Procedures for Quality Control of GNSS Surveying Results Based on Network RTK Corrections.

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Key words: GNSS Rover RTK operations, GNSS Network RTK corrections, RTCM format, Quality Control, Error Analysis.

SUMMARY

It is well recognized today that a reference network comprised of permanent stations operating Global Navigation Satellite System (GNSS) receivers on a continuous basis provides the fundamental infrastructure required to meet the needs not only of geodesy and the geosciences, but also of professional GNSS users in areas of surveying, mapping and navigation.

These high accuracy applications can only be satisfied through the use of the carrier phase-based, differential GNSS technique, whereby the "reference" or "base" receiver is part of a network whose coordinates are known in a geocentric datum or reference frame.

Furthermore, the widespread use of the GPS Real-Time Kinematic (RTK) technique has encouraged surveying and mapping institutes to look for ways to use GNSS reference receivers to support ever expanding non-geodetic, real-time applications of high accuracy positioning for engineering, machine guidance, precision agriculture, fleet management, etc.

Based on practical experiences in that field of investigation, the authors review the necessary procedures that both a GNSS Network RTK operator and a surveying RTK end user should consider to achieve optimal results. The services provided by such positioning infrastructure operator is not limited to only broadcast corrections and the RTK user must still consider good practices to control his results.

The newly adopted RTCM 3.1 Master Auxiliary Concept is emphasized as a key component in such quality control approach.

The examples provided are based on daily operations in Kunming area in the context of the GNSS Network RTK owned and operated by the Surveying and Mapping Institute experts.

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1. FUNDAMENTALS OF GPS NETWORK RTK POSITIONING

GPS Network RTK is a recent technology that has been developed on the basis of conventional RTK and differential GPS.

Conventional RTK is established on the hypothesis that reference station errors are highly correlated with rovers' error. When the rover is close to the reference station (e.g. less than 10 to 15 km), the result of the baseline computation is within the centimeter level. But by increasing the range between the reference station and the rover, the errors that are less correlated are decreasing the performances and it will be harder to obtain the same level of accuracy.

In order to obtain precise positioning results independly of that situation, the interest to deploy continuously operating reference stations for covering the production area of RTK users is increasing.

GPS Network RTK is using de same concept and method of the wide area differential GPS but by considering the phase measurements instead of the ranges adding more complexity.

2. OPERATIONS OF NETWORK RTK

2.1 Operational conditions of network RTK

2.1.1 <u>Normal Working Conditions of Reference Station System</u>

- Reference stations must track all satellites signals at the lowest elevation to ensure a complete coverage and must receive the signals from the same satellites preferably at the same time.
- The common ambiguities level must be solved for the complete network in order to compute the appropriated corrections for any rover RTL users operating in the area of the network.
- The corrections delivered must provide 95-99% availability. The users of a such infrastructure must have the same and even better performances than with standard RTK operations.
- System reliability must reach more than 95% level of confidence.

- When receiving the request information of rover, it can provide correction data of network RTK immediately “on demand”.
- It must provide differential data with all kinds of formats.

2.1.2 Working Conditions of Rover

- The rover RTK can receive data (observations and corrections) from the data center that are managing the reference stations normally by radio signals, GSM, CDMA etc.
- They can process the correction values and fixed the ambiguities after receiving the network correction value.

2.1.3 Basic Conditions of normal Operation of Network RTK

- Reference stations and rover can receive same signals of more than 5 satellites at the same time.
- Rover can receive differential signals of reference stations and satellite signals normally.
- Rover can receive differential signals of reference stations and GPS satellite signals continually.
- Data center of reference station and rover can communicate data without any delay.

There is no strong interference (radio jamming) around the reference station and the rover RTK.

2.2 Operational flow line of network RTK

2.2.1 Mission Planning

Perform satellite ephemeris forecasting before RTK operation, it’s better to select the time window (GDOP<4 and satellite numbers>6) and so on.

2.2.2 Rover’s Configuration of Network RTK

Before the operation of network RTK, set the operational mode and communication mode of reference station and rover.

2.2.3 Selecting Configuration File of Rover

When preparing a rover to operate in a GPS network RTK context, the user must pay attention to select the appropriated configuration set.

2.2.4 Initialization of RTK Measurement

Complete Initialization must be performed before logging position results. The so –called static initialization mode is preferable if the highest accuracy is requested. There must be no direct relation between initialization time of reference station system and the distance to a reference point.

