RTK System Check

A RTK system check shall be made prior to any RTK Cadastral Measurements.

A RTK system check may also be made at any time during the course of each RTK survey session or at any time the base receiver(s) and rover receiver(s) are setup and initialized per the manufacturer's recommended procedures.

This check is a measurement from the RTK base setup to another Cadastral Project Control station or a previously observed Cadastral Measurement point.

When observing these measurements, the rover will be set to manufacturer's specifications for ***duplicate point tolerance*** for the measurement of a known point and existing point name.

This check consists of re-observing a known position within the survey. The resulting observed position is then compared by inverse to the previously observed position for the known point. This inverse should be within the manufacturer's recommended values for duplicate point tolerance measurements.

This RTK system check is designed to check the following:

- The correct reference base station is occupied.
- The GPS antenna height is correctly measured and entered at the base and rover.
- The receiver antennas are plumb over station at base and rover.
- The base coordinates are in the correct datum and plane projections are correct.
- The reference base stations or the remote stations have not been disturbed.
- The radio-communication link is working.
- The RTK system is initialized correctly.
- RMS values are within manufacturer's limits.

RTK Corner Measurements

Corner measurements are usually made with RTK using one or more base and one or more rover receiver configurations.

RTK corner measurements shall be made after the system setup check procedures have been completed.

Specified observation times for the highest level of accuracy using RTK for corner measurements as per manufacturer's recommendations are recommended, (for example, 180 seconds of time or when the horizontal (0.02m) and vertical (0.050m) precision has been met for a Trimble kinematic control point).

Under optimal conditions (clear sky, low RMS) a deviation from the manufactures suggested times is appropriate, (for example, a corner may be observed using 30 seconds of time and 20 epochs of measurement data). However, observation times should be set to account for field conditions, measurement methods (i.e. Trimble "topo point" or "kinematic control point") and the type of measurement checks being performed.

Recommended methods for RTK corner measurement:

One method is to observe the unknown point two or more times with the same point name (e.g. 100700) and use a duplicate point tolerance measurement criteria of 2.5 cm. When observing these measurements, the antenna shall be dumped between observations.

Another method at each found corner location or temporary point (unknown position), two baselines measurements (M1 and M2) are stored to the data collector or receiver for a specified number of seconds or epochs to meet a specified level of precision, (for example, the time requirement for a Trimble kinematic control point) depending upon manufacturer's recommended procedures.

Observation time may be increased due to the constraints of on-the-fly (OTF) post-processing kinematic (i.e. 200+ sec) if the field data is post-processed as a check.

- The antenna should be inverted to force a loss of satellite lock, in between the M1 and M2 measurements, to force the system to reinitialize. The point values resulting from the first baseline measurement is stored and labeled (e.g. 100700M1), and the point resulting from the second baseline measurement is stored and labeled (e.g. 100700M2)

- A field check of the level of accuracy between the measurements may be done by an inverse between M1 and M2. The resulting inverse distance should be less than the Duplicate Point Tolerance of 2.5 cm.

Note: The ***Cadastral Measurement Tolerance*** of 8.6 cm is the maximum acceptable distance for M1 – M2 inverse. It should be accepted only under extremely poor GPS conditions due to tree cover, multi-path, etc. This worst-case condition should only be encountered in the most marginal field conditions for RTK surveys.

The Cadastral Measurement Tolerance value of 8.6 cm is derived from standard error propagation relationships. It is based on the following formula, the square root of the sum of the squares of the Cadastral Measurement Tolerance (8.6 cm) and the maximum allowable error of the Cadastral Project Control (5cm) should approximately equal the maximum allowable error budget of the Cadastral Measurements (10cm).

The baseline measurements (i.e. M1/M2) to the found corner locations or temporary points shall be verified by at least one of the following methods (i.e. static, fast-static, PPK or RTK).

Perform a check measurement (M3) from the same Cadastral Project Control station at a time at least 15 minutes after the M1 and M2 measurements are taken.

An example of one of the many possible observation schemes is described below:

- Using RTK, make a new measurement (M3) to the unknown point (e.g. 100700) from the same base receiver setup separated in time by a minimum of 15 minutes.

