# GPS-RTK in Online and Continuous Deformation Measurement

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**ABSTRACT:**

Scientific justifications as well as the technical feasibility of using Global Positioning System Real-Time Kinematic (GPS-RTK) positioning technique in recording the responses of structure or measuring the deformation have been proven. Nevertheless, using the purely RTK solution in online and continuous deformation measurement will require additional procedures to prevent detecting the false deformation. The paper describes prototype software, GPS Alternative (GALT), which is specially developed to serve for the purposes and is currently being developed at Department of Geomatics Engineering, Universiti Teknologi Malaysia (UTM). Basically GALT consists of two major segments: system segment and field segment. Moreover, GALT features three main functionalities: outlier filtering, reference station stability checking and RTK quality identification.

**INTRODUCTION**

Conventionally, geodetic modelling of the object (and its surrounding) means dissecting the continuum by discrete points in such a way that the points characterize the object, and that the movements of the points represent the movements and distortions of the object. Furthermore, modelling the deformation process means conventionally to observe (by geodetic means) the characteristic points in certain time intervals in order to monitor properly the temporal course of the movements. This kind of modelling and monitoring an object under deformation in space and time has been the traditional geodetic procedure (Table 1) (Ad-Hoc Committee of FIG, 2001).

Table 1: Geodetic modelling of deformation processes in space and time.

| | Real object | Model of the object |
|---|---|---|
| Geometry domain | The object is a continuum | The object is dissected by characteristic points |
| Time domain | The object is (more or less) permanently in motion | The object is monitored in certain time intervals |

While on the contrary, advanced evaluation models for deformation analysis do not only consider the change of the geometry of an object in space and time. They rather investigate and incorporate also the influencing factors (causative forces, internal and external loads) causing the deformation. They regard in addition the object’s physical properties (material constants, extension coefficients, etc.) which are characteristic and responsible for the response of the object to the acting forces. To put it simply, they consider the three elements:

i) “acting forces” or causative forces as input signal,
ii) “transmission through the object” as transfer process, and
iii) “response of the object” or deformation as output signal.

Hence, according to terminology of system theory, form a dynamic process or dynamic system (Figure 1) (Ad-Hoc Committee of FIG, 2001).

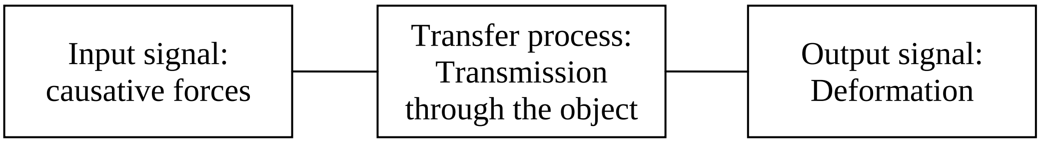


Figure 1: Deformation as an element of a dynamic system.

In small-scale deformation monitoring applications, GPS is now used to observe structures which, in the past, may have been monitored using conventional terrestrial surveying instrument. Advances in GPS-RTK technology, which can record the response of the monitored object in term of coordinates in real time at 10 sample per second (sps) with the accuracy of 1cm horizontally and 2cm vertically, provide great opportunity to reliably monitor the long-period structure. Examples of successful monitoring using GPS can be found for tall buildings (e.g. Celebi and Sanli, 2001; Yoshida et al., 2003; Li et al., 2006). Nevertheless, using the manufacturers' GPS-RTK solution in online and continuous monitoring requires additional procedure to prevent any false deformation detection. In other words, the integrity of GPS-RTK will need to be monitored as well.

## FALSE DEFORMATION

In general, higher accuracy is achieved in relative positioning. This is because several biases (e.g. clock biases, atmospheric delays, orbit biases, etc.) burdening the observed ranges are either identical or at least similar at both ends of the baseline. These biases then get either eliminated or, at least, significantly reduced when relative positions are sought. However, there are still the errors (e.g. cycle slips, multipath and other residual biases) which are hardly removed and these errors may cause the false deformation. Figure 2 below shows the outlier / residual bias contained in the sampled RTK data (using centimetre-accuracy receiver). Therefore, additional outlier filtering must be applied to the RTK solution so that the outlier will not be misrecognised as deformation in automated and online monitoring.

