TOWARDS ROBUST LOCALIZATION OF RTK-GPS TOPOGRAPHIC SURVEYS

Jerry W. Nave, North Carolina A&T University; Tarig A. Ali, American University of Sharjah

Abstract

Localization is performed to fit the observed GPS positions to the local datum at the survey site. Mathematically, localization is a coordinate transformation between the GPS and local systems. When RTK techniques are used for topographic mapping, localization is crucial as it adjusts observed GPS ellipsoid elevations to the local vertical datum, thus accounting for geoid undulations. Localization uses a set of coordinates of points in both WGS-84 and the local coordinate system. Commonly, the number of points that can be used in localization depends on the size of project area and the type of the adopted GPS hardware and/or software. These points should be well distributed in the project area. One measure of the quality of localization is the maximum values of horizontal and vertical residuals, which depend on the accuracy of the GPS-derived coordinates of the points. In this paper, the authors present the requirements for robust localization and addresses some related issues.

Introduction and Background

The global positioning system (GPS), which is known as the Navigation Satellite Timing and Ranging (NAVSTAR) system, is an all-weather, day-and-night satellite-based radio navigation system initially established by the United States Department of Defense in the 1970s for military navigation applications. GPS is the principal component of the global navigation satellite system (GNSS) and provides positions at any location in terms of coordinates defined in a geocentric earth-fixed reference frame such as the International Terrestrial Reference Frame (ITRF). Other components of GNSS include the Russian GLObal NAvigation Satellite System (GLONASS) and the European GALILEO project. GLONASS is a Russian space-based navigation system comparable to the NAVSTAR GPS. GALILEO is a European initiative, which provides accurate and guaranteed global positioning services under civilian control with the new L3 civil signal. It was anticipated to be operational in 2008 [1].

The NAVSTAR system is composed of 24 to 32 medium earth orbiting satellites, which transmit signals from space on the L-band in the microwave wavelength range. The transmitted signals can be received by a GPS receiver and used to calculate the precise time and location of the receiver. GPS satellites transmit the following information to the receiver: a) approximate orbital information (known as the almanac), b) time information, and c) precise orbital information (known as the ephemeris). The receiver uses this information set to determine the distances to each satellite (known as the pseudo-range). These distances along with the satellites orbital information at the time of transmission are utilized by the receiver to determine its position [2]. The three-dimensional coordinates of the antenna position and the receiver clock error can be solved for, provided that sufficient satellites (usually more than four) are simultaneously tracked and their positions are accurately provided. The position and velocity vectors of each satellite can be acquired from the broadcast ephemerides. With longer latency, more precise ephemerides are provided by the International GPS Services (IGS). Positioning accuracy can be improved with more observations either from other satellites that are simultaneously tracked or from the same set of satellites with longer observing times.

The range from an antenna to a satellite can be obtained from two GPS observables a) pseudo ranges (from codes) and b) phase ranges. The pseudorange observable is a measure of the distance between the satellite and the receiver's antenna, referring to the epoch of emission and reception of the codes [3]. The range can be determined by multiplying the speed of light by the total travel time, which is inferred from correlating the identical pseudo-random noise (PRN) of the received codes to the receiver-generated replica. On the other hand, the range can also be expressed by the total number of waves, including the integer and the fractional parts, multiplied by the wavelength of the carrier wave [4]. The phase observable is the fractional part of the phase difference between the received wave and that of the internal receiver oscillator. The integer part of the exact number of carrier waves from each satellite to the antenna, called the initial integer ambiguity, remains unknown and needs to be solved for. The correct ambiguity solution is a key to achieve higher accuracy in the kinematic GPS positioning. It is common to use both code and phase observations, provided that the receiver is equipped with such capabilities.

