Low Cost, High Accuracy, GNSS Survey and Mapping

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SUMMARY

Global Navigation Satellite Systems (GNSS) use has dramatically increased over the last decade. GNSS receivers are reliable, effective and highly productive tools for determining precise position and time.

The primary GNSS today is the United States' Global Positioning System (GPS). These satellites broadcast two L-band radio frequencies commonly known as L1 and L2. The dual-frequency GNSS receivers on the market today are very expensive, but they have been considered necessary to be productive in many situations. A major consideration in the productivity equation has been the ability of dual-frequency receivers to perform GNSS surveys and get immediate results. This possibility to perform Real-Time Kinematic (RTK) surveys had been the strict domain of dual-frequency receivers until techniques were developed that could utilize multiple satellite systems such as the GPS+GLONASS™ (Kozlov, 1998) L1 technology introduced in the late 1990's. Historically, single-frequency, GPS-only RTK has been considered impractical due to the longer Time To First Fix (TTFF) which can range from a few seconds with dual-frequency to several minutes with single-frequency systems.

Magellan engineers have concentrated many years of GNSS expertise into a new satellite signal processing engine that can dramatically reduce the TTFF in single-frequency GNSS receivers. BLADE™ - BaseLine Accurate Determination Engine computes centimeter and decimeter level positions by combining range information from GPS and Satellite Based Augmentation Systems (SBAS). This allows the delivery of high-accuracy, single-frequency solutions in real-time at a lower cost than dual-frequency receivers and with a TTFF which approaches that of the more expensive systems. BLADE™ also negates the biases that can be introduced when working with mixed constellations or in heterogeneous networks.

These newest developments have significantly lowered the cost barrier for entry into the precision world of GNSS RTK surveying and mapping by providing single-frequency, GPS+SBAS receivers that perform at nearly the level of dual-frequency receivers but at less than half the price. These receivers also embrace the trend to combine functionality in a single device by providing both centimeter and decimeter level applications for surveying and mapping.

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1. INTRODUCTION

The use of GPS and other GNSS is revolutionizing our world. Over the past decade, GPS has become a common term to most people in North America, Europe and parts of Asia. The market demands have driven receiver manufacturers to pack more features into a smaller box at a cheaper price. This combination of forces is reaping huge benefits for GNSS users around the world.

Ten years ago, if a surveyor wanted to get centimeter solutions using GPS, that system likely cost over US$80,000. Today, a surveyor can get that same precision for about US$7,000. Lowering the cost barrier has created new opportunities within many disciplines.

Added functionality combined with lower costs results in more potential users. The field work has gotten less physically demanding and more productive while the measurements that are achieved maintain the same precision or better than those provided with previous techniques.

The FIG committee has chosen a perfect location to highlight the benefits that low-cost GNSS surveying and mapping can bring to developing regions. Mexico, Venezuela and Brazil are just three of the countries in Latin America that are deploying large numbers of these low-cost receivers to improve their cadastral knowledge. GIS databases are being grown as local, state and federal agencies increase their awareness of the importance of these data. GNSS technology unifies the process. It provides worldwide coverage, is highly precise, helps to keep all of the measurements on the same datum by providing a consistent reference frame and because it does not rely on visible landmarks to calculate a position, the information does not become obsolete over time.

This paper will describe the features and benefits of new, low-cost, real-time surveying and mapping systems.

2. PERFORMANCE CHARACTERISTICS OF SINGLE-FREQUENCY RTK

A GNSS receiver is really just an expensive radio with multiple channels. The number of channels generally ranges from 12 to 72. Typically, the more channels a GNSS receiver has, the faster it can compute a solution. The current generation of GPS satellites broadcast two L-band radio frequencies commonly referred to as L1 and L2. Nearly all of today's survey grade GNSS receivers, whether they are single-frequency (L1) or dual-frequency (L1 and L2) have the same accuracy specifications, which hover around one centimeter horizontally and two centimeters vertically. The performance differences between single-frequency and dual-frequency systems can be broken down into three categories: The physical environment that is required, the Time To First Fix (TTFF) and the length of the baselines that can be computed in real-time.

