\sqrt{a^2 + b^2}}}{k}$$

Where, DE_{avg} is the mean dynamic error, and a, b, c are the coefficients of the trajectory line equation.

The error calculation for UTM easting and northing in the stationary condition was calculated by finding the difference between the recorded value by the GPS device and the estimated ground truth as follows:

$$E_{avg} = \frac{\sum_{i=1}^{k} |v_{GT} - v_i|}{k}$$

Where E_{avg} is the mean error (UTM easting or northing), v_{GT} is the ground truth value, and v_i is the respective value evaluated (both are also either UTM easting or northing).

Results

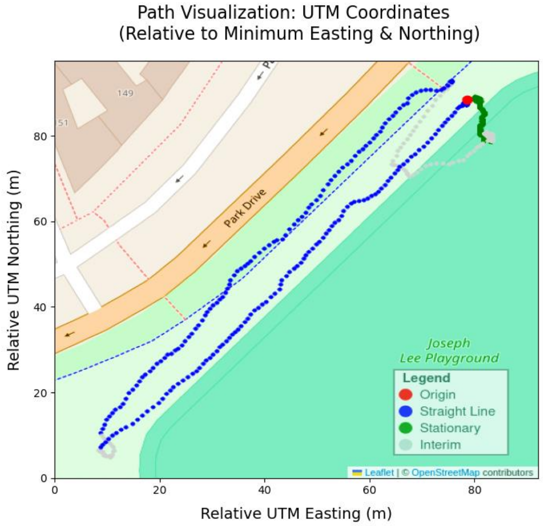

Figure 1. GPS data plot.

Figure 1 presents the full dataset, including both stationary and dynamic GPS data, as well as intermediate steps between both setups. The stationary data reveals a noticeable drift, as points become more dispersed over time. In contrast, the dynamic data follows a relatively straight line, suggesting that GPS navigation tends to be more accurate when the device is in motion.

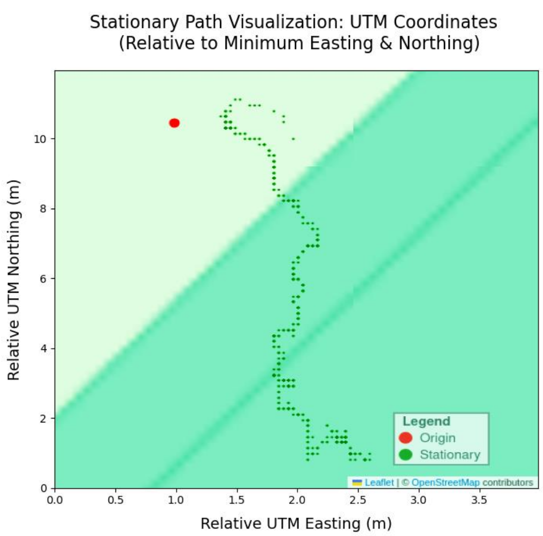

Figure 2. Stationary condition data plot.

The GPS data collected in the stationary condition is plotted in Figure 2. The error for this setup was calculated to have a mean of 7.37 meters and a standard deviation of 3.45 meters, with a noticeable increase in error over time. Initially, samples had errors below 1 meter, but by the end of the 10-minute period, errors had increased to approximately 12 meters.

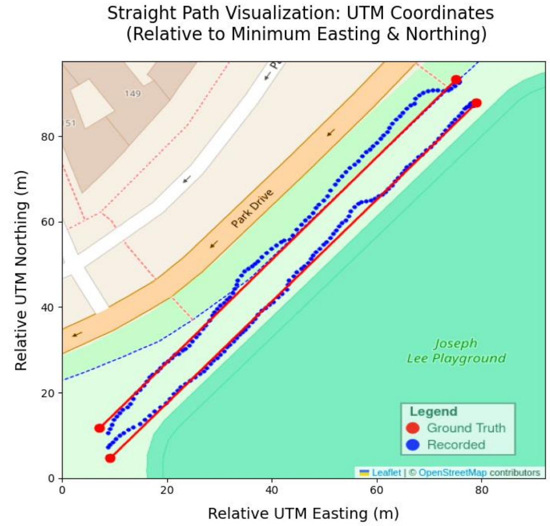

Figure 3. Dynamic condition data plot.

