ADDENDUM II: GUIDELINES AND BEST PRACTICES FOR FIELD SURVEYING OF GROUND CONTROL AND CHECKPOINTS

CONTENTS

PURPOSE

The purpose of this addendum is to provide best practices for the field surveying of ground control and checkpoints as referred to throughout the ASPRS Positional Accuracy Standard for Geospatial Data. These guidelines are intentionally sensor and manufacturer agnostic. These best practices are not intended to replace the manufacturer's manual, nor do they replace a textbook on surveying. Best practices recommended herein assume that the equipment operator and data processor understand the fundamentals of type of surveying referred to and can competently operate the equipment and software being used. These guidelines do not instruct a novice in the performance of surveying tasks; rather they represent a consensus reached by learned practitioners with recommendations that can be followed by experienced and knowledgeable surveyors.

SCOPE

Five methodologies for field surveying of ground control and checkpoints are covered in this addendum.

1. Establishment of static control and best practices for utilizing Global Navigation Satellite System (GNSS) for Real Time Kinematic (RTK) surveying using base and rover methodologies.
2. Use of GNSS Real Time Networks (RTN).
3. Use of GNSS Real Time Precise Point Positioning (RT-PPP) techniques to establish ground control in clear open sky areas only.
4. Use of conventional surveying techniques (total station) to establish Vegetated Vertical Accuracy (VVA) checkpoints under tree canopy, incorporating RTK/RTN techniques for local control.
5. Use of terrestrial scanning and mobile mapping methodologies to establish ground control point (GCPs) and Non-Vegetated Vertical Accuracy (NVA) checkpoints under controlled circumstances.

CONTRIBUTORS

Jim Gillis, VeriDaaS Corporation - Lead
David Kuxhausen - Woolpert, Inc.
Jeff Irwin - USGS
Jamie Gillis - GeoTerra
Colin Lee - Minnesota Department of Transportation
Michael Zarlengo - Woolpert, Inc.
Kyle Ince - Ohio Department of Transportation

A: COORDINATE QUALITY OF CONTROL POINTS AND CHECKPOINTS

In order to assist field surveyors and office QC personnel in determining the reliability of field measurements for the purposes of controlling aerial data, the following guidelines are recommended.

Coordinate quality is a measure of the calculated precision of an observation, or series of observations. Coordinate quality values are represented by different statistical means by different manufacturers and the professional surveyor must understand the coordinate quality definition particular to the software being used. When establishing appropriate coordinate quality limits to meet ASPRS specifications, the surveyor should ensure that his equipment, software, and field survey practices collectively will guarantee that the accuracy of the horizontal and vertical positions of each of the individual control points and checkpoints is two times better than that of the aerial data being controlled and verified. It is always the professional surveyor's responsibility to do this correctly.

As is known, not all survey equipment is manufactured to the same standard. The use of different technologies and different equipment manufacturers will provide different results. It is up to the surveyors to know their equipment and to understand what field techniques are necessary to obtain results that meet the necessary standards. To reliably estimate the quality of the positions of these surveyed points**,** *multiple independent observations of each surveyed point must be made*. Coordinate Quality indicators need always be provided in a standardized format. One-sigma standard deviations, RMSE, CQ or another appropriate standard, should be included with all coordinate data, one value to be provided for each dimension. This information must be provided in any coordinate listing and/or survey report, as with the following examples:

Point ID	Northing	Easting	Ortho Height	Horizontal RMSE	Vertical RMSE
G0001	496353.356	5941936.542	832.743	0.009	0.012

Point ID	Northing	Easting	Ortho Height	Hz Precision CQ 2D	Vert Precision CQ 1D
G0137	396353.356	3941936.542	1832.743	0.004	0.002

Point ID	Northing	Easting	Ortho Height	SD Northing	SD Easting	SD Ortho Height
N0108	460624.421	2641766.062	1083.664	0.01	0.01	0.00

B: STATIC CONTROL AND RTK SURVEYING

The purpose of this section is to set forth practical guidelines and best practices for the establishment of GNSS static control points and the use of GNSS RTK using base and rover methodologies. These guidelines provide practical suggestions for obtaining consistent and accurate three-dimensional survey control.

B.1 Static Surveying with GNSS

Static surveying requires that two or more GNSS receivers occupy stations at the ends of baselines for an time period deemed adequate based on baseline lengths, satellite constellations, and the potential for satellite signal interference, multipath, or blockage caused by trees, buildings, and the like. Most manufacturers quote the recommended observation times and accuracy specifications based on ideal conditions, but survey points are frequently in located in less-than-ideal GNSS environments. It is always advisable err on the side of caution by extending the duration of occupations, to avoid having to go back and resurvey due to poor data.

