Leica Viva GNSS Receivers

White Paper

- when it has to be **right**

Leica Geosystems

Dr. Peter Fairhurst, Ulf Glueckert, Bernhard Richter
Leica Geosystems AG, Switzerland

Biographies

Peter Fairhurst received a PhD in Geodesy from the Newcastle University, in 2007. In October 2007 he joined the GNSS Product Management as an GNSS Application Engineer.

Ulf Glueckert graduated in geodesy at the Technical University of Munich, Germany, in 2009. From April to December 2008 he has worked for Leica Geosystems in the GNSS positioning algorithms group. He was working on his diploma thesis doing research on GLONASS interfrequency biases. In January 2009 he joined the GNSS Product Management group as a GNSS application engineer.

Bernhard Richter received a M.Sc. in Geodesy and Geophysics in 1999 from the Technical University of Vienna. He was a research assistant at the Technical University of Graz. He received a Master of Business Administration at the University of Gloucestershire in 2005. Since 2000 he is working for Leica Geosystems in Switzerland and was for a long time focused on real time kinematic (RTK) processing kernel improvements. Since 2006 he is GNSS Program Director heading the GNSS Surveying business.

Abstract

The new Leica Viva GNSS receiver series consist of 4 different GNSS receiver suited for a wide range of applications in the field of high precision GNSS. The main focus of this paper is on the Leica Viva GS15, but much of the described functionality is common to the entire Leica Viva GNSS receiver series including the brand new Leica Viva GS08 and Leica Viva GS12 and the well known Leica Viva GS10.

Figure 1 shows a cutaway image of the Leica Viva GS15. This is the only worldwide all-in-one, fully flexible professional GNSS receiver to support all future GNSS signals. The Leica Viva GS15 contains unique and innovative features, including the new Leica Geosystems Intenna technology (a patent application has been filed), making it the most functional and flexible professional GNSS receiver on the market. The new Intenna concept integrates the UHF, GSM, UMTS & HSDPA (3.5G), CDMA and GPS antennas inside a single GNSS housing.

The Leica Viva GS15 is the only on the pole GNSS receiver to fully support a complete range of communication devices including CDMA, 3.5G, GSM, GPRS, Japanese CDMA, UHF and spread spectrum radios. Combining this with the Leica Geosystems Intenna technology makes changing communication devices seamless and fully flexible.

The third generation of Leica Geosystems SmartTrack+ measurement engine can track all existing GNSS satellite signals and all those currently planned for the future. The Leica Viva GNSS receiver series include the Leica Geosystems SmartTrack+ measurement engine and all GNSS tracking features. SmartTrack+ includes the GPS L5, Galileo, GAGAN, WAAS, EGNOS, MSAS signals and is compliant with the planned Compass signals. Currently the Leica Viva GNSS series are the only civil GNSS receivers that offer Galileo Alt-BOC tracking which includes unique signal modulation and low multipath. The paper describes the unique advantages of SmartTrack+ and moreover presents first results of the expected quality of the Galileo and L5 signals by analysing the existing signals.

Beside superior tracking performance, proven RTK algorithms are the key to an accurate position. The Leica Geosystems SmartCheck+ algorithm is continuously monitoring the data integrity to provide the highest possible reliability. This unique and proven technology has again been advanced with the Leica Viva GNSS series.

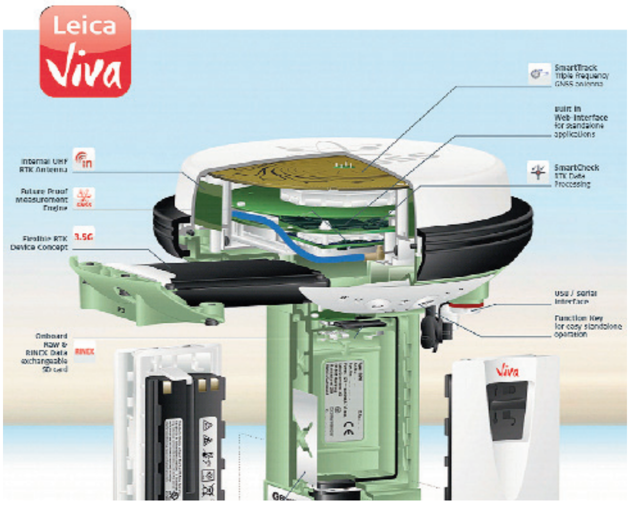

Figure 1 - Leica Viva GS15 cutaway image

Users of GNSS Reference Station Networks expect their results to be consistent throughout the complete Network, but they are often unaware that virtually computed Reference Stations compromise consistency. With Leica Geosystems SmartRTK and RTCM 3.1 correction data, consistency is guaranteed. Combined with the Leica Geosystems SmartTrack+ and SmartCheck+ algorithms the Leica Viva GNSS receiver series provides the most complete GNSS positioning concept on the market. This paper presents one of Leica Geosystems' visions, which is to provide the most easy-to-use professional GNSS equipment available. Leica Viva GNSS is supported by the most modern and flexible surveying field software on the market. With Leica SmartWorx Viva field software Leica Geosystems takes a new path and sets new standards for precise positioning for 2010 and beyond.

