

Combining Cors Networks, Automated Observations and Processing, for Network Rtk Integrity Analysis and Deformation Monitoring

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Key words: GNSS, networks, monitoring, CORS, hazards

SUMMARY

GNSS CORS networks are providing new opportunities for public and private sector business for a variety of positioning needs. This paper will explore how networks and GNSS based monitoring technology advancements are combining to open new markets for positioning technology. GNSS methods and monitoring will be explored, along with the role of the surveyor in implementing this technology. These trends include the installation of active GNSS control, automation of observations and processing, multi-observable and multi-constellation observations, and the importance of network integrity management for RTK services. This presentation will explore the combination of an existing GNSS CORS network with project specific installations used for GNSS based monitoring. Examples will be drawn from international examples of hazard management and engineering projects where GNSS based monitoring is providing new insights. Experience is showing GNSS is able to provide a new level of comparatively high resolution data, which is providing new insight for decision makers and financial planners.

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1. INTRODUCTION

Global Positioning Systems (GPS) technology has revolutionized the way we realize location and changes of position over a broad range of spatial and temporal scales for an ever expanding range of applications. In addition to this, user friendly Geographic Information Systems (GIS) are becoming a part of everyday life. We are now much more knowledgeable about where things are, where they were, when they are where they are, what path they took to get there, and how we can communicate that to our clients, colleagues, or friends. This paradigm shift has been particularly visible in the surveying, mapping and construction industries where locating something quickly and precisely saves time and money and ultimately in some applications may even save lives.

GPS, the most famous and widely used Global Navigation Satellite System (GNSS) is operated by the US Department of Defence. Other nations are seeing benefits to running satellite based positioning systems and several projects to build satellite based positioning systems are under way. Other examples of GNSS include the Russian GLONASS system, European Galileo project, and the Chinese Compass system. Today, only GPS and GLONASS operate with global coverage that is usable in the field, but this will imminently change in the next 5-10 years.

This expansion of the available GNSS and improvements in the receiving technology and processing software has prompted growth in the ways in which GNSS can be used to streamline survey and particularly monitoring operations. Through technological improvements in GNSS and communication technologies, we are now able to perform monitoring with GNSS that provides a high rate of observations easily obtained and intuitive for analysis. This paper explores the core GNSS components that need to be understood for full realization of GNSS based monitoring around two themes of integrity management for RTK networks and deformation monitoring for structures and hazards.

2. POSITIONING WITH GNSS

GNSS positioning has two main methods of computing the location of an object. One is based on the time delay seen between the generation of the signal at an orbiting satellite and the arrival of that message at a receiver, usually called “code based” or “autonomous” positioning methods. The other is based on computing how many full cycles the carrier wave of the signal being processed travels through between the transmission source (satellite broadcast antenna)

and the receiving source (GNSS antenna). A brief, somewhat simplified, explanation of how these work is provided through section 2.

2.1 Code/autonomous positioning

All GNSS satellites have onboard extremely precise atomic clocks. GNSS receivers do not, but by tracking signals from four or more satellites, a receiver can synchronize its clock for timing computations. The code transmitted from GNSS satellites includes a time stamp which identifies what point in the message the transmitting satellite is at. All GNSS receivers know these codes, referred to as Pseudo Random Code (PRC), and similarly an identifier is given to each satellite which is its Pseudo Random Number (PRN), identifying its PRC. Any GNSS receiver knows exactly what this code looks like, and is repeating it and matching it with the as-received signal from each satellite. We know the radio signal travels at the speed of light, and thanks to a satellite almanac also transmitted in the signal we also know exactly where every satellite is. From here, it's a matter of calculating the distance travelled by the signal, taking the difference in time from the transmitted version to the version the receiver made itself. If you calculate this for four satellites as shown in Figure 1, it is possible to locate the intersection with about 10 m precision horizontally. (Some methods allow this calculation with three satellites, but accuracy can be greatly degraded.)

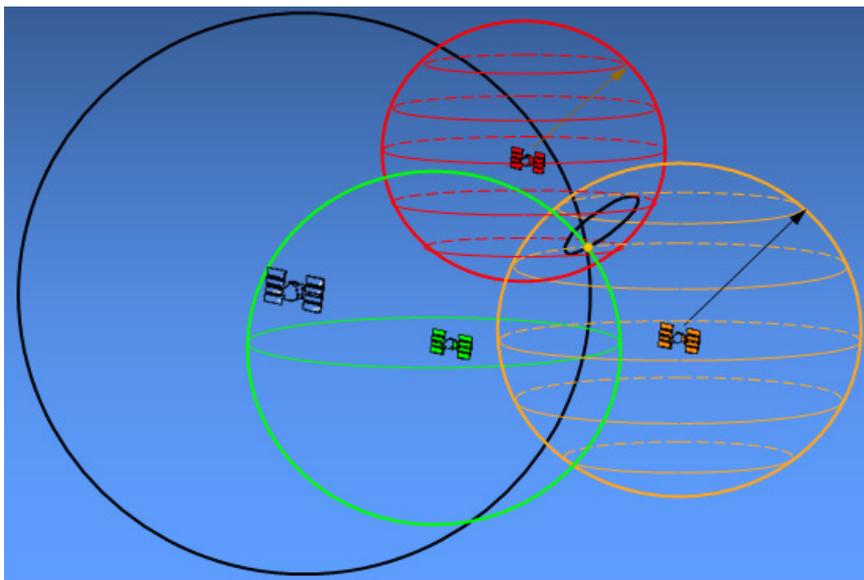


Figure 1: The intersection of four satellite signals in space produces one position (yellow dot). Earth not shown in this image.