2.2.5 Rover Observation

Check the information of survey stations, including the number of satellites, health status of satellites, signal-noise ratio, real time position product of phase measurement residual error, convergence value and communication state of rover and reference station's data center.

3. ERROR SOURCE AND ANALYSIS OF NETWORK RTK

GPS Positioning has many errors. There are two kinds of error according to error pattern, one is systematic error or biases, and the other is random error or gaussian error type. According to error source, there are three kind of error that are error related to satellite, error related to signal transmission and error related to receiver.

3.1 Error related to GPS satellite, its properties and its reduction

3.1.1 Satellite Ephemeris Error

The difference between satellite real position and satellite position given by the ephemeris is the satellite orbital error. Ephemeris error can be reduced effectively by using an appropriated modeling, differential methods and the use of precise ephemeris information provided by the International GPS Service (IGS).

Satellite orbit parameters attained from ephemeris error act as unknowing parameters, and then are used in adjustment model. Survey station position and orbit deviation parameters can be estimated by adjustment. Orbit improvement methods are based on semi-arc and semi minor arc approach.

3.1.2 Satellite Clock Error

Though using precise satellite clock, there are still errors including system error and random error. Systematic error on clock offset can be determined by checking and comparison, and corrected by model. Random error of clock offset can only be described by adjustment and modeling.

3.1.3 Effect of Relativity Theory

Effect of relativity theory is a phenomenon of relative clock offset due to different states of satellite clock and receiver clock. There are correct methods of approximate formulas and rigorous formulas. The influence of these errors on distance measurement processed by using code and carrier phase observations is equal.

3.2 Error Related to Signal Transmission, its Properties and its Reduction

3.2.1 Ionosphere Delay

Ionosphere leads to electromagnetic wave propagation’s delay and induce errors .The delay strengths is related to total electronic content density. The total electronic content of ionosphere is changing with the sun activity, the geographic location of the receiver, the seasonal change and the difference between day and night.

Ionosphere’s effect to the distance measurement processed by using code and carrier phase measurements is equal but with a sign difference. Ionosphere ‘s error can be mitigated or reduced by using the following methods:

- Linear integration of L1 and L2’s observation value by using dual-frequency receiver can eliminate the ionosphere’s influence.
- The difference (short or medium base line range) of simultaneous satellite observations and at least two stations can mitigate the influence as well. An ionosphere model is used in first approximation.

3.2.2 Troposphere Delay

Troposphere is the atmospheric layer located above the ground up to 20-50km. We consider a dry and a wet component. GPS signals have velocity delay and path flexure. Distance measurements based on pseudo range and carrier phase are contaminated with systematic erro!s. Generally, we are using an unconstraint parameter and a random model method associated to improve the observation precision as well as to estimate the troposphere delay that can be used in weather forecasting applications.

3.2.3 Multipath Error

Multipath error is the most serious error in GPS RTK surveying. Reflection and diffraction of the signals depends on the environment around the antenna. Multipath errors can introduce some centimeters biases on horizontal position and even more than 10 cm in vertical.

Multipath error can be mitigated by using some methods, such as selecting positions of terrain with no reflecting surfaces, by using choke ring antenna based design, by using special geodetic antenna that can reduce multipath error and by using materials that can absorb the reflection of radio waves around reference stations and rover.

3.3 Error Eelated to Receiver, its Properties and its Reduction

3.3.1 Clock Error of Receiver

Just like satellite clock erros, receiver clock has errors that are more manageable. It depends overall of the oscillator performance. It has the same effect on distance measurement performed by using code and carrier phase.

3.3.2 Position Error of Receiver

Antenna's mechanical center is not coinciding with the electronic phase center. Even more, the electronic phase center is varying all the time, and depends on signal frequency, azimuth and elevation angle. Ignoring that effect a point coordinate error can easily reach 3-5cm errors. Therefore, in order to improve RTK positioning accuracy, antenna must be checked and calibrated. There are absolute calibration technique and field check method based on relative measurements.

3.4 Error Related to Reference Station System and Communication, its Properties and its Reduction

Using GPS Networking technology can reduced the errors related to distance. Those errors also can be reduced thank to network RTK's modeling and software's performances. Meanwhile, good communication conditions lead to reliable results. When the distance to the base stations get larger, the residual error will get larger as well if the modeling is inappropriate.

