Ultimate Advance in GNSS RTK Monitoring Accuracy

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SUMMARY

Nowadays engineers are considering more and more the resource of GNSS RTK for their monitoring projects not only because of the inherent advantages provided by the GNSS but mainly because of the high accuracy and the sampling rate. They often process the time series delivered by standard GNSS RTK grade receivers in the frequency domain to retrieve information that are compared with values from the structure design (Finite Element Model) and correlated with other sensors.

To achieve such GNSS RTK highest accuracy in monitoring projects, they are keeping the baselines between the reference station and the monitoring receivers as shorter as possible with the problems that the reference station could by inadvertence be installed in the deformation area itself or the signals tracked by the GNSS antenna obstructed by the structure itself. This is the case for bridges and buildings for instance.

In that paper, the authors present a new conceptual methodology with the results of a first trial in the Hong Kong area where clearly the results of single GNSS RTK were affected especially in the afternoon period of time by the ionosphere turbulences typical in areas located in low latitude bands.

Fortunately and essentially for that reason, a GNSS Network RTK has been installed some years ago by the department of geodesy of the Hong Kong Lands Department Administration. So the idea developed by one of the authors (Chris Rizos) years ago to combine a GPS Network with low cost single frequency receiver (GPS L1) in Indonesia for volcanoes monitoring has encouraged the combination of a sub-set of the Hong Kong GNSS Network RTK (cluster) with GNSS monitoring receivers and even single frequency GPS L1 receivers in a pilot project to evaluate how much the results could be unbiased and uncorrelated from the ionosphere remaining large errors for sea walls health monitoring case.

The first results are indeed very promising and the comparison between single GNSS RTK and the one obtained by using the GNSS Network RTK corrections opens just a new era for GNSS monitoring in real time. Post-processing operations can also benefit of the GNSS Network support but has not yet been investigated in that present case however.

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1. SINGLE GNSS RTK FOR MONITORING

With the advent of powerful GNSS RTK processor, engineers who are involved in monitoring projects are considering more and more that technology for getting results that would even not be possible before. They often express however the results of the 3D time series into the frequency domain and compute the correlation between different epochs.

However and because of the inherent errors that affect the GNSS signals, the distance between the GNSS monitoring stations and the GNSS base station must be kept as short as possible with the risk that even the GNSS base station could be located in the area subject to deformation. In some cases even the object is causing signal refraction and in the worst case reduced signal availability impacting on the geometry (GDOP) of the solution.

To prevent an interruption of service, it has also became a good practice to consider more than only one GNSS base station to surround the monitoring project. But the single RTK results that are processed even if the noise is scaled down by the short distance between the GNSS base station and the GNSS monitoring receivers still contain biases from the remaining un-modeled atmospheric corrections.

This is much more annoying in projects located in the low latitude band where the ionosphere turbulences can simply prevent the use of GNSS RTK in the local afternoon period of time.

Needless to mention that when the GNSS monitoring project contains more than one reference station, a network adjustment of the baselines is requested to provide the best linear unbiased estimates (BLUE) and this is rarely considered or simply ignored if not available.

2. GNSS NETWORK RTK

The GNSS RTK specialists know very well that this distance dependency between the GNSS base station and the GNSS receivers can seriously affect their productivity. This is the reason why the GNSS Network RTK infrastructures are deploying intensively worldwide today to mitigate most of the atmospheric and geometric errors affecting the GNSS signals.

A GNSS Network RTK is a network of permanently installed reference stations streaming in real time and simultaneously their observations to a central computing facility. With the deployment of high speed broadband Internet communication lines the operational expensive are largely mitigated. The reference stations are located on very stable sites and the coordinates of their antenna phase centre are determined with a relative accuracy of few millimeters.

In the central computing facility, a software is processing all the observations to estimate and model the residuals (computed observations – measured observations) largely spoiled by the remaining non modeled errors and to derive the so called corrections that has to be transferred to the RTK rovers on the field and in real time using standardized data format.