Early mariners figured out where they were from star charts and *triangulation*. Similar to this, code-based GNSS positioning uses satellites as known stars in the sky and uses the calculated *distances* from these to locate the receiver. This method is generally described as *trilateration* – using known distances computed by intersecting the distance the signal has travelled from multiple satellites, from the transmitter to the user at the point of intersection. The black arrow

in Figure 1 represents one of these distances. All GNSS positioning tools use this method, including consumer market GNSS like in-car navigation systems, and also the high precision survey and construction equipment. This method can also be employed by a single GNSS receiver, there is no additional point of reference needed other than the satellites themselves.

2.2 Carrier phase positioning with traditional base and rover

Achieving sub-centimetre precise results for monitoring with GNSS requires another level of processing in addition to the code based techniques, and requires an additional Earth based point of reference. At a minimum we need two GNSS receivers, often referred to as a base and rover. (This pairing of base and rover has matured in recent years to the point now where many observations use a reference *network* and a rover. Further explanation is given later.) Carrier phase processing uses the position established using code techniques as a starting point and from here computes the number of wavelengths the GNSS signal travels through in its journey from the transmission source at the satellite, through the atmosphere, to the receiving antenna on the GNSS receiver. In the GPS system, two signals are transmitted currently, known as L1 and L2. L1 has an effective wavelength of 19cm, and L2 24cm. GPS satellites orbit at around 20,200km above the surface of the Earth, so some pretty large number combinations are computed when you consider at times there may be around 14 GPS (and maybe 6 GLONASS) satellites in view. (This process is known as initialization, or resolving the integer ambiguity, the unknown number of wavelengths between GPS satellites and GPS receivers.) Figure 2 depicts the intersection of wave fronts of GNSS signals as seen by the GNSS receiver.

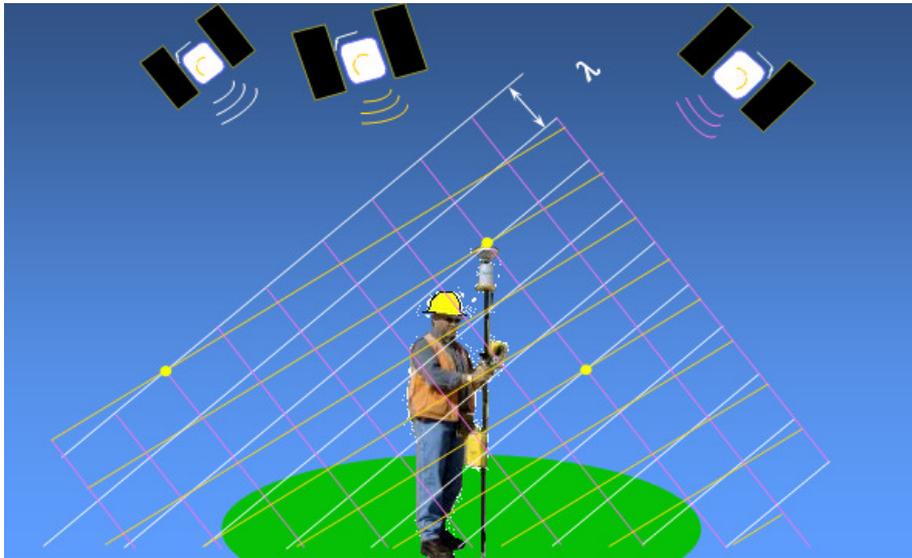


Figure 2: Two dimensional representation of the intersecting waves of L1 signals from three satellites. A 3 dimensional lattice of intersecting wave fronts is represented depicting the potential initialization values (true position of the antenna - yellow dots in image) within the search window defined by the code-based position calculation. The GNSS receiver must statistically prove which wave intersection is in fact the GNSS antenna, and which are false answers. The process takes a few seconds, and once computed the system is ready for centimetre level surveying.

The “base” acts as a point of reference for computations, and observed carrier phase differences between the rover observations and base observations are computed. A baseline between the rover and base is established, and the statistically proven result is called a vector, and this yields the highest precision of any GNSS positioning method. Surveying historically required one base as the fixed point of reference, and one or multiple rovers using that point of reference to compute their location by processing a vector result, either in real-time or in a postprocessed sense. In real-time, this vector can be computed with sub-centimetre precision if a network solution is computed from a number of reference stations, explained more in the following section 3.3. If only a single GNSS receiver is used as the reference (base), the greater the distance from the base, the larger the distance dependent error or part-per million (PPM) grows for the rover. Typically 1cm horizontally of additional error per 10km of base-rover distance is added when only a single base is used, with some additional component for the type of rover used. (Vertical performances of GNSS positioning methods are typically 1.5-3 times worse in the vertical – depending on the GNSS constellation and observing environment.)

The precision achieved with carrier phase processing is necessary for any monitoring application, and it can be achieved in two ways previously mentioned, via postprocessing or real-time observations. It is possible to set up a receiver on a portable, stable mount and record the observed GNSS data, for postprocessing against base station data back in the office. This is sometimes called static surveying. Postprocessing can yield a small gain in precision (around the millimetre level) and does not need any real-time communications, but typically the productivity gains from getting the results in real-time and with very quick observation times (seconds) far out weigh the small gain in precision postprocessing gives. Postprocessing requires longer observations times, stringent observation techniques, and after-the-fact in office processing. There may be days between observation and result calculation. Where a cellular data or radio link is available between the base and rover, it is also possible to compute a carrier phase GNSS position in real-time. Real-time survey is often referred to as RTK, short for real-time kinematic, and as the name suggests the results are in real time and movement is involved. RTK requires real-time communications between the base and the rover so that the rover can take the observed data from the base in real-time, and do all the processing.

GNSS receivers capable of both carrier phase and computations for postprocessing or RTK are often called “survey grade” receivers. Survey grade receivers are necessary for monitoring.

2.3 Carrier phase positioning with a network solution

Frequent GNSS users are installing networks for several reasons. There are significant economic benefits to any region installing a GNSS network. Also, permanent reference stations (Continuously Operating Reference Stations - CORS) can be installed at secure

locations and do not require a human guard. Plus, once a network is in place, users can focus more personnel and financial resources on rovers. A CORS network in place can provide data to a wide variety of applications, from surveying, mapping, agriculture and construction to more scientific work such as plate tectonic studies and water vapour modelling.

