Guidelines for RTK/RTN GNSS Surveying in Canada

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Table of Acronyms

- **ARP:** Antenna Reference Point
- **CACS:** Canadian Active Control System
- **CBN:** Canadian Base Network
- **CSRS:** Canadian Spatial Reference System
- **CSRS-PPP:** Online Precise Point Positioning (PPP) Service
- **GDOP:** Geometric Dilution of Precision
- **GLONASS:** *Globalnaya Navigatsionnaya Sputnikovaya Sistema* or Global Navigation Satellite System
- **GNSS:** Global Navigation Satellite System
- **GPS:** Global Positioning System
- **HI:** Height of Instrument. In RTK this refers to the distance from the physical point to the Antenna Reference Point (ARP)
- **HPN:** Provincial High Precision Networks
- **NAD83:** North American Datum 1983
- **RTK:** Real Time Kinematic
- **RTN:** Real Time Network

1. Introduction

Real Time Kinematic (RTK) surveying using Global Navigation Satellite Systems (GNSS) is now a common method used for both cadastral and engineering surveys in Canada. In recent years the number and extent of public and private Real Time Networks (RTN) in Canada has been rapidly increasing. RTN surveys are becoming more popular where available, but RTK surveys are still the only option available in many parts of Canada. To see the current RTN coverage in Canada refer to the coverage map in Appendix D.

Both RTK and RTN GNSS surveys can achieve relative positioning with centimetre (cm) precision when following a set of best practices. There are several important factors that need to be accounted for when doing RTK/RTN surveys. Many of these are common to other types of GNSS surveys and include: equipment calibration, atmospheric errors, multipath, satellite geometry, reference system integration, redundancy, and validation. There are also some recommendations in this document which are unique to RTK/RTN surveying and include things such as rover setup, communication problems, time windowing, and initialization.

The goal of this document is to provide Professional Surveyors with a set of concise and easy to follow best practice guidelines for achieving centimetre level RTK/RTN surveys. This document contains recommendations for all aspects of RTK/RTN surveying, including a comparison of RTK and RTN methods. Additional recommended references and web links have also been included for users. This document serves as a reference, as well as a reminder of what is important. Appendix B includes a field checklist that can be used as a quick reference when doing RTK/RTN surveys and Appendix C lists important questions that any RTN user should ask their provider as part of their project planning.

These guidelines were developed by a working group which included: Brian Donahue from the Geodetic Survey Division (GSD) of Natural Resources Canada, Jan Wentzel from the Surveyor General Branch (SGB) of Natural Resources Canada, and Ron Berg from the Ministry of Transportation for the Province of Ontario (MTO). The recommendations in this document are based on a combination of author experiences, guidelines from other agencies, and theoretical studies.

Throughout this document the following terms are used:

- **Users**: Anyone performing either RTK or RTN surveys.
- **GNSS**: Global Navigation Satellite System and will be used to describe GPS, or GPS+GLONASS (as well as other systems (e.g. Galileo) as they come online). Users should generally apply the same practices whether using GPS only or GNSS. The main advantage of GNSS is the increased number of satellites which improves the geometry (especially when working in urban canyons or other partially blocked areas).
- **RTK**: Single base Real Time Kinematic GNSS surveys.
- **RTN**: Real Time Network GNSS surveys. Also used to describe the network of Real Time base stations. RTN is also known as Network RTK (NRTK)

- **Reference System**: The official reference frame for Canada is NAD83 (CSRS) but there are many versions (or adoptions) of this frame used. This document usesl reference system to describe a particular version of the reference frame.

2. RTK/RTN Surveying Overview & Description

RTK surveying is a relative positioning technique which measures the position of two GNSS antennas relative to each other in real-time. One antenna is setup on a static point with fixed coordinates and is known as the base station. The RTK base station transmits its raw observations to the rover(s) in real-time and the rover uses both the rover and base observations to compute its position relative to the base (see figure 2-1).

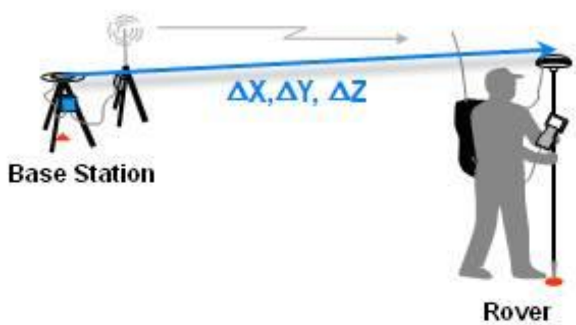

Figure 2-1 *Typical RTK Setup*.

After a short initialization time (<1min) the rover can continuously determine a precise 3D vector relative to the base station. This type of surveying requires a reliable communications link between the base and rover as the rover needs continuous observations from the base. When working with short baselines (<20km), in open sky areas, and with good satellite geometry these relative 3D baselines can be determined to several cm (or better).