In monitoring projects the engineers are trying to keep the baselines between the base station and the monitoring receivers very short to avoid sudden jumps and non-Gaussian noise in the results. However short ranges cannot be fulfilled in every case (especially for monitoring high-rise buildings in city area) and even worse, the countries located in the low latitude band (+/- 23° latitude) can encounter – even with short distances – issue to fix the ambiguities in their afternoon local time. The solar activities that will increase again till a maximum expected around the year 2011 will definitively present a challenging situation.

In the low latitude regions, the use of GNSS RTK for monitoring can even be questionable but as there is no other competitive solution; the engineers often try to stay confident about the results of new developments. And this is the topic of that paper.

Basically the resource of a GNSS Network RTK must be available to surround the deformation area. If three (3) reference stations are the minimum a GNSS Network RTK software can process, the authors recommend however to consider five (5) reference stations for a better modeling with enough redundancy to increase the estimates accuracy.

The monitoring receivers deployed over the deformation area will stream their observations to a PC server running the GNSS Network RTK modeling software while GNSS Network RTK corrections will be generated in real time and integrated as Master Auxiliary or Virtual Reference stations in the baseline processing. The results obtained for the monitoring receivers will integrate all the network corrections and a further adjustment of the baselines not needed anymore.

Because of the contribution a GNSS Network RTK can offer, there is more and more worldwide coverage of such positioning infrastructure. Interesting enough is that in the area that engineers are deploying monitoring projects often a GNSS Network RTK is planned, designed or even implemented already.

And if a large monitoring project is standing in the middle of nowhere? In that case the benefit will be considerable to deploy some reference stations more than the only one as today. The good news is also that GNSS and GPS L1 monitoring receivers are today very accurate at an affordable price. The investment in more reference stations to surround the deformation/monitoring area will be less than ever and the effort will pay off immediately.

3. PRACTICAL TRIAL IN HONG KONG

For demonstrating the benefits of GNSS technology for monitoring sea walls a pilot project in Hong Kong has been setup by an engineering company. They were using equipments and software's produced and delivered by Leica Geosystems.

Fig 1: GPS monitoring antenna installed on a sea wall in Hong Kong.

The Leica GPS GMX902 dual frequency monitoring receiver and the Leica GNSS AX1202 antenna have been installed with power supply and the communication equipment in a all weather proved cabinet.

Fig 2: GPS receiver Leica GMX902 with power supply and communication interface

The reference station – in that project even two reference stations have been selected initially – were provided as a service by the Hong Kong Lands Department Administration, department of Geodesy. Those stations are in fact part of the Hong Kong Satellite Positioning Reference Station Network.

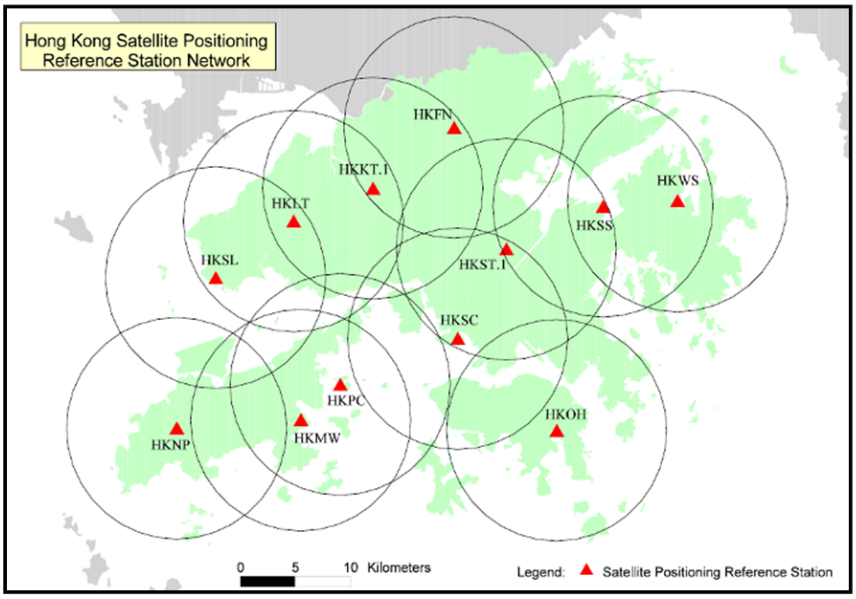


Fig 3: The Hong Kong Satellite Positioning Reference Station Network

The processing of the real time data was based on the centralized RTK processing software Leica GNSS Spider Positioning.