Introduction

Today, modern, high precision GNSS receivers are much more than a pure "GNSS tracking engines". A modern GNSS receiver has to support a multitude of communication devices, has to be future proven in terms of GNSS modernization and needs the intelligence to fully automate complex processes. Moreover a simple user interface is mandatory.

With the new Leica Viva GNSS receivers the user can complete a multitude of varying measurement tasks without having to worry about which GNSS constellation they are tracking, whether they are inside the correct RTK network or whether they are using the correct transformations and projections. Instead the user can fully focus on the task at hand with the confidence that there is an intelligent and vigilant system working in the background to provide them with the most accurate and reliable position possible in any situation. This paper links all the important elements of the Leica Viva GNSS field receiver together.

The flexible Communication Device Concept of the GS15

Looking at the high precision GNSS market, more than 90 percent of the high end GNSS receivers are sold as receivers with RTK capability. The communication device therefore has become extremely important and is an integral part of every modern GNSS receiver. Not only has the number of different communication devices increased over the last decade, but the amount of data that needs to be transmitted over the air has increased. Due to an increasing number of GNSS observations (e.g. a full GLONASS constellation) and an increasing need for transmitting additional information such as RTCM v3.1 transformation messages or proprietary messages to the rover, transmission bandwidth has become essential.

The Leica Viva GS15 is certainly the most functional and flexible professional GNSS receiver with regards to communication devices. Its unique design allows easy exchange of integrated RTK communication devices and together with Intenna technology provides unmatched versatility. It is the only on the pole GNSS receiver to fully support a complete range of communication devices.

A series of new broadband UHF transmitters have been designed for the Leica Viva GS15 including a range of Satelline and Pacific Crest radios. Not only has the size, weight and power consumption been significantly improved with these radios, but also another advantage over older conventional radios is that the tuning range is from 400 to 470 MHz and the same radio can therefore be used in almost every country in the world. With regards to communication protocols, all new UHF radios are backward-compatible with standard RTK protocols and Pacific Crest and Satelline are now even interoperable. Now the new Leica Viva radios are 100 percent compatible with radios of older Leica GNSS receivers.

Besides the UHF devices, new high-speed GSM, GPRS, UMTS and CDMA phones are an integral part of the Leica Viva GS15. The requirements for mobile phones differ between countries and for example CDMAs which are certified for Japan would not work in the US. The Leica Viva GS15 by far offers the most complete cell phone portfolio and can also serve a wider range of markets.

Depending on the area of operation and the required application, it is possible to easily exchange the RTK communication devices without any need of a service technician. Warranty is not affected if RTK devices are exchanged in the field.

In addition to the integrated flexible RTK device management, the new Intenna concept integrates a 5-band GSM, UMTS & HSDPA (3.5G), CDMA antenna and a wideband UHF antenna. Together with the Bluetooth antenna that connects with the Leica Viva CS field-controllers, the Leica Viva GS15 has all antennas inside a single housing, where they cannot be lost, broken or forgotten. The unique design also means that antennas are located in the best possible location where they are not obstructed by the range pole. The selection of the correct Intenna is fully automated on selecting the RTK communication device.

In areas of weak cell-phone coverage or for long range UHF radio applications, an external radio antenna can be attached to the Leica Viva GS15 in order to increase the sensitivity and range. New combined multi-band GSM, UMTS & HSDPA (3.5G), CDMA RTK antennas and wideband UHF antennas are available to allow best possible performance for these applications.

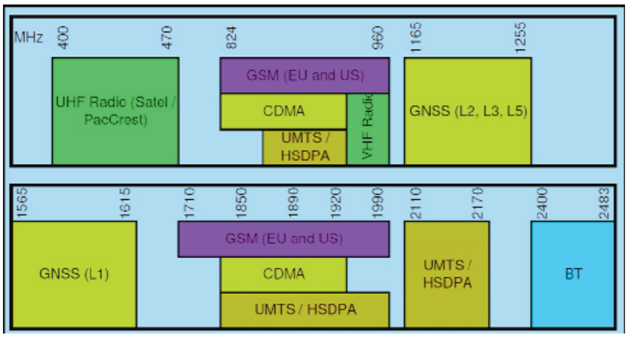

Figure 2 - Supported frequencies by the GS15 INTENNA technology and the corresponding RTK communication devices

An overview of the frequency-ranges covered by the unique Leica Intenna technology and the corresponding RTK communication devices is given in Figure 2. It also shows the GNSS frequencies which are covered later in this paper.

Tracking Technology: Leica SmartTrack+

All new Leica Viva GNSS incorporate the latest third generation of Leica Geosystems SmartTrack+ measurement engine. SmartTrack+ measurement engines can track all the current and future Global Navigation Satellite System (GNSS) and Satellite Based Augmentation Systems (SBAS) civil signals (see Table 1) giving the Leica Viva GNSS receiver family unparalleled tracking performance.

