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Automated Quality Control of Global Navigation Satellite System (GNSS) Data

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Summary

Global Navigation Satellite System (GNSS), includes GPS, GLONASS and upcoming Galileo satellites, has almost replaced the conventional method of surveying in oil industry, particularly in seismic data acquisition.

Due to the high challenges faced in seismic data acquisition, the present day acquisition geometries demands increased no of channels, in the order of 6000-7000 and very precise positioning in the order 1 to 2 cm accuracy in both horizontal & vertical positioning. Huge volume of topographic survey data is being acquired with GNSS in Real Time Kinematic (RTK) mode on daily basis, in tough logistics conditions. Almost all receiver and source locations are being staked precisely with GNSS, except in GPS signal blockage areas, where total station is being used.

Quality control of GNSS, RTK data and the performance of GNSS receivers is a must to ensure data integrity. Manual QC on GNSS data will be very cumbersome and may not be feasible on daily huge volume of data. An attempt has been made for the automated QC of GNSS data in Cambay Basin, India using advanced software like GPSeismic. The parameters used, methodology and advantages of automated QC on GNSS RTK data were discussed.

Quality control of Receiver Independent Exchange (RINEX) data also plays a vital role, while working with data acquired on different GPS receivers of different manufactures. The quality control aspects of RINEX data were also discussed in detail.

Keywords*: GNSS, GPS, GLONASS, RTK, RINEX, WGS, PZ-90*

Introduction

GPS is not the only GNSS currently broadcasting positioning signals to civilian users. GLONASS, developed by the Russian Federation, shares many similarities with its U.S counterpart. A minimum constellation of 21 GLONASS is now available and full constellation of 24 satellites is planned for 2011. The European Union (EU) is also developing an independent GNSS known as Galileo. The full constellation of 30 satellites of Galileo is expected before 2016. Today users can benefit from a combined GNSS satellite constellation comprising of 30 GPS and 21 GLONASS satellites.

The combined solution of using both GPS and GLONASS satellites is able to reduce the time-to-fix ambiguities and increase the availability of precise position even when sufficient GPS satellites are not available. However, the task of combining mixed GNSS observations is not trivial. Differences in coordinate reference frames and time scales as well as inter-channel hardware biases have to be taken into account. GPS adopts WGS84 as reference frame and time scale called GPS time. GLONASS broadcast satellite ephemerides in the PZ-90 reference frame and works with GLONASS time. Hence quality control of combined data (GPS + GLONASS) becomes quite cumbersome or tricky.

GNSS data is normally acquired in two modes, i.e. Static / Fast Static mode and Real Time Kinematic (RTK) mode, depending on the application and requirements. As far as the seismic data acquisition is concerned, both the modes of operations are used. Static / Fast static mode is used for establishing precise GPS network and control stations and RTK mode of surveying is used for precise staking &

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obtaining positions (x,y,z) in real time. GNSS raw data observed on both static and RTK modes needs through quality control and analysis, to ensure data integrity.

Quality testing of static raw data, in Receiver Independent Exchange Format (RINEX) format can be carried out using exclusive quality control software like Leica GNSS QC, for various tests specifically for GPS (L1&L2 frequency, C1&C2code, P1&P2code, D1&D2 doppler frequency) and GLONASS (L1&L2 frequency, C1&C2code, P1&P2code, D1&D2 doppler frequency) signals, Satellite-Based Augmentation System (SBAS) payloads, receiver clock offsets , antenna offsets, multipath etc. Quality control of RTK data in native format can be carried out using GPSeismic software. Customized automatic quality control on various parameters like dilution of precision (PDOP, HDOP & VDOP), number of satellite, number of epochs, variance, horizontal and vertical precision, standard deviation, reliability etc. can also be done.

Quality control of RINEX data

Receiver Independent Exchange Format ***(RINEX)*** was developed by the Astronomical Institute of the University of Berne during 1989, for the easy exchange of the GPS / GNSS data collected by different GPS / GNSS receivers of different manufacturers. Understanding RINEX data and quality control of RINEX data is very essential while

- Working with GNSS data, acquired on different receivers of different manufactures
- Processing RINEX data in third party / advanced software.
- Using International GNSS services (IGS) data and products

The International GNSS services (IGS) data, particularly observation, navigation and meteorological data comes in compact RINEX V2.10, along with precise orbits, ionosphere maps of total electronic content (TEC) and other data. RINEX data currently consists of six ASCII file types:

1. Observation Data File
2. Navigation Message File (GPS)
3. Meteorological Data File
4. GLONASS Navigation Message File
5. GEO Navigation Message File
6. Satellite and Receiver Clock Date File

The integrity and quality of data acquired with receivers of different manufactures can only be ascertained, by converting them into RINEX format and by doing a rigorous quality control. The following table lists many of the common problems that may be found with GPS/ GNSS data.