Localization or site calibration is a procedure performed to fit the observed GPS positions to the local datum at the survey site. Mathematically, localization is nothing but a coordinate transformation (2D- or 3D-conformal, affine, other) between GPS-based and local systems. This transformation can be a 3-parameter (small-scale projects) or a 7-paramter transformation (large-scale projects). When RTK techniques are used for topographic mapping, site calibration of the local geoid undulations (if geoid model is loaded) is crucial because the observed GPS ellipsoid elevations need to be adjusted to the local vertical datum in order to account for geoid undulations. The existing control points only give a separation at their location. Localization normally reports residuals from the least-squares adjustment without a geoid model, unless one is loaded. In this context, there are three sources of errors: the hybrid geoid model, the user's GPS-derived ellipsoid heights, and the published orthometric heights. Consequently, the observed GPS positions would be correlated to the local coordinate system, e.g., the State Plane Coordinate System (SPCS). In order to determine accurate orthometric elevations from GPS ellipsoid elevation observations, geoid undulation must be accounted for using existing control points. In addition, the published orthometric elevations at each of the established control points may not fit exactly with the geoid model. Therefore, the GPS software must be able to adjust for both of the variations in the geoid model and in the established control benchmarks given that the GPS observations are performed between the points.

Localization uses a set of coordinates of points in both WGS-84 and the local coordinate system, and it can be performed in the field during the data-collection phase or in the office at the network-adjustment phase. Commonly, the number of points that can be used in localization depends on the size of the project area and the type of the adopted GPS hardware and/or software. The points used in this process should be well distributed in the project area. One measure of the quality of site calibration are the maximum values of horizontal and vertical residuals, which depend on the accuracy of the GPS-derived coordinates of the points.

Study Area

The size of the study area was approximately 0.75km by 0.5km, and is located near the NCAT University campus in Greensboro, NC. Figure 1 shows the location of the study area as well the initial layout of the survey stations within the study area.

Prior to the field work, a site reconnaissance was performed using standard station visibility diagrams to determine the location of obstructions near each control station. Results indicated few obstructions above the target 15º horizon. Station visibility diagrams were input into the TGO planning software in order to determine the optimal times for observing the stations. The Sky plot and the positional Dilution of Precision at the base station location in the study area are shown in Figures 2 and 3.