Perform a check measurement (M3) from another Cadastral Control Project Station taken either simultaneously with the M1 and M2 measurements or at least 15 minutes after the M1/M2 measurements.

An example of one of many possible observation schemes is listed below:

- Using PPK, FS or static, make a new measurement (M3) to the unknown point (e.g. 100700) with the base receiver setup on another Cadastral Project Control station operating simultaneously.

RTK Calibrations

In real-time surveying (RTS) to relate GPS positions measured in terms of the World Geodetic System of 1984 (WGS-84) ellipsoid and coordinates, to local map coordinates, some type of a calibration is required. This calibration may be done in the field in the data collectors or it may be done in the office and uploaded to the data collector.

A calibration is similar to a least squares adjustment, which establishes or refines a transformation of the WGS-84 coordinates to local Northing, Easting, and Elevation (NEE) coordinates. This transformation consists of a datum transformation, between the WGS-84 ellipsoid and the local ellipsoid, a mapping projection and horizontal and vertical adjustment.

The set of derived WGS-84 coordinates must be homogeneous (all in terms of each other) for use in a calibration to establish the relationship between WGS-84 data collected by GPS receivers and local control positions, expressed as a local map grid with elevations above sea level. This relationship is defined by a series of mathematical transformations.

A calibration may be a minimum of one point up to twenty points depending upon the size of the project. When using calibrations, the manufacturer's recommendation should be followed.

The accuracy of points staked out depends on the accuracy of the calibration. Always use known Project Cadastral Control and ties to the NSRS for this reason.

RTK Corner Moves (stakeout)

RTK technology allows the surveyor to make a corner move or stakeout from a known position to an unknown (calculated) position relative to the controlling corners for a PLSS survey or resurvey.

The system check should be done any time throughout the survey to detect for blunders and the initialization quality of the survey prior to making any RTK observation for Cadastral Measurements and prior to making any corner moves.

Note: Caution should be exercised when using grid coordinated for stakeout. It is important to insure the appropriate corrections for convergence, elevation and distance are accounted for relative to the rules of the PLSS.

To make a corner move using RTK the following is a recommended procedure:

- Navigate to the calculated corner location (e.g. 140700CP) using coordinates. For example, navigate "from" station number (100700) and "to" station number (140700CP).

- Take a measurement (e.g. 140700M1), inverse between M1 and compare to the calculated position (e.g. 140700CP) and move the remaining distance and direction to the true (calculated) location as necessary. Repeat as required until satisfied you are at the position then store M1 and overwrite previously stored point.

- Force loss of satellite lock and initialization by inverting the rover antenna. Reinitialize and take another measurement (e.g. 140700M2) and store.

- Inverse between the measured one (140700M1) and the measured (140700M2). If the measured positions (M1 and M2) are within the duplicate point tolerance of the calculated position then the initializations and measurements are correct. Note, these M1 and M2 measurements are of a shorter duration (30 seconds).

- Set the monument at the true corner location.

- Take a measurement on the set monument (e.g. for 180 seconds) and store the position with a different name (e.g. 140700). Optionally, set the receiver or data collector to store data for subsequent post-processing.

- As a check, inverse from the stored position (e.g. 140700) to the calculated corner position to determine the set true corner location, next inverse to the controlling corners and check the bearing and distance to insure the correct procedures were followed. The established corner location should be within the defined local spatial accuracy standards required of the survey.

Section Three

Data Processing and Data Analysis

All data processing (baseline solutions) and data analysis (least squares or weighted mean average) shall follow the manufacturer's recommended procedures.

A double difference fixed integer solution is required for all cadastral measurements regardless of the positioning technique used.

Project Control network shall be processed to derive the baseline solutions and be adjusted by least squares independently of the observed Cadastral Measurements.

When integrating GPS observations into conventional terrestrial survey procedures it is imperative the surveyor verify the following:

- The State Plane or local plane horizontal scale factors, angular rotation factors, zone and units of measure are applied correctly.

- The combined scale factors for elevation, to determine ground distance at project elevation or an average project elevation are applied correctly.

- The appropriate datum has been used.

- A check to insure no hidden transformation or double transformations of the data has occurred.