RTK has proven to be a reliable and efficient means for determining precise relative baselines. However, this method is limited to baselines of approximately 10 – 20km due to the effect that distance related errors (atmosphere, and satellite orbits) have on the ambiguity resolution (initialization), and solution precision. The precision of RTK decreases as the baseline length increases. Real Time Network (RTN) surveying has been developed to overcome this base-to-rover range limitation. The RTN concept is that a group of reference or base stations will collect GNSS observations and send them in real-time to a central processing system. The central processor will then combine the observations from all (or subset) of the reference stations and compute a network solution. From this network solution the observation errors and their corrections are computed and broadcast to rovers working within the bounds of the RTN. There are several different RTN approaches in use including the virtual reference station (VRS), master auxiliary concept (MAC), and Flächen Korrektur Parameter (FKP). For more information on the different RTN approaches the reader is encouraged to check their manufacturer's documentation, or to check some of the references in this document.

2.1 RTK vs. RTN

This section will compare the major differences between working with RTK and RTN. Both methods can provide relative 3D accuracies of 1 to several cm and most of the differences are related to increased productivity and reduced cost.

Base Station
Working with RTK requires the purchase, maintenance, monitoring, and setup of a base station(s). This can be both time consuming and costly, as well as technically challenging for novice users. Working with RTN allows the users to leave the burden of setting up, maintaining, and monitoring the base station(s) to the network operator. The RTN user is required only to purchase a network subscription for access to the base stations. For some expert users however, working with their own base station(s) does allow for more control over the technical aspects of the base station setup and correction delivery.

Communications
RTN operators normally use cellular phone networks. This means that corrections can only be received where cellular coverage exists. Single base RTK surveys normally use UHF, VHF or broad spectrum radios. This removes the reliance on cellular coverage but limits the baseline length to the range of the radio link making RTK surveys over large areas challenging.

Solution Quality
The precision of single base RTK decreases as the baseline length increases. RTN has been developed to overcome this base-to-rover range limitation and will give comparable results from anywhere within the polygon of the network. To achieve the same accuracy with RTK it might be necessary to set/up multiple base stations or to use a leap frog method with relatively short baselines, both of which will increase the cost and reduce the efficiency of the survey.

2.2 RTN Issues

Working with a public or private RTN can be a very precise and efficient way to perform cadastral and engineering surveys. This can however lead to erroneous results if the RTN user is not aware of some important details of the RTN. As mentioned in section 2, RTK/RTN surveying determines the position of the roving antenna relative to the base station(s). In the case of RTN solutions, the rover position is determined within the reference system of the network as determined by the fixed coordinates of the network stations. The user needs to know what reference system is used by the network provider. Good communication with the network provider is essential to know this information. It is the responsibility of the user to ensure their results are properly aligned to the required reference system. In most cases it will be necessary to verify the accuracy of their RTN derived rover positions by measuring to known points in the users required system.

In Canada the official reference frame is NAD83 CSRS but it is important to know what version and epoch of NAD83 CSRS is required for your survey. There are different versions of the official reference frame which have been adopted in Canada. Appendix A summarizes the evolution of the CSRS and the adoption of the CSRS within Canada as of 2012. In addition to working with different versions of NAD83 CSRS there may also be cases where the user is required to work in a completely different local reference system. In this case the user will need to calibrate their survey using the procedure found in section 4.4.

Another important issue to consider when working with a RTN is whether the network operator is performing any integrity monitoring of their stations. A discontinuity in the fixed coordinate for one or several network base stations will be passed on directly or partially to the user in their rover positions. It is recommended that users request both a confirmation of the reference system used, as well as some demonstration of coordinate stability from the network providers.

2.3 RTK Issues

Many of the issues discussed in section 2.2 are also important when working with RTK. The difference with RTK is that the responsibility generally lies with the user to ensure the quality of the base station, the base station metadata, and the integrity of the base station coordinates. There are some instances where a user can access RTK corrections from another source such as an Active Control Point (ACP) but these are rare due to the sparse spacing and quantity of these points in Canada.

2.3.1 Site Conditions

When installing a RTK base station the user should be familiar with the chapter 4 recommendations for using a RTK rover. Many of the issues which are important for the rover are even more important for the base station setup. In addition, there are several other important considerations when installing a RTK base station. These include sky visibility, stability of base setup, and access to the desired reference system. The importance of each of these issues needs to be considered when deciding where (and how) to set up a base station.

RTK surveying requires common satellites to be observed at both the base and rover antennas. To take full advantage of the base station observations it is necessary that the base antenna has an unobstructed view of the sky above 10-15 degrees. It is much better to establish a new station with good satellite visibility than it is to try to occupy an existing reliable, well known monument with poor sky visibility (Henning, 2011).

As with any type of GNSS survey the base station stability (repeatability) is very important. The following steps should be taken to ensure repeatable positions for the base station.

- Temporary base stations should be installed with calibrated centering, levelling, and HI measuring equipment.
- Receivers should be configured to save raw observations which can be processed using CSRS-PPP or with the vendor software to verify the stability of the setup.

2.3.2 Base Station Coordinates

Access to the desired reference system is another important consideration when installing a RTK base station. There are 3 approaches to accessing the desired reference system. The first is to setup on a known point, the other 2 options require setting up a new base station and establishing coordinates.

Occupy Existing Control

When possible the preferred choice to access the reference system is to setup the base station on an existing control point of sufficient accuracy. This could be a CBN, HPN, or lower order control point. Any time a user sets up on existing control it is recommended to tie into other existing control in the area to verify the coordinates of the base station. Another good practice is to record raw observations in the base station and post process these data to verify the setup.