While it is possible to use only two receivers for a static survey, multiple receivers configured in a network using multiple known and unknown points will give better results. At least one receiver must occupy a point with precise, known coordinates; other receivers may be set up unknown points. Raw data is collected at all receivers simultaneously for a predetermined amount of time, which, after post processing of the baselines, will produce the coordinates of the unknown points.

This method of survey is most often used to perform precise positioning over large areas where baseline lengths than real time observations allow. The accuracy of the post-processed positions will be affected by the length of the various baselines, the observation duration of the survey, the precision of the equipment mounting system used, the number of independent redundant observations, and the accuracy of the existing control points used to constrain the survey.

B.1.1 Equipment

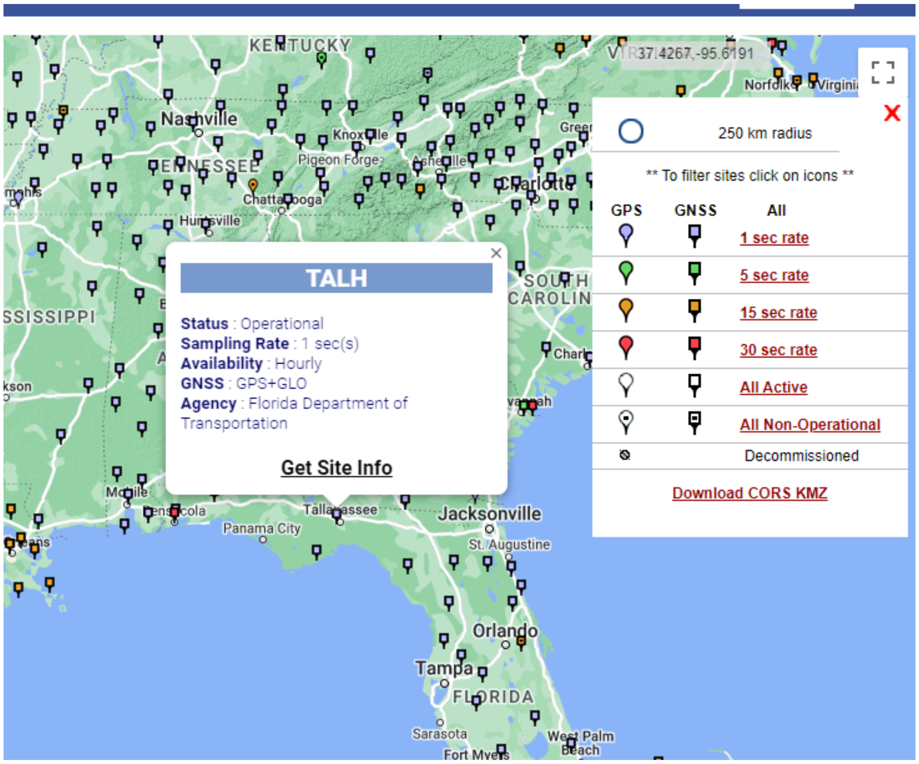
Numerous makes, models, and combinations of GNSS antennas, GNSS receivers, and data controllers are available on the current market and are continuously evolving. Usually, it is easiest to conduct surveys with antennas, receivers and mounting equipment (tripods, tribrachs, and height measuring devices) from the same equipment manufacturer. However, surveyors should make equipment choices based on best practices, desired accuracy results, and project requirements. Be mindful that processing software and workflows can be manufacturer dependent.

B.1.2 Data Management

When planning static surveys be mindful of data size and storage requirements as well as pre-project observation planning. Consider the following when planning static surveys:

File Size & Storage Capacity: Consider the size and duration of your files and where the data will be logged. This is not usually a concern with modern GNSS receivers but can be with some older models. There must be enough free memory in the receiver for the desired survey. Modern receivers possess a large memory capacity and have much larger storage than their predecessors.

Data Sample Rate: For static surveys it is usual to collect data at a 5 to 15-second sampling interval, rather than at a 1-second interval. Data should be collected at the same interval for all receivers, if possible, although some Continuously Operating Reference Stations (CORS) will collect and disseminate data at a minimum of a 30-second rate, as shown in Figure B.1. This setting will directly affect the file size.