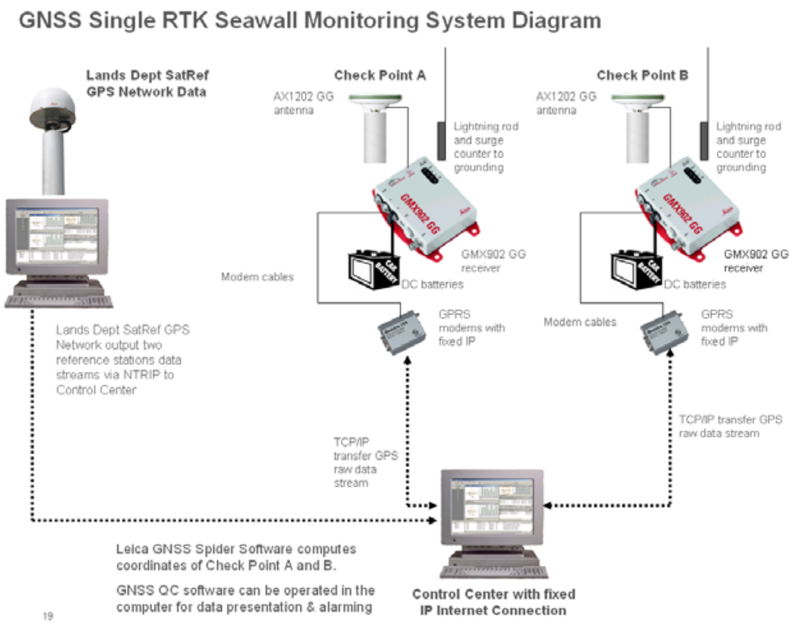


Fig 3 : GNSS Single RTK System Diagram

It appeared however quite clearly that in the afternoon period of time but also randomly sometime along the day, sudden jumps occurred in the time series (Easting, Northing and Height) making the analysis difficult or even impossible. It should be noted that variation in GPS RTK time series are something users have to coop with and usually smoothing and filtering are part of the process. But in that case it was clear enough that the outliers were containing large biases resulting of the chaotic ionosphere conditions.

After a meeting with the engineering company who reported by the way other similar cases occurred in other monitoring projects in Hong Kong, the authors decided to contact the Hong Kong Lands Department Administration – Department of Geodesy, to present the case and to request their assistance in delivering the real time data streams of several reference stations located in and around the monitoring project. The director of the Department of Geodesy acknowledged the interest of such study and even manifested his interest to see how the Kong Satellite Positioning Reference Station Network services could be used for new type of users.

Leica GNSS SPiderNET software has been installed with the necessary options to process the network cluster and to redirect the RTK network corrections as observations for one of the closest reference station located nearby the monitoring receivers. That reference station acted as a MAX station (RTCM v3.n Master Auxiliary Concept) in the Leica Spider site server (Positioning option). It should be underlined however that any other reference station participating to that cluster would have been selected without affecting the results.