2.1 Physical Environment

GNSS receivers need to have a clear view of the sky. The more satellites that have a line of sight to the GNSS antenna, the better the system will perform. This performance increase is characterized by more robustness, better precision and higher levels of confidence. Therefore, GNSS technology is not suited to conditions that have moderate to complete sky obscurity. Single-frequency Real-Time Kinematic (RTK) performance is especially affected by sky blockage and the number of satellites whose signals are being tracked.

2.2 Time To First Fix

Time To First Fix or TTFF refers to the length of time that it takes a GNSS receiver to calculate its position to the centimeter level using RTK techniques. Certain dual-frequency systems on the market can perform this task in a matter of a few seconds, while some GPS-only, L1 receivers may require thirty minutes or more. Depending upon the requirements of the job being performed, this may or may not be important. For instance, if the receiver is running continuously and has a clear view of the sky, the length of time it takes the receiver to compute its first solution is trivial since the receiver will likely maintain its fixed position over a long period of time. However, if the receiver is constantly losing its view of the sky, thereby causing a loss of the fixed position or satellite signal tracking, the length of time required to re-fix the position becomes more important.

2.3 Baselines

Most surveyors and engineers using GNSS technology possess two or more receivers. One receiver is set up on a known reference point and another receiver is moved about to make the necessary measurements. The kinematic rover positions are referenced against the static base position to compute centimeter level solutions. The vector between the reference receiver and the roving receiver is referred to as a baseline.

In a post-processing scenario and with sufficient data ranging from several minutes to many hours, there is no difference in the baseline length that can be computed with a single-frequency versus dual-frequency system. However, in a real-time situation, there is a noticeable decrease in the baseline length that can be computed with a single-frequency system. Some dual-frequency RTK systems have the ability to measure 40 kilometer baselines while maintaining centimeter level accuracy. The maximum practical baseline length for real-time single-frequency solutions is less than 10 kilometers. This 10 kilometer baseline limit might be considered a handicap to some users. However, many RTK surveys are performed within a few kilometers of the base station. In these cases, the baseline length may not be an appropriate performance indicator.

3. TECHNOLOGY ADVANCES

Moore's Law of integrated circuits infers that technology doubles every 18 to 24 months. If this is true, then GNSS technology has increased by about 3000 percent over the last decade. In other words, the last ten years have seen GNSS technology expanding at a rate of over 40% per annum. The most visible expansion of GNSS use can be seen in the consumer sector where GPS has gained entrance into many aspects of daily life including our vehicles and cell phones. Starting with the Z-set GPS receiver at a cost of US$225,000 and continuing up to today's cell phone with an integrated GPS chip, the price of the lowest-cost GPS chip-set has been reduced 50 percent every 18 months since 1978 (Green, 2007). There have been many enhancements to the professional GNSS receivers during this evolution. The TTFF for early generation, dual-frequency systems was in the range of three to seven minutes. Thanks to improved digital hardware, signal processing and positioning algorithms, this same class of instrument can now gain a fixed position in seconds. The elevation mask, or the angle above the horizon at which the receiver begins tracking satellites has been lowered from an industry standard 15 degrees down to 5 degrees with the newest generation of receivers.

Other technology advances have less to do with GNSS and more to do with global trends in general. Cell phones and the infrastructure surrounding cellular technology have driven many of today's innovations. GNSS receivers now need to be Internet and Bluetooth enabled. Removable memory is a must. Color displays for the field application software has become the standard. Data sets have gone from being 10 kilobytes to 10 megabytes and the system must be able to cope with all these data.

GNSS engineers are continuously examining new ways to do things. Improved satellite signal processing, controlling TTFF efficiently and reducing error sources consume a majority of their efforts.

3.1 BLADE™: BaseLine Accurate Determination Engine

BaseLine Accurate Determination Engine is a new GNSS processing technique that allows Satellite Based Augmentation Systems, or SBAS measurements to be used in the position computation. This may sound like old technology, but in fact it is quite new.