- If using GPS with terrestrial data, then a check (e.g. measure the distance between two know points with an EDM) should be done to insure the computation of the combined scale factors are correct. This is done to insure the ***ground distances*** are appropriate.

- A check to insure the computation and reporting of basis of bearing are appropriate.

Section Four

Documentation

The use of GPS surveying methods to establish geodetic Project Cadastral Control and/or Cadastral Measurements for survey and resurvey of Public Lands is considered the practice of Professional Land Surveying in all states. Therefore, all GPS surveying projects must be performed under responsible charge of a federally authorized Land Surveyor or a Professional Land Surveyor licensed to practice Land Surveying in the applicable state.

A surveyor's narrative report shall be prepared and submitted to the project file by the surveyor in responsible charge as documentation of the successful completion of the land survey or cadastral survey project.

A surveyor's narrative report should include:

- Make and Model of the GPS receiver, Antenna, and related equipment.
- A processing generated report or summary of all RTK field operations, including calibrations, duplicate point measurements.
- A processing generated report regarding the baseline processing results and the software and version number used.
- A processing generated report regarding the Network adjustment results including a summary of covariance's, standard deviation or RMS values and the software and version number used.
- A network diagram, true line diagram or map showing the network configuration as designed.
- A list of the HARN, CORS or reference stations used in the survey.
- A list of coordinates by station including the datum, geoid model, epoch, and measurement units used.
- Local and Network Accuracies.
- A GMM .LZH file for inclusion into GCDB.
- Document any variations from these guidelines.

Reporting bearings and Distances:

A Basis of Bearing for a Government Cadastral Survey, when using GPS technology shall be expressed as "Geodetic Bearing or Azimuth". This bearing or azimuth shall be determined at the midpoint of the observed line as the "mean" between the Normal Section Forward Azimuth (NSFA) and the Normal Section Back Azimuth (NSBA) between points.

All ground distances shall be determined at elevation, except where the requirements are for sea level, using the appropriate geoid model to determine the geoid separation. For a cadastral survey, the height above the geoid and the orthometric height shall be considered the same.

Appendix A

DEFINITIONS

Cadastral Project Control is the network of the GPS baselines tied to the NSRS, which is surveyed to control all subsequent GPS Cadastral Measurements. The Project Control is adjusted independently of other cadastral measurements.

Cadastral Measurement Tolerance is the maximum acceptable distance for inverse between two measurements to the same point. This value is 8.6 cm. When measurements are made within this tolerance is in an RTK survey the two observations may be recorded as the same point number. These redundant measurements can then be included in a least squares or multi-baseline analysis. This worst-case condition should only be encountered in the most marginal field conditions for RTK surveys. These points should be noted in the RTK report.
The Cadastral Measurement Tolerance value of 8.6 cm is derived from standard error propagation relationships. It is based on the following formula, the square root of the sum of the squares of the Cadastral Measurement Tolerance (8.6 cm) and the maximum allowable error of the Cadastral Project Control (5cm) should approximately equal the maximum allowable error budget of the Cadastral Measurements (10cm).

Cadastral Measurements are the measurements used to define the location of ***Public Land Survey System (PLSS)*** corners and boundaries. Cadastral Measurements are based on the Cadastral Project Control coordinates or direct ties to the NSRS.

Duplicate Point Tolerance is the maximum distance in an RTK system setup check that two observations of the same point can differ by. It also the desired distance in an RTK survey that two observations of the same point should differ by and still be recorded as the same point for least squares or multi-baseline analysis. The duplicate point tolerance for these guidelines is 2.5 cm.

The **Geographic Coordinate Data Base (GCDB)** is a database containing geographic coordinates, and their associated attributes, for all corners of the Public Land Survey System.

Ground distance is the horizontal distance measured at the mean elevation between two points.

Independent (Non-Trivial Baseline): For each observing session there are n-1 independent baselines where n is the number of receivers collecting data simultaneously during a session.

Independent Occupation: Two or more independent occupations for the stations of a network are specified to help detect instrument and operator errors. Operator errors include those caused by antenna centering and height offset blunders. When a station is occupied during two or more sessions, back-to-back, the antenna pole or tripod will be reset and plumbed between sessions to meet the criteria for an independent occupation.