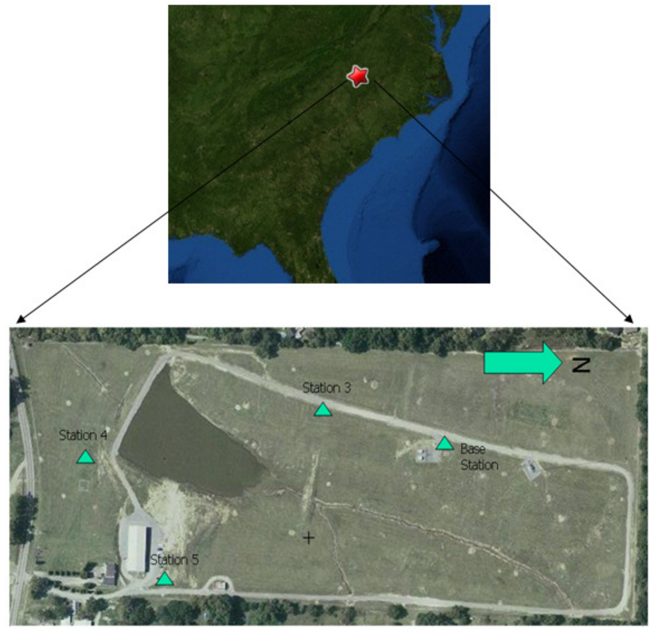

Figure 1. Study Area

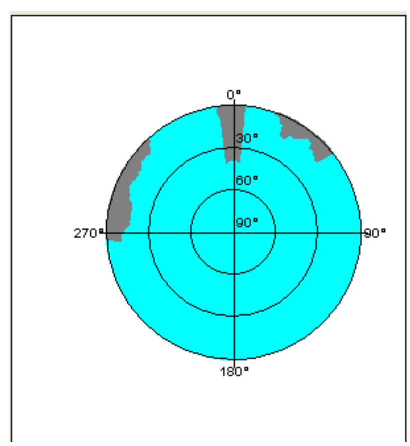

Figure 2. Sky Plot at the Location of the Base Station in the Study Area

Data Collection

The base station was placed on a fixed–height, two-meter tripod on NGS monument GRN1 A, which is a GPS horizontal First Order Class I monument with a vertical First Order Class II and an Ellipsoid order of Fourth Class II. The horizontal coordinates were established by the North Carolina Geodetic Survey in August of 2004 by GPS observations based on NAD 83(2007). The orthometric height was established by differential leveling and adjusted by Geoid09 in August, 2009. After allowing 15 minutes for the base to initialize, the station was allowed to establish a geodetic location from the satellites before starting the survey experiment.

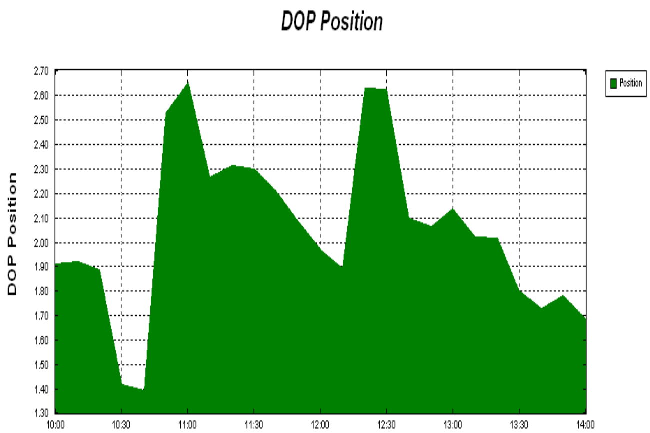

Figure 3. Positional Dilution of Precision

The three stations used for the localization are unpublished monuments that have been established by North Carolina Geodetic Survey using GPS, and the elevations were established by Geodetic differential leveling. The three stations (NCAT 3, NCAT 4 and NCAT 5) monuments are disks set in concrete, established in 2007. The experiment was broken into three different parts using 10 epochs, 25 epochs and 50 epochs of data, respectively (refer to Tables 1, 2, and 3). The rover was mounted on a two-meter, fixed-height pole with bipod and allowed to sit for approximately one minute prior to gathering data. For data collection, a Topcon Hiperlite+ unit (base and rover) was used and the processing was performed using TopSurv PC software. In the datasets shown in Tables 1, 2, and 3, the columns "Horizontal" and "Vertical" show the horizontal and vertical RMSE values, respectively, obtained for the base station and the three stations used in the study. The "US Satellites" column displays the number of NAVSTAR satellites used to estimate the positions in this study. The columns titled "Northing of the Base", "Easting of the Base", and "Elevation of the Base", show the estimated northing, easting, and elevation of the base stations along with the corresponding residuals with the rover setup at stations 1, 2, and 3, respectively. It is worth mentioning that all occupations were done with different initializations and that the calibration points were observed for at least three minutes using stable setups (i.e., bipod).

Table 1. Dataset 1 (10 epochs)

Base Station	PDOP	Horizontal	Veritical	US Satellites	Est of Elev	Northing of Base	Easting of Base	Elevation of Base
	1.60	2.122m	3.095m	9	0.00m			
Rover @ Station 3								
	1.70	0.018m	0.020	9		257377.208	542499.438	238.829
						-0.446	1.314	0.007
Rover @ Station 4								
	1.80	0.019m	0.024	9		257376.775	542500.729	238.834
						-0.013	0.023	0.002
Rover @ Station 5								
	1.90	0.018m	0.019m	9		257376.780	542500.729	238.800
						-0.018	0.023	0.036

Table 2. Dataset 2 (25 epochs)

Base Station	PDOP	Horizontal	Veritical	US Satellites	Est of Elev	Northing of Base	Easting of Base	Elevation of Base
	2.00	2.491	3.819	8	0.00m			
Rover @ Station 3								
	1.90	0.012	0.017	7		257377.213	542499.434	238.832
						-0.451	1.318	0.004
Rover @ Station 4								
	1.80	0.022	0.029	7		257376.782	542500.732	238.834
						-0.020	0.020	0.002
Rover @ Station 5								
	2.30	0.021	0.026	6		257376.770	542500.739	238.826
						-0.008	0.013	0.010