The description of carrier phase positioning so far in the paper has focused on the concept of a base and rover. The PPM error observed at the rover and the logistical constraints (i.e. power, security, human resources, and setup) of running the two separate pieces of hardware have been motivations for the development of wide-area *network* solutions for the rover. Wide area networks are prolific throughout the world. (A network is typically 4 or more permanently installed GNSS receivers, controlled by central processing software.) In 1998 Trimble Navigation Ltd introduced a method of surveying with a non-physical or computed base station, called Trimble VRS. VRS is the most reliable, most compact and most widely supported, method of producing a network solution for precise carrier phase positioning in the industry. VRS is an industry accepted standard for computing a network solution.

The power of VRS is in the ability to compute a real-time wide-area solution to the unknowns (PPM) that cause single base methods to degrade with distance. Namely, ionospheric and tropospheric modelling, and satellite orbit corrections. This is achieved by the reference network of CORS. A wide scattering of CORS across a large geographic area, typically 50-70km spacing in mid-latitudes, creates a ground based sampling which enables wide –area modelling to significantly reduce the PPM errors that accumulate in the single base-rover relationship described early. In addition to this, a network of CORS stops gross errors occurring caused by a base coordinate that is incorrectly entered, and all the purchasing and logistical problems of running your own base stations are eliminated. Essentially the VRS improves the precision by doing three things:

- Ionospheric modelling – Ground based stations allow the network to determine the localized affects of the ionosphere on GNSS signals as they pass through them, and to compute correction parameters.
- Tropospheric modelling – wet atmosphere introduces delays to the GNSS signals, and the wide area network solution is able to refine models of these delays.
- Satellite orbit improvements – By downloading and applying ultra-rapid orbits, VRS is able to improve the real-time coordinates used for the satellites we position our rover from. By knowing better where our points of reference are, we can better determine the rover’s locations.

The performance of VRS is so good it’s like your reference station is right there with you all the time, eliminating those distance dependant errors - a virtual reference station. Other methods exist for providing a network RTK solution to a rover including the RTCM committee Master Auxiliary Concept, or MAC. This method is also supported by a number of network RTK software solutions but is not discussed in detail in this paper as the bandwidth, processing requirements and supported GNSS are less conducive towards monitoring than those of VRS.

2.4 CORS – building VRS

To build a VRS, you need continuously operating reference stations or CORS spaced out over the focus geographic area. These are the full time operational base stations used as the fixed point for observations and modelling of the GNSS data used in VRS observations. CORS can be a single base station, or a small network of 4-5 stations, or large (global) networks of 1000s of stations. The spacing and geographic area covered vary depending on the focus of the CORS. For VRS the CORS should be evenly spaced around 50km apart, for science purposes the CORS may be clustered around an area of interest (i.e. volcano) or broadly distributed across a continent. Some CORS share dual roles in both and many science, public and private CORS operators are sharing hardware and data streams to reduce duplication where mutual benefit can be established.

CORS often have a primary and backup power source including combinations of solar, wind, battery or DC, and communications such as LAN Ethernet, GPRS or other.

2.5 An example of VRS creating efficiency and enabling monitoring

For the state of Louisiana, Hurricane Katrina has initiated a number of corrective policies and investment initiatives. One initiative for the state has been to invest in CORS and a Trimble VRS network, providing state wide coverage for real-time survey and construction users. Figure 3 shows a network coverage map for “GULFNet”. GULFNet is a CORS network providing real-time VRS and postprocessed data in support of surveying, GIS, agriculture and construction, and research in geology, subsidence, hurricane safety engineering and more. The network is run by the Louisiana State University’s Center for GeoInformatics (C4G) and is bringing together positioning professionals across Louisiana. Yellow circles with blue/white centres are the symbol for GNSS reference stations owned by GULFNet, red circles are supporting networks.

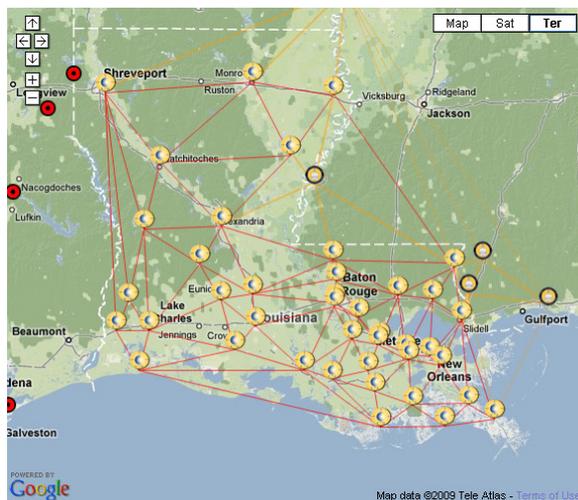


Figure 3 – GULFNet network coverage and permanently installed GPS/GNSS reference stations (source: http://geoinfo.lsu.edu/joomla/index.php?option=com_wrapper&Itemid=8 retrieved January 2009)