On the other hand, in continuous monitoring, reliable reference station is required to again prevent misrecognising deformation when other sensors mounted on the monitored object are unmoved while the reference station is disturbed. Reference station stability checking can be done using statistical solutions (e.g. Generalized Method of Geometrical Deformation Analysis) through the network formed by at least two additional GPS stations with the reference station. As a result, the base data (which is collected at the reference station) must be obtained for stability checking. Static positioning is preferred for the stability checking and postmision processing is acceptable.

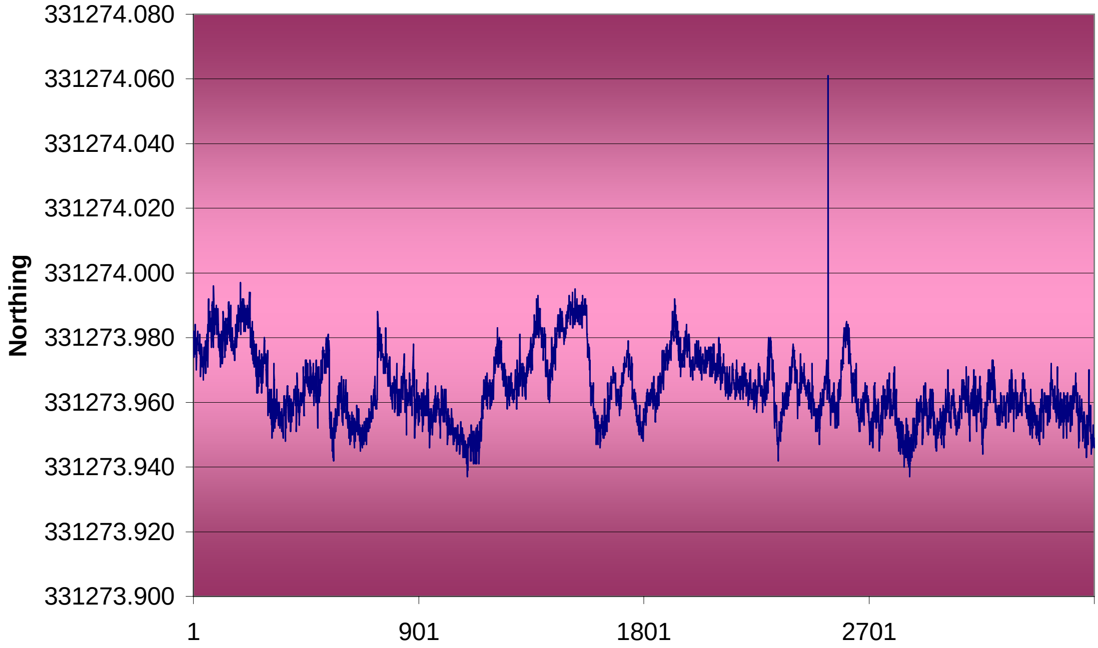


Figure 2: Time series of sampled RTK data containing outliers.

**GPS ALTERNATIVE (GALT)**

A prototype software of GPS-RTK based deformation monitoring system, GALT, of which the RTK positioning integrity monitoring and deformation detection are incorporated, is currently being developed in Department of Geomatic Engineering, UTM. The objective of the software development is mainly to expand the usability of RTK in automated deformation monitoring and to serve for the online and continuous deformation monitoring. GALT, basically, consists of two major segments: system segment and field segment. In addition, GALT features three main functionalities: outlier filtering, reference station stability checking and RTK quality identification.