TALH

Status : Operational
Sampling Rate : 1 sec(s)
Availability : Hourly
GNSS : GPS+GLO
Agency : Florida Department of Transportation

Figure B1 CORS Station Data Sample Intervals

Elevation Mask/Cutoff Angle: Consider the environment and obstructions that may potentially block GNSS signals. Above what elevation mask do you want the receiver to log raw data? Remember that a low elevation mask will allow the collection of poorer quality raw data due to signal blockage, multipath, atmospheric interference, etc. The use of a higher elevation mask will eliminate much of the poorer data and will almost always improve the vertical component of the solution. The most advanced processing software can mitigate most of the effects of low-quality raw data but not everyone uses the same software. It is better to err on the side of caution rather than to have to go back and re-observe due to poor quality raw data.

B.1.3 Workflow

Initial site analysis and pre-project planning are essential to project success. Planning missions and pre-determining locations that possess adequate sky coverage and minimizing potential multi-path contributors will aid in the project success. Always consider the environment in which you are surveying and account for potential obstacles such as vegetation, structures, canyon walls, and any objects that can obstruct your receiver’s view of the satellites.

B.1.4 Preparation

- Plan for power needs with adequate chargers and batteries.
- Plan for memory needs and observation duration.
- Perform field reconnaissance in advance utilizing:
    - TOPO Maps
    - Google Earth
- Provide for GNSS session pre-planning by anticipate the number of sessions and observers and ensure observation times are adequate.
- Prepare a project mission plan with equipment checklists and GNSS planning schedules.
- Ensure good communication between the project teams while observations are ongoing in case of problems.

B.1.5 Post Processing

Post Processing (Interactive using commercially available software)

GNSS static data collected for high precision applications must be post-processed to produce accurate results. There are many hardware and manufacturer specific processing software platforms available. Specific workflows for post processing are software / manufacturer dependent and the user manual should be consulted for best results.

Post Processing (Online Positioning)

Today there are several online positioning processing programs that can serve different surveying needs. The requirements for each of these can be slightly different. The following are some of the most common options.

- OPUS (National Geodetic Survey). Users should always wait for the publication of the precise ephemeris for the most accurate results when utilizing the OPUS processing network
- CSRS-PPP (Canadian Geodetic Survey)
- AusPos (Geoscience Australia)
- APPS (NASA/Jet Propulsion Laboratory)

B.2 GNSS RTK Positioning

RTK surveying is a relative positioning practice that measures the three-dimensional (3D) vector between two or more GNSS receivers in real-time. One GNSS receiver is set up on a known point with fixed coordinates and is frequently referred to as the BASE station. The base station transmits its known 3D position and the raw GNSS data it receives to the rover receiver in real-time and the rover employs both the rover and base GNSS data to compute its position relative to the base. RTK surveying requires a consistent and dependable communication link between the two receivers so that the rover receives continuous observation data from the base. The communication method used from the base to the rover can be by a UHF or VHF radio link, via cellular network modems or with a combination of these two methods with use of an RTK bridge.

B.2.1 Base Station Setup

- A clear unobstructed view of the sky above a 15-degree elevation mask is mandatory.
- The base stations should be erected utilizing a stable environment with proper centering, leveling, and tripod leg weights where necessary.
- All setups should be performed with properly adjusted, leveled, and maintained tripods and tribrachs.
- Before sending crews to the field, it is preferable to upload to the data collector/field controller the verified NAD83 geographic coordinates and ellipsoidal height for the monument to be used for the base station receiver. This methodology is the most reliable way of setting up the base station and thereby avoids the need for the field crew to choose a datum, map projection and geoid model, or to key in the coordinates manually. Entering incorrect base station data is the most common error associated with RTK surveying.
- Ensure that the antenna height is properly measured, checked, and verified by independent means. The use of fixed height tripods or manufacturer-specific survey-grade height hooks, which both provide vertical height measurements to the millimeter level, are preferable.
- Please refer to Section C.2 when obtaining data from a real-time reference network.

B.2.2 Rover Setup

When starting an RTK survey, it is imperative to ensure that the rover is configured to achieve the desired accuracy of the survey. The following are important fundamentals that must be confirmed for quality data collection.

- Constellations tracked should be set in both the base and rover receivers to ensure that both are set up to track the same satellite constellations (GPS, GLONASS, GALILEO, BEIDOU) and signals (L1, L2, L5 and their equivalents)
- A geoid model may be assigned if REQUIRED. Heights observed by the GNNS receivers are ellipsoid heights. Geoid models are used to convert ellipsoidal heights to orthometric heights or elevations. At the present time, the most common geoid model used to convert ellipsoid heights to the NAVD88 datum in the US is Geoid18, although Geoid12B is still used occasionally. It is anticipated that a new vertical datum based on a new 3D Coordinate Reference System (CRS) and a new gravity-based geoid model will be adopted by the National Geodetic Survey (NGS).