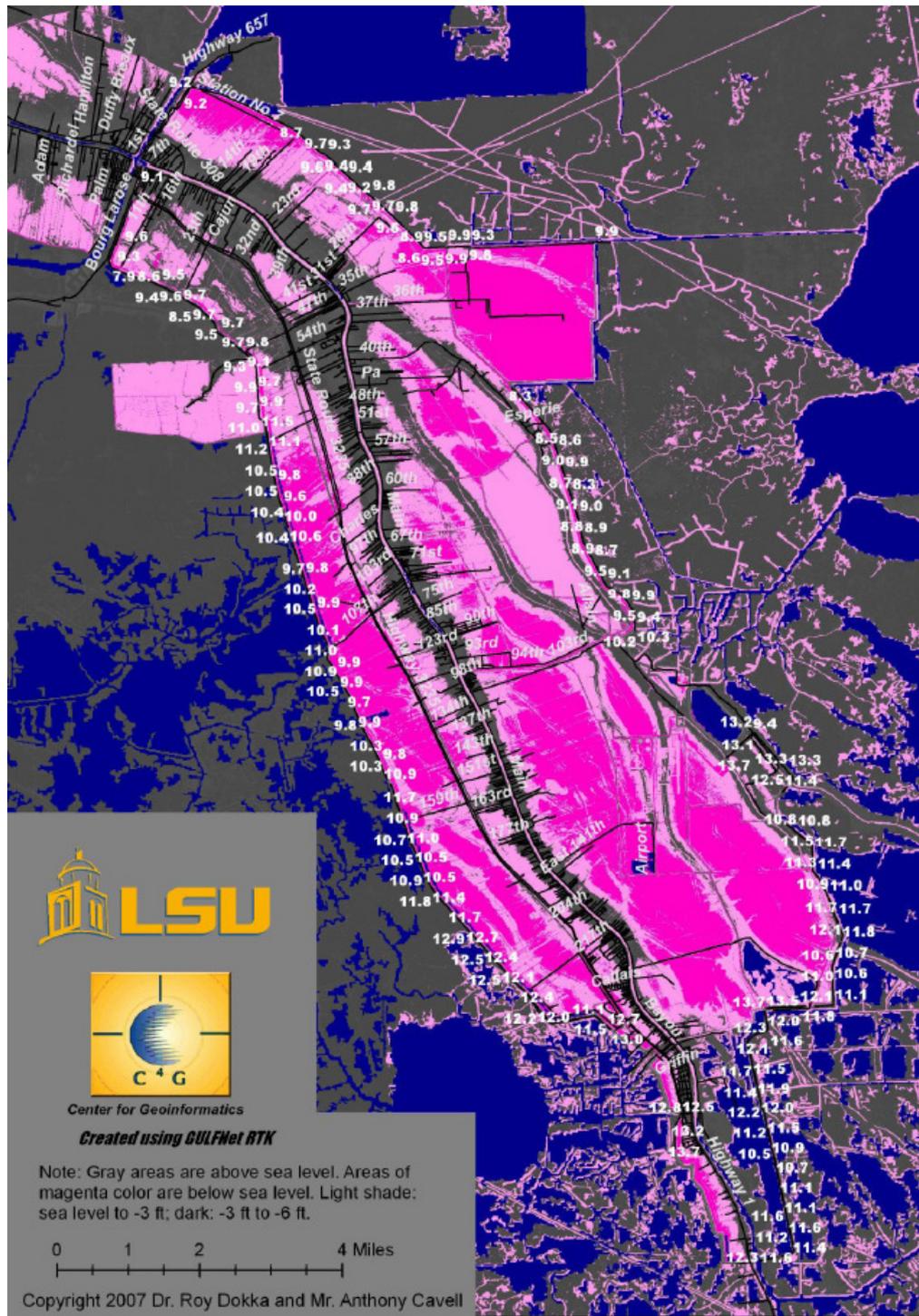


Figure 4 showing vertical data collected along levees in South Lafourche. Pink areas are below sea level, gray above. White numbers indicate levee height (source: <http://www.slld.net/lvmap.html> retrieved October 2008).

In 2006 new legislature was put in place that required levees in Louisiana are measured every 3 years. This was seen by some as too much to complete, cost estimates based on using traditional optical survey monitoring methods priced this at best \$400 per mile of levee. Using GULFNet, C4G was able to map all the levees at a cost of about \$100 per mile. *The project to measure every wall, sheet pile and earthen levee from Donaldsonville to the mouth of the Mississippi River cost about \$150,000 and took only three months—10 to 20 times faster than had it been done by conventional surveying* (Clark 2008). Figure 4 is one levee of 30-50 more now being surveyed yearly using methods developed by C4G and run by the individual levee districts and Corps of Engineers. More detailed benefits of using GNSS compared with other methods for maintaining vertical data are explored in a number of papers such as Berman (2005). Using CORS over a large area is one of the most cost effective and efficient methods of maintaining vertical data. Using the GULFNet VRS system, levee districts and Corps of Engineers are now able to observe true elevations yearly, at a cost far less than the original projected costs for 3 yearly observations. Already several levees have been shown to be 2-4 feet lower than the published pre-Katrina records showed (R.K. Dokka, personal communication, 28 January 2009). If this information had been available prior to Katrina, correct levee data would have provided better models for SLOSH (sea, lake, and overland surges from hurricanes) and other models, and motivated corrective actions better preparing the states engineering, structures, and event preparedness plans. The findings of work by C4G are proving the strength of the technology, and other groups in addition to the Levee Districts and Corps of Engineers such as the USGS are coming to visit to learn about and adopt the techniques (Collins et al, 2006).

Repeated in-field measurement and later in-office comparison of previous records with the most recent epoch is one method of monitoring a structure such as a levee. This method over time requires that reference stations (CORS) are closely monitored, so that any change in position reported in monitoring can take into account the migration of the reference frame CORS. Monitoring is highly intolerant of moving reference stations. Undetected, it can produce a false motion. It's critical any network provider be aware of this kind of application for the network and be able to provide reference details for users. This is one reason why public government providers such as Land Information New Zealand (LINZ) of New Zealand and the National Geodetic Survey (NGS) of the United States provide details of CORS motion using published time series data, enabling those using the CORS for monitoring purposes to be able to clearly identify what is actual movement at their monitored location and what may be larger scale motion caused by plate tectonics, ground water extract or other seasonal affect.

This becomes even more critical in network RTK situation where the set of network reference station coordinates must have minimized differences between actual and operational coordinates –a set of homogenous coordinates for reference stations. A network that moves as a single entity with similar trajectories and velocities for all stations has less of a problem, but

networks where reference stations diverge from each other and varying rates due to localised affects or plate tectonics, can experience unnecessary errors being passed to rovers as random error from least squares adjustments, buried in network RTK observables. These coordinate errors being to add PPM residuals to rover observations undoing the positive effect the network solution would otherwise have, compromising the rover's precision. All CORS networks offering RTK services need to have automated tools to manage the integrity of their solution.