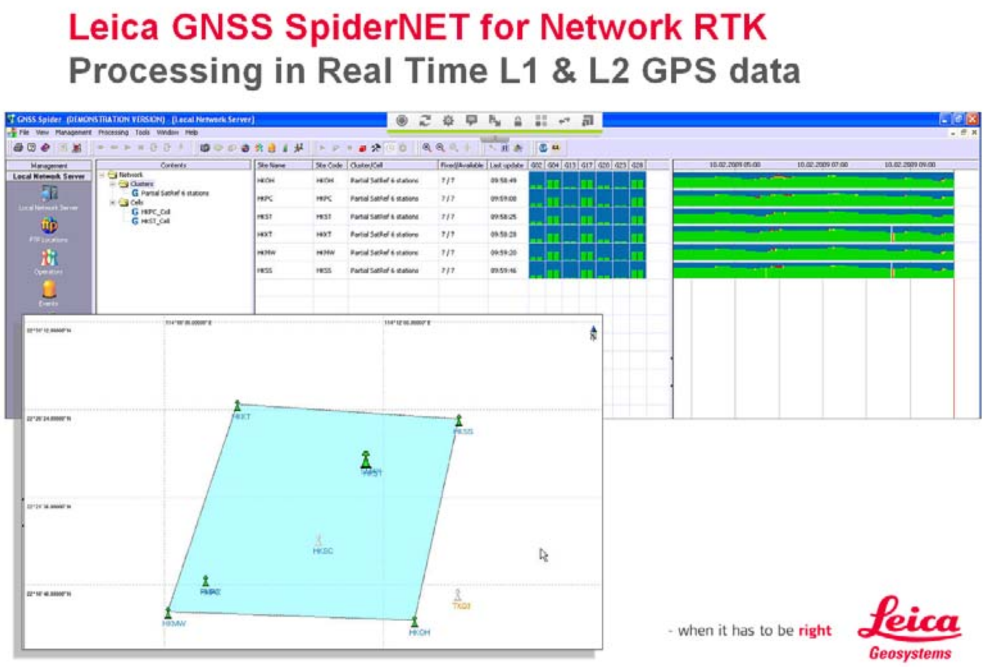


Fig 4 : GNSS Network RTK

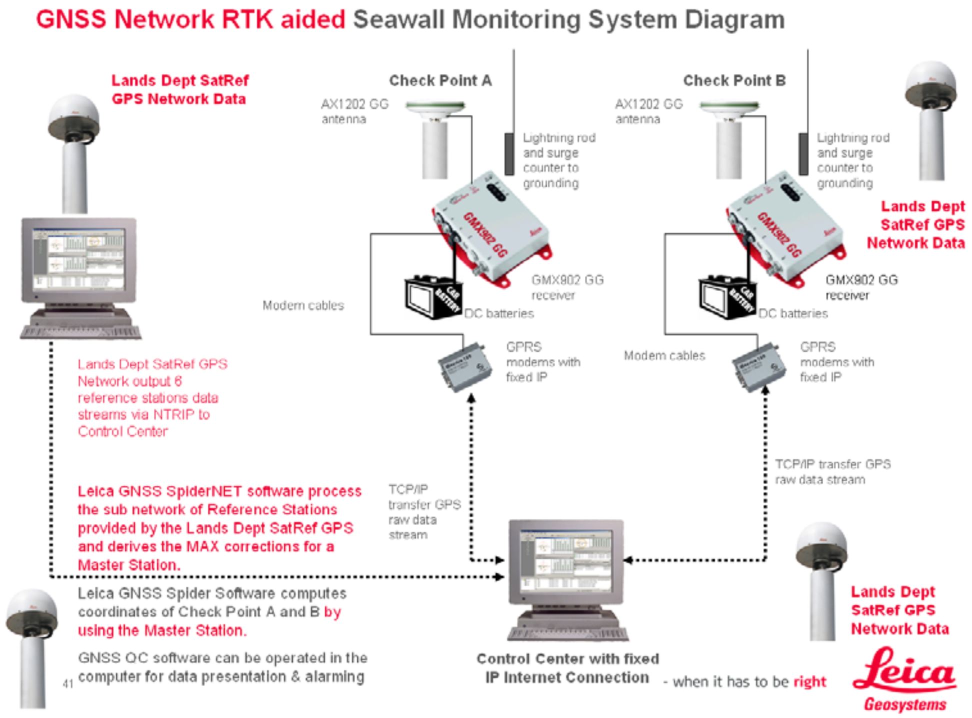


Fig 5: Cluster of GPS Network RTK System Diagram

Comparison has been made between the “standard” single GPS RTK and the GPS Network solution in 2D and in height by using the Leica GNSS QC software.

