Guideline **for using GNSS-RTK in Cadastral Surveying**

CADASTRAL INFORMATION DIVISION

Department of Survey and Mapping

National Land Commission Secretariat

@nlcsbhutan www.nlcs.gov.bt

Foreword

Owing to the rapid development in satellite-based positioning, the Global Navigation Satellite Systems (GNSS) has been adopted and widely used by the surveying professions worldwide. This technique has also become a very popular methodology in cadastral surveying over the last decade due to cost benefits and ease of use of the technique. Bhutan has also adopted this technique in cadastral surveys since last few years and today almost all the surveyors in the country are conversant in using this technology/method.

In light of the growing users, the need for establishing a comprehensive guideline is perceived to be indispensable. The Land Act 2007 and Land Rules and Regulation of Kingdom of Bhutan 2007 sets out the role & responsibilities of the Cadastral Information Division (CID) under the Department of Surveying and Mapping (DoSAM), NLCS, to develop technical standards, manuals and guidelines related to Cadastral Surveys.

This guideline will guide and assist the Cadastral surveyors to adopt the best practices/ procedures in using the GNSS-RTK Positioning and to ensure data standards and uniformity as mandated by the Land Act 2007.

The guideline is prepared with reference to the international best practices and in due consultation with the expert users of the National Land Commission Secretariat. It shall be regularly updated as and when new developments in the surveying technology and methods arise.

(Dasho Pema Chewang)
Secretary

Table of Acronyms

NCRP: National Cadastral Resurvey Program
GNSS: Global Navigation Satellite System
RTK: Real-Time Kinematic
RTN: Real-Time Network. RTN is also known as Network RTK (NRTK).
FIG: International Federation of Surveyors
SNR: Signal-to-Noise Ratio
PDOP: Position Dilution of Precision
QC Values: Quality Control Values

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1. Introduction

The GNSS based surveying although was predominately used for high precision geodetic surveys and topographic surveys, the method is now being increasingly used for cadastral surveys owing to cost benefits and ease of use. The GNSS-RTK positioning method can achieve relative position within centimeter precision when a set of international best practices are followed. Therefore this guideline is developed in order to outline the general procedure for using RTK positioning method for cadastral Surveying in line with Land Act 2007 and international best practices for cadastral surveys. It should be noted that the use of GNSS positioning method is not recommended in areas such as built up areas where satellite visibility is poor.

2. Legislative Framework

The Guideline is formulated based on the Section 218 (a), (b), and (h) of the Land Rules and regulations:

a) This agency (CID) shall be responsible for the development of standards related to all cadastral activities in the country.

b) It shall be directly responsible for the quality control of all cadastral work.

h) It shall be responsible for development of technical manuals and guidelines related to cadastral surveys.

3. GNSS-RTK Positioning Overview & Description

As defined, GNSS-RTK surveying is a relative positioning technique that measures the position of two GNSS antennas relative to each other in real-time. One GNSS receiver/ antenna is set up on a static point with fixed coordinates and is commonly known as the BASE station. The RTK base station transmits its corrections 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. This type of surveying requires a reliable communications link between the base and rover as the rover needs continuous observations from the base. In conventional single-base Real Time Positioning, the communication between the base and rover is over radio link.

NTRIP (Network Transport of RTCM via Internet Protocol) and CORS (Continuously Operating Reference Station) are forms of RTK differential correction method where instead of using the conventional base station and radio to send correction data to the rover, data is sent using the internet. The advantage of using NTRIP is the capability of achieving sub-inch RTK accuracies without having to purchase and manage a base station.

Studies show that the type of data link can limit the baseline length. When using radio link, the users can measure fixed baseline up to 20km while with data links using internet can cover up to 30km (Londe, 2019). In single base RT positioning, it is assumed both the base station and the rover are experiencing nearly identical atmospheric conditions and there is minimal atmospheric modeling. Therefore, the baseline (base-rover distance) should not be too long so as to avoid making conditions from base to rover different. According to the new research (Geodetic Section, Topographic Division, National Land Commission, 2021), for cadastral Surveys using CORS as base station, a baseline up to 40km is acceptable.