Quality Issue	Comments
Data gaps	• The number of epochs with data will be less than the expected number for the length of the file and the observation rate.
Poor tracking	• The receiver has a low percentage of recorded versus possible observations. • The receiver shows a high number of cycle slips. If the cycle slip count is high enough, then the cycle slip test will fail.

	• The receiver does not track some satellites at high elevation.
Poor tracking (contd..)	• The percentage of complete observations will be low. • L2 multipath estimate (MP2) is much higher than the (MP1) estimate. This is typical for receivers that use a poor P-code reconstruction technique. • The signal to noise ratio will be lower than could be expected. SNR S1 and S2 values can differ based on the receiver manufacturer and model. • Poor tracking can be the result of the antenna, antenna environment (e.g. trees, obstructions, interference), antenna cable (quality and length), inline amplification and receiver.
Files do not comply with RINEX standard	• Important header information, such as receiver coordinates may be missing. • Individual format problems will be listed in the Obs file / Nav file / General error messages sections depending on the nature of the format error.
Navigation file is incomplete or contains errors	• The navigation file may not contain all of the necessary orbit records for the associated observation file • It can be that there is ephemeris data available for the satellite but that it is out of date • The number of observations with invalid navigation data will be greater than zero.
Site has obstructions	• The receiver has a low percentage of recorded versus possible observations. • The receiver is not tracking some satellites at low elevation. • The SNR skyplot will show gaps.
High multipath	• The multipath MP1/MP2 RMS estimates are significantly higher at one site than another with the same antenna/receiver. • A time series of MP1 and MP2 values (as either a line graph or skyplot) can be used to see the multipath estimates directly.
Receiver clock is not correctly synchronized	• The maximum receiver clock offset will be greater than one millisecond. • A short interval between clock resets or a high number of clock slips is an indicator of a poor clock.

GNSS RINEX data has to be thoroughly analyzed for all the above mentioned parameters using quality control software. Manual QC and automatic processing to check data after every defined interval of observation is quite possible and it can be used for both stand alone and networking.

Quality control of GNSS, Real Time Kinematic (RTK) Data

A minimum of five common satellites with good geometry is required for RTK surveying and in order to obtain cm-level accuracy with differential kinematic GNSS positioning, the carrier phase ambiguities in the measurement update have to be resolved over the initial baseline before the GNSS receiver goes into the kinematic mode and phase lock should be maintained on a minimum number of 4 satellites thereafter in a good geometry .

However, during the period of kinematic GPS surveys, cycle slips on all or most of the available satellites may occur due to carrier signal obstruction by objects or other tracking problems. In such a situation, the initially resolved carrier phase ambiguities N of all the corresponding satellites, which are held fixed initially, will change by an arbitrary integer number of cycles. Therefore, the new carrier phase ambiguities N of all or most of the satellites have to be resolved again or re-initialized during the kinematic surveying mode in order to maintain the cm-level positioning accuracy.

If RTK initialization takes place under circumstances of high RMS, then the elevations of all stations surveyed after that initialization will have an error of more than 1 m approximately. Mostly this error in elevation goes unnoticed, if not checked properly. Cycle slips and re-initialization with high RMS is often encountered in the highly vegetated areas like Assam, Cambay, Cauvery and Krishna Godavari Basins in Indian context.

Exclusive GPS quality control and management software like GPSeismic will help deducting elevation spikes and to customize automatic quality control on various parameters like PDOP, HDOP, VDOP, number of satellite, number of epochs, variance, horizontal and vertical precision, standard deviation, reliability etc. The following case study helps to understand the procedures normally adopted for automated QC on RTK data.

Case Study (Cambay Basin, India)

A case study was carried in Cambay Basin with Trimble R-6 GNSS data, to study the feasibility of automated QC on RTK data using GPSeismic software. The software is designed exclusively for catering the needs of seismic data acquisition with GNSS systems. Based on the requirements, the pre-plots (the theoretical coordinates) can be generated for 2-D lines, crooked lines, 3-D grids, brick patterns, diagonal grids, zig-zag patterns, oblique grids etc.

The generated pre plots can be partially or fully uploaded into various model / make of GNSS receivers, by creating an upload file. The actual staked location (post-plots) can be viewed and analyzed, by directly downloading from the GNSS receivers.