Table 3. Dataset 3 (50 epochs)

Base Station	PDOP	Horizontal	Veritical	US Satellites	Est of Elev	Northing of Base	Easting of Base	Elevation of Base
	1.80	2.441	3.370	7	0.00m			
Rover @ Station 3								
	1.60	0.013	0.018	8		257377.209	542499.427	238.829
						-0.447	1.325	0.007
Rover @ Station 4								
	1.60	0.020	0.026	9		257376.779	542500.717	238.826
						-0.017	0.035	0.010
Rover @ Station 5								
	1.90	0.021	0.025	8		257376.733	542500.731	238.844
						0.029	0.021	-0.008

Results and Discussion

It was evident in this study that the quality of localization was affected by the accuracy and consistency of the GPS coordinates of the control points. The results show that the residual in the horizontal coordinates were larger than that in the vertical coordinates. This was evident in Figures 4 through 9, which show that the residual in the easting and northing were relatively large for the three epochs of data collection. It was also noticed that: a) for small- to medium-size topographic surveys projects, using three horizontal and four vertical points for site calibration seemed optimal, given that the points should be well distributed within the project area; and, b) connecting the survey with existing control resulted in a refined localization model. The mathematics of localization suggests that there is a need to consider the geometric distribution of the control points within the project area. Furthermore, any systematic error in the control will translate into the localization, further compounding the geometric distribution problem as well.

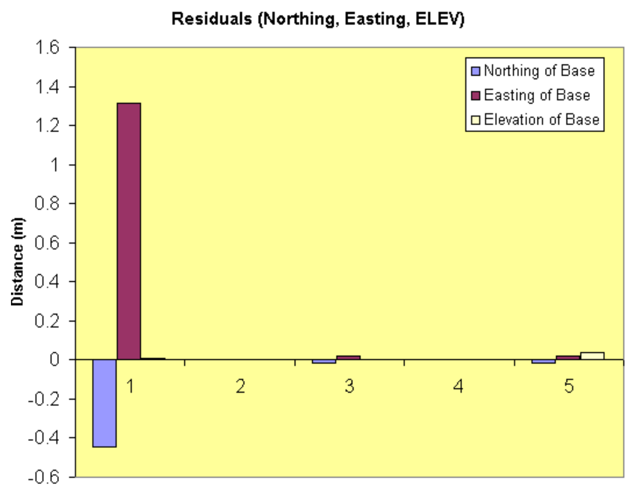

Figure 4. Plot of the Residuals in Computed Values of Northing, Easting, and Elevation of Base Station (Dataset 1–10 epochs)

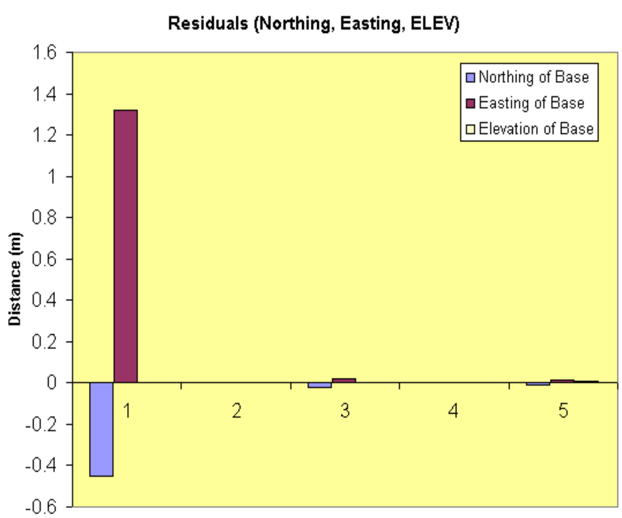

Figure 5. Plot of the Residuals in Computed Values of Northing, Easting, and Elevation of Base Station (Dataset 2–25 epochs)

In this study, the difference between the easting and northing computed for the base station was reasonable for all but that from Station 3 in all of the three experiments. The cause of this big residual difference remains unknown, but because the three stations used in this study are unpublished monuments that have been established by North Carolina Geodetic Survey in 2007, it was suspected that the monument of Station 3, which is a disk set in concrete, might have moved from its position.