4. Environmental Errors and Precautions

There are several environmental factors that can reduce the precision and/or accuracy of RTK/NRTK derived positions. These can include site specific factors such as signal blockage and multipath; or atmospheric factors such as tropospheric and ionospheric errors.

4.1. Signal Blockage

GNSS signal blockage is a common problem when performing RTK/RTN surveys under tree canopy or built up areas and can weaken the satellite geometry, lengthen the time required for a solution to initialize, and cause erroneous positioning.

4.2. Multipath

When GNSS signals are reflected off nearby structures (buildings, water bodies, glazed surfaces, trees, metal power poles, high power transmission lines, Cellular Towers etc) and reach the antenna via an indirect path, there is an increase in the range error. Multipath error cannot be easily detected in the rover or modeled in the RT processing. Basically, anything which can reflect a satellite signal can cause multipath and introduce error into a coordinate calculation. Multipath errors over a short period of time can go undetected in the receiver and cause position errors unknown to the user. Users should always be aware of these conditions.

4.3. Tropospheric error

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.

4.4. Ionospheric Errors

The ionosphere is the upper part of the atmosphere and (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.

4.5. Precautions

It is the duty of the surveyor to access the survey environment before using the RTK-GNSS method of survey. The following factors should be considered prior to field survey.

- If the environment does not provide a clear view of the sky or the multipath effect is high, RTK-GNSS surveying method is not recommended since it will cause position errors. For example, in densely built-up urban areas and forested areas, RTK-GNSS should not be used.
- When using conventional single-base, the base stations should not be near reflective objects and when surveyed points are near reflective objects, users should re-occupy important points with a new initialization after a suitable amount of time has passed and the satellite geometry has changed to rule out unknown errors caused due to multipath effects.
- Key to a successful RTK survey is the communication between the base and the rover(s). For NTRIP/CORS RTK surveys, it's important to also check the network coverage of

the site of survey prior to departing to the site.

5. GNSS-RTK Positioning Limitation

Since GNSS-based Surveying is dependent on the signals received from satellites and the corrections from the base stations, the surveying environment plays a key role in determining the reliability and accuracy of GNSS measurements. In the new research from Cadastral Survey Section, Cadastral Information Division, National Land Commission (2021), RTK-GNSS receivers could not receive signals under densely built-up areas. Therefore, it is recommended that GNSS-RTK instruments should not be used in built-up urban areas. Only Total stations shall be used in the densely built-up urban area.

6. Field Procedures

6.1. Equipment Validation

As per Section 235 of Land Rules and Regulation of the Kingdom of Bhutan, the boundary markers shall be fixed to a minimum absolute accuracy of ±10cm on National Datum. Therefore, it is the duty of surveyors to check and ensure that survey equipment used for cadastral surveys is capable of meeting the minimum required accuracy.

6.1.1. Instrument Calibration

It is important to ensure proper calibration of all survey equipment before starting a survey. According to Section 233 of land Rules and Regulation 2007, all survey equipment must be calibrated at least once a year.

6.1.2. Additional Validation Checks

- Additionally, the following checks may also be performed before usage of the equipment.
- GNSS receivers/antenna and processing/reduction software must be internationally certified.
- All receivers must be checked to ensure that the manufacturer's recommended firmware and software are being used.
- All ancillary equipment must be in good working condition.

6.2. Projection and Datum

As mandated by the Land Act 2007, all cadastral surveys shall be based on National geodetic reference datum. The current reference system in use is DrukRef 03 System which is realized on the ITRF 2000 reference system and the GRS 80 (≈WGS 84) ellipsoid.
Therefore, all cadastral surveys must be conducted using the above projection. All parameter settings must be carefully examined to ensure data correctness.

6.3. Base Station Setup

6.3.1. Conventional Single-base Setup

There are several important considerations when installing an RTK base station. These include sky visibility, stability of base setup, and access to the desired reference system. RTK surveying requires common satellites to be observed at both the base and rover antennas. The base antenna must have an unobstructed view of the sky above 10-15 degrees (Elevation Mask/Cut-off Angle). In addition, the following steps should be taken to ensure repeatable positions for the base station.