The graphics show clearly how the GNSS Network RTK corrections are improving dramatically the results.

The results presented here are not filtered or smoothed as they were just the output in the NMEA format of the baselines solutions computed by Leica GNSS Spider Site server – positioning option.

It’s clear enough that a recursive low pass band filter (Exponential Weighted Moving Average) could now be successfully applied on those unbiased results to deliver a few millimeters accuracy and in real time.

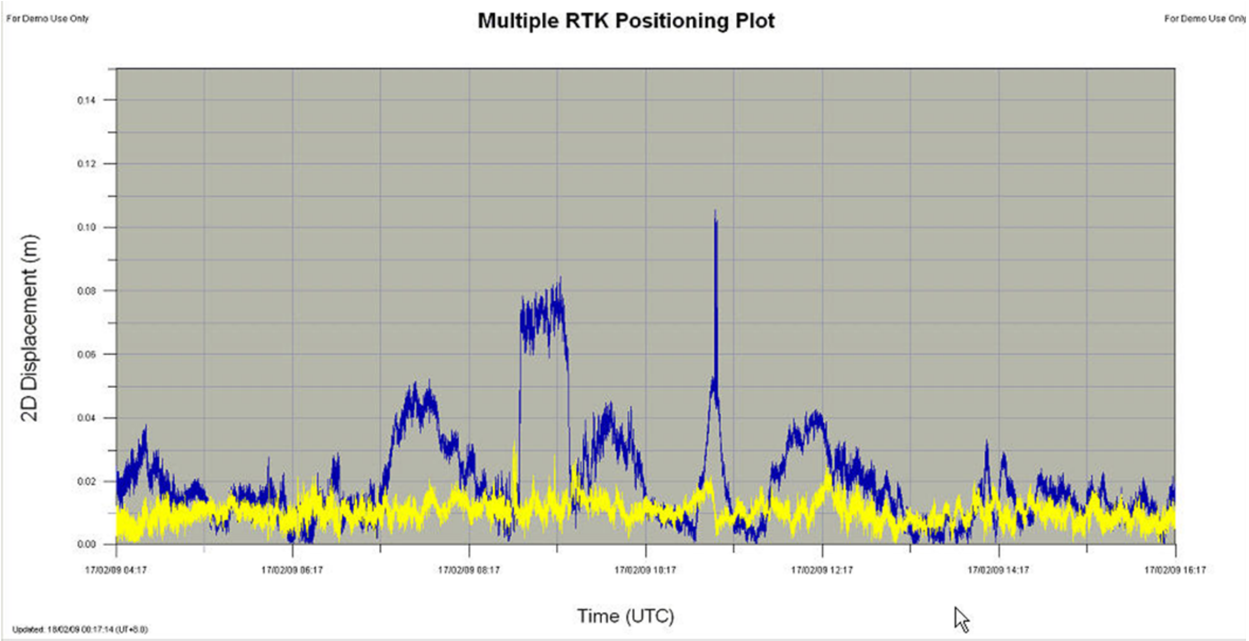


Fig 6: Multiple RTK positioning 2D Plot – Leica GNSS QC software- the blue line is the single RTK solution and the yellow line is the GPS Network solution.