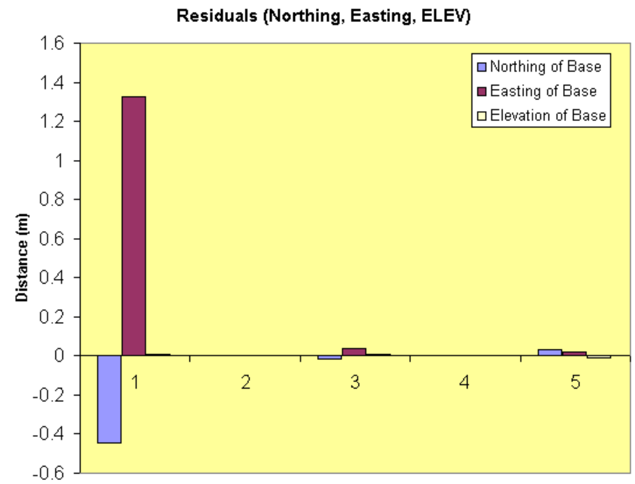

Figure 6. Plot of the Residuals in Computed Values of Northing, Easting, and Elevation of Base Station (Dataset 3–50 epochs)

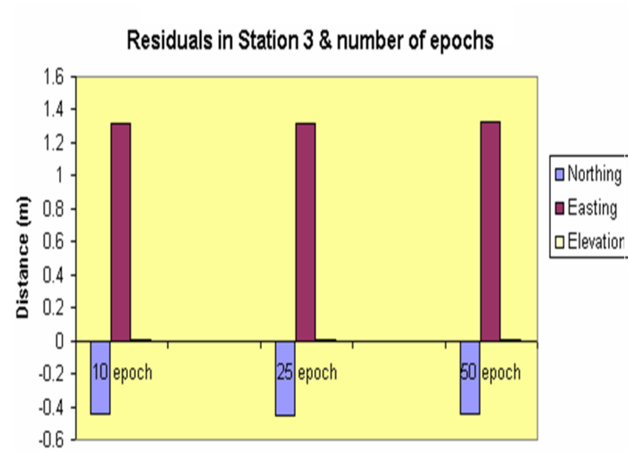

Figure 7. Plot of the Residuals in Computed Values of Northing, Easting, and Elevation of Station 3 (NCAT 3)

From this experiment the authors could not arrive at an ideal time for RTK control point observations; however, they did find that there is a need to have redundant observations with probably a minimum separation and a few independent RTK initializations. Recommendations from practicing surveyors suggest 2 to 4 hours, but no scientific ground to support that could be found. It is worth mentioning that the authors used existing published control points and assumed that they were network relative and consistent. In other words, the authors could not validate the control independently; rather they used it assuming that it was correct.

It is essential that the GPS software be capable of compensating for the variations in the geoid model and the variations in the established control benchmarks [5]. In order to accomplish this, GPS observations need to be connected between fixed benchmarks; specifically, vertical control points. In summary, localization is seemingly easy when you first approach it but, as you execute it, it quickly becomes complicated. Some surveyors suggest the use of more robust geodetic methods of data evaluation and not use localizations at all, excluding the most rudimentary tasks like searching for site control initially followed always by a more robust evaluation of the data.