The system segment comprises two major modules: Conveyor and Compiler. To put it simply, Conveyor is the module to collect the data from the receiver and transfer them to Compiler. The module is installed in the field components that include Sensor and Core Reference Station (CRS) (or also Reserved Reference Station (RRS)). Conveyor offers two options of positioning technique: Kinematic mode and Static mode. Kinematic mode is used for Sensor to record responses of monitored object; Static mode is used for CRS (and RRS) to collect the base data for reference station stability checking. On the other hand, Compiler is the module to present the computed data received from Conveyor. Compiler is installed in Control Centre (CC) only. Compiler offers two options of result presentation: real-time and past result. Figure 3 and 4 below show the screenshots of the main window of Conveyor and Compiler respectively.

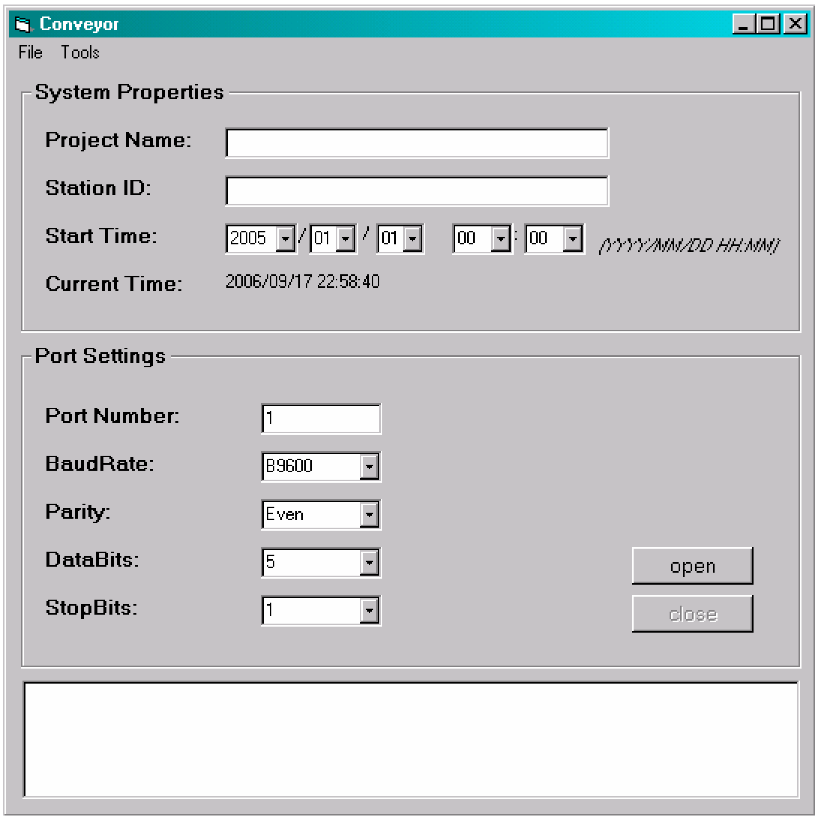

Figure 3: Screenshot of main window of Conveyor.