The usual method for utilizing SBAS signals has been to apply the differential corrections contained within the signal's message. This is a very good meter level differential source for much of the northern hemisphere. However, these correctors can have deleterious effects on regions outside of the SBAS service area. This is especially problematic for Central and South American countries that can receive the US Wide Area Augmentation System (WAAS) corrections and for the African continent and Indian sub-continent that can receive the European Geostationary Navigation Overlay Service (EGNOS) corrections. Because the correction information is specific to the system's area of interest, these correctors actually degrade positioning solutions when applied outside their geographic boundaries.

BLADE™ does not always use the SBAS correctors. The service areas of WAAS and EGNOS are well known. Therefore, BLADE™ incorporates algorithms that determine when the correction information should be utilized, and when it should not. BLADE™ does more than this though. Besides knowing when to apply the SBAS correction information, BLADE™ can use these SBAS signals in the same way that GPS signals are used to obtain ranging information. Instead of using the correction information, the receiver calculates its range from the SBAS satellite. And because these satellites are geostationary, there is no Doppler effect to take into account. This facilitates a faster TTFF which is the beginning of a productive, single-frequency RTK system that makes economic sense.

3.2 Networks

When addressing audiences familiar with GNSS, the word "Network" must be understood in the context in which it is being used. There are at least three different connotations of networks that need to be considered.

3.2.1 Cellular Networks

The expansion of the cellular infrastructure throughout the world has done much to change the model for GNSS applications. In order to perform RTK surveys, there must be a data link between the reference and rover receivers. Traditionally, this link has been a UHF radio. The UHF radio paradigm has several limiters including range and licensure issues that cellular technology does not. The use of cellular services for the delivery of GNSS corrections has grown dramatically over the last five years and will continue to do so because of a number of advantages that this technique offers:

- Communication range limitations are removed
- Cell coverage is widely available, inexpensive and has no licensing requirements
- Bi-directional communication between reference station and rover is possible
- Fee-based services become practical
- Enables "State space corrections" which can improve performance over large regions

3.2.2 GNSS Reference Networks

Due in part to the growth of cellular networks, there has been a dramatic increase in the number of permanently installed GNSS reference station networks throughout the world. Many regions are discovering the advantages of having GNSS stations that are permanent and positioned within a single datum. This mitigates the need to set up a temporary base station every day, keeps all of the measurements in the same coordinate system and has the ability to serve many clients at the same time over a large region. Much of this growth has been driven by the GIS and mapping communities with oversight and management of the networks performed by land surveyors. GNSS reference station networks also offer the benefit of providing a constant, stable and well-defined reference frame which allows measurements to have a relational value without the need to translate or transform coordinates. Additionally, the capability to separate the GNSS data provider from the GNSS service provider permits more agencies to submit their data streams for use by the general public.

3.2.3 Network Connections

This marriage of cellular technology with Internet-enabled reference station networks connected through Bluetooth cell phones has generated the need to be functional in areas which most of us have no expertise. Dial-Up Networking skills have become a requirement for the surveyor that wants to connect an Internet-enabled cell phone to their GNSS receiver. On the provider side of a GNSS network, most reference stations are connected to computer networks which enable rovers to access their data streams via the Internet. This inevitably leads to IT security concerns, firewalls, permissions and more. Network connections have many variations and potential complications. Life was simpler when all the parameters that needed to be set were on one page. Baud rate, stop bits and parity are one thing, but now the modern land surveyor must negotiate proxies, pairings, gateways, subnets, IP, HTTP, TCP, ports, DNS and the list keeps growing.

4. APPLICATIONS

The demand for professional GNSS receivers is being driven in part by the software applications that have been developed. Today's field software has functionality that was previously limited to desktop computers. Surface model generation, road designing, coordinate geometry calculations and datum transformations are just a few of the advanced tools that surveyors can utilize in the field. Professionals from many industries have also found useful applications for GNSS receivers. Land and asset managers are reaping the benefits of GNSS techniques by increasing efficiencies and reducing the time required to complete their projects. Field applications such as ArcPad have facilitated the collection and homogenization of GIS databases throughout the world.