Local Accuracy, as defined in Part 2, Standards for Geodetic Networks, FGDC Geospatial Positioning Accuracy Standards, is an average measure (e.g. mean, median, etc.) of the relative accuracies of the coordinates for a point with respect to other adjacent points at the 95% confidence level. For horizontal coordinate accuracy, the local accuracy is computed using an average of the radii of the 95% relative confidence circles between the point in question and other adjacent points. This indicates how accurately a point is positioned with respect to other adjacent points in the local network. Based upon computed relative accuracies, local accuracy provides practical information for users conducting local surveys between control monuments of known position. Local accuracy is dependent upon the positioning method used to establish a point. If very precise instruments and techniques are used, the relative and local accuracies related to the point will be very good.

The reported Local Accuracy for cadastral survey purposes will be computed from the error ellipses generated by a least squares or other multiple baseline statistical analysis, which is fully constrained to the Cadastral Project Control.

National Spatial Reference System (NSRS) is defined and managed by the National Geodetic Survey (NGS). It is a consistent national coordinate system that specifies latitude, longitude, height, scale, gravity, and orientation throughout the Nation, as well as how these values change with time. NSRS consists of the following components:

- The National CORS, a set of Global Positioning System Continuously Operating Reference Stations meeting NOAA geodetic standards for installation, operation, and data distribution;
- A network of permanently marked points including the Federal Base Network (FBN), the Cooperative Base Network (CBN), and the User Densification Network (UDN); and
- A set of accurate models describing dynamic geophysical processes affecting spatial measurements.
- High Accuracy Reference Network or High Precision Geodetic Network stations established by GPS observations.
- Vertical control marks, which define elevation and are referenced to NGVD 29 or NAVD 88.
- All other horizontal and vertical marks established to define the NSRS.

NSRS provides a highly accurate, precise, and consistent geographic reference framework throughout the United States. Only stations or marks established by GPS or High order levels should be used with GPS survey projects

Network Accuracy is the absolute accuracy of the coordinates for a point at the 95% confidence level, with respect to the defined reference system. Network accuracy can be computed for any positioning project that is connected to the National Spatial Reference System (NSRS).

The network accuracy of a control point is a number, expressed in centimeters, that represents the uncertainty in the coordinates, at the 95% confidence level, of this control point with respects to the geodetic datum. For NSRS network accuracy classification, the datum is expressed by the geodetic Values at the Continuously Operated Reference Site (CORS) supported by National Geodetic Survey (NGS). By this definition, the local and network accuracy values at CORS sites are considered to be infinitesimal, i.e., to approach zero.

Network accuracy for cadastral survey reporting purposes will be computed from the error ellipses generated in a least squares adjustment fully constrained to CORS or HARN stations.

APPENDIX B

COMPUTATION OF ACCURACIES

The local accuracies of the PLSS corners are based upon the results of a least squares adjustment of the survey observations used to establish their positions. They can be computed from elements of a covariance matrix of the adjusted parameters, where the known NSRS control coordinate values have been weighted using their one-sigma network accuracies.

95% Confidence Circle

The 95% confidence circle representing a local accuracy can be derived from the major and minor semi-axes of the standard relative ellipse between two selected points. The 95% confidence circle is closely approximated from the major (a) and minor (b) semi-axis parameters of the standard ellipse and a set of coefficients. For circular error ellipses, the circle coincides with the ellipse. For elongated error ellipses, the radius of the circle will be slightly shorter than the major semi-axis of the ellipse. The radius r of the 95% confidence circle is approximated by:

$r = K_p a$
Where
$K_p = 1.960790 + 0.004071\ C + 0.114276\ C^2 + 0.371625\ C^3$,
$C = b/a$.

Note that the coefficients in the above expression are specific to the 95% confidence level, such that when the major semi-axis of the standard ellipse is multiplied by the value of K_p, the radius of the 95% confidence circle is obtained directly, and no further conversion is required.

Appendix C

References

"Analysis of Real-Time Kinematic and Fast Static/Kinematic Least Squares Derived Coordinates Using a Wisconsin County UDN"; Paul Hartzheim and Darin Henkel, Wisconsin Department of Transportation, Trimble User Conference Proceedings, 1998

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