- Base stations should be installed in a stable environment with proper centering, leveling, and proper equipment for measuring the height of the instrument.
- Observations should be conducted with properly adjusted and maintained tripods and tribrach must be preferred over prism and pole setup.
- Before recording the known Coordinates, the autonomously observed coordinates of the base receiver must match with the actual coordinates within sub-meter accuracy.
- In case where the autonomously observed coordinates do not match with the true coordinates, it may be noted that either the projection defined may be incorrect or the actual coordinates obtained may have been wrongly noted.

6.3.2. CORS Base

When using CORS as base station, the following criteria should be considered

- The nearest CORS should be chosen as base station.
- The baseline length should not exceed 40 kilometers.

6.4. Rover Setting

Before starting an RTK survey, it is important to ensure that the rover is configured in the best possible way to achieve the desired accuracy. Besides the general requirement, the following are few important requisites that must be ensured for quality data.

6.4.1. Satellite Tracking

Three related settings which are configurable in most receivers are;

Elevation mask or Cut-off Angle

It is the minimum angle below which the receiver will not track GNSS signals. A minimum of 10 degrees and preferably to 15 degrees angle restricts signals traveling close to the horizon as they are susceptible to errors. Signals from low-lying satellites have the longest path through the atmosphere, have a lower Signal-to-Noise Ratio (SNR), and are more affected by local multipath conditions. On the other hand, increasing the elevation mask/cutoff to higher than 15 degrees can reduce the number of satellites tracked and increase the PDOP to a higher than the desired level.

The minimum number of satellites tracked:

Satellite geometry directly impacts on the quality of the position solution estimated by the receiver. A minimum of five satellites is required for RTK surveying (six when combining GPS and GLONASS satellites since the GPS/GLONASS system time offset must also be resolved). Studies have shown that a minimum of seven GNSS satellites will give more accurate results. Tracking more satellites will resolve the ambiguity much faster and more reliably.

The maximum PDOP (Positional Dilution of Precision)

PDOP is a unit less measure of the satellite geometry relative to the roving receiver. The lower PDOP value indicates good satellite geometry accuracy and hence better accuracy while higher PDOP Value indicates weak satellite geometry. Ideally, PDOP should not exceed 2-3.

6.4.2. Orthometric and Ellipsoidal Heights

All heights observed by the GNNS receivers are heights on the defined ellipsoid. The ellipsoid used in Drukref 03 Reference System is GRS80 and all heights calculated based on the ellipsoid are known as ellipsoidal heights. The Orthometric height on the other hand refers to the physical height system which is based on the earth's gravity field. A Geoid model or height transformation parameter is used to convert the ellipsoidal height to Orthometric/ MSL height. In Bhutan, the official vertical datum in use is DrukGeoid 2015.

Although the ideal height for cadastral purpose is the ellipsoidal height, research has shown that the choice of height has no effect on the horizontal component (Namgay, 2022). Therefore, it is recommended to use MSL/Orthometric height in Cadastral Surveys to maintain uniformity and compatibility/interoperability with other geodetic data.

When using GNSS-RTK receiver for cadastral surveys, the Geoid model file should be uploaded in the rover to obtain MSL height while in Total station, the MSL height of the known Stations shall be used during station set-up.

6.4.3. Scale Factor

Measurements are conducted on the topography, which are then projected on to a mapping surface. This involves applying 2 different scale factors; point scale factor and height scale factor, the product of which is referred to as the combined scale factor.

According to new research (Namgay, 2022), failure to apply the height scale factor during field survey will render most measurements unsuitable for cadastral applications. Further research from Cadastral Survey Section, Cadastral Information Division, National Land Commission (2022) showed that applying the combined scale factor of the occupied station achieved better accuracy than the average gewog scale factor or the value 1. Therefore, it is mandatory to apply combined scale factor of the occupied station during field survey.

6.4.3.1. GNSS-RTK

In GNSS-RTK Receivers for, the scale factor computation are done internally by the receiver software. Therefore, there is no need to enter the scale factor manually in the Rover.

6.4.3.2. Total Station

When using Total station, the Combined Scale factor of the station where the machine is setup must be used.