3. INTEGRITY MANAGEMENT FOR CORS NETWORK SOLUTIONS

Network RTK providers need to be the first to know if their reference station moves an amount that could affect the quality of their service. In 2008 Trimble Navigation Ltd introduced a new product to the GNSS industry, one designed to help VRS operators track their CORS GNSS antennas so they knew immediately if their network solution was compromised by a shifted antenna. Whether it be an abrupt shift caused by vandalism or plate tectonics, or a slow moving long term trend such as subsidence. Trimble Integrity Manager software automates all aspects of GNSS methods for monitoring CORS antennas. This includes an automated postprocessed tool giving baseline processing and network adjustment results at user specified time intervals. Also, a server-based RTK technique combining multiple observed vectors for the solving of a real-time adjusted coordinate for an RTK monitored point. Additionally, two new methods including a Rapid Motion detection tool capable of detecting in real-time 3cm/second or faster movement over thousands of kilometres, and a network motion processor using ionosphere free delta phase measurements through a Kalman filtering approach to smooth GNSS noise and detect long term trends. Now, far more can be achieved than before. Data can be observed autonomously 24 hours a day, 7 days a week, 365 days a year using real-time communications, providing truly complete data for integrity management of CORS. Plus that data can be modelled using a variety of techniques to ensure the full spectrum of time scales (short-long term) and spatial scales (local-global) on which movement can affect GNSS antennas is analyzed and reported on.

Figure 5 contains two time series from an analysis engine showing a gradual slip in Figure 5a from mid-December 2008 through early February 2009. After a site visit, this was identified to be a loose antenna levelling mount, detected by this automated system and identified by the operator for investigation. (The spike in 5a is caused by a communications reset and does not indicate movement.) In 5b it is clearly visible where the off-level mount was corrected on May 28th 2009, and precision returned to about 1 millimetre after it had been drifting towards 5mm of error in the coordinate. Correcting this removes the unnecessary error from the calculations for network RTK solutions. It also ensures rovers operating in the vicinity of this reference station to operate with optimum precision.

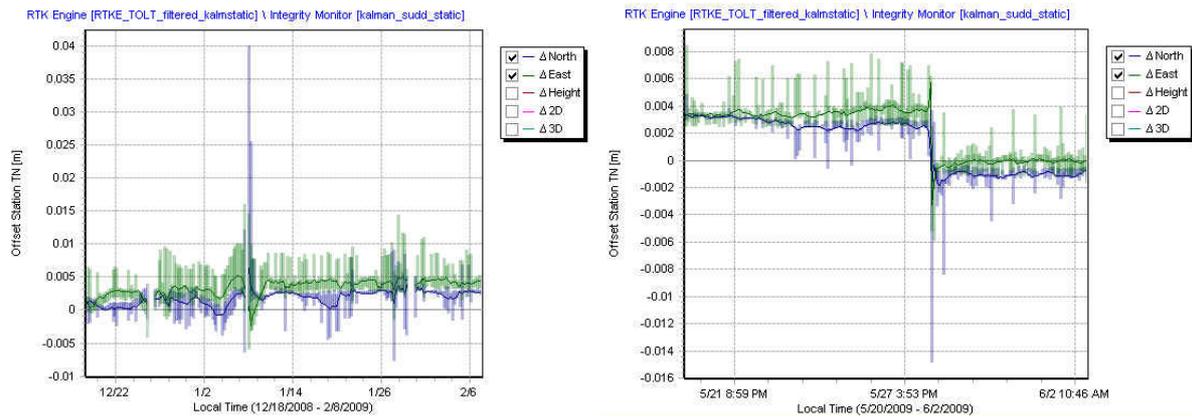


Figure 5a (left) and 5b (right) showing calculated northing (blue line) and easting (green line) values for a reference station (source: Schrock, G., personal communication).

Figure 6 shows one week of data from the automated postprocessed data analysis results for a CORS, part of a VRS network. The operator has indicated to the author he can tell when the sun is shining at this station, based on the range of movement affecting this CORS. Daily oscillations can be seen in Figure 6. This data has prompted the operator to investigate new mounting for materials for this CORS.

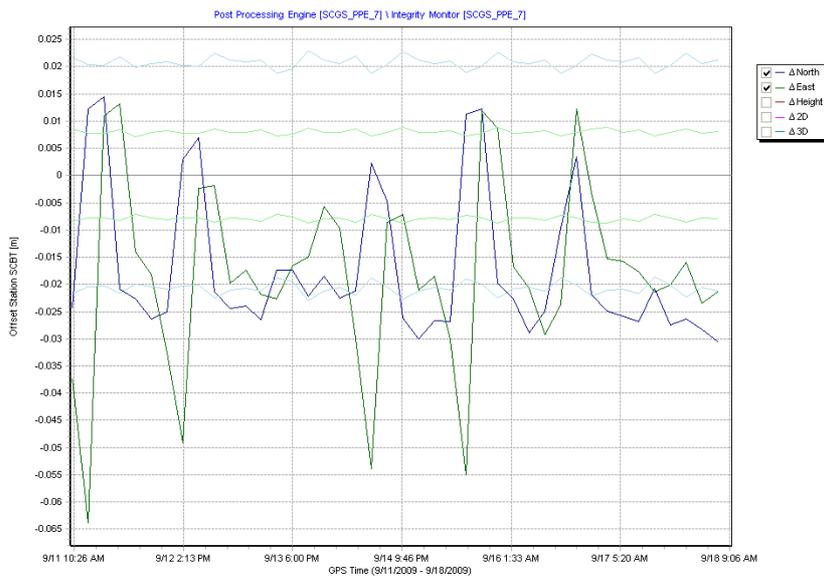


Figure 6 showing calculated northing (blue line) and easting (green line) values for a reference station, showing daily position oscillations (source: anon, personal communication).