The data collected during the dynamic (straight-line) motion is shown in Figure 3. The calculated error for the dynamic condition was significantly lower than in the stationary scenario, with a mean error of 0.68 meters and a standard deviation of 0.86 meters.

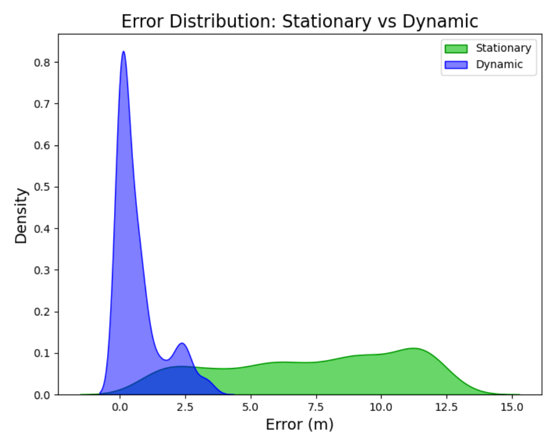

Figure 4. Error distributions for Stationary and Dynamic Conditions.

Figure 4 illustrates the distribution of GPS error data for both stationary and dynamic conditions. The error distribution for the stationary condition resembles a uniform distribution. This distribution suggests that while errors are consistently present, there is variability in the magnitude of the errors observed over time. Whether the errors continue to escalate indefinitely in stationary settings or not requires more data to be collected. However, the slight increase in error density towards the higher end of the curve could suggest a convergence in a longer stationary period setting.

In contrast, the error distribution for the dynamic condition shows a positively skewed pattern, with most values clustering around lower error ranges. The average error recorded was 0.68 meters, which aligns with the horizontal accuracy specifications stated in the datasheet for the GPS device, indicating a 2D RMS accuracy of less than 2.5 meters.

Comparing the two distributions, GPS performance seems better during movement, yielding lower error estimates and a tighter distribution of values. Sources of error may include variable atmospheric conditions, as data collection occurred on a notably cloudy day following a period of heavy rain, which could affect signal quality. Additionally, multipath effects, where signals bounce off nearby structures, likely contributed to the increased error. Finally, while the ground truth points and trajectory lines were based on known landmarks, they are approximations and do not represent the true ground truth. This introduces another source of error, though it could not be precisely modeled/quantified due to hardware constraints and the scope of this experiment.

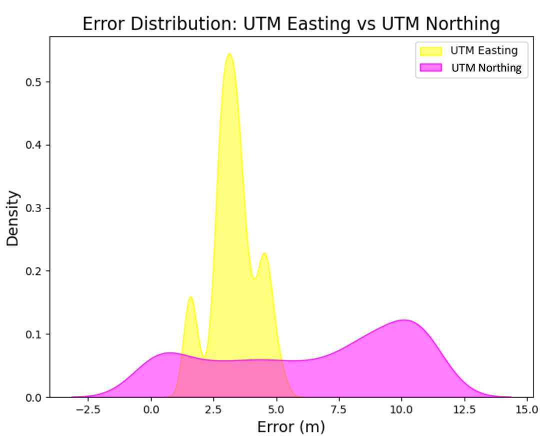

Figure 5. Error distributions for UTM Easting & Northing.

An interesting note to address is the difference in error between the stationary UTM easting and northing. Figure 5 presents the separate error distributions for both coordinates. The mean easting error was 3.29 meters with a standard deviation of 0.90 meters, closely resembling the mean error distribution of the dynamic scenario. In contrast, the northing error had a higher mean of 6.34 meters and a much larger standard deviation of 3.79 meters, resembling the uniform distribution observed in the overall stationary error data. This suggests that the primary driver of the overall error in the stationary scenario is the northing error rather than the easting error.

The discrepancy between UTM easting and northing errors suggests directional bias in GPS accuracy. One possible cause is satellite geometry, where signals affecting the north-south axis may be more prone to interference. Environmental factors, such as terrain or obstacles, could also contribute to this imbalance. These findings suggest that GPS errors aren't evenly distributed across directions, and further investigation is needed to identify the exact causes of this asymmetry.