Positioning and Measurement
Recent Advances in High Accuracy Positioning

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SUMMARY

In the early 1990s GPS was described as the 9^{th} Utility, having the potential to provide positioning around the globe. Since the 1990s satellite positioning has been enhanced with the provision of the GLONASS, Beidou, and Galileo systems together with regional augmentation to become the GNSS system. The advent of the US 911 mandate created a market demand for ubiquitous positioning at an accuracy of 300 meters (90%), while the development of RTK technology enabled professional application of GNSS at centimeter accuracies.

With the introduction of smartphones the applications for GNSS positioning have grown with consumer level apps available for everything from navigation to distance measurement and area measurement and professional applications such as GIS data collection and asset management.

In parallel with the evolution of the smartphone, demand for improved positioning accuracy for automotive applications is being driven by the requirements of safety system initiatives and the evolution of semi and fully autonomous vehicles, bringing the need for sub-lane width accuracy.

This paper discusses the challenges and recent advances in positioning technology to meet the needs for improved accuracy for automotive and smartphone applications, addressing the needs of both the professional and consumer applications for ubiquitous high accuracy positioning.

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1. INTRODUCTION

GNSS positioning has truly become the "Ninth Utility" providing positioning across the globe for a host of applications ranging from personal navigation through autonomous machinery. To date high accuracy (sub metre) applications have been confined to professional/industrial applications, in part because of cost, but more importantly because of the ease of use.

2. THE SMARTPHONE – A UNIVERSAL TOOL

Today, with more than 1 billion smartphones being sold per year, the smartphone has emerged as a universal tool, and whilst all smartphones contain GNSS, the accuracy available from a smartphone is limited by four factors:

1) The quality of the antenna. Cost and form factor are two key reasons why smartphone antenna performance is limited today.
2) The available signals. While today's smartphones are multi-constellation using GPS and GLONASS satellites, cost and power consumption have been key drivers for the smartphone manufacturers continuing to use single frequency receivers.
3) The receiver design. Typical survey receivers are wideband, enabling better code phase accuracy and multi-path rejection, whereas smartphone GNSS receivers are narrow band receivers optimized for power consumption.
4) The availability and quality of correction services. Some smartphone and many consumer GNSS receivers use the free SBAS correction services, but no phones today.

Recent research at the University of Texas has demonstrated the feasibility of achieving centimetre accuracy from a standard cell phone antenna [1] by extracting the signal data and undertaking external processing, however this is only one part of what is required to deliver a viable solution to the user. The authors conclude that GNSS reference stations will "proliferate so that the vast majority of users can expect to be within a few kilometers of one". This is required to address the inherent limitations of a single frequency based solution, for centimetre level accuracy. The economic viability of establishing the thousands of reference stations receivers required globally for spacing of a few kilometres remains an impediment to using single frequency GNSS for high accuracy applications.


To address the current limitations of the internal GNSS receivers while enabling the use of smartphones and tablets in the field as the data collection device, manufacturers have developed smartphone applications that work with a range of Bluetooth based receivers. The key benefits of this approach are:

1) The user can select to use the internal receiver for applications requiring a few meters of accuracy, lower cost single frequency receivers for sub-meter accuracy or multi-frequency, multi constellation receivers for centimeter accuracy.
2) The higher quality external antennas enable reliable accuracy across a broader range of environments, from pocket sized devices for sub-meter positioning to traditional “survey” antennas for centimeter positioning.
3) Proven multi-path rejection for better accuracy.

Ease of use is enabled through the ability to use globally available high accuracy correction services delivered via satellite or cellular communications.

3. EMERGING NEEDS IN AUTOMOTIVE

Today there is a growing demand for high accuracy positioning driven by two major initiatives in the automobile industry. The first is the initiative for improving safety through the use of V2X (vehicle to vehicle and vehicle to infrastructure) systems. The second is the progressive move to autonomous vehicles.

There are multiple national initiatives for automobile safety applications. In the United States the Department of Transportation has been driving for the adoption of V2X technology for many years, running extensive trial. In parallel with the efforts in the United States the Car2Car consortium in Europe has been driving for European standards, and similar efforts are going on in Japan and other nations. Key for the positioning industry is the emerging requirement for sub-lane level accuracy with required accuracies of sub-metre at a 95% confidence level, or better.

In the area of autonomous vehicles technology companies like Google have been developing self-driving vehicles, while traditional automotive manufacturers are progressively introducing more and more safety features and driver aids such as pre-collision systems, lane following systems, dynamic cruise control and fuel optimization systems. All of these systems benefit from both accurate mapping of the road infrastructure and accurate location of vehicles along that infrastructure.

The composite of the needs between these safety systems and the development of advanced driver assist and ultimately autonomous vehicles, is a change in the need from "what road am I on" for in-car navigation to "what lane am I in", and in the future "where in the lane am I", creating a need for a globally available, high accuracy positioning solution where reliability and ease of use for the consumer is paramount.

4. ACCURACY, CONVENIENCE AND EASE OF USE

From the consumer's perspective one of the key benefits of GNSS as a positioning technology has been the "infrastructure free" nature of the system. For the consumer it appears to be infrastructure free, because the satellite systems are managed by the government agencies with no required input from the consumer.

In the mid-1990s the precision agriculture market emerged, initially requiring meter level accuracy for guidance applications, but to achieve the simplicity, ease of use and the cost required the market needed an "infrastructure free" solution. These accuracies were achieved using satellite delivered differential corrections from commercial providers such as Omnistar, and later by the free Coast Guard, WAAS and EGNOS correction services, combined with higher quality receivers and antennas, using wide band receiver designs. With the widespread adoption of GNSS in agriculture the demand for accuracy increased from meter level to sub-meter, and for high value crops accuracies were needed in the centimeter range.

In response to these market needs the GNSS industry has been continuing to

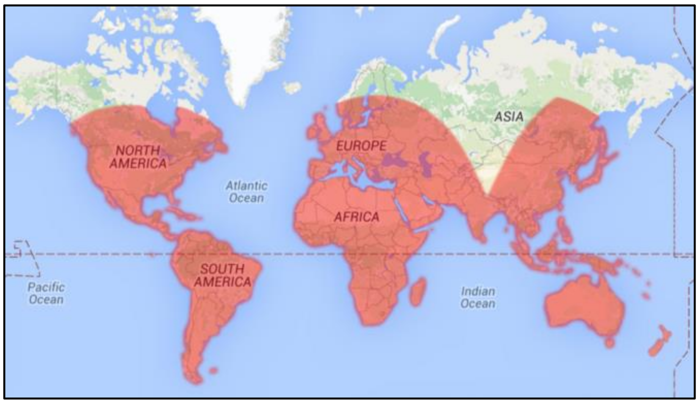


Figure 1: RTX coverage using L band satellite delivery

improve the accuracy achievable using commercial satellite and cellular delivered correction services. In 2011 Trimble Navigation introduced the CenterPoint RTX ™ system supporting the delivery of corrections via satellite or cellular communications. When used with high grade receivers these corrections enable an accuracy of 4cm, after convergence. The satellite delivered corrections cover most of the world, addressing the emerging needs for automotive users, smartphone users and many countries that are undertaking land reform and establishing robust cadastral systems.

The key benefit of satellite delivery is that the corrections can be received in rural areas, on highways etc., where there may be limited cellular coverage, and in built up urban areas where cellular coverage is normally good the corrections can be received via cellular to address any issues associated with shadowing of the satellite delivered correction data