Both these examples show how integrity management can ensure quality of service for network operators. This level of data quality and resolution is not available where field observations are taken at sites. Snapshot, long-interval (time between) field observations generally do not capture the trends to reveal the source of error so clearly. The least squares

mathematics used in the generation of network RTK solutions performs at its best when errors are eliminated from the adjustment, coordinate values are homogenous, and only true random error exists.

The positioning community has seen a shift from being based on flat maps and static reference marks (i.e. brass monuments in cement) with coordinate systems locked in time, to a world of truly geodetic (Earth representative) positioning methods on ellipsoidal systems, active control or GNSS CORS stations with updateable coordinates, and reference frames that can be regularly updated. Thanks to GNSS, the community has shifted from a set of constraints where the Earth was flat and never changing, to a new paradigm with acknowledgement that nothing is static. The tools to compensate, work with, and better represent this are vital to success.

4. DEFORMATION MONITORING WITH CORS NETWORK SOLUTIONS

Presented is an example of using a CORS network as an active control platform from which to base automated observations. Active control refers the fact the CORS stations have the highest quality geodetic coordinates, and are available for basing observations from in real-time. This is in contrast to classical survey control marks (passive control), which are limited to marks in the ground which need to be observed themselves, and require an instrument set up in order to be used as a tie to other marks. Another advantage of active control is they can be constantly and automatically monitored for integrity. This all builds into the survey concept of surveying from the whole to the part, tying new observations into existing control and minimizing the transfer of errors from one observation to another. Active control also promotes the types of automated monitoring projects described in this section and section 5. Hereon this is referred to as “installation-style” monitoring, where permanently located sensors can provide full time analysis as they are instruments dedicated to monitoring. Previously discussed in section 2 was a “campaign-style” method of monitoring, where field observation schedules and instrument setups need to be coordinated as field equipment is not left in-situ for full time monitoring, and instead field observations are taken in a more typical surveying sense. It can be seen that the CORS network providing active control is instrumental in this example of installation-style monitoring.

4.1 Earthen dam monitoring using Trimble Integrity Manager software

Since 1999 Washington State’s Seattle Public Utilities (SPU) has set about creating a state wide VRS network, and the result is a CORS network with 1cm relative position (horizontal) precision between any two CORS across the state. With an active CORS network of 95+ reference stations and running Trimble VRS software to manage them, as of May 2009 this network has reached final and state-wide operational status. The technology has brought together all the positioning community users and is creating new opportunities. With an active GNSS control network in operation, and the purchase of Trimble Integrity Manager software, a number of monitoring projects suited to GNSS have been presented to the network

operators. These include the monitoring of an earthen dam, concrete dams, floating bridges, and floating RTK buoy projects.

In June 2008, SPU installed the Trimble Integrity Manager software as a dam monitoring system. Previously, the earthen dam was surveyed once a year using optical methods. The long time between optical observations and inherent setup and equipment discrepancies between observations mean these particular optical observations cannot be compared year-over-year to provide any comprehensive trend analysis for the Tolt Dam (D. Huang, personal communication, 20 January 2009). Using Trimble Integrity Manager software and permanently installed CORS hardware with real-time communications, the following advantages have been achieved over other monitoring methods:

- 24/7/365 monitoring with no site visit required. Depending on the season this dam may not be accessible.
- Time series data with comparable values over time. 1 second or faster position computations are simple.
- Ability to correlate dam water volume information and meteorological records with dam movement detected with GNSS.
- Ability to correlate dam health indicators such as strain meters, and water seepage tests with dam movement detected with GNSS.
- The Trimble Integrity Manager software and GNSS solution is more cost effective and less susceptible to mechanical failure or weather related problems (i.e. frozen robotic instrument or snow on prisms) than other methods.
- Trimble Integrity Manager software operating inside an existing network identifies if movement is just the dam wall, localized, or some other movement like plate tectonic drift. Ties to control outside the immediate geology provide feedback as to whether movement is limited to the structure, watershed, or larger geographic region.

4.2 Dam GNSS sensor and reference station setup

The monitored site, Tolt Dam, has an array of 5 Trimble NetRS GPS reference stations with Trimble Zephyr Geodetic antennas, with 3 along the crest of the dam and two at the base. Figure 7a shows an aerial view of the site. Tilt sensors are mounted on each of antenna mount to ensure any reported movement is actual dam movement, and not surface material slip or antenna failure, and this data is fed into and alarmed by the Trimble Integrity Manager software. Also visible in Figure 7a, a control point is located onsite, off the dam and mounted into the local bedrock with a triple drill braced mount, station LSIG. Additionally 3 other control stations spread about 25-40 km away are used in the Trimble Integrity Manager software's various movement analysis engines.



Figure 7a: (source. Schrock, G. Personal communication June 2008)