B.2.3 GNSS Solution Types

- *Autonomous*: The rover is observing independently without any corrections and is not receiving data from the base. Therefore, the coordinates do not meet survey grade accuracy standards.
- *Float*: The data obtained at the rover are not of sufficient quality to calculate a fixed integer position, the most accurate type of position.
- *Fixed Integer*: The GNSS rover can calculate a fixed integer solution, and the positional results are normally within the desired accuracy limits. This is the most accurate solution type.

Be mindful that not all survey grade GNSS systems employ the float/fixed method of RTK ambiguity resolution. This equipment variation may determine adequate RTK precisions based on a more rigorous float solution.

B.2.4 Rover Quality Control

- In the field, field operators must ensure that all surveyed points meet minimum quality standards as set for the project. Revisiting points to re-survey those that do not meet minimum quality standards is not efficient and delivering sub-standard survey data is not at all acceptable.
- Coordinate quality thresholds should be set to meet minimum project accuracy requirements.
- On older equipment, monitor PDOP and RMS values to ensure a quality solution and measurement are obtained. Most modern GNSS equipment allows the user to set rigorous Coordinate Quality (CQ) standards and therefore do not require the monitoring of PDOP or RMS values. Depending on the make and model of your equipment, many modern receivers do not display RMS, as it is a computed part of the precisions and handled through a threshold accuracy setting.
- A minimum of two independent measurements with totally independent initializations should be made on each point, more if necessary. Subsequently, these independent measurements should be averaged or computed as a weighted mean to arrive at the best estimate of the true position.
- It is recommended that a minimum observation period of 180 seconds should be collected for each individual observation.

B.2.5 Accuracy Check

- It is always the obligation of the surveyor to use appropriate equipment and procedures to achieve and verify the required accuracy for the survey.
- RTK data collected in the field should always be checked and verified using the manufacturer's proprietary office processing software. Data collected in the field should never be exported directly to an ASCII file without an office QC process to catch any field errors and verify the correctness of the data before export.
- As a verification that your base broadcast data and your Coordinate System are correct, the wise surveyor shall locate and tie in existing NGS or other monuments with known or published values using the same rigorous observation methodology as delineated above. Compare the coordinates published by NGS or other agencies to the surveyed coordinates as derived by your field crews to determine if they match within the standards required for the project.

C: GNSS REAL-TIME NETWORKS (RTN)

The purpose of this section is to set forth best practices and guidelines for using a Real Time Network (RTN) as the reference stations for ground control using RTK.

C.1 Introduction and Definitions

C.1.1 Network Solutions vs. Single Baseline Solutions

An awareness of whether the reference being utilized is single station (baseline) or a network solution is a critical step in the realistic prediction of the coordinate quality values of a control survey.

The baseline length at which acceptable results can be achieved is sometimes shorter with a single baseline solution (receiving corrections from a single reference station – although the distance can be extended through the use of cellular networks) than with a network solution, which models for satellite orbit variations and ionospheric and tropospheric differences/ interference using multiple reference stations in the area surrounding the rover, helping the rover to estimate the atmospheric conditions at its location.

C.1.2 GPS vs. GNSS

Knowing not only which GNSS signals and constellations the rover is able to track, but which signals and constellations the reference station/network is able to track is critical for a determination of what type of accuracy and precision can be expected. It doesn't matter how many constellations (GPS, GLONASS, GALILEO, BEIDOU) and signals (L1, L2, L5 and their equivalents) the rover is tracking if they aren't also being tracked and utilized by the RTN. An RTK solution can only use common satellites and signals that are being tracked at both the base and rover.

C.1.3 VRS vs. MAC(X) vs. iMAX vs. FKP

There are significant differences in the type of RTN and how it affects the calculated rover position.

VRS – Virtual Reference Station: A virtual base station is created, close to the rover's position, and mitigates baseline dependent errors. The server sends modeled corrections to the rover but the rover is unaware of the errors the VRS is modeling for. As a result, there may be some degree of error in the virtual position that the rover is not accounting for which can result in overly optimistic quality predictions.