Currently, there are four GNSS constellations of main interest. The fully operational GNSS constellations are the United States of America Department of Defense (US DOD) owned Global Positioning System (GPS) and the Russian Government owned Global Navigation Satellite System (GLONASS). The GNSS constellations currently in development are the European Union (EU) owned Galileo and the Chinese Government owned COMPASS. The planned Regional Navigation Satellite Systems (RNSS) for Indian and Japan, the Indian Regional Navigation Satellite System (IRNSS) and the Quasi-Zenith Satellite System (QZSS) respectively, should be frequency compliant with Leica Geosystems SmartTrack+ concept.

GPS	L1, L2, L2C, L5
GLONASS	L1, L2, L3
Galileo	E1, E5a, E5b, E6
COMPASS	B1, B2, B3
SBAS	WAAS, EGNOS, GAGAN, MSAS

Table 1 - Tracking capabilities of the SmartTrack+ measurement engine

The central frequencies for each of the GNSS constellations can be seen in Figure 3. These values are according to the latest interface control documents (ICD) of the respective GNSS constellations [1], [2] and [3]. The central frequencies for COMPASS are the latest frequency values the Chinese Space Agency announced at the Munich Satellite Navigation Summit in March 2010 [4]. The Leica Geosystems SmartTrack+ measurement engine concept has been developed to be compliant with all four GNSS constellations and all civil GNSS signals.

The fully operational GNSS constellations GPS and GLONASS transmit signals in the frequency bands L1 and L2 as a minimum. This stable form is the basis of which all Leica Viva GNSS receivers are built upon. However, the GNSS modernization plans are evolving and with the Leica Geosystems SmartTrack+ concept the Leica Viva GNSS series is prepared to support all future civil signals.

The U.S. DOD recently launched and set healthy the first GPS IIF satellite. The GPS IIF is the latest generation of GPS satellites and is capable of transmitting signals on three civil frequencies L1, L2 and L5. Figure 4 shows that Leica Viva GNSS is already capable of tracking the new L5 signal from the GPS PRN25 satellite.

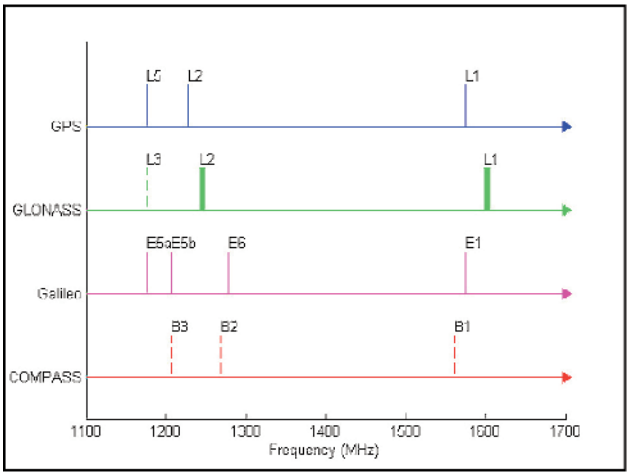

Figure 3 - Centre Frequencies of current and future satellites signals (frequencies not defined in their respective ICD is shown in dashed lines)

The Russian Space Agency launched 3 more GLONASS-M satellites on the 9th of September 2010. The GLONASS-M satellite is the second generation of GLONASS satellites and once the recently launched GLONASS-M satellites are set healthy the GLONASS constellation will have reached 24 available satellites. GLONASS will be fully operational for the first time since the nineties.

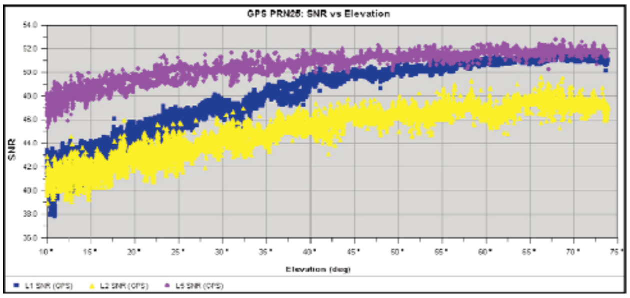

Figure 4 - Leica Viva GNSS tracking the L5 signal

By December 2010 the Russian Space Agency will have launched an additional 3 GLONASS-M satellites and a single GLONASS-K satellite. The GLONASS-K satellite will introduce the third GLONASS civil signal L3 and begin the testing of the new GLONASS CDMA signal concept. The Leica Viva GNSS sensors are designed to be 100 percent compliant to the GLONASS modernization including the L3 civil signal and the new GLONASS CDMA signals.

The developing GNSS constellations, Galileo and COMPASS, are currently in a test phase. In 2005 the European Space Agency (ESA) launched the first Galileo test satellite GIOVE A transmitting on the E1 and E5 signals.

In 2008 ESA launched a second Galileo test satellite GIOVE B to transmit the test signals for E1, E5a, E5b and Alternative BOC (Alt-BOC).

The Galileo Alt-BOC signal is a unique GNSS signal that multiplexes the Binary Phase Shift Keying (BSPK) modulated E5a and E5b signals and injects it through a very wide band channel creating the Alt-BOC signal seen in Figure 5.