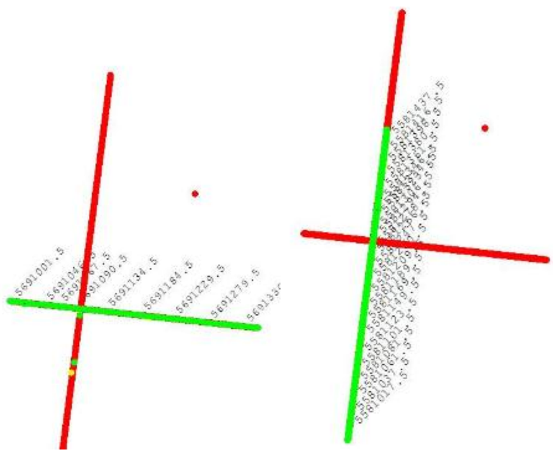

Fig. 1 (Post-plot of 2D survey campaign)

The above figure 1 shows the post-plots of 2D survey campaign. Red colour indicates input / stranded points in the instrument, green colour indicates actual surveyed locations, Yellow indicates surveyed points without pre-plots. The blue colour in figure 2 below indicates input / visited. The actual staked offset locations (green), in place of input / theoretical locations (blue) and their displacements can well be seen in the chart below.

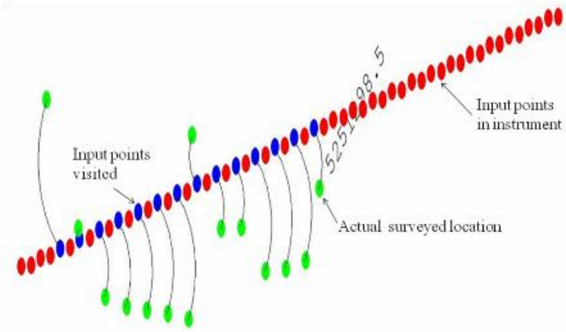

Fig. 2 (Survey post plot with colour notations)

The downloaded RTK raw data observations gives complete information on station ID, track, bin ,descriptor (receiver/source) WGSLat, WGS Long, WGS Height, Survey mode (Autonomous, Code, Float or Phase), instrument height, offset information on coordinate difference between theoretical (pre-plot) and actual locations (post-plot), quality information on horizontal and vertical precision, number of satellites tracked, PDOP, HDOP, VDOP & GDOP values, observation time, baseline length, base station details, occupation time, Initialization block, unit variance etc, for every single point occupation.

The reliability analysis and statistical testing on various parameters can then be carried out using GPSQL, an application tool for management of data containing in a Microsoft Access Database. The following are some of the important analysis to be carried out for ensuring data quality and its reliability.

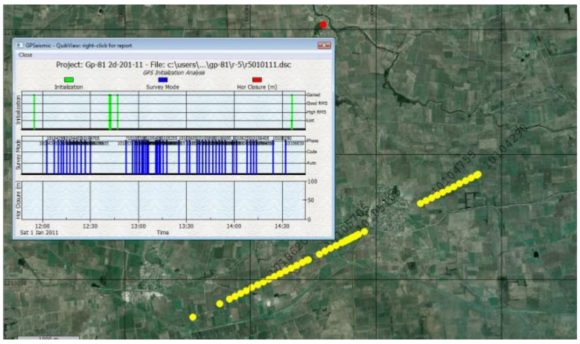

Fig. 3 (RTK initialization analysis)

Analysis on RKT initialization, the above figure 3 shows that re-initialization has taken place almost 6 times during the whole day field operation (in this case, all lost initialization has gained subsequently).

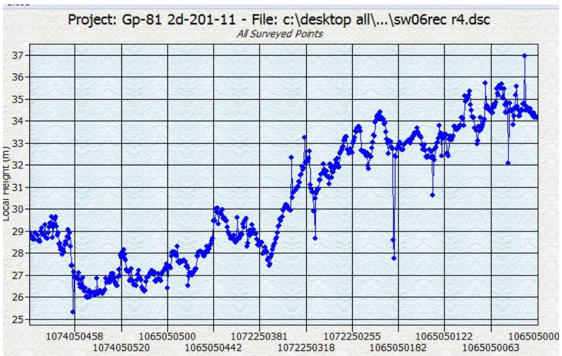

Fig. 4 (Elevation chart)

If the re-initialization takes place under high RMS, then elevation values have to be cross checked by taking a check shot in field. It is also advisable to generate an elevation chart, as shown above in figure 4 to look for elevation spikes

Fig. 5 (Google elevation chart)

Also the elevation values need to be cross checked with the actual topography (figure 5) for ensuring data reliability.

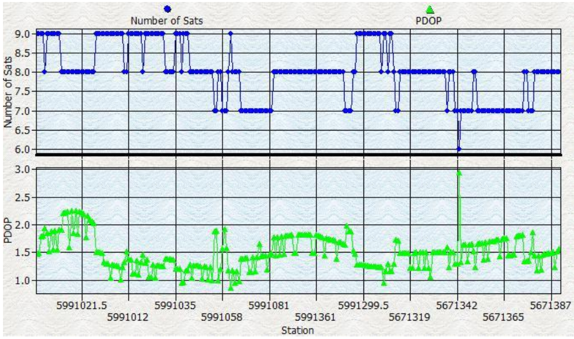

Fig. 6 (Number of Satellites vs. PDOP chart)

The next important parameter is PDOP. The data quality, particularly vertical positioning depends on PDOP values. It is advisable to stake locations by having less than 5 PDOP value as threshold limit, if orthometric heights need to be derived from GNSS data.