MAC(X) - Master Auxiliary Concept/Correction: Correction and modeling data from multiple stations are provided to the rover, as well as data from a primary, or master station, which is a physical reference station from which the rover receives corrections which can be traced and repeated. Correction info from the master station and auxiliary stations are broadcast to the rover and the modeling is done by the rover based on its position, information received from surrounding stations, baseline length to the closest physical station, etc.

iMAX – Individualized Master Auxiliary Correction: Based on the MAC(X) concept but modified for lower bandwidth so that full GNSS, multi-signal messages can be transmitted successfully. Correction info is calculated at the server rather than the rover, but correction info and baseline vectors from the closest physical station are still transmitted to the rover. This allows the rover to predict coordinate quality based on the true baseline length.

FKP – Flachen-Korrektur-Parameter: A model of distance-dependent errors is transmitted to the rover, while the calculations are done at the rover. Because more data is transmitted to the rover than most network correction types, the bandwidth requirements are high. FKP is much more common in Europe and elsewhere than in North America.

C.1.4 Vertical and Horizontal Datums and Broadcast Coordinates

An understanding of reference frames, projections, geoid models, and their various realizations is critical when working with RTNs. The method and frequency of processing and adjusting the physical reference station coordinates can have a significant impact on the accuracy and precision possible at the rover, especially in areas of above average horizontal or vertical movement.

C.1.5 Vertical and Horizontal Accuracy

The factors and variables at play in estimating and validating vertical and horizontal accuracy in an RTN are numerous, but with an understanding of the network type, rover capabilities, baseline length, best practices, etc. high accuracy and high precision results can be obtained with using an RTN.

C.1.6 Baseline Length

Weather and ionospheric/tropospheric interference/differences are largely dependent on baseline length, which plays a huge role in the accuracy and precision of all RTK surveying. While network corrections are, to a certain extent, able to mitigate ionospheric and tropospheric differences through modeling, the more similar the atmosphere through which GNSS signals being received at the base and rover, the better the coordinate quality that can be expected. This is particularly true of the vertical component due to the difficulty in estimating the tropospheric changes over long distances.

C.1.7 Dilution of Precision (DOP), Root Mean Square Error (RMS), and Coordinate Quality (CQ)

The same factors that affect accuracy and precision in traditional base-and-rover RTK surveying are factors when using an RTN, but more variables are introduced into the solution. Things such as satellite constellations and signals tracked, satellite geometry, dilution of precision, become more complicated when we are talking about baseline lengths in excess of twelve miles.

C.2 Procedures and Best Practices

C.2.1 Coordinate Quality/Root Mean Square Dilution of Precision Guidelines

To keep coordinate quality (CQ) and Root Mean Square (RMS) error (noise) values at an acceptable level, factors such as baseline length (especially in network RTK when baselines are not limited by radio range) and Dilution of Precision (DOP) values should be monitored and understood. Reliable results are possible at longer baseline lengths when the corrections are coming from a network cluster and modeled for ionospheric and tropospheric differences, as opposed to a single baseline solution in which baseline length has a direct impact on coordinate quality (roughly 1-2cm plus one part per million with most survey grade GNSS receivers).

C.2.2 Satellite Constellation

Full GNSS tracking of constellations (GPS, GLONASS, GALILEO, BEIDOU) and signals (L1, L2, L5 and their equivalents) on both the network and the rover side will improve results on longer baselines in comparison to GPS or GPS & GLONASS only, as most modern GNSS receivers are able to automatically remove noisy or redundant signals from the solution. The more signals there are to choose from, the more lower-grade signals the solution can reject while still maintaining a sufficient number to fix integer ambiguities (initialize).

C.2.3 Baseline Length

Depending on the network type and signals being tracked/used, longer baselines can allow reliable results with proper procedures due to the ionospheric and tropospheric modeling that is inherent in network RTK (not single baseline) corrections. While the network type (VRS, MAC(X), iMAX) has an effect on the achievable accuracy at the rover, any network correction type will greatly improve rover accuracy when dealing with longer baselines, due to the modeling that is not possible in a single baseline solution.

CAUTION: Be aware that VRS networks can display overly optimistic CQ and RMS values due to the proximity of the rover to the virtual station, as opposed to the true baseline length to a physical station.

C.2.4 Occupation Time

Occupation time of 180 seconds is recommended (seconds rather than epochs, due to the fact that many manufacturers allow epoch rates of less than 1 second (e.g. 20Hz, in which case a 180 epoch observation would only be 9 seconds long). This gives the rover enough time to improve the solution slightly, and allows modern units from some manufacturers time for secondary measurement engine calculations and checks to be completed, improving confidence in the solution.