Relative Carrier Phase Processing

When there are no usable control points in the immediate survey location to set the base station on, but control exists within 30-50km it is possible for the user to establish local control relative to these known control points by static GNSS survey methods. This can be done by computing redundant GNSS baselines with post processing software. When establishing control for RTK base stations it is important to follow the guidelines in this document (see sections 4.3 and 4.4) and to have the receiver save raw observations so that the estimated coordinates can be computed using post processing software.

Precise Point Positioning (PPP)

Many GNSS users are now using PPP to establish control. This is especially useful in remote areas where accurate control does not exist. However, even when control does exist within a reasonable distance it is sometimes advantageous to use PPP to establish new control. In Canada, there is a free on-line service operated by the Geodetic Survey Division (GSD) of Natural Resources Canada called CSRS-PPP. Figure 2-2 shows the typical flow of a CSRS-PPP job.

Figure 2-2 *CSRS-PPP Overview.*

Notes about CSRS-PPP:
- User submits a RINEX format data file and gets back computed positions and processing reports.
- Antenna information including type and HI is obtained from the RINEX header.
- User has choice of selecting NAD83 CSRS reference system at various epochs.
- Computed position is relative to precise satellite orbits and clocks giving absolute accuracy (no reference station required).
- 12-24 hours of dual-frequency GNSS observations can achieve cm level accuracy while 1-2 hours can achieve < 5 cm accuracy.

The user must collect sufficient dual-frequency GNSS observations to meet their accuracy requirements.

3. Project Planning

This section of the guidelines specifically deals with the planning required to conduct a RTK/RTN survey. It is assumed that, as part of any positioning survey, that the user has already determined:

- The reference system to be used
- The accuracy required

3.1 Theoretical Suitability

Given the positioning requirements of the project (accuracy, reference system, etc.), it is part of the users responsibility to determine if RTK/RTN methods and technology will provide those results. There may even be instances where only part of a project is suitable for RTK. An example might be a project where the horizontal accuracy is suitable for RTK but the vertical accuracy requirements can only be achieved using spirit levelling (CRGB, 2009).

In order to determine this, users should refer to:
- Technical specifications supplied by the equipment manufacturers.
- Information supplied by RTN service suppliers.
- Independent research and documentation on the capabilities of RTK/RTN systems.
- Results of validation testing of the user's particular equipment configuration.

- The user's personal experience gained through the repeated use of the equipment under varying conditions.

This information will help users determine:

- .
- If RTK/RTN methods will be able to achieve the required results.
- The type of RTK/RTN equipment, and configuration to use.
- The field methodology to follow.

3.2 Practical Considerations

Once it has been determined that a RTK/RTN survey should be able to achieve the required results for the project in theory, there are a number of other project specific elements that must be considered from a practical sense.

3.2.1 Area of project

Unique project specific site conditions may dictate that RTK or RTN is not the appropriate tool to use. Project areas consisting largely of forests or tall concrete buildings (urban canyons) may make it impossible to achieve any results let alone results of a certain required accuracy. Even if forests or urban canyons are not an issue, individual sites within the project should be evaluated to avoid obstructions that would block satellite signals, or sources of multipath that would reflect signals.

Where RTN exist, it is important for users to be aware of the extent of the RTN and where their project lies within that network. Accuracy rapidly declines the further a survey project lies outside the umbrella of a RTN (Henning 2011a).

In most RTK/RTN surveys it will be necessary to occupy existing control points either for base stations or for verification of the RTN computed positions. Project planning should include gathering as much information as possible with respect to the location of these control points to aid field staff in locating control while in the field.

3.2.2 Communication

Key to a successful RTK/RTN survey is the communication between the base and the rover(s). For RTN surveys the most common method of communication is through cellular phone networks. RTN service providers should be consulted to determine optimum configurations of hardware and software required to fully utilize the services provided. They should also be able to provide guidance with respect to maximum ranges within or outside the network and any unique areas of outages or weak service.

For RTK surveys, communication between the base and the rover is usually through UHF, VHF or broad spectrum radios. Equipment manufacturers can supply information with respect to maximum ranges however results experienced in the field can vary due to things such as terrain. More than one base station may be required for a particular project area because of radio communication limitations. Comprehensive user knowledge of the limitations and maximum ranges of their particular telemetry system will dictate network design and in particular the number of base stations required and their optimum locations.

3.2.3 RTN Base Stations

If an RTN service provider is being used, they should be contacted prior to the project to confirm the service status. The user should confirm the current reference system being used and inquire about any changes to the hardware, software, base station coordinates or other service delivery components since the last time that the service was used. Any required hardware or software updates recommended by the provider should be investigated. Service provider contact information should be provided to field personnel to ensure that the service is operational at the time of survey.

3.2.4 RTK Base Stations

A number of factors must be considered with respect to a RTK base station. The use of a known CBN, or HPN station, with a forced centering plate on a pillar would be ideal. However, these points are rarely close enough to the project site and in most cases only secondary control points are available. There will also be cases where no suitable control points are available and local control must be established on site. In all cases, the user should consider the following criteria for base station selection.

- Coordinates and accuracy of known points – are they consistent with those required for the project?
- Is the selected base station site accessible, stable and clear to the sky?
- Is the base station site in a secure area? Can it be left alone or will it need supervision?
- How will a local base station be positioned? Section 2.3.2 gives a few common methods.