It is interesting to note from figure 6, that the PDOP values decreases, with increase in number of satellites available. Having more number of additional satellites, will always helps in reducing the time-to-fix ambiguity, and to have more productivity with fixed solution.

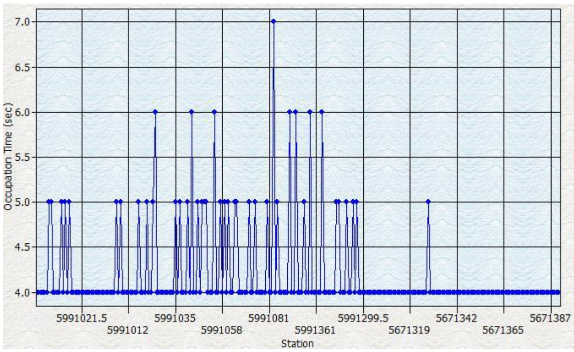

Fig. 7 (Observation time plot)

Figure 7 shows the observation time plot. It is better to have a minimum of 4 epoch data (as per industry standards), though 1 epoch RTK data is also theoretically acceptable.

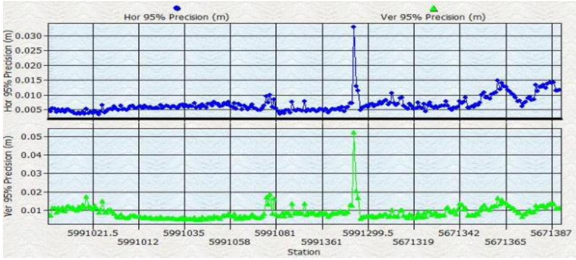

Fig. 8 (Precision quality chart)

The above figure 8 shows the 95 % precision quality chart for both Horizontal & Vertical positioning, the points which does not comply quality norms can easily be indentified.

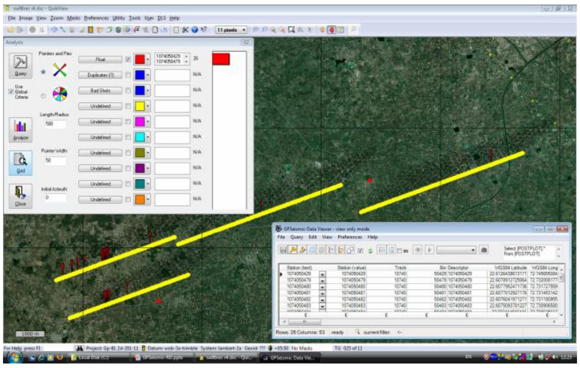
Fig. 9 (Identifying bad RTK observations)

Queries can also be made on combination of various parameters as per the quality requirements. Figure 9 shows an example for identifying bad RTK observation {Query : Select (`Survey Mode (value)`=Code) And PDOP`>5 Or Number of Satellites`<5)} Quality reports / charts can be generated for auditing and output of data can be given in various formats.

Conclusions

The quality assessment of surveying results generally involves accuracy analysis, reliability analysis and statistical testing. Accuracy analysis deals with the propagation of random errors through the geometric strength of the network or the adjustment model, while reliability analysis and statistical testing ,which are the primary elements of quality control deals with the self-check ability of the model or system to blunders or biases that occur in observations or in the systems.

Hence the reliability analysis and statistical testing of both static (RINEX) and RTK data is very important. If the blunders or biases in the observations are indentified and removed, then it becomes easier for processing the data and to do final adjustments thereafter.

Automated quality control of RTK data with GPSeismic software version 2010.10 was experimented in Cambay Basin. Queries including all vital quality control parameters like PDOP, number of satellite, number of epochs, float or fixed solution, distance between master & rover, horizontal & vertical precision, standard deviation etc developed and run on daily huge volume of RTK data. Bad observation or poor quality data were automatically identified, based on the quality norms / parameters defined in the query. Thus enabling the surveyors to identify and resurvey the poor quality data on daily basis, avoiding time delay.

Survey data base was also maintained incorporating the correct coordinate and elevation of staked locations, for ready access to the seismic crew for precise seismic data acquisition.

The results achieved was highly encouraging, particularly while dealing with more channels, which involves huge volume of RTK data. Performing manual QC will be very cumbersome and may not be feasible on daily huge volume of data.

Hence automated quality control using exclusive quality control software for static (RINEX) & RTK data like GNSS QC and GPSeismic software respectively, will help in a big way for doing a complete QC on both the data, for ensuring the data reliability.

References

“GPSeismic software manuals

GNSS QC (Free version) software tutorials

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