Research by several authors, [5] and [6] show that the Galileo Alt-BOC signal has low multipath and tracking noise capabilities. This makes the Alt-BOC signal the most accurate GNSS signal transmitted and will improve the quality of differential code solutions. The Leica Viva GNSS system is currently the only civil GNSS receiver to track the Galileo Alt-BOC signal. Figure 6 shows the Leica Viva GNSS receiver tracking the Galileo Alt-BOC signal and Figure 7 shows the code multipath performance for the Alt-BOC. Both prove Leica Geosystems' dedication in providing full GNSS tracking.

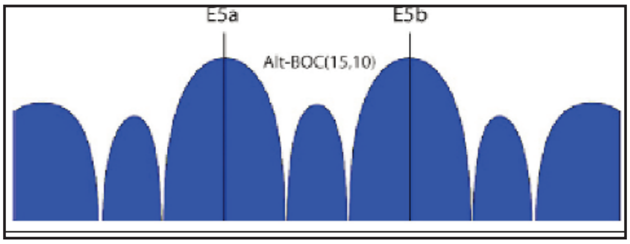

Figure 5 - Power Spectral Density of the Galileo E5 Alt-BOC signal

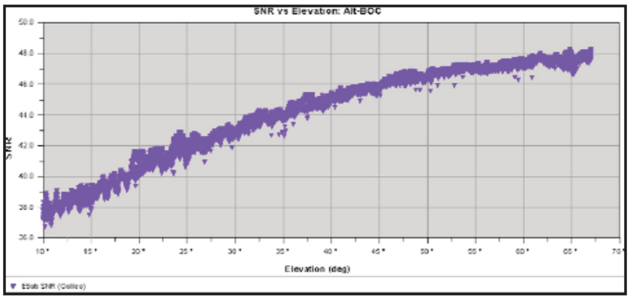

Figure 6 - Leica Viva GNSS tracking the Alt-BOC signal

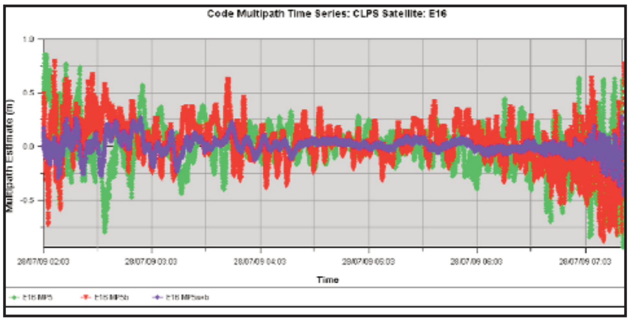

Figure 7 - Code multipath for GIOVE-B tracked by Leica Viva GNSS

ESA have since released the first issue of the Galileo OS SIS ICD on the 13th of August 2010 and it can be confirmed that Leica Geosystems SmartTrack+ is 100 percent compliant with the Galileo OS SIS ICD. The COMPASS constellation currently has a single MEO test satellite, 3 Geosynchronous Earth Orbiters (GEO) and a single Inclined Geosynchronous Orbiters (IGSO) transmitting test signals.
The Chinese Space Agency plan is to have 4 MEO, 5 GEO and 5 IGSO satellites in orbit by 2012. Their ultimate goal is to have a full constellation (27 MEO, 3 IGSO and 5 GEO) by 2020 [7].
Currently, the Chinese Space Agency have not published an ICD but in October 2009 they announced plans to publish their ICD "step-by-step within a year" [8] but the Leica Geosystems SmartTrack+ measurement engine concept is fully compliant with the published information for the COMPASS signals.

The future GNSS constellations offer a huge choice of GNSS satellites and signals. There will be a time when 100 GNSS observations will be available per epoch hugely increasing the availability and reliability of GNSS positioning. The introduction of additional GNSS constellations and the third civil frequency opens some interesting areas of research. The work into new linear combination possibilities to improve initialization times using concepts such as TCAR [9] and [10], increasing the maximum baseline length between Reference Stations in Network RTK using Geometry-Free Triple Frequency Carrier Ambiguity [11] and multi-GNSS constellation instantaneous initialization techniques such as GECCAR [12] are just some of the enhancements to the GNSS precision positioning world we can expect in the future.

However, multi-GNSS constellation processing has it's own issues to over come. In GNSS processing the receiver clock generally absorb the differential code biases caused by using multiple frequencies but only when using signals and signal combinations from the same GNSS constellation. When using multiple GNSS constellations together differential code biases are present for each GNSS constellation and the respective signals. These are called Inter-System Biases (ISB) and are an additional source of error in different Code processing especially when using GNSS observations measured from different GNSS hardware manufacturers [13]. In today's world of GNSS using a single GNSS (e.g. GPS only) is a huge disadvantage and consequently a variety of receivers on the market are GPS and GLONASS capable. It is important that a GNSS receiver minimizes the ISB when used in multiple GNSS constellation processing without introducing additional errors. Figure 8 shows how Leica Geosystems GNSS receivers compare against other GNSS manufacturers when measuring the ISB between GPS and GLONASS [14]. Other GNSS manufacturer hardware showed large ISB (> 100 ns) between GPS and GLONASS and Leica Geosystems GNSS hardware has the smallest ISB of any GNSS civil receiver in the IGS network. Proving the Leica Geosystems SmartTrack+ measurement engine concept gives unrivalled performance in this area for all Leica Viva GNSS receivers.