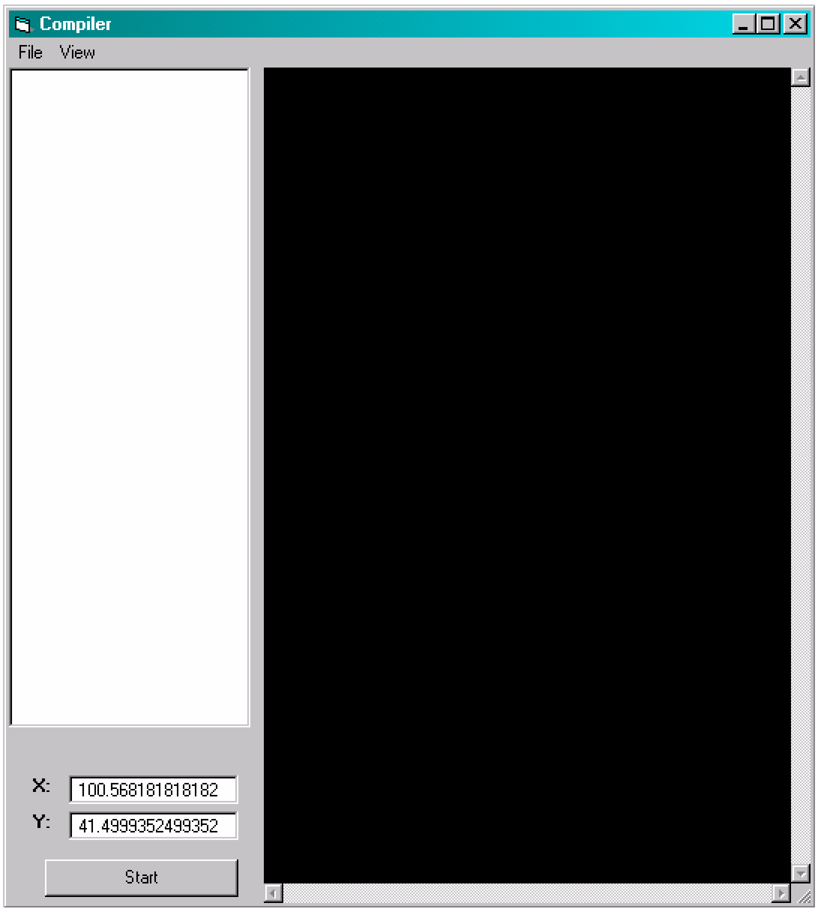

Figure 4: Screenshot of main window of Compiler.

Field segment contains four different components: Sensor, Core Reference Station (CRS), Reserved Reference Station (RRS) and Control Centre (CC). Sensor is the GPS antenna / receiver mounted on the monitored object to record the responses in terms of coordinate. The number of the sensors depends on the requirement or purpose of the monitoring. CRS is the reference station to the Sensors. CRS broadcasts the real-time corrections to Sensors using an external device (e.g. radio link). RRSs are the stations employed to form a network with the CRS for reference station stability checking. CC is the component where the results are presented.

## Outlier Filtering

GPS positioning is highly time-correlated. For this reason, the GPS positioning trend is learnt for filtering the outliers, so that the reliable deformation detection can be made. The positioning trend is learnt using a method called Normal Point (NP). NP is the average of the last certain epochs of data. From the NP obtained, an appropriate tolerance extent is given to establish the threshold for detecting the outliers. This threshold is called Local Threshold (LT). If outliers exist, they will be removed and will not be taken into generating the next NP.

From the original point or initial point, the required / desired tolerance extent is given to establish the threshold, which is referred as Global Threshold (GT), for deformation detection. When the recorded responses of the monitored object cross the LT and GT continuously for a certain number (preset), the deformation is then recognised. Deformation detection in real time provides great opportunity to secure public safety (e.g. siren wailing, auto-dialling, etc.). Figure 5 below shows the time series of the NP generated from the same sampled RTK dataset as mentioned above (Figure 2).