C.2.5 Redundant Occupation

A minimum of two, and preferably three or more, occupations should be taken on each point. It is strongly recommended that the unit be re-initialized in a different location, at least 15 feet different horizontally and at least two feet different vertically, between observations to ensure any bad initializations are identified. It is statistically very difficult for two independent initializations, when initialized in different locations, to come up with bad initializations that agree with one another. If, on the other hand, no re-initialization is completed, or if a re-initialization is completed in the same location, the chances of bad solutions that are in agreement goes up drastically.

In general, more occupations of a shorter duration (as long as the system is re-initialized between each observation) are preferrable to fewer observations of a longer duration, due to the accuracy advantages of identifying bad initializations and the benefits of point averaging that are possible with multiple observations.

C.2.6 Point Averaging

Averaging multiple observations is a critical component of control surveying. Having multiple observations, from separate RTK initializations and, preferably, under different satellite constellations (different times of day), creating a mean (or ideally, a weighted mean based on coordinate quality values), not only identifies outliers or bad initializations, but results in an averaged value closer to the true coordinate than individual measurements are likely to be.

C.2.7 QA/QC

Best practices dictate that all field data is analyzed in the office utilizing QA/QC software, preferably the proprietary software of the hardware manufacturer, to ensure field data was collected properly. Confirmation that measurements were based on initialized or fixed integer solutions, with acceptable CQ and/or RMS error values, individual point averages to include (or exclude) the appropriate measurements per best practices, and other QA/QC routines must be performed independently in the office by a competent staff member who understands the QC process and is very familiar with the software being used. It is an extremely dangerous practice to accept and use a file exported directly from a data collector/ field controller without any true QA/QC of the raw data and metadata in the appropriate office software.

D: GNSS REAL-TIME PRECISE POINT POSITIONING (RT-PPP) IN OPEN SKY AREAS

This section explains the fundamentals of and demonstrates best practices for using Real-Time Precise Point Positioning (RT-PPP) methodologies to establish control networks for remote sensing applications.

The following guidelines provide a practical method to obtain consistent, three-dimensional positions using a single rover. This is accomplished with real-time signal augmentation corrections designed to remove system errors due to satellite, atmospheric, and receiver-related influences through an inbound data feed.

D.1 Real-Time Precise Point Positioning (RT-PPP)

Real-Time Precise Point Positioning (PPP or RT-PPP) is an alternative to Base and Rover RTK, RTN and Post Processed Kinematic (PPK) or static surveys utilizing a hybridization of these methodologies. PPP relies on access to precise satellite orbit and clock products received through a data stream which can be received from the satellites themselves or through an internet-based subscription. This data stream removes the need for a base station or a two-way connection to a real-time network to alleviate the broadcast and system positioning errors associated with a single roving receiver configuration. One benefit to utilizing a standalone receiver is the removal of the required tied baseline, thus resulting in a coordinate based on the satellite geometry instead of a conventional coordinate derivation relative to a base station as calculated in a RTN solution or similar RTK system.

D.1.1 PPP Convergence

Convergence relates to the positioning errors reaching a tolerable level resulting in a final acceptable coordinate solution. This will vary depending on the required accuracy of the control point.

The time the receiver takes to converge is known as the convergence time.

D.1.2 Rover Setup

- A clear unobstructed view of the sky above a 15-degree elevation mask
- Efforts should be taken to minimize the introduction of signal blockage and multipath errors generated from surfaces reflecting signal to the receiver (e.g., trees, buildings, etc.).
- All setups should be performed with adequately adjusted, leveled, and maintained tripods and tribrachs within a stable set-up.
- Due to potentially long convergence and observation times, up to 15 minutes or more, a rod and bipod configuration is not the recommended method.
- Ensure that the proper datum and projection are pre-selected, and that the antenna height is appropriately measured.
- PPP coordinates are computed in a global-based reference frame, such as the International Terrestrial Reference Frame ITRF, with the current epoch and transformed to a fixed epoch within the selected coordinate system of the user. This transformation may also introduce errors to the final coordinate solution due to inaccurate correlations between some coordinate systems. Changes to the desired datum and projection are not easily made after the fact.
- If a specific project-related coordinate system and datum are not specified, follow the National Spatial Reference System (NSRS) for the current coordinate system guidelines.