RTK Algorithm Technology: Leica SmartCheck+

A key requirement for modern, professional GNSS receivers in realizing the full potential of high precision GNSS in real-time is in achieving fast and reliable ambiguity resolution. However, the time to fix the integer ambiguities is always a trade-off between speed, performance and reliability of the whole system [15].

The Leica Viva GS15 employs the Leica Geosystems SmartCheck+ algorithm. SmartCheck+ initializes the integer ambiguities in a fast and reliable way employing GNSS integer ambiguity resolution for both GPS and GLONASS measurement data. Additionally, it is a continuous integrity monitoring system for the integer ambiguities. SmartCheck+ is an enhancement of the already known SmartCheck ambiguity search and monitoring strategy used in the Leica System1200 GNSS receivers.

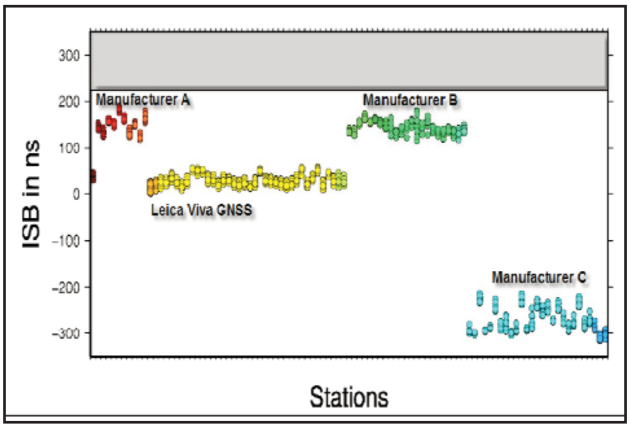

Figure 8 - GPS/GLONASS-combined Clock Estimate: SmartTrack+ ISB values from the IGS network compared to other GNSS manufacturers.

In order to ensure a reliable integer ambiguity initialization, the ambiguities are checked twice within eight seconds before the phase fixed position is displayed [16]. After this, the repeated search strategy is employed in order to confirm the initial integer ambiguities. The integer ambiguities are continuously re-calculated and compared to the previous set of ambiguities with the aid of the repeated search strategy. This smart strategy helps to monitor GNSS data and an early alarm state can be given once the previous solution has been proven wrong [17].

The continuous computation and checking process ensures the highest possible RTK reliability and accuracy for baselines up to 30 km and beyond, even in obstructed areas such as dense canopy or urban canyons. Additionally, position inconsistencies are detected much quicker with Leica Geosystems SmartCheck+ than with conventional ambiguity verification strategies.

An example for this can be seen in Figure 9, showing the height displacement for a Leica and a competitor rover. The test was performed on a 140 m baseline, with the rovers located under a tree. The Leica rover (top) directly went from a phase fixed solution to a DGPS position since the previous set of ambiguities could not be confirmed. The competitor rover (bottom) detects a wrong initialization significantly later and retained this wrong initialization for six minutes before switching to a DGPS position.

Network Technology: Leica SmartRTK

Network RTK is a maturing technology that has the potential to overcome several limitations of conventional (single-baseline) RTK. To meet the accuracy demands of high-precision RTK applications, estimates of the dispersive and non-dispersive errors are derived from a fixed ambiguity solution of the RTK network. Therefore, correction information might only be available for a subset of satellites observed in the RTK network. Traditionally, raw observations without corrections are not included in the position solution. In many cases, these observations still contain valuable information for positioning and with the Leica Geosystems MAX concept the observations can be included in the GNSS positioning.

The Leica Geosystems MAX concept transmits the dispersive and non-dispersive corrections for each satellite and each reference network stations in the RTK network to the GNSS rover receiver. The Leica Geosystems SmartRTK algorithms are able to mitigate the dispersive and non-dispersive errors from GNSS RTK processing that often limit accuracy and availability of single baseline solutions [18].

One disadvantage of the Standard Network RTK solution arises when the number of available satellites with corrections is less than the critical threshold needed for positioning.