3.2.5 RTK/RTN Rovers

Rover equipment including radio telemetry equipment should be checked to ensure that the manufacturer's recommended firmware and software are being used. Given the size of the project, the number of Rovers required to complete a project within a certain time frame must be evaluated.

3.3 Project Configuration

Given the number of stations to be positioned, accessibility, base stations to be used, telemetry or RTN range limitations it would be wise to prepare a field logistics plan so that all members of the crew are aware of what is expected of them as a group and as individual crew members.

To achieve maximum measurement efficiency, each receiver operator should be supplied with an individual plan that itemizes:

- Which points will be occupied
- Survey procedures (see section 4.3)
- Information to be recorded manually
- Access issues
- Point descriptions
- Timing constraints

4. Survey Procedures

This chapter will outline the procedures to be followed during a RTK/RTN survey. The chapter will be divided into 4 sections with section 4.1 describing how to best set/up the rover. Section 4.2 will talk about initialization of the rover and how to mitigate errors related to the survey environment. Section 4.3 will describe procedures during the field survey and finally section 4.4 will discuss post processing and reference system issues.

4.1 Equipment Calibration & Setup

As with traditional GPS surveys it is important to ensure proper calibration of all equipment before starting a survey. With RTK/RTN surveying it is also necessary to ensure the rover (and base if applicable) has been set up with the desired settings for the current project. Even when no known rover configuration changes were made it is necessary to confirm the setup. Things such as a receiver firmware update could unknowingly reset some rover settings to the factory default.

4.1.1 Rover Receiver Settings

Before beginning a RTK/RTN survey it is important to ensure that the rover is configured in the best possible way to achieve the desired accuracy. There are several important settings which need to be saved in the rover.

Satellite Tracking

Three related settings which are configurable in most receivers are the elevation mask, the minimum number of satellites tracked, and the maximum PDOP. PDOP (Positional Dilution of Precision) is a unitless measure of the satellite geometry relative to the roving receiver. The lower the PDOP the better and it is recommended to set the maximum PDOP to 2-3 in the receiver.

The elevation mask sets an elevation angle in the receiver below which the receiver will not track GNSS signals. This should be set to a minimum of 10 degrees and preferably to 15 degrees since signals traveling close to the horizon have the longest path through the atmosphere, have a lower Signal to Noise Ratio (SNR), and are more affected by local multipath conditions. Increasing the elevation cutoff higher than 15 degrees can reduce the number of satellites tracked and increase the PDOP to a higher than desired level.

A minimum of 5 satellites are required for RTK/RTN surveying (6 when combining GPS and GLONASS satellites since the GPS/GLONASS system time offset must also be resolved). Studies have shown that a minimum of 7 GPS satellites will give more accurate results (Aponte et al. 2009). The recommendation is to configure the rover to track a minimum of 6 satellites for GPS only surveys, and 7-8 when doing GNSS surveys. The added benefit of tracking more satellites is that ambiguity resolution will generally be faster and more reliable.

Mission Planning

Even with both GPS and GLONASS now having fully operational constellations there are still times during the day when the number of satellites visible above 15 degrees in a particular area may be as low as 4 (GPS only). It is important to use your manufacturer's mission planning software to determine the best time to perform RTK/RTN surveys in your area. Most mission planning software will also allow you to set azimuth and elevation masks to simulate working in environments where the horizon is not clear. When working in urban canyons it is recommended to use GNSS capable equipment and to use mission planning software to determine the optimal time to perform your survey.

Interoperability

Users should also ensure that their GNSS equipment is interoperable when mixing equipment from different manufacturers. This can be verified by the RTN operator or the equipment vendor. To ensure interoperability it is recommended to keep your receiver firmware updated with the latest recommended version from the manufacturer.

Orthometric and Ellipsoidal Heights

In order to get real time orthometric heights, a geoid model or height transformation must be loaded into the rover. In Canada the official vertical datum is the Canadian Geodetic Vertical Datum of 1928 (CGVD28) and can be accessed using the HT2 hybrid geoid model. This model transforms ellipsoidal heights to orthometric heights by applying a geoid model which has been distorted to fit the CGVD28 benchmarks. It should be noted that a new vertical datum (CGVD2013) will be introduced in Canada in late 2013.

In local areas where the geoid model may not meet the accuracy requirements of the project there may also be a need to calibrate the heights to local vertical benchmarks (see section 4.4.2). The user must apply the official transformation (HT2_0) or a local vertical calibration if there is a requirement for real time orthometric heights. It is also recommended to save ellipsoidal heights which can be transformed to any vertical datum in post processing.

RTK Solution Type

Another parameter which should be set in the rover receiver is the RTK type to use. It is recommended to use only **FIXED** ambiguity solutions where the integer phase ambiguities have been resolved. Never use float or DGPS solutions for any kind of survey work. The accuracy of float and DGPS solutions will be in the meter level and should only be used for low accuracy work. If the rover unit displays the RTK age it is also important to monitor this value. If the RTK age is older than a few seconds it might indicate communication problems and the results will need to be used with caution.

QC Values

Many receivers also allow the user to set the horizontal and vertical QC values. These values are calculated internally by the receiver and give an indication of the precision of a single measurement. Typically horizontal and vertical QC values should be set to 1 cm for control points and 2-3 cm for topographic points.