D.1.3 Rover Quality Control

- Observations can begin once convergence has been achieved.
- Coordinate auto-store accuracy thresholds should be lower than project accuracy requirements.
- Routinely re-measure previously measured points to ensure quality.
- A minimum of two and preferably three independent measurements that all meet the required project accuracy specifications, each with a different initialization shall be made on each point to ensure quality.
- It is recommended that a minimum observation time of 300 seconds or more should be collected for each observation. Due to the nature of how the real time PPP solution is derived, it requires longer observation times to achieve acceptable results than with RTK or RTN.

D.1.4 Accuracy Check

- The surveyor must always use appropriate equipment and procedures to achieve the required accuracy for the survey.

- To ensure that appropriate results are being achieved, locate and observe existing NGS or other known geodetic monuments using the same rigorous observation methodology as delineated above. Compare the coordinates published by NGS or other agencies to the surveyed coordinates as derived by your field crews to determine if they match the standards required for the project.

D.1.5 PPP Limitations

- Convergence times may vary greatly. They typically range from 1-20 minutes, depending on the performance of the correction services within the rover's region.
- The achievable accuracy, though variable, for PPP is within the magnitude of 1-2 cm horizontal and 3-5 cm vertical if rigorous quality control methodologies are followed, multiple observations are made, and we are operating under optimal conditions.
- Current PPP broadcast correction services may require an access fee or only include certain constellations (e.g., International GNSS Service (IGS) Real-Time Service (RTS) is only offered with GPS-related data).

E: CONVENTIONAL SURVEYING FOR VVA CHECKPOINTS UNDER TREE CANOPY

The purpose of this section is to lay out the guidelines and best practices for utilizing a total station to measure Vegetated Vertical Accuracy (VVA) assessment points under tree canopy. This section is only meant to highlight these guidelines and is not a replacement for adequate education and experience in surveying practices. A total station is a modern surveying instrument that measures horizontal and vertical angles along with slope distances between the total station and an object, which is usually a prism on a range pole. Total stations have microprocessors on board to assist with level compensation, as well as averaging multiple angle and distance measurements. Total stations are rated based upon their angular accuracy and distance measuring capabilities. Common total station angular accuracies include 1”, 3”, and 5”, with 1” being the most accurate. Combining a total station with a data collector, or onboard software accessible through a user interface on some total stations, allows for real time conversion of the angular and distance measurements into x, y, z coordinates in the form of northings, eastings, and elevations. More advanced total stations have robotic (for potential single person operation) and some limited scanning capabilities. It is important to note that total stations are precision instruments that require regular adjustment and calibration.

This section assumes that control points will be established for a total station with GNSS RTK or RTN methods. Please see Sections 1 and 2 for more information on real time GNSS surveying techniques.

E.1 Temporary Control Points for Total Stations

A temporary control point is a semipermanent point with a known northing, easting, and elevation that can used as a total station occupation point, backsight point, or check point. This section assumes that temporary control points will be measured in real time with GNSS methods. Please see Sections 1 and 2 for more detailed information on these technologies. Temporary control points established using Real Time GNSS techniques should be located in locations with clear views of the sky and limited multi-path issues. The control points should be placed in relatively stable materials to ensure the position of the control point does not change over the duration of the survey. A minimum of three temporary control points should be established for total station work, consisting of an occupation point for the total station, a backsight point, and a check point to verify that horizontal and vertical errors are within acceptable limits. The occupation point should provide a good view into the area of interest where the VVA points are to be collected. The back sight point should be located as far away from the occupation point as is practical to minimize the angular errors in the data collection.

E.2 Total Station Data Collection Recommendations

The following is a list of recommended best practices for collecting data with a total station:

- Verify total station calibration.
- Follow a systematic data collection methodology to ensure adequate and accurate data is collected.
- Verify the height of the range pole and, if necessary, adjust before beginning the survey.
- Ensure that the range pole is plum (in vertical adjustment) .
- Use a bipod or tripod.
- Direct and reverse measurements should be taken and averaged when backsighting and collecting points (foresights) with a total station.
- Utilize checkpoints.
- A hardened point should be used on bottom of the range pole for temporary control points and a topo foot should be used to collect VVA or other topographic points.
- If the height of the range pole is changed during data collection, ensure that the data collector, or onboard software, is updated to reflect the correct height.
- No data collection points should be farther away from the occupation point than the distance between the occupation point and the backsight point. This is especially important when establishing GCPs and NVA checkpoints.

E.3 Traversing into Vegetated Areas

When it is necessary to traverse into vegetated areas, the guidance above still applies. As the total station is a line-of-sight instrument, planning and forethought is required to set subsequent instrument occupation points. In addition to finding an occupation point that allows adequate visibility of the region of interest, the previous occupation point needs to be visible. It is also recommended that the check point remains visible, or another check point is set. When additional traversing is required, a traverse closure and adjustment routine should be used.