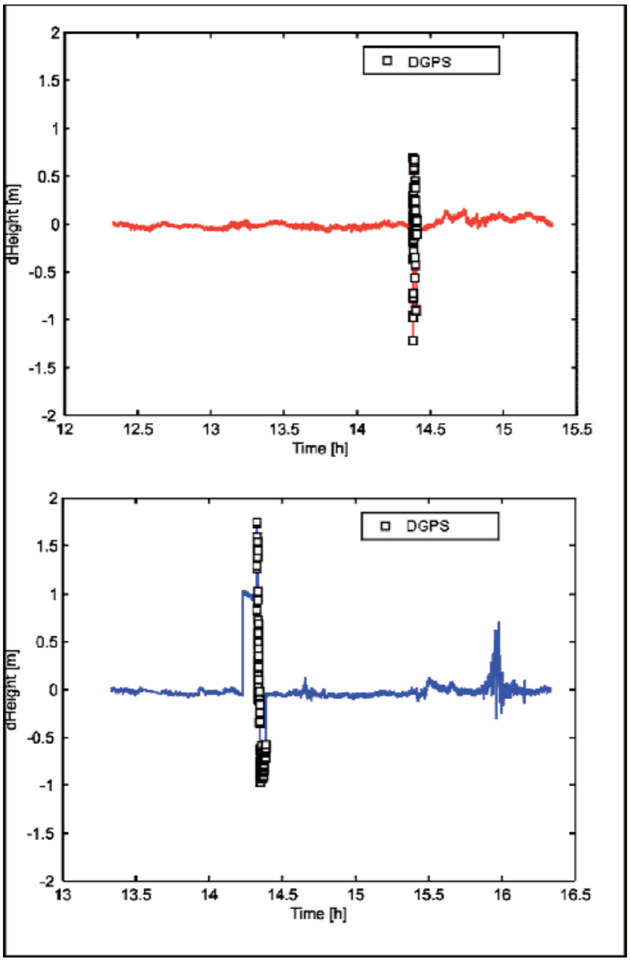

Figure 9 - Height displacement for a Leica rover (top) and a competition rover (bottom) on a 140 m baseline and heavy canopy. Leica switches to a DGPS position immediately whereas the competitor rover keeps a wrong fix for about 6 minutes.

In the case where uncorrected satellites are ignored, the fixed position will be lost in the case of standard network RTK. In contrast, SmartRTK is able to maintain the solution without the need for re-initialization by employing the raw observations of satellites without corrections.

An example is given in Figure 10, showing the position errors for the Standard Network RTK and SmartRTK solutions. The number of satellites with corrections falls below 5 after epoch 395805, however there are at least 6 satellites observed at the master and rover stations during the whole period.

The Leica Geosystems SmartRTK concept, which is part of all Leica Viva GNSS receivers, effectively includes uncorrected observations in order to improve the precision of the position solution. In addition, an atmospheric decorrelator, using optimal combinations of the L1 and L2 observations and atmospheric stochastic modeling, mitigates the effects of residual modeling errors. As a result, the positioning accuracy throughout the network is more homogenous even in disturbed atmospheric conditions [19]. This can be seen in Figure 11.

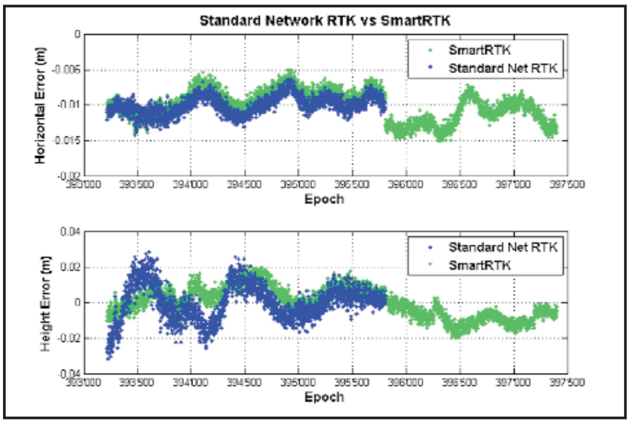

Figure 10 - Position errors for the standard network and SmartRTK solutions. SmartRTK maintains a fixed solution even when the number of available satellites with corrections falls below 5 [19].

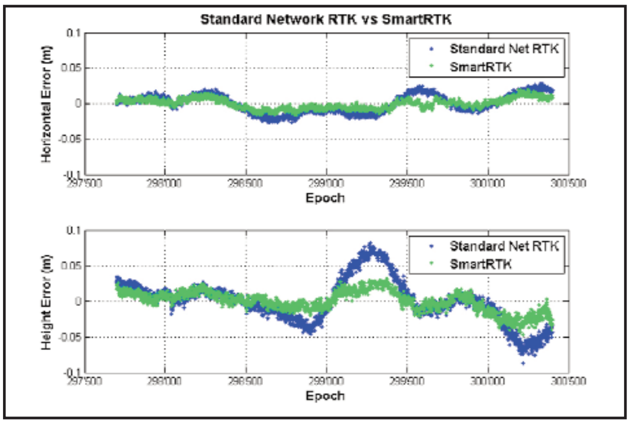

Figure 11 - Position errors for the SmartRTK and Standard Network RTK solutions. The combination of all available information and the atmospheric decorrelator yields the most precise results [19].

SmartWorx Viva and its concept

Beside the vision of providing the best hardware to meet the daily challenges of measurement professionals, another of Leica Geosystems' visions is to provide the most easy-to-use professional GNSS equipment. The key to this is the intuitive field software, SmartWorx Viva which controls not only all Leica Viva GNSS, but also the Leica total stations. SmartWorx Viva is the latest field software from Leica Geosystems, designed to complete measurement tasks with minimum fuss and effort in the shortest time. The goal for this software is to achieve high levels of usability whilst maintaining and expanding a high level of functionality. SmartWorx Viva is an incredibly easy to use, yet highly configurable software. Achieving both of these, almost contradicting, goals is a difficult balancing act.