4.1.2 Rover Antenna

The measured GNSS position is always determined relative to the Antenna Phase Center (APC). However the surveyor in the field is normally interested in the coordinates of a point on the ground. Several important factors must be accounted for to translate the APC position to the monument (or ground) position.

- Use an absolutely calibrated antenna type and apply the calibration model. In most cases this requires entering the correct antenna type into the rover and the receiver software will take care of applying the model. Information and absolute calibration models can be found at http://www.ngs.noaa.gov/ANTCAL/
- Align both the base and rover antenna to true North when possible since the absolute calibrations have an azimuthal component.
- Record the antenna HI in both metric and imperial (or use a fixed height pole) to ensure an accurate HI. It is also recommended to manually record the antenna HI for future verification.
- It is also important to record the Antenna Reference Point (ARP) used, and the antenna type manually.
- Ensure the circular level vials are calibrated before beginning a survey.

- Use a tripod or bipole when more accurate positions are required.

Another important piece of equipment which should be checked before beginning a survey is the antenna cable. Loose cable connectors, or kinked cables will lead to noisier signal reception and can cause loss of signals for low elevation satellites, higher code noise, incorrect ambiguity resolution and erroneous results.

4.2 Rover Initialization & Survey Environment

The following sections will describe issues related to resolving the integer number of carrier phase wavelengths from each satellite to the rover (so called RTK initialization), as well as problems caused by environmental conditions.

4.2.1 RTK Initialization

When the rover is turned on and starts to track signals from the satellites it first measures a partial phase of the GPS carrier and then begins counting whole wavelengths. Initially, the receiver does not know the exact number of whole wavelengths between the satellite and receiver antenna phase center (APC). Determining the full number of cycles between the receiver and the satellite is referred to as integer ambiguity resolution and is necessary for surveys that require cm level precision. For RTK, the rover receiver determines this integer number of cycles during initialization. The 2 most common methods used to resolve the ambiguities are explained below.

On-The-Fly (OTF)

On-the-fly initialization requires a minimum of 5 common satellites tracked by the base and the rover and allows the user to be moving while the ambiguities get resolved. Once the ambiguities are resolved and a **FIXED** solution is obtained the user should re-measure a known or previously determined point to verify the initialization. If there are no known points nearby the user should measure a point, reinitialize and check in to the initial point. Re-initialization requires complete loss of lock to all satellite signals.

Known Point

With known point initialization the user enters known coordinates into the rover and initializes while stationary over the known point. This method can be used to verify the initialization by comparing the measured position of the point after initialization to its known coordinates. If the system fails to initialize in a normal amount of time then the user should verify that the input coordinates are correct, and that the location is not in a high multipath environment. It might also be necessary to move to a new location and try initializing using OTF.

Under normal conditions the ambiguities should be resolved in less than 1 minute. It is good practice to monitor how long it takes to obtain a fixed solution and if 1-2 minutes is exceeded then a new independent fixed solution should be obtained. It is also good practice to regularly re-initialize and re-measure known or previously measured points during the survey to verify the validity of each new initialization. Many receivers continuously compute new initializations during the survey as a validation tool. Users should observe all important points at least twice with a new initialization as a validation.

4.2.2 Environmental Error Sources

There are several environmental factors that can reduce the precision and/or accuracy of RTK/RTN derived positions. These can include site specific factors such as multipath or atmospheric factors such as troposphere or ionosphere errors.

Multipath

Multipath is the relative phase offset or time delay between directly and indirectly received radio signals (GSD 1992). When GNSS signals are reflected off nearby structures and reach the antenna via an indirect path there is an increase in the range error. Multipath errors over a short period of time can go undetected in the receiver and cause position errors unknown to the user. Users should re-occupy important points after a suitable amount of time has passed and the satellite geometry has changed.

Tropospheric Errors

The troposphere is the neutral atmosphere from the Earth's surface to about 10km altitude and causes a frequency independent delay on GNSS signals. RTK differences the tropospheric delay between the base and rover, so users should be aware that differences in elevation or atmospheric conditions between the base and rover can cause a relative troposphere bias which will cause a bias of the estimated height of the rover. RTK users should keep the base and rover at similar elevations and to avoid performing surveys when weather fronts are passing through the area. RTN strategies seem to be able to mitigate most of the residual troposphere errors due to rover elevation differences (Edwards et al 2008), but RTN users should still avoid working when a weather front is passing through the project area.

Ionospheric Errors

The Ionosphere (unlike the troposphere) is dispersive (frequency dependent). Dual frequency GNSS systems take advantage of the dispersive nature of the ionosphere and during normal conditions are able to calculate and remove the majority of the bias. For this reason it is recommended to only perform RTK surveys with dual frequency receivers. It is also recommended that prior to departing to the project area, check on NOAA's Space Weather Prediction Centre (SWPC) to ensure that significant atmospheric disturbances are not predicted for the time of the survey. These severe conditions can affect communications, GNSS tracking, and RTK/RTN results. This is something that users are better equipped to determine with experience and knowledge of their particular equipment and area of work.

4.3 Field Survey

This section will discuss some practical considerations when performing RTK/RTN field surveys. These considerations include various rover outputs which can be monitored to ensure quality and precision, as well as applying techniques to ensure accuracy through redundancy, validation, and calibration.