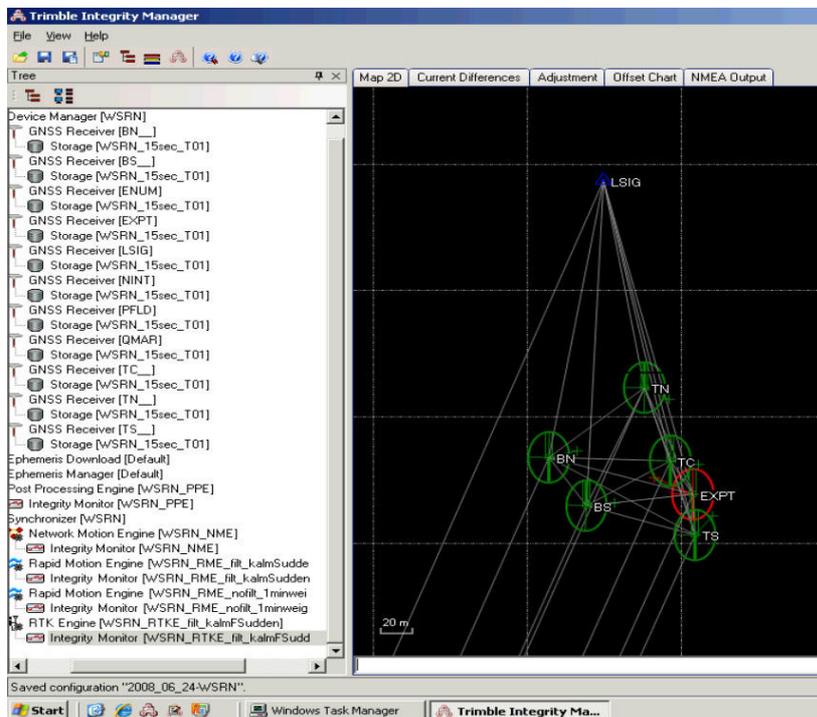


Figure 7b: Software visualization of movement (red ellipse).

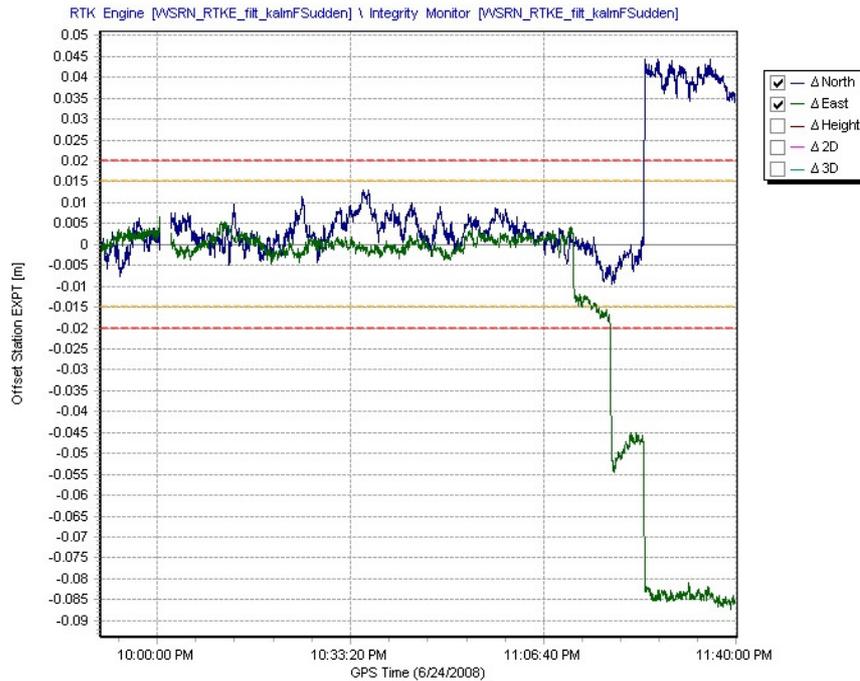


Figure 7c:

Figure 7: (a.): Tolt Dam elevated view showing station locations. (b.) Trimble Integrity Manager software screen image, showing local control station LSIG (blue triangle) and Tolt Dam sensors (green circles). Station EXPT on the dam is red due to a motion alarm being triggered during a field test. (c.) Movement test graph that caused the red circle for EXPT (an alarm state), caused by the Northing (blue line) and Easting (green) lines breaching the alarm threshold (red dotted line).

The combination of real-time and postprocessing tools in the Trimble Integrity Manager software is designed to provide immediate notification, and a more precise verification of alarms, post event. Figures 7b and 7c show examples of an alarm reaction by the software to a movement event, which triggers automated emails to the system operator. The real-time results to date have outperformed the needs of the client and provided previously unknown data about the dam structural behaviour. Two main factors as to why this is successful are; onsite control with the station LSIG meant vectors for all engines were very short; and, WSRN has extremely good geodesy so that any antenna movement is immediately identified.

5. DEFORMATION MONITORING LEVERAGING CORS AND OPTICAL POSITIONING TECHNOLOGIES

With the successful deployment of active CORS GNSS control for GNSS projects, new integrated surveying methodologies allow for cross sensor projects to take advantage of the strengths of each technology. Figure 8 presents some aspects of the sensor technology and the strengths/weakness of each.

GNSS sensor technology		Terrestrial / Optical sensor technology	
Advantages	Disadvantages	Advantages	Disadvantages
No line of sight	Needs open sky	No sky view required	Line of sight required
Reference can be kilometres away	Nearby objects can cause multipath	Very high precision	Dust, fog and rain can reduce the maximum distance
Continuous all weather operation	Power and communication may be required at each point	Power and communication only required at the instrument	Refraction errors increase over distance
Antenna setup simple		Passive targets relatively cheap	Higher latency with many targets
Low latency		Easy to increase the point number/coverage	
Network RTK solution i.e. VRS			

Figure 8: Short list of advantages and disadvantages of two sensor technologies used for position based monitoring

By assessing monitoring projects where installation style monitoring is preferred, operators can select a combined approach to take advantage of the strengths the location has towards a sensor. A combined system can have

- The advantage of the stable reference frame GNSS can provide.
- No need for prior control surveying to define a control network (as it already exists in an active GNSS control).
- Reference points can be kilometres away to be completely removed from an unstable monitoring area, ensuring monitored point observations are not influenced by degradation of control caused by local affects.
- Total station and combined GNSS/optical back sight points can be close to the monitoring structure.
- Mixing technologies creates flexibility for finances.

Figure 9 depicts two possible setups combining CORS and optical monitoring setups, in an installation-style monitoring project. Installers should assess the needs of a monitored point and choose the right sensor technology or combination.