The underlying question is how to make an easy to use software. To achieve this, Leica Geosystems was collaborating with a leading provider of user interfaces, the German company ERGOSIGN. Together with ERGOSIGN, Leica Geosystems achieved a new standard for surveying field software that is until now unmatched in terms of user friendliness. The entire software is based on a simple concept where the screen is split up in 4 sections, shown in Figure 12.

The icon toolbar and title line of the panel is the 1st section. It provides live status information and useful links to access status panels or quickly access configuration settings. Clear icons immediately inform whether the system is running as expected. It is somehow the cockpit of the GNSS receiver. Colours also play an important role in the design of a user interface. Even though the full VGA screen could display more than 65000 colours the underlying concept is to use soft colours as long as the system operates well and only in case of problems such as a lost reference link, bright colours indicate the incident. The human eye gets tired more quicker if it is attracted by too many details. Information that is not permanently needed should therefore be kept in the background.

The 2nd section is the main working area. The key to making intuitive software is to use clear and simple language and graphics. A picture very often is much easier to interpret than just text or pure numbers as indicated below in Figure 13.

The goal of SmartWorx Viva is to have most routines automated, but sometimes manually configuring special setups is unavoidable. For example, pairing a Bluetooth mobile phone and setting it up as an NTRIP client. In order to fulfil such complex tasks, SmartWorx Viva breaks it down in small individual steps with wizards. The wizards guide the user step by step through the different settings using clear questions. This brings us to one of the major rules of software interface design.

The options provided to the user must be absolutely clear, since every time you provide an option, you are asking the user to make a decision [20].

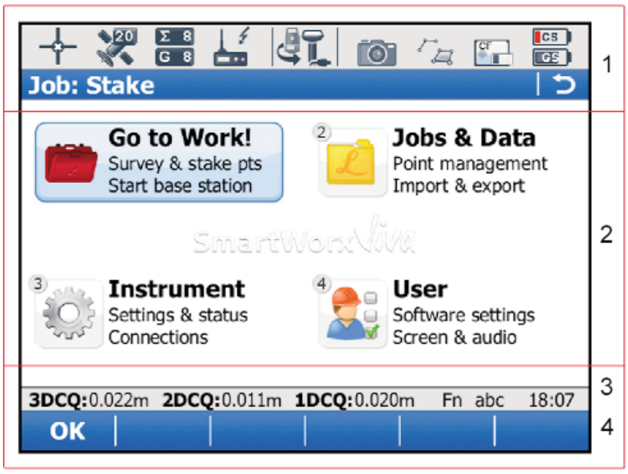

Figure 12 - Leica Viva SmartWorx - Main Menu

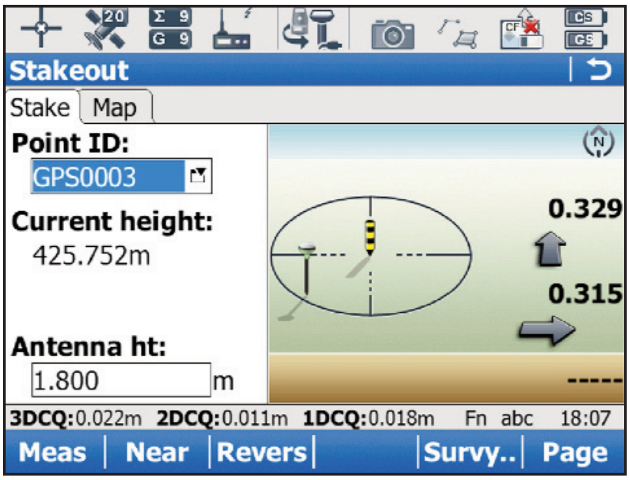

Figure 13 - Leica Viva SmartWorx - Stakeout

The 3rd section is the information line and provides useful information such as point accuracy or time. The 4th section shows the six function buttons which change depending on the current panel. Again, clear, simple language is used for the function buttons to make the decision for the user as clear as possible.

Outlook: Surveying Beyond 2010

As described in the abstract this paper also gives an outlook as to how Leica Geosystems sees the GNSS measurement process beyond 2010. Already now a high percentage of GNSS users are online and connected to the Internet in the field. With the brand new CS10 3.5G and CS15 3.5G field controllers, the measurement professional has high speed Internet connection wherever there is 3.5G coverage. The new CS10 and CS15 3.5G field controllers do not need any external communication devices. External communication devices such as mobile phones are usually not protected against water, dust and shock. In addition, these devices often have a poor battery life. Therefore an integrated high-speed cell phone brings obvious advantages.

High speed Internet connection in the field offers a series of new possibilities for the measurement professional. Receiving RTK corrections via NTRIP servers is already state-of-the-art technology. In future the entire connection process such as selecting a mount point or selecting correction services could be fully automated without any interaction by the operator.