6.4.4. RTK Solution Type

Another parameter that should be set in the rover receiver is the RTK Solution type to use.
In general, there are 3 types of RTK solutions, namely

a. Autonomous: In this case, the ROVER is observing independently. It is not receiving any sort of corrections/signals from the Base.

b. Float: It means, although the Rover and the Base are initialized, the signals obtained are not sufficient to calculate a fixed position

c. Fixed: The solutions obtained are within the desired accuracy. This is the most accurate solution type.

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 at the meter level and should only be used for low accuracy work.

6.4.5. Rover Antenna

The measured GNSS position is always determined relative to the APC(Antenna Phase Center). 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.
- 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 these antenna HI measurements for future verification, and to verify these measurements in the field.
- It is also important to record the Antenna Reference Point (ARP) used, and the antenna type manually.
- Adjust the base and rover circular level vial before every survey.
- Use a tripod or bi-pole when more accurate positions are required.

6.5. Field Survey

6.5.1. RTK Initialization

The process of determining the full number of cycles between the receiver and the satellite is referred to as integer ambiguity resolution. The two most common methods used to resolve the ambiguities are

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.

On the Fly(OTF)

On-the-fly initialization requires a minimum of five 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, re-initialize and check in to the initial point. Re-initialization requires complete loss of lock to all satellite signals.

Under normal conditions the ambiguities should be resolved in less than 1 minute. Users should 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.

Latency of correction (RTK Age)

If the RTK age is older than a few seconds it might indicate communication problems. It is recommended to use data with latencies no greater than 2 seconds.

6.5.2. Rover QC Indicators

Many of these QC measures can have tolerances configured in the rover, outside of which the observed points will be rejected. The following receiver indicators should be constantly monitored during the survey.

- The status of the initialization should remain FIXED.
- Coordinate Precision (QC value) 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.
- The user should monitor the SNR values (Signal-Noise Ratio) calculated by the receiver. The SNR values can be useful to diagnose multipath errors, atmospheric disturbances, and initialization issues. When the SNR of a satellite is over 45, it will be marked green. You should aim to achieve as many satellite signals in the "green zone" as possible.

6.6. Accuracy Check

It is always the responsibility of the surveyor to use appropriate equipment and procedure in order to achieve the required accuracy for the survey.

6.6.1. Check to Known Point

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. Therefore,it is mandatory to validate the coordinates with a known control point after initialization. The coordinate differences should be within the accuracy requirements of your survey. In addition, the following should be practiced:

- Users should regularly re-initialize and re-measure known or previously measured points during the survey to verify the validity of each new initialization.
- Users should observe all important points at least twice, with independent initializations as a validation.

Note: re-initialization is done either by restarting the receiver or by turning the antenna upside down so that lock is lost to all satellites and then re-initialized.

6.6.2. Other Quality Control Procedures

Since all points determined by RTK are single vectors radiating from the base (physical or virtual) to the rover, it is necessary to incorporate some quality control procedures to check the reliability of the results. The degree of checking is dependent on the importance of the point being surveyed.

6.6.2.1. Time Window Averaging

Most receivers will allow the user to compute a mean position over a specified time (time window averaging). Studies have shown significant benefits of time window averaging on the precision of computed positions.

- For Cadastral/topographic points at least 5 seconds and until the desired QC indicators are achieved.
- For control station establishment, longer time windows of up to 5 minutes should be used.

6.6.2.2. 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). For important cadastral points, a window separation of 20 mins is recommended.

7. Control Provision

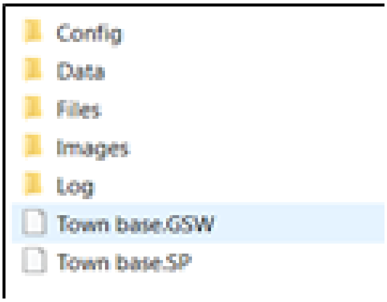
For Control point provisioning following should be adopted:

- At Each Control Point, observe an averaged window of around 3-5 minutes followed by another averaged window of the same length separated from the first by 45 minutes.
- These two sets of coordinates should be in agreement of better than 2 cm on horizontal and 5 cm in vertical.
- For control point observation only tripod mount GNSS should be used.
- If coordinates of both sets are not in agreement, Static mode observation for 45- 60 minute duration may be taken for post processing work.
- For more precise control work, Static surveys using post processing should be used.