4.3.1 Communications

The quality of the communication link and the age of corrections should be monitored during the survey. Accurate RTK positioning requires a full and complete set of correction messages. If the correction latencies are greater than 2 seconds or the communication link becomes intermittent the coordinate accuracy will suffer (Henning, 2011a). After communication outages the user should verify the initialization by re-initializing the solution and checking on a previously measured (or known) point.

4.3.2 Rover QC Indicators

When performing RTK surveys it is important for the user to be familiar with the various quality indicators that are normally displayed by the rover. Many of these QC measures can have tolerances configured in the rover, outside of which the observed points will be rejected. The user should be familiar with the recommendations in section 4.1.1 before configuring the receiver. The following receiver indicators should be constantly monitored during a survey.

- Status of the initialization should remain **FIXED**.
- Coordinate Precision (QC value). This ~~is normally displayed as 1 sigma and~~ should be monitored to ensure that both the horizontal and vertical precision is satisfactory.
- If possible, the coordinate quality threshold should be set slightly lower than the precision required for the survey. Do not set the QC threshold significantly lower than the desired precision or a significant number of observations may be rejected. This will lead to longer than necessary observation times at each point (Bisnath 2011).
- The user should monitor the Signal to Noise Ratio (SNR) values calculated by the receiver. Different manufacturers display the SNR values differently so the user will need to consult their manual and use experience to determine the *normal* range. The SNR values can be useful to diagnose multipath errors, atmospheric disturbances, and initialization issues.

4.3.3 Quality Control

As with any measurement technique, repeated measurements are required for an accurate and reliable solution. The receiver quality indicators are useful in alerting the user of potential problems but the user must also take steps to minimize the random and systematic errors associated with RTK/RTN surveys. All points determined by RTK are single vectors radiating from the base (physical or virtual) to the rover. Some quality control should be incorporated to check the reliability of the results. The degree of checking is dependent on the importance of the point being surveyed. For instance, a project control point is much more critical than an individual shot on a topographic feature, and accordingly the quality control procedures should account for such circumstances (Berg, 1998).

Time Window Averaging

Most receivers will allow the user to compute a mean position over a specified time period (time window averaging). Studies have shown significant benefits of time window averaging on the precision of computed positions (Bisnath 2011, Edwards et al 2008). Control points should use a time window average of at least 1 minute, topographic points at least 5 seconds, and until the desired QC indicators are achieved. For topographic surveys, the use of this 5 second window average will reduce the effect of individual coordinate solution variations (Edwards et al, 2008). For precise work such as control station establishment, longer time windows of up to 5 minutes should be used.

Re-Occupation

Time window averaging on its own is not enough to provide an accurate and reliable solution. All the individual epochs in the time window are still relying on the same initialization and have had very little geometry and atmosphere change. So for important points it will also be necessary to re-observe after a suitable time has passed and with a new initialization (double windowing). To take advantage of changes to the satellite geometry and atmospheric conditions, a window separation of 1-2 hours is recommended, however a separation of only 20 minutes has shown to improve the coordinate accuracy by 10 – 20% (Edwards et al, 2008). A further advantage of the double window averaging is that it can also detect human blunders related to the station metadata and/or setup. If a fixed height rover is not used then changing antenna heights at the rover between measurements provides a check on the largest source of human error in GPS surveying – recording incorrect antenna heights. For control points the minimum recommendation is 2 separate time windowed observations with unique initializations and a time separation of at least 20 minutes.

Checks to Known Control

Another important aspect of a quality survey is determining the accuracy. The receiver QC values, redundant measurements, and time window averaging are all useful in determining and improving the precision of the survey. The accuracy of the survey will also need to be verified to ensure there are no biases between the survey and the project reference system. The accuracy of the survey can be determined by performing checks to well known or accurately determined points. These ties to known points will also help to eliminate any human blunders. The recommendation is to survey known points after initialization and compare the coordinates. The coordinate differences should be within the accuracy requirements of your survey. When there is no local control available it is recommended to establish control by running a static session and using one of the methods described in section 2.3.2. These check points should be surveyed as a minimum at the start and end of the survey, and any time communications or initialization is lost. Since many equipment sets are continuously checking the initialization and re-initializing it is important to check into known points as often as practical.

4.3.4 RTK Base Station Quality Control

When working with RTK, the user is responsible to verify not only the quality of the rover positions but also the quality of the base station setup. The best check is to establish multiple base stations and to measure each rover point from different base station locations. This provides verification on all factors in the point determination: base station setup, base station (reference) coordinates, rover setup, antenna heights, and GPS measurements. This method ensures the highest confidence but takes the longest to carry out (Berg, 1998). If this is not practical then the quality control recommendations (section 4.3.3) should be followed as a minimum.

4.4 Post Processing

4.4.1 Horizontal Calibration

When working with RTK/RTN it is necessary to ensure the computed coordinates are compatible with the desired reference system. If the coordinates are not compatible then an empirical fitting of field RTK measurements to published control monument coordinates is required. This fitting is known as a local **transformation** or **calibration** (MTO, 2006).