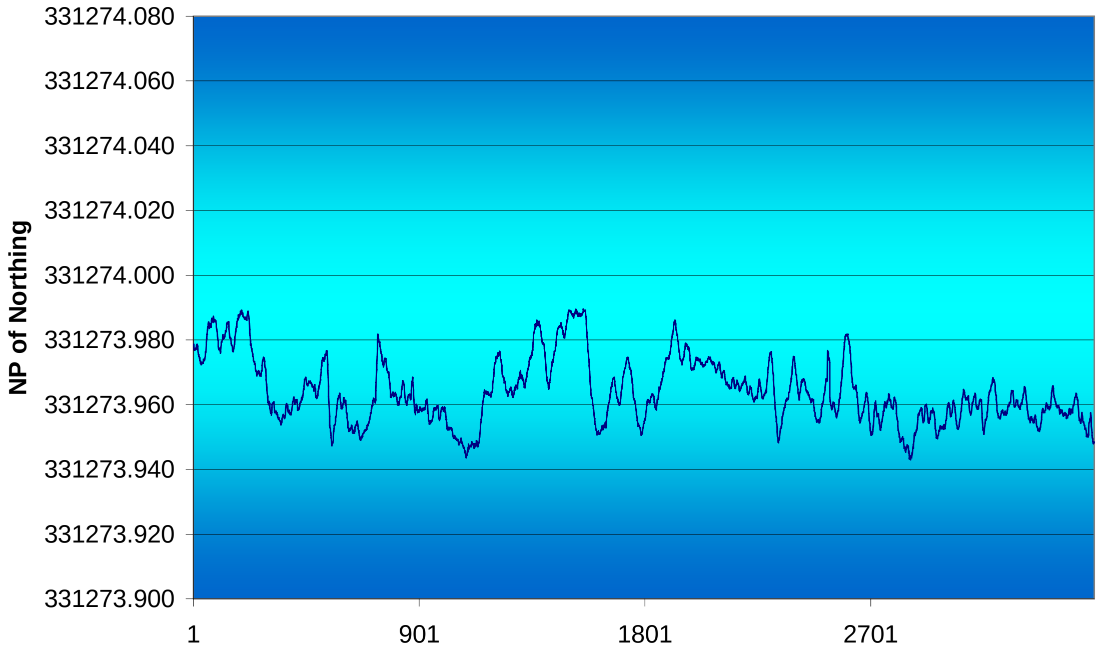


Figure 5: Time series of NP generated from the sampled RTK data.

## Reference Station Stability Checking

RRSs are particularly included to form a network CRS for reference station stability checking. For this reason, CRS is not only used as the reference station for broadcasting the corrections to Sensors for RTK solution, but also used to collect the base data for static positioning. In usual surveying practices, only either one of the positioning is employed for one station. The collected base data are then used to check the reference station stability using any of the statistical estimation. When the base data is collected and processed, an in-house software, GPSAD2000 (Setan and Bong, 2001), that features least squares estimation (LSE) of GPS baseline vectors and 3-D deformation detection (via congruency testing), is then used check the stability of CRS. If the CRS is found to be unstable or disturbed, one of the additional GPS stations (RRSs) can then be used to substitute for the disturbed reference station.

## RTK Quality Identification

In past result presentation, a simple "coded" Excel workbook (History.xls) is used to present the response which are grouped in every one hour. The result include:

i) time series of the three-dimensional position,
ii) time series of variation of the three-dimensional position,
iii) time series of NP of the three-dimensional position,
iv) time series of the combined three-dimensional position, LT and GT,
v) standard deviation of the dataset, and
vi) number of failed data (that crosses the threshold).

Using GALT, variation is the difference between one data and its previous one. Variation is particularly used to identify discontinuity of RTK data (which may be caused by the cycle slips). Discontinuity of data is more observably identified through the time series of Variation than the time series of position (purely RTK data). Figure 6 and 7 show the time series of sampled RTK data and the Variation of the same dataset.