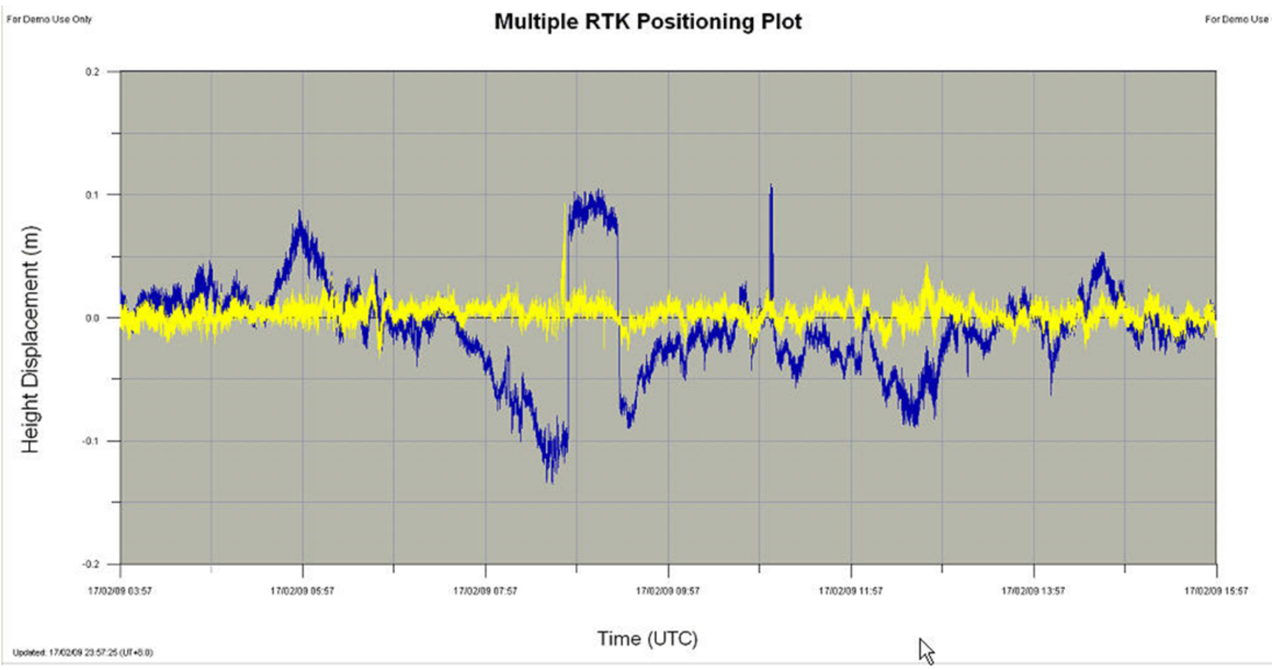


Fig 7: Multiple RTK Positioning Height Plot – Leica GNSS QC software- the blue line is the single RTK solution and the yellow line is the GPS Network solution.

In the same time and to verify how single frequency GPS L1 receivers could also benefit of a GPS Network solution, it has been decided to process jointly and simultaneously also the different baselines using only the GPS L1 frequency.

The "Quasi-Static" method of initialization has been selected to allow fast L1 RTK.

In that case the results are even more impressive in term of initialization (ambiguities resolution) and accuracy.

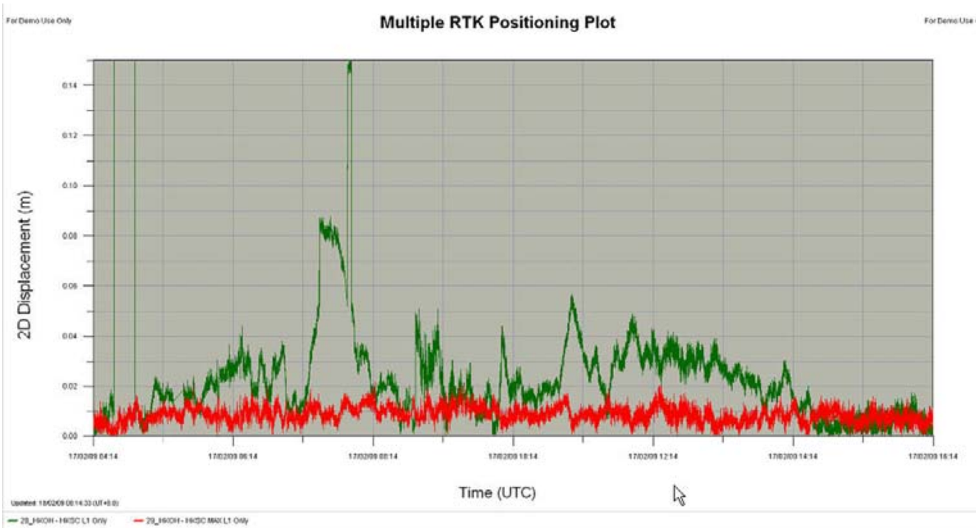


Fig 8: Multiple RTK Positioning 2D Plot – Leica GNSS QC software- the green line is the single RTK L1 solution and the red line is the GPS Network solution.