There are two opposing trends fueling the application software evolution. On one side, the software development companies would like an open system for their field software that can be loaded onto a variety of data collectors. This model creates three separate propositions for the buyer: What data collector should be used? Which software best fits the job requirements? And to what measurement engine should the data collector be connected? Conversely, GNSS manufacturers would like to create a turn-key system which supplies the data collection platform, the field software and the measurement device. There are pros and cons to each model. In both cases, the end user becomes the beneficiary of a competitive landscape which offers more features and benefits.

In an effort to capture a larger share of the potential world market, the newest low-cost GNSS receivers are feature rich with pertinence to a wider audience. The professional field applications on the market today can be summarized into three groups.

4.1 Surveying

In addition to land surveyors, this group also includes marine surveyors and civil engineers. The application software must contain routines specific to the discipline and be flexible in the way it can be configured and used. Precision and accuracy are of vital importance with most of the measurement tolerances in the one to two centimeter range.

4.2 GIS

GIS data collection represents a very large group of GNSS users. This is because GIS cuts across so many different disciplines. Scientists, environmentalists, planners, farmers, corporations, governments and many other professionals are involved in the acquisition and management of GIS databases. As the awareness of geospatial data and its importance has grown, so have these databases. The GIS applications available today offer a feature and attribute styled interface that drives the data collection process. Field entries are generally managed through choice lists and the drive for data homogeneity is crucial.

Unlike the surveying profession, precision requirements for GIS vary. If a forest is being delineated from a wetland area, there is typically no reason to seek centimeter results. Meter or decimeter level solutions are very likely adequate. However, if a water company needs to differentiate between two valves in a 30 centimeter vault, the need for precise solutions becomes more of a factor.

4.3 Construction

Construction companies have discovered the power of GNSS technology and are changing the way work is done on many construction sites. Construction companies are using this technology for the navigation or stakeout function of RTK surveying and the GIS-styled process of collecting asset locations as their projects are built. The newest low-cost GNSS receivers combine both of these applications within a single platform.

For many surveyors, the possibility for a contractor to move large amounts of earth without the need for grading stakes has been a contentious issue. Nonetheless, GNSS receivers are being mounted onto earthmovers, electronic designs are being loaded on a computer inside the cab of the heavy equipment which then allows large volumes of dirt to be moved very efficiently and precisely.

Other contractors have discovered the usefulness of recording where their assets are located as they are being built. This is especially useful in the underground utilities sector. Recovery of underground assets has been problematic and tedious, but with GNSS, the positions that are measured one time can be retrieved quickly and navigation back to the position can be accomplished even if the entire landscape surrounding the area has changed. This has proven to be such a safety of life issue that the GIS departments of many governmental agencies are requiring this information from the contractors as they build projects in their area.

5. RETURNS ON INVESTMENT

Using GNSS technology does not cost any money, it makes money. The word investment implies that monies must be laid out in advance before a return and gain on the investment will occur. Unfortunately, high receiver costs combined with unknown or uncertain returns have prevented many users from investing in this technology. Investment returns can be demonstrated in several different ways.

5.1 Productivity

The explosion in GNSS use has occurred because it makes sense. Prices have come down making the technology available to more people. Never before have measurements been so easy to execute. They can be made over long distances with very little physical effort. The precision can be scaled to meet the project budget and needs. There is likely a well suited application that can meet the job requirements. GNSS receiver performance has risen, the selection of applications continues to grow, and now, a job that would have required two weeks to complete a decade ago, can be accomplished in one day.

5.2 Infrastructure management

Assets depreciate. Conditions change. Regional needs get redefined. Emergencies happen and rapid responses are required. Having precise knowledge of an asset’s location, type and condition has risen in importance as managers of these assets realize the power that this knowledge provides. Instead of responding to disasters, regions can prepare for disasters. Instead of responding to problems, GIS managers can preempt and prevent many problems. Return on investment in the management of infrastructure is often seen in the form of saved lives. A comprehensive geospatial database can shorten reaction times, increase reaction efficiency and raise confidence during critical times when accurate information is most needed. During these stressful events, often the landscape is altered beyond recognition as in a hurricane. Alternatively, sometimes the landscape is occluded due to smoke or darkness. GNSS technology is independent of these factors so its reliability remains very high at times when other positioning techniques simply fail.