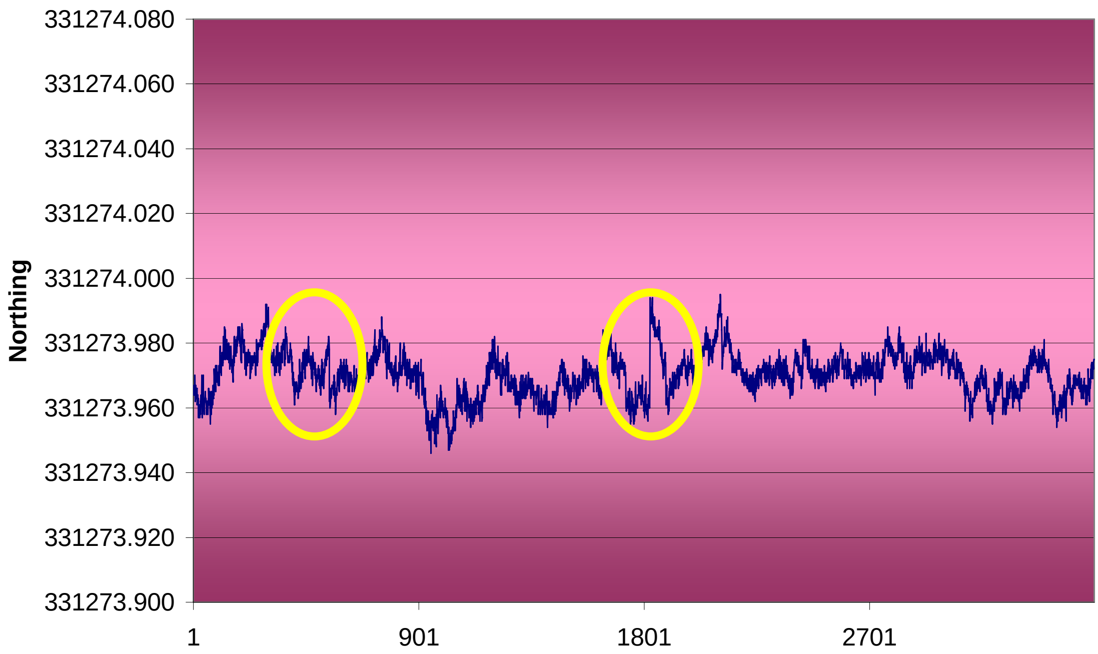


Figure 6: Discontinuities (yellow ovals) of sampled RTK data.

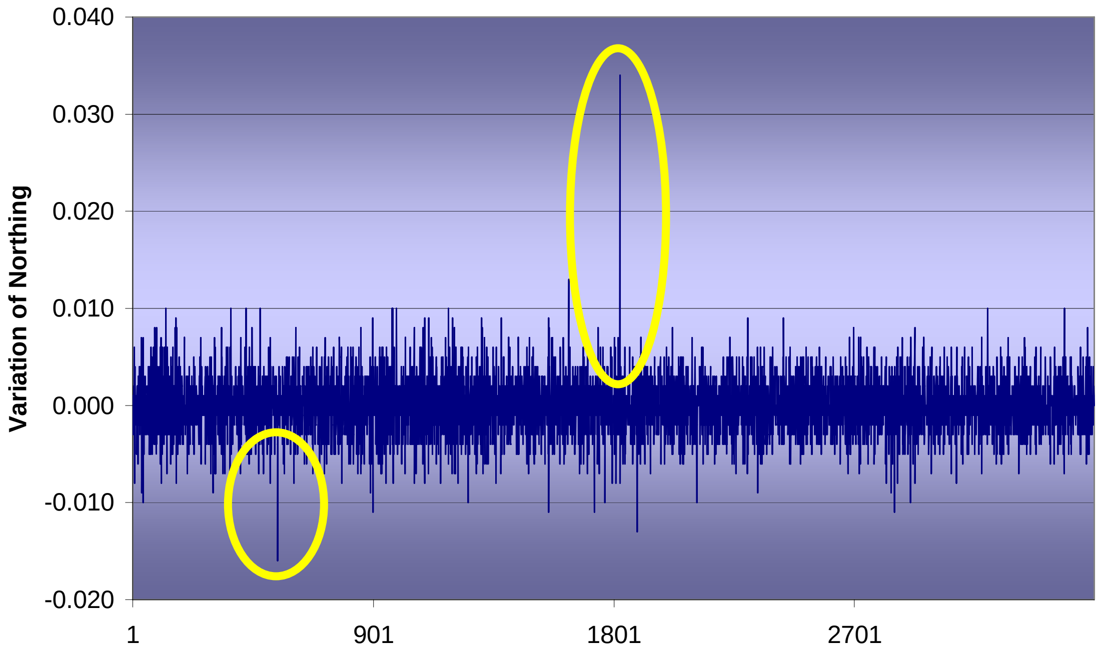


Figure 7: Discontinuities are more noticeably shown in time series of RTK data variation.