4. QUALITY CONTROL OF NETWORK RTK POSITIONING

4.1 Quality Control's Importance

Some researches indicate that common level ambiguity reliability is around 95 - 99% in network RTK processing. GPS Network RTK has more potential error factors than static GPS and conventional GPS RTK because we deal with much more information such as fixed results' reliability of reference stations, the reliability of data communication back between data center and rover and all the errors that has been described above.

At the same time, GPS Network RTK operations can't benefit of fast or conventional static measurements post processing methods, such as selecting a much more appropriated satellite elevation angle mask, excluding near unhealthy satellites, and slicing the observations into different group to control the quality. Hence, compared with GPS static measurements and conventional RTK measurement, GPS network RTK measurement is complex and can produce errors on position that can be reduced if appropriated methods are considered.

4.2 Quality Control

4.2.1 Coordinate Transformation Parameters

Network RTK operation acquire the WGS coordinate directly. But we often use in Kunming and in China the Beijing 1954 coordinate or local coordinate in practice. So coordinates transformation is mandatory in practical surveying operations. Through lots of practice, GPS Network RTK's coordinate transformation parameters should be solved from the control points covering the whole GPS reference station network. Seven parameters transformation method is often used. If the points aren't enough in the coverage, the user may consider a four parameters transformation method. After the parameters transformation, the user must check his performance using known points. The quality of the transformation plays a major role in the end results.

4.2.2 Ephemeris Forecasting

The user should perform an ephemeris forecast before his field operations. The used ephemeris should not be older than one week before the operations. Then the user should record or print the ephemeris forecasting results. In order to guarantee the efficiency and quality, the user should better select the ideal observation condition (satellite availability and GDOP) to make the RTK operations effective.

4.2.3 Setting up the Accuracy Indicator

When the rover RTK user operates within a GPS network RTK infrastructure, he has to set up an accuracy threshold on the rover to insure that the solutions logged will be within his requirements. Generally the point’s mean square error is 2 cm, and the elevation’s mean square error is 3 cm.

4.2.4 Network RTK’s Occupying

The surveying points should fit to the GPS practice and the user must arrange the observation time according to the forecast ephemeris information. Generally the GDOP must be less than 4.When the GDOP is higher no accurate results could be expected. So the user should not be in operation during that period of time. The rule is still “when the GDOP is good, the operation is efficiency and the accuracy is good”.

In order to reduce the mean square error and speed up the initialization process, it is also preferable to use a tripod or a quick stand to maintain the antenna static.

4.2.5 Network RTK’s Observation

4.2.5.1 Good Communication Conditions

It is critical to guarantee the highest results’ quality that the communication line between the reference station center and the rover is stable (no interruption) and reliable (no latency).

4.2.5.2 Ionosphere and Troposphere’s Forecasting and Checking

The GPS Network RTK software can check ionosphere and troposphere state. In order to improve RTK surveying efficiency and to guarantee its quality, the users should select the period of time when the ionosphere and troposphere activities are reduced.

4.2.5.3 Observation Rate and Coordinates Accuracy

The sampling interval of GPS network RTK reference station is generally based on 1Hz rate. The horizontal accuracy of the antenna's coordinates should be less than 1 cm, and the elevation accuracy should be less than 2cm in position. The coordinates must refer the same datum than the satellites.

4.2.6 Clearing the Blunder

GPS Network RTK operation may still have gross errors and it is quite difficult to take a decision on what could be eliminated as all the process is running in real time. Post processing analysis can help the user to clean and filter the observations while in real time operations it's nearly impossible. The main method is still based on redundant observations to maintain a certain level of control, but the redundant observation's number must be balanced as it may also affect the operation efficiency and impact the advantage of RTK operations.

The authors are promoting some practical methods to identify and remove blunders. Double initialization on the same points, observing redundant points and re-occupation of the surveyed points with another GPS satellites constellation will guarantee the user final results quality.

5. CONCLUSION

With the development and application of GPS reference station technology, conventional operation of RTK is going to be handled more and more by using the advantages of GPS network RTK infrastructures, and the operational efficiency will rise greatly.

At present time, by selecting appropriated GPS Network RTK concepts and operational modes, by using all methods of quality control, the user can attain more stable and reliable positioning results. The author's believe that, with the development and application of GPS reference station technology, GPS network RTK will play a great role in more applications.

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BIOGRAPHICAL NOTES

- Academic experience: Published a monograph —"The Theory and Practice of GPS Reference Stations System" Sep. 2006,
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