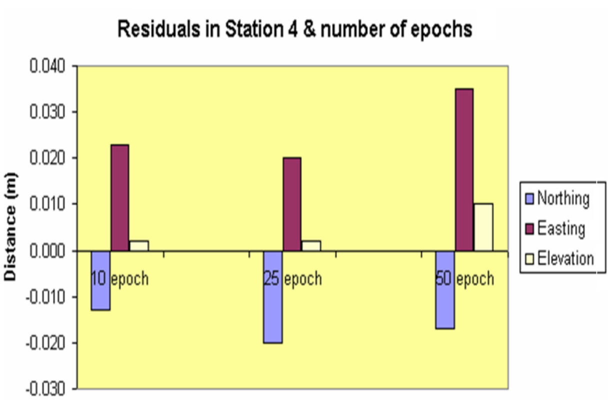

Figure 8. Plot of the Residuals in Computed Values of Northing, Easting, and Elevation of Station 4 (NCAT 4)

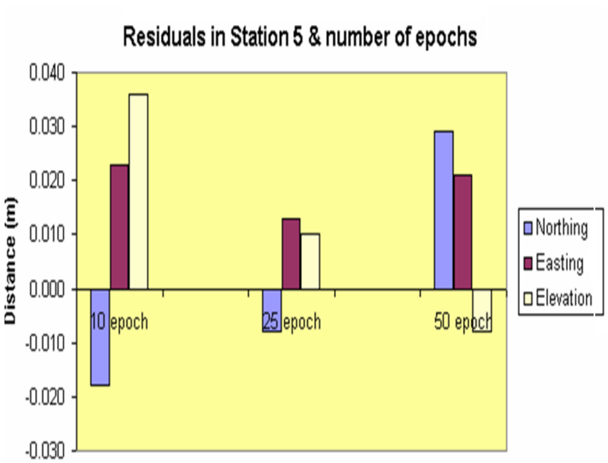

Figure 9. Plot of the Residuals in Computed Values of Northing, Easting, and Elevation of Station 5 (NCAT 5)

Summary

The quality of localization is affected by the accuracy and consistency of the observations and the GPS coordinates of the control points. Based on this study, it seems that the largest residuals are the planar, while the vertical remained at a minimum. For small- to medium-size topographic survey projects, using three horizontal and four vertical points for site calibration seems optimal, given that the points are well distributed within the project area. GPS software must be able to compensate for a) the variations in the geoid model and b) the variations in the established control benchmarks. In order to accomplish this, GPS observations need to be connected between fixed benchmarks (vertical control points).

References

[1] European Commission 2003. The Galileo Project, GALILEO Design Consolidation, Guildford/ U.K.:ESYS.

[2] Kaplan, E., & Hegarty, C. (2006). *GPS: Principles and Applications*. (2nd ed.). Artech House.

[3] Leick, A. (1994). *GPS Satellite Surveying*. (2nd ed.). New York: Wiley.

[4] Langley, R. (1993). The GPS Observables, GPS World, 4(4), pp. 55-69. Paper presented at the 12th European Frequency and Time Forum (EFTF 98), March, Warsaw, Poland.

[5] Ali, T., & Mehrabian, A. (2009). Localization of Topographic GPS Surveys with TOPSurv PC. A Software Review. *International Journal of Modern Engineering*, *9*(2), 73-75.

Biographies

JERRY W. NAVE received the B.S. degree in Surveying and Mapping Science in 1986, the M.S. degree in Geosciences in 1999, and the Ed. D. in 2003 from East Tennessee State University. Currently, he is an assistant professor in Department of CAAE at the North Carolina A&T State University. His teaching and research areas include boundary and Legal Issues; Surveying Law; GPS Height Modernization; Geodesy; Satellite Positioning; Subdivision Design; Professional Ethics; 3-D mapping of Archeological and Paleontological Sites. Dr. Nave may be reached at jwnave@ncat.edu

TARIG A. ALI received the B.S. degree in Civil Engineering (Honors) in 1993 from Khartoum University, Sudan, the M.S. and Ph.D. degrees in Geodetic Science and Surveying in 1999 and 2003, respectively, from the Ohio State University. Currently, he is an associate professor in the Department of Civil Engineering at the American University of Sharjah, United Arab Emirates. His teaching and research areas include surveying and mapping, terrain modeling, wide-area GPS networks, LiDAR Mapping, and applications of geographic information systems and remote sensing in environmental and transportation engineering. Dr. Ali may be reached at atarig@aus.edu