The following steps are recommended to ensure this compatibility:

- Communicate with the RTN operator to determine what reference system and epoch they are using as their reference.
- If doing single base RTK verify the reference system for the base station(s) coordinates.
- If the RTN or base coordinates are NAD83 CSRS but the wrong version or epoch, then propagate the computed coordinates to the epoch of the desired version (using TRX). TRX software is available from NRCan/GSD.

http://www.nrcan.gc.ca/earth-sciences/products-services/land-geodetic-survey/geodetic-tools/11647

- After ensuring coordinates are in the proper epoch, measure the RTK/RTN position of as many known points as practical.
- If the published coordinates do not fit with the measurements to known points a local calibration can be done. This calibration will require a minimum of 4 points well distributed around the local project area.

In some cases it may be better to skip directly to the last step and estimate and apply parameters from a calibration to transform the RTK positions into the official reference system used by the known control. This approach is sometimes more preferable locally than applying a transformation based on official reference system transformation parameters, since there can be biases in the existing local control points. (Bisnath, 2011).

4.4.2 Vertical Calibration

Using the ellipsoidal heights determined in the correct NAD83 CSRS epoch, the user can transform to orthometric heights using the HT2_0 hybrid geoid model. This will transform the NAD83 CSRS ellipsoidal heights to orthometric heights compatible with the Canadian Geodetic Vertical Datum of 1928 (CGVD28). However the geoid model may not provide sufficient vertical accuracy for survey requirements.

Similar to the horizontal calibration, a vertical calibration can be done by performing a localization to at least four trusted benchmark monuments. These benchmarks should form a rectangle on the outside of the project area to the best extent possible (Henning, 2011a).

5. Summary and Conclusions

The goal of this document was to provide the users of both RTK and RTN surveys with a set of concise and easy to follow best practice guidelines. Some of the most important recommendations are summarized in this chapter. Appendix B also contains a checklist which can be used to verify all aspects of the survey.

Summary of Recommendations

- Be aware of what reference system the RTK/RTN corrections are in.
- Monitor RTK/RTN reference station coordinate stability.
- If installing a base station establish coordinates using relative carrier phase GNSS or CSRS-PPP processing.
- Plan project to ensure RTK is suitable for project requirements (mixed survey methods might be most appropriate/efficient for project requirements).
- Ensure communication and RTN corrections are available throughout project area.
- Rover/Base Settings
    - Elevation Mask of 10-15 degrees

    - PDOP 2-3
    - Minimum tracked satellites set to 6
    - Use mission planning software to determine optimal survey times
    - Use latest firmware recommended by manufacturer
    - Save ellipsoidal heights in rover
    - Use only FIXED solutions
    - Set receiver QC value to slightly less than project accuracy requirement
- Check initialization as often as practical.
- Do not survey when a weather front is passing through the survey area.
- Be cautious when working during increased ionospheric activity.
- Ensure GNSS is interoperable when mixing equipment from different manufacturers.
- Re-initialize after communication and verify on a known or previously determined point.
- Monitor SNR values during survey.
- For important points do 2 separate time windowed observations of at least 2 minutes with unique initializations.
- Verify accuracy of methods by checking into known points as often as practical.
- Use 2 base stations (recording raw observations) when working with single base RTK. Survey rover points from both base stations.
- If required perform a horizontal and vertical calibration after the survey.

The field of GNSS surveying is rapidly developing and this document was written with the intent that it will be updated as required. In the near future more navigation satellite systems and signals will be coming online (e.g. Galileo). As new systems and signals become available in user equipment there will be a requirement to adjust these recommendations accordingly.

REFERENCES

Aponte, J., X. Meng, C. Hill, T. Moore, M. Burbidge and A. Dodson (2009). "Quality assessment of a network based RTK GPS service in the UK," Journal of Applied Geodesy, Vol. 3, pp. 25-34.

Berg, R.E. (1998). "Utilizing Real-Time Kinematic GPS for Control Surveys," Proceedings, Trimble Surveying and Mapping Users Conference 1998. Trimble Navigation Ltd., October 14 – 16, San Jose, California.

Bisnath, S., J. Wang, A. Saeidi, G. Seepersad (2011). "Utilization of Network RTK GPS in MTO Highway Surveys," Department of Earth and Space Science and Engineering, York University.

Crown Registry and Geographic Base (2009). "Province of British Columbia Guidelines for RTK GPS Surveys," Version 1.2 November 2009.

Dach, R., U. Hugentobler, P. Fridez and M. Meindl (2007). Bernese GPS Software Version 5.0, Astronomical Institute, University of Bern.

Edwards, S., P. Clarke, S. Goebell and N. Penna (2008). "An Examination of Commercial Network RTK GPS Services in Great Britain," Newcastle University, UK.

Geodetic Survey Division, Natural Resources Canada (1992). "Guidelines and Specifications for GPS Surveys," Version 2.1, Ottawa, Ontario.

Henning, W. (2011a). NGS Guidelines for Real Time GNSS Networks, National Geodetic Survey, Version 2.0 March 2011.

Henning, W. (2011b), NGS User Guidelines for Single Base Real Time GNSS Positioning, National Geodetic Survey, Version 2.1 August 2011.

MTO (2006). "Engineering Survey Manual," Ministry of Transportation of Ontario, Geomatics Office.

Odolinski, R. (2010). "Swedish User Guidelines for Network RTK". FIG, Congress 2010, April 11-16, 2010, Sydney, Australia.