Another possibility that needs internet connectivity and that would simplify GNSS surveying significantly is the full support of coordinate systems via RTCM v3.1. Leica Viva GNSS receivers already fully support the RTCM v3.1 transformation message, but unfortunately only a hand full of RTK reference network providers transmit a complete transformation message with country specific corrections and a geoid model. Field calibrations are both time consuming and a source of error. The coordinate system and the geoid model are part of the RTCM v3.1 correction message and applied automatically within Leica Viva GNSS. With the transformation message it is no longer necessary to measure control points and determine the transformation manually. The manual calibration would be obsolete and the RTK network provider would take full responsibility of the quality of the transformation. In case of the availability of accurate geoid models, GNSS could even more often be used for surveying tasks where - the height is of importance. Due to the fact that Leica Viva GNSS supports all GNSS systems and GLONASS will soon reach full operational capability, the height quality of GNSS precise positioning has improved compared to 5 years before. The height quality of GNSS precise positioning now meets the requirements for a variety of applications, particularly in construction.

In addition, when we consider GNSS modernization, multi GNSS systems as already mentioned will significantly increase the reliability of the computed position. For example if Galileo will keep its promises with regards to system integrity, if the wonderfully low multipath Alt-BOC signals (which is already 100% supported by Leica Viva sensors) will become reality and if more than 100 observations per epoch will be available, then accuracy checks are a thing of the past. The reliability of positions with fixed ambiguities will then be in the order of six sigma.

References

[1] ICD-GPS-200 (2010): Navstar GPS Space Segment / Navigation User Interface, rev. E.

[2] GLONASS ICD (2008): GLONASS Interface Control Document Version 5.1. Coordination Scientific Centre. Moscow, Russia.

[3] Galileo OS SIS ICD (2010): Galileo Open Service, Signal In Space Interface Control Document Issue 1. European Space Agency / European GNSS Supervisory Authority.

[4] GPS World (2010): Vistas from the Summit. Volume 21, Number 4, April 2010, pp. 20-21.

[5] Simsky A., Mertens D., Sleewaegen J.-M. & de Wilde W. (2008): MBOC vs BOC(1,1) multipath comparision based on GIOVE-B data. Inside GNSS, Volume 3, Number 6, September/October 2008, pp. 36-44.

[6] Eisfeller B., Sch ler T. (2006): Das Europäische Satellitenavigationssystem Galileo. Proc. 66. DVW Seminar, Schriftenreihe des DVW, issue 49, Augsburg, Germany, pp. 17-39.

[7] Inside GNSS (2010b): Signals Start on Latest Compass GEO Satellite. Inside GNSS Volume 5, Number 5, January/February 2010, pp. 15-18.

[8] Inside GNSS (2009): Draft Compass ICD May Appear. Inside GNSS volume 4, Number 6, November/December 2009, pp. 15-16.

[9] Forsell B., Martin-Neira M., Harris R. A. (1997): Carrier Phase Ambiguity in GNSS-2. Proc. ION GPS-97, Kanas City, September 1997, pp. 1727-1736.

[10] Feng Y., Li B. (2009): Three Carrier Ambiguity Resolutions: Generalised Problems, Models and Solutions. Journal of GPS, Volume 8, Number 2, 2009, pp. 115–123.

[11] Feng Y., Li B (2008): A benefit of multiple carrier GNSS signals: regional scale network-based RTK with double inter-station distances. Journal of Spatial Sciences, 2009, Volume 53, Number 1, pp. 135-147.

[12] Morujo D. B., Mendes V. B. (2008): Investigation of Instantaneous Carrier Phase Ambiguity Resolution with the GPS/Galileo Combination using the General Ambiguity Search Criterion. Journal of GPS, Volume 7, Number 1, 2008, pp. 34-45.

[13] Montenbrak O., Hauschild A. (2010): Characterization of GPS/GIOVE Sensor Stations in the CONGO Network. DLR-GSOC TN 10-05, Deutsches Zentrum for Luft- and Raumfahrt, Oberpfaffenhofen, 20th May 2010.

[14] Schaer S., Dach R. (2010): Bias in GNSS analysis. IGS Workshop, Newcastle, England, 28th June – 2nd July 2010.

[15] Kotthoff H., Hilker C., Ziegler C.. Strategy of Reliable Ambiguity Resolution for Static and Kinematic Applications. In: Proc of ION GPS 2003, Portlan, Oregon, September 9-12, 2003.

[16] Leica Geosystems AG. System 1200 Newsletter – No.1. http://www.leica-geosystems.com/downloads123/zz/general/general/System1200_01_RTK_en.pdf

[17] Euler H.-J., Ziegler C.. Advances in Ambiguity Resolution for Surveying Type Applications. Published in ION GPS 2000 Proceedings, Salt Lake City, Utah, September 19-22, 2000.

[18] Brown N., Keenan R., Richter B., Troyer L.. Advances in Ambiguity Resolution for RTK Applications using the new RTCM V3.0 Master-Auxiliary Messages. Published in ION GPS 2005 Proceedings, Long Beach, California, September 12-16, 2005.

[19] Takac F., Lienhart W.. SmartRTK: A Novel Method Of Processing Standardised RTCM Network RTK Information For High Precision Positioning. Published in ENC GNSS 2008 Proceedings, Toulouse, France, April 22-25, 2008.

[20] Spolsky J., [online] [cited 12 April 2000] Available from http://www.joelonsoftware.com/uibook/chapters/fog0000000059.html

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