5.3 Land use management

In many countries, GNSS technology is reaping huge dividends in the management of natural resources. Many regions do not have precise knowledge of their land divisions and boundaries. With the protection of ecological resources rising in prominence, so has the use of GNSS technology to assist in its management. Low-cost surveying and mapping systems are being purchased in large quantities as the cost-effective benefits are realized. Governmental agencies are coming to understand that as land ownership and boundaries become refined, taxes can be assessed more accurately (Niemann, 1989). Water tables, regional subsidence, tectonic motion and other natural forces can be monitored with GNSS technology. The return on investment in land use management utilizing GNSS technology is characterized by facilitating the distribution and assessment of taxes, effective and informed long-term planning, protection of environmental resources and a more thorough understanding of the potentials for a region, both positively and negatively.

6. CONCLUSION

GNSS technology is an efficient and reliable tool for precise positioning and timing. The cost of these systems has been prohibitively high for many agencies and the applications have been limited to a handful of disciplines. GNSS receiver prices have declined over the past decade while performance has increased. The field acquisition software has gotten more intuitive and flexible.

New satellite signal processing engines such as BLADE™ which combines ranging information from multiple GNSS signals have enabled the merging of RTK positioning with an affordable system. Performance in single-frequency RTK systems is nearly at the same levels of dual-frequency systems subject to certain conditions. These low-cost systems will benefit developing regions by lowering the price barrier while providing scalable solutions with positioning integrity.

We are witnessing the creation of a new world-wide infrastructure. GNSS technology will continue to infiltrate and embed itself into more aspects of our daily lives. Today our watches, cell phones and vehicles have GNSS receivers. Where will they be in the future and what will they control? Will GNSS guard my personal property? Will it geo-fence animals? Will it guide my automobile and provide hands-free driving? These are exciting times for GNSS. Lower cost GNSS positioning systems will affect many layers of society. As surveyors and engineers, we have a great deal of technological power within our grasp. Innovation and performance have converged with cost effectiveness. Now is the time for implementation.

The engineers at Magellan are looking forward. What can be done better? How can GNSS positioning systems be improved? Our competitors are doing the same. This arena of competition benefits the surveying and mapping professions. Productivity and usefulness will continue to increase. The benefits of precise geospatial information will be realized by more disciplines as manufacturers continue their quest for additional ways to pack useful applications into a smaller box for less money.

APPENDIX A: List of Abbreviations

BLADE™--BaseLine Accurate Determination Engine: A new satellite signal processing engine that combines ranging signals from multiple Global Navigation Satellite Systems.

EGNOS--European Geostationary Navigation Overlay Service: European managed Satellite Based Augmentation System.

FIG--Fédération Internationale des Géomètres (also known as the International Federation of Surveyors) is an international, non-government organization whose purpose is to support international collaboration for the progress of surveying in all fields and applications.

GIS--Geographic Information System: A feature and attribute driven database possessing geospatial information.

GLONASS--GLObal'naya NAvigatsionnaya Sputnikovaya Sistema: Soviet managed Global Navigation Satellite System.

GNSS--Global Navigation Satellite System(s): Constellation(s) of space based radio-navigation satellites.

GPS--Global Position System: United States managed Global Navigation Satellite System.

L1--Industry nomenclature referring to single-frequency Global Navigation Satellite System receivers.

L1 and L2--Industry nomenclature referring to dual-frequency Global Navigation Satellite System receivers.

RTK--Real-Time Kinematic: Surveying and mapping technique utilizing the Global Navigation Satellite Systems to compute centimeter level positions in real-time.

SBAS--Satellite Based Augmentation System(s).

TTFF--Time To First Fix: The length of time required for a Global Navigation Satellite System receiver to compute a centimeter level position using a Real-Time Kinematic processing technique.

UHF--Ultra-High Frequency: Radio frequency range (300 MHz to 3 GHz) commonly used for Real-Time Kinematic positioning.

WAAS--Wide Area Augmentation System: United States managed Satellite Based Augmentation System.

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BIOGRAPHICAL NOTES

Professional Experience: Technical Support Manager, Sales Support Engineer, Sales Engineer, system validation and testing, corporate trainer with Magellan Professional

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