Figure 8 below shows the time series of combined position (RTK data), LT and GT of the same sampled data as shown in Figure 6.

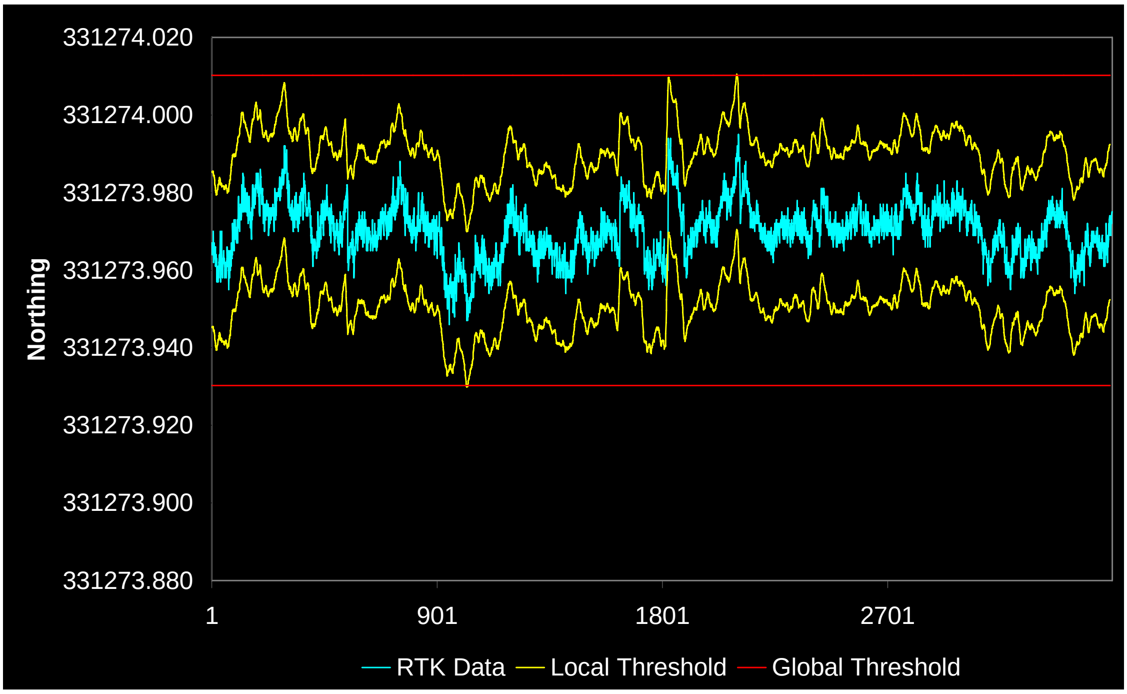


Figure 8: Time series of combined RTK data (position), LT and GT.

## FUTURE WORK

In the research, the result is only presented in time domain. It is suggested to add in frequency-domain result presentation using Fast Fourier Transformation (FFT).

Currently, the result could be presented in frequency domain manually using MATLAB. As a result, it is recommended to plug in the FFT in the software as a fully automated and customizable monitoring solution.

In addition, it is also recommended to extent the easy-accessibility of the solution to internet-based application. To put it simply, the CC is to be turned into a server so that users can access (to terminate the monitoring, to replace the unstable CRS with one of the RRSs, etc.) the project away from CC.

## CONCLUSION

GALT offers the automated GPS-RTK based deformation monitoring application. GALT features three main functionalities: outlier filtering, reference station stability checking and RTK quality identification. The functionalities make the pure RTK solution able to be employed in online and continuous deformation monitoring.

## REFERENCES


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