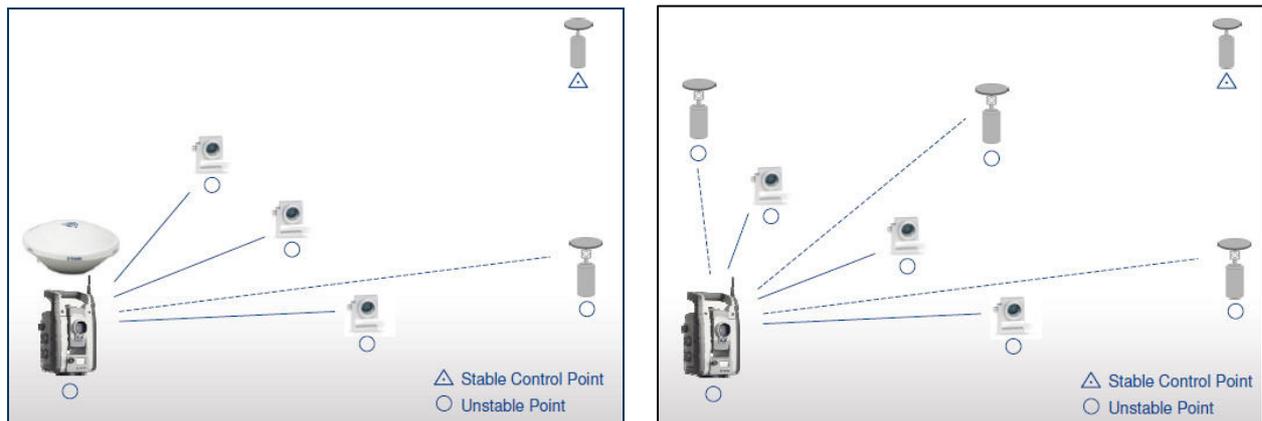


Figure 9: Two possible layouts for combined systems, where GNSS control and dual-sensor monitored points offer redundancy and ties between sensor technologies.

Trimble 4D Control is another software product building on the GNSS monitoring capabilities, and combining the GNSS and optical data to allow integrated monitoring. Integrated surveying is not a new concept, combining optical and GNSS data in adjustment software packages has been available in the market for some years. However, combining the two into one adjustment and enabling *installation-style* monitoring projects to automate the observations, and having the software automate the calculations, has not been widely used in the survey industry. Campaign-style methods have been preferred. Additionally the product automates alarming and outputs so the operator is free for other work and is advised by the system should motion trigger an alarm.

GNSS offers the ability to monitor a point with a once-per-second (or faster) position computation being achieved easily. Therefore, a dedicated GNSS sensor is able to truly model at high rates the response of an object to external forces. Combining this with optical means that where a monitored point needs to be tracked second by second, dedicated GNSS can take care of this. For higher precision, combined observations achieved by a combination GNSS/prism mount, can then tie this monitored point into other optical observations. Therefore the benefits of higher data rates achieved with GNSS and higher precision from optical observations can be combined.

The integrated approach frees up human resources and should be evaluated for its cost benefit on any monitoring project.

6. ROLE OF THE SURVEYOR OR POSITIONING PROFESSIONAL IN DELIVERING MONITORING

GNSS and optical surveying have been the tools of the surveyor for many years. No other discipline better understands the nature of position and the integration of these two sensor technologies, nor the complications of coordinate systems and how to operate within a clients desired system. By simplifying technology tools, the realm of high precision positioning is no

longer limited to surveyors only, and some projects may not use a surveyor on site at all, but a surveyors expertise will remain fundamental to validating monitoring projects. Tools can only provide so much information, analysis comes from interpretation of all available data and the ability to identify cause and effect, and make management decisions based on that interpretation of the information. The role of the surveyor in any monitoring project may run from observation through analysis and into management decision making, and these tools will make the site less dependent on the surveyor's presence to provide the data for analysis.

As a profession the surveyor needs to be focused on integrated surveying techniques and technology, while remaining the positioning authority. Some training in IT and communications is also useful so as to be able to communicate the needs of projects to installation specialists. Those wanting to provide total consultation on monitoring projects will need geo-technical training as well.

The business opportunities take a variety of forms. CORS networks vary in the way they are provided from fully private, paid-for-service networks through to fully public free-to-all networks. In some places a combination or compromise of models exists. Any monitoring project looking to leverage CORS should research the availability of data and responsibility for provision of that data before installation. The surveyor has the opportunity to provide spatially relevant information that informs financial and political planners particularly at this time of aging infrastructure concerns.

Projects that can purchase equipment as part of a construction phase are able to absorb the cost in the development, which can have benefits to the post-build monitoring phase. The benefits to engineering of optical and GNSS positioning technology are well known within the industry, and being involved in the equipment purchasing phase for construction on a project can benefit the monitoring resources available to the surveyor.

7. CONCLUSION

What has been presented is a definition of GNSS based positioning and it's applications towards monitoring, along with integrated surveying methodologies and how automation for instruments and software can grow the monitoring business for surveyors and other position oriented disciplines. Tools are available that enable operators to run multiple projects and combine sensor technologies to create a best sensor for the detection of motion.

While a VRS network solution is not vital to monitoring, it does offer improved precision and should be considered where larger scale projects need to achieve maximum precision for GNSS or integrated monitoring.

Integrity management of CORS networks has been presented as vital to promoting the concept of "active control" from GNSS networks. Additionally, deformation monitoring leveraging that network solution for GNSS and network solution as a viable combination with

optical monitoring. Active control promotes the concept of installation style monitoring, particularly with GNSS where observations can be easily made at high rates and promote new data about structural motion after installation.

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BIOGRAPHICAL NOTES

I have worked with Trimble Navigation since 1999 in a number of business areas including Mapping and GIS, Surveying and Infrastructure. The past 4 years have been focused on GNSS Infrastructure and more recently in monitoring with GNSS, for both network RTK integrity management and deformation monitoring. I have a background in geography, completing a Master of Science degree focused on meteorology in 1999 at the University of Canterbury in Christchurch, New Zealand.

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