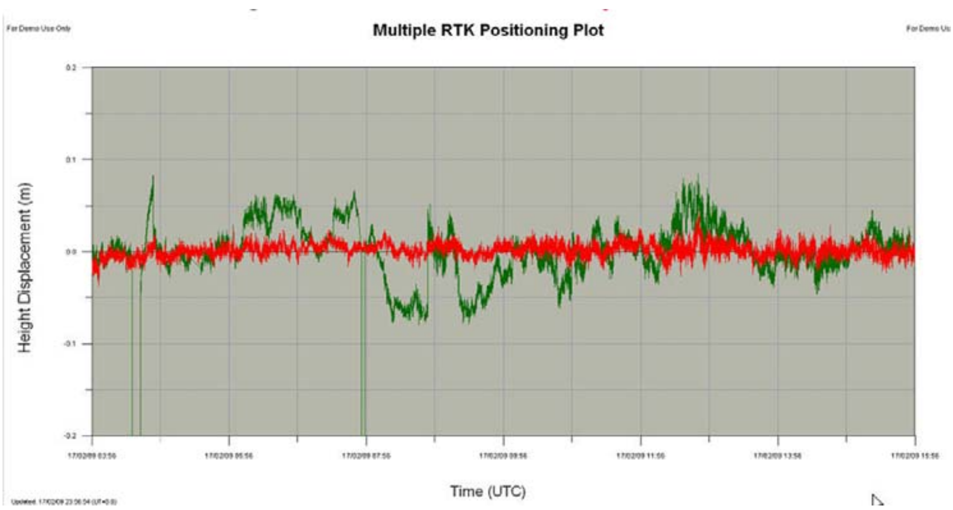


Fig 9: Multiple RTK Positioning Height Plot – Leica GNSS QC software- the green line is the single RTK L1 solution and the red line is the GPS Network solution.

4. CONCLUSION AND PROSPECTIVE

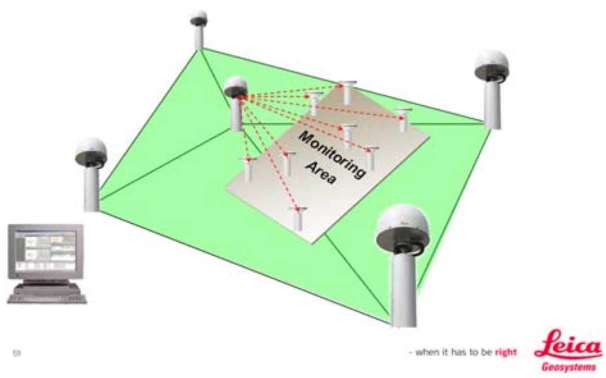
The practical results are demonstrating that the combination of GPS Network RTK resources within a GPS Monitoring projects have outstanding advantages such as maximum (unbiased) accuracy and reliability with effective quality indicators that allow the responsible of a monitoring project :

- To better control the operations and the results,
- The lonely solution for projects located in the low latitude band where the ionosphere turbulences are affecting severely the signals processing,
- The possibility to mix dual frequency receivers (GNSS Network) with affordable single frequency receivers for slow motion operations,
- No need of networked baselines adjustment,
- No need to establish single base station in urban area (obstructions) for high rise building monitoring and bridge monitoring projects e.g.

Implemented for a trial in Hong Kong area with the support of the HK Land Department Administration, the authors believe that with the return of highest peaks in the sun activities, that solution will have to be considered in other places than only those exposed in ionosphere turbulences due to their low latitudes.

Actually the authors are also working on effective projects like in South Korea and will present their results in other publication. The support of a GNSS Network can be also beneficial for monitoring operations in post-processing mode and will be also investigated by the authors.

At the end, the authors would like to express their gratitude to Simon Kwok, director of the Geodetic Department of the Hong Kong Lands Department Administration for his support during the trial.



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