8. Final Data Formats

The point data format (.CSV) file shall be used as the field file format from GNSS receivers. However, surveyors should download the whole project file at the end of the project and submit (zipped) it along with other survey report forms.

The project folder should contain the following folders/files;



Sample project Folder

9. Other essential field documentation

When performing the survey, the following documents must also be duly filled and submitted along with the technical files in section 5.

- Field Book: The record of all proceedings of the Survey(annexure 1)
- Survey Report: The legal endorsement of the survey. (annex 2)

Reference

Donahue, B. (2013). *Guidelines for RTK/RTN GNSS surveying in Canada. Natural Resources Canada.*

Gibbings, P. D. (2013, May). Surveyors Board of Queensland RTK GNSS for cadastral surveys: guideline. In *Proceedings of the Joint Central and Northern Groups Conference (SSSIQ 2013).* Surveyors Board of Queensland.

Londe, M. (2019b, June 18). *"Guidelines for the Use of Global Navigation Satellite Systems*

(GNSS) in Cadastral Surveys" and "Standards for Positional Accuracy for Cadastral Surveys Conducted Using GNSS" | Bureau of Land Management. U.S DEPARTMENT OF THE INTERIOR,THE BUREAU OF LAND MANAGEMENT. https://www.blm.gov/policy/pim-2020-004.

Geodetic Section, Topographic Division, National Land Commission. (2021, October). *Validation of Permanent Reference Station for RTK Surveying for Cadastral Application.*

Cadastral Survey Section, Cadastral Information Division, National Land Commission. (2021, June). *Comparative study on using GNSS, Total Station & CORS for Cadastral Surveys.* Cadastral Information Division, National Land Commission.

Namgay, T. (2022, February). *Investigating the differences in reducing distances to the geoid and the ellipsoid and subsequent impacts on cadastral surveying.* Department of Surveying & Mapping, National Land Commission Secretariat.

Cadastral Survey Section, Cadastral Information Division, National Land Commission. (2022, May). *Investigating the effect of different values of Scale Factor on accuracy of measurement in Cadastral Surveying.* Cadastral Information Division, National Land Commission.

Annexure

Cadastral Field Book

1. Survey Information Dzongkhag: ....Gewog/Thromde:..........................Village.................... Thram No:..........................Plot No: .... Name of Surveyor: .... License No/EmployeeNo: .... Date of Survey:.............................. Surveying instrument(s): Total Station/GNSS RTK/Other (...................................) Instrument Model..

2. **Reference/Base Station(s)**

Receiver No.(if using conventional RTK base station): CORS Station Name (if using CORS): Coordinates: National Grid/Local Grid Station Id: Station Id: Easting(m): Easting(m): Northing(m): Northing(m): Elevation(m) : Elevation(m):

3. Rover

Receiver No: **Rover Antenna HI(m):**

4. Pre Field Checks

Fields	Status/Value
Set Max PDOP (2-3)	
Elevation Mask (10-15deg)	
Set Min # of satellites tracked(GPS only (6); GNSS (7-8)	
Initialization time(1-2 mins max)	
Initialization status(Fixed)	
RTK age(2 sec max)	
Is Geoid model loaded into the Controller or Rover?	

(Surveyor's Signature)

Date:

5. Point Identifiers

Dzongkhag:……………………Gewog/Thromde:…….…………..Village/LAP:………

Starting	Closing	Feature	Ht. of	Remarks
Point Id	Point Id	Code	Reflector/ GNSS Pole (m)	

Surveyed By (Name and Sign): **Date:**

6. Traverse Information

Sl No	Station	Observed Coordinates			Instrument Height (m)			Remarks
		Easting (m)	Northing (m)	Elevation (m)	RO	Occupied	New station	

Sketch of Traverse Length

Traversed by (Name and Sign): **Date:**