Appendix A – Summary of NAD83 CSRS in Canada

Evolution of NAD83 CSRS in Canada

Version(epoch)	Frame	Adopted	Description
V0	Original	1986-1993	Horizontal adjustments
V1 (1998.0)	CSRS96	1996	Transformed from ITRF93
V2 (1997.0)	CSRS98=CSRS	1998	Transformed from ITRF96
V3 (1997.0)		2000	Transformed from ITRF97 (1st complete CBN)
V4 (2002.0)		2002	Transformed from ITRF2000
V5 (2006.0)		2009	Transformed from ITRF2005
V6 (2010.0)		2011	Transformed from ITRF2008

Summary of NAD83 CSRS Adoption in Canada

Agency	Version	Comments
GSD	V4.0.0 (2002.0) on CACS/CBN, v0 others	Moving to v6.0.0
CHS	V5.0 (2006.0)	
BC	V4.0.0 (2002.0)	Vancouver Island Public Network v3.0 (1997.0)
AB	V4.0.0 (2002.0) on 1140 subset, v0 others	
SK	V2.0.0 (1997.0)	
MB	V2.0.0 (1997.0)	Moving to v3.0.1
ON	V3.0.1 (1997.0) on 6600 subset, v0 others	Moving to v6.0.0
QC	V2.0.0 (1997.0)	
NB	V2.0.0 (1997.0) on HPN	
PEI	V2.0.0 (1997.0) on HPN, NAD27 others	Moving to v6.0.0
NS	V3.0.0 (1997.0) on HPN, ATS77 others	Moving to v3.0.1
NL	V6.0.0 (2010.0)	
Territories	V4.0.0 (2002.0)	

Appendix B – Field Checklist

Item	✓ or n/a	Notes
General Planning		
Number of stations to be positioned		
Time available		
Number of rovers req'd		
Number of base stations req'd		
Rover occupation strategy		Loops, repeated occupations etc.
Search control agency records		Known stations in area
Get control description sheets		For locating stations
Use of multiple systems req'd?		GLONASS, GPS
Check satellite availability		
Check RTN availability		Is project within the "net"
Pre Field Equipment Checks		
All measuring hardware complete and operational		GPS equipment
Receiver firmware and software		Base & Rovers; Radios - up to date
All radio hardware complete and operational		Radio receiver, transmitter, antenna – check settings & communication between units
All accessories accounted for and checked		Tripods, bipods, poles, bubbles, tribrachs, mounts, backpacks, tape measures
Batteries (GPS, Radios etc.)		Good condition and charged
Cables (GPS, Radios etc.)		All present and in good condition
Project data		Checked and uploaded to Base & Rovers
Project parameters input		Datum, mapping system, geoid model
Set Max PDOP/elevation mask		Max PDOP (2-3); elev. Mask (10-15deg)
Set Min # sats		GPS only (6); GNSS (7-8)
Pre Field RTN Checks		
Contact RTN provider		Verify current updates to hardware & software, datum, base coordinates and other system issues
Check operation		Ensure corrections can be received
Field Checks - Base Stations		
Identification and verification of control station		Check condition, markings, description, ties to reference marks
Sky visibility		Clear if possible and allowable
Check for multipath sources		Remove or note as appropriate

Security, accessibility		Secure site or supervision req'd? Permission req'd?, gate keys etc Drive, short/long walk, terrain
Place nail, monument etc.		If required for future use
Field Checks – Base		
Land owner permission		As applicable
GPS Antenna set up		Centered, levelled and connected
Batteries		Connected, sufficient charge for duration
Receiver operational and tracking		Check number of sats tracked
Check Rx settings		Project parameters, PDOP, elev mask etc.
Radio antenna		extended to max and connected
Radio connected to GPS and transmitting		
Equipment secured		Against weather, animals, theft etc.
Field Operations – Rover		
Rover Antenna HI		Record Manually (metric and imperial)
Rover Antenna Type		Verify correct antenna type (or NULL)
Check Rx settings		PDOP, elev mask
Record station # and approx. time of occupation		Manually in field book
Monitor QC reports from Rover		Verify if 1 or 2 sigma
Monitor Initialization time		Usually 1-2 min for fixed solution
Observe quality of radio link		
Monitor RTK age		2 sec max
Monitor initialization status		Fixed Solution
Monitor weather		Avoid significant differences in weather between base and rover
Verification of Results		
Time Windowing		Min. 2 minutes for control/5 sec for topo
Occupy known points		To check Rx settings, initialization Within 3cm horz, 5cm vert @ 95%
Re-occupy points using different base		Best for redundancy.
Re-occupy points using same base or RTN		Re-initialize every time, minimum 20 min time separation, agreement within 6cm Horz, 8cm vert @ 95%
Check atmospheric conditions		Be aware of Geomagnetic and Solar Radiation Storms

Appendix C – Questions To Ask Your RTN Service Provider

1. What reference system and epoch are the RTN corrections with respect to?
2. What type of integrity monitoring is performed on the stations? Where can I see a demonstration of coordinate stability?
3. Where can I get a network map? Does my project area lie within the RTN?
4. Are there any recommended hardware or software updates for my equipment? Are there any interoperability issues with my equipment set?
5. Are there any unique areas of outages or weak service within the RTN?
6. Where can I find real-time information on the service status?

Appendix D – RTN Coverage in Canada

Current extent of private real time networks in Canada