F: TERRESTRIAL SCANNING OR MOBILE MAPPING FOR GCPS AND NVA CHECKPOINTS

This section is intended to provide guidelines and best practices when utilizing existing point cloud data collected either by mobile mapping systems (MMS) or static terrestrial based lidar for controlling or verifying aerial lidar & photogrammetric derived products. The cost to acquire MMS or terrestrial based lidar data for the sole purpose of establishing control points/checkpoints would be cost prohibitive.

Therefore, this section will focus on the re-use of existing ground-based point clouds to extract ground control and/or check points.

Mobile mapping system (MMS) is a vehicle mounted array of sensors and a computer that can incorporate three-dimensional positions with data collected from a variety of active and passive sensors. The most common sensors in the array are the GNSS receiver, inertial measurement unit (imu), lidar, and cameras. As the vehicle moves a constant stream of three-dimensional coordinates is sent to the computer, at the same time the other sensors are sending data to the computer. This allows the computer to relate the position of the vehicle to the measurement taken from the sensors and compile one large point cloud that contains all the measurements acquired.

Static terrestrial lidar is mounted on a tripod and positioned at various locations. The scans collected at each location are combined into one point cloud by registering the scans together. This is accomplished either by aligning common features that appear in multiple scans or through registration by known coordinates of the features visible in the individual scans.

F.1 Permitted Use

Determine if the point cloud to be used from which to harvest data was collected for another client or deliverables produced from that point cloud were contracted by another client. It is a good idea to seek permission from the client for whom the data was originally collected.

F.2 Selecting a Suitable Point Cloud

There are many factors that can affect the suitability of reusing previously collected data. Care should be taken when selecting a suitable point cloud to use. Below are some areas that should be investigated to determine if the point cloud is suitable.

- What sensor was used for the ground-based collection? Do the ground-based sensor specifications meet/exceed the airborne project's specifications?
- Determine if the point cloud density meets/exceeds the current project specifications.
- Are photo-identifiable points easily recognized?
- Is the point cloud density high enough that features are not hidden due to the point spacing?
- Was the point cloud constrained to survey control or uncontrolled?
- If the former, what survey techniques were used to establish the control?
    - Static GNSS, RTK or RTN GNSS, Leveling, Total Station?
    - Were redundant measurements obtained?
- Review the point cloud registration statistics. These statistics should exceed the requirements for the airborne project.

F.3 Spatial Reference System

The spatial reference system of the existing dataset will need to align with the aerial product's spatial reference system, or a transformation will need to be applied. To ensure the data aligns between the two projects, the horizontal datum, projection, adjustment date, epoch, vertical datum, and geoid model should be identified. If one of the products has been taken to ground coordinates the combined factor and scaling origin also need to be determined in order to reverse the process.

F.4 Verifying the Point Cloud

Perform a site visit to see if any noticeable alterations have taken place since the point cloud collection.

- Have any of the roads been realigned?
- Does any of the pavement look different or newer?
- Is there evidence of earthwork or construction?
- Has any pavement restriping occurred?

F.5. Field Checking the Point Cloud

It is prudent to check the ground-based lidar by surveying features in the point cloud. This can bring to light discrepancies in the stated horizontal and vertical datum as well as unnoticed alterations to the site. Compare the point cloud derived position to the recently surveyed position and determine if the error is within the project specifications.

F.6 Extracting Control from the Point Cloud

- Once it has been verified that the point cloud represents the current conditions and is on the same datum as the aerial project, the extraction process can begin.
- When selecting points from a point cloud that was collected on the ground, be sure that the points selected have an unobstructed view of the sky. Think about tree canopy, building overhangs, and shadows that would prevent the point from being recognized in the aerial data.
- For aerial products, it is a good idea to locate features that do not have a sudden elevation change nearby. Selecting a point at the edge of a roadway that has an adjacent ditch, tops or bottoms of walls, or headwalls are poor choices. Depending on the aerial lidar point spacing, or shadows in the photography, these points may not be discernable in the aerial data.
- It is a good idea to make sure the point cloud has been cleaned of points that were measurements on transient objects, vehicles, or pedestrians that were present during the collection.
- When selecting points to extract, rotate your perspective to verify the location picked is the location that was intended to be selected. Often, different parts of the point cloud are selected unknowingly, but rotating the view will show you if the intended position was selected.