**Introduction**

Typical use of the global positioning satellite system (GNSS) has signals from multiple satellites (containing information such as when the signal was sent and where it was sent from) being intercepted by a single receiver. Each signal communicates the distance this receiver is from the satellite-of-known-position. These distances can be used as the radii of spheres whose centers are these satellites. The intersection of these spheres indicates the position of the receiver. However, atmospheric interference, objects that occlude the receiver from these signals, and the signal being reflected off of surfaces near the receiver all introduces sources of error in the calculated position. To correct for these errors, a base station can be used in conjunction with a “rover” receiver. This local base station is of a known position and also has a receiver whose position can be calculated from the GNSS signals it obtains. By comparing this calculated position to its known position, the base station can send correction data to the rover. This correction data enables RTK GNSS to have an accuracy measured in centimeters. In this lab, the Massachusetts Continuously Operating Reference Station Network (MaCORS) was used to connect to a base station and collect RTK GNSS data and examine its accuracy.

**Procedure**

Before collecting data, the RTK GNSS receiver was set up with the MaCORS base stations by following the instructions outlined in the Lab 2 Emlid and NTRIP handout. Once ready, four separate data sets were collected. The first data set was in an open spot clear of any obstructions; at the elliptical green space at the center of Centennial Common. Here, ten minutes of stationary data was recorded. After recording stationary data, data from walking along a structured path in an open space was recorded by walking along the edge of the elliptical green space. Next, partially occluded stationary data was recorded for ten minutes by recording outside the entrance to Behrakis. Walking data within a partially occluded space was taken by walking along the perimeter of Behrakis and West Village E.

**Results**

Using the UTM Easting, UTM Northing, and the GNSS fix quality, scatterplots could be constructed that display the stationary and walking data from the open and partially occluded spaces. These can be seen in Figures 1-4 below and on the next page.

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Figure : Centennial Stationary Data Scatterplot Figure : Centennial Walking Data Scatterplot

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Figure : Behrakis Stationary Data Scatterplot Figure : Behrakis Walking Data Scatterplot

The color of each point within each of the scatterplots reflects its fix quality as described in the plot’s legend. In order to find the error within the open and partially occluded stationary data sets shows in Figure 1 and Figure 3 respectively, the final data point within each set was considered the “known position” for said set. Then, the Euclidean distance between the known and measured positions could be found using Equation 1,

(1)

where ‘x’ and ‘y’ are the easting and northing values respectively. This yields an “error distance” for each point. These error distances for the open and partially occluded data sets are reflected in the histograms of Figures 5 and 6 below.

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Figure : Histogram of Stationary Centennial Error Distances Figure : Histogram of Stationary Behrakis Error Distances

An average error distance for both stationary data sets was found by finding the root mean square of all the error distances using Equation 2 below,

(2)

As seen in Figure 2, the walking open data set had an ellipse of best fit applied to it using the fit\_ellipse function in MATLAB. To find the error distance of each measured point, I first found the Euclidean distance, as described by Equation 1, between the measured point and all of the “known” positions that made up the ellipse of best fit. The minimum error distance from these calculations was taken as the error distance of that measured point. This was repeated for all measured points. Then, the average of these error distances was found using Equation 2. The complexity of the path in the walking partially occluded data said can be seen in Figure 4. Given its complexity, the errors from two straight paths of the route were taken. This is seen by the 1st and 2nd lines of best fit in Figure 4. The average error the two straight paths were each found using the mean squared error formula shown in Equation 3 below,

where and are the measured and predicted northing values respectively. The average errors across the data sets can be seen in Table 1 below.

Table : Average Errors from RTK GNSS Data Sets

|  |  |
| --- | --- |
| **Data Set** | **Average Error (m)** |
| Stationary Centennial | 0.6570 |
| Walking Centennial | 0.6441 |
| Stationary Behrakis | 1.0740 |
| Walking Behrakis | 1st Path: 337.1; 2nd Path: 0.2649 |

**Conclusion**

As seen in Table 1, across all of the data sets (apart from the 1st path of the walking Behrakis data set), the average error in position for the RTK GNSS is far less than in Lab 1 where only GNSS was used. The errors seen for the RTK GNSS data sets are measured in fractions of a meter as opposed to the errors of the GNSS data sets of Lab 1 that were measured in multiple meters. This improvement in accuracy is also reflected in the distribution of measured positions. While the spread visible in Figure 1’s stationary centennial data implies inaccuracy, this can be attributed to starting the recording of the data from a “cold” state. The RTK GNSS needed time to calibrate. This can be seen in how, after a period of time, the sensor calibrates and its measured positions begin to cluster with barely any error – as seen by the high frequency of errors between 0-0.2m in Figure 5. Additionally, for both walking paths the measured positions follow the “predicted” positions of the curves of best fit closely. The only exception to this is with respect to the 1st path of the walking Behrakis data. This can be attributed to the occlusions from the building resulting in loss of connection to the base station, reflected by the RTK fix quality values in this path going down to 1 (which means that it is only gathering its position from GNSS satellites). It can be inferred by the increases in spread when a fix quality of 1 is reported that GNSS results in a greater spread of positions and is less accurate. The consistent fix qualities of 4 (RTK fixed, an accuracy of 1-2 centimeters seen at the end position of Figure 1) and of 5 (RTK float, an accuracy of 0.2-0.5 meters) across the data sets reveals that high fix qualities demonstrate lower spread and reflect the higher accuracy of RTK GNSS. While the spread within Figure 3 of the stationary Behrakis data appears large, its error still remains less than 1 meter. It is more spread out than the open stationary data, and this is reflected in how the partially occluded stationary data has a greater frequency of a fix quality of 5 throughout its recording as opposed to the more accurate fix quality of 4 that characterizes the majority of the open stationary data. In summary, it would appear that while either stationary or walking, RTK GNSS is more accurate and precise than GNSS. This can be attributed to the correction factor the base station provides. Said point is underlined in how the accuracy and precision of the data is lessened as connection to the base station weakens (as fix qualities go from 4 to 5 to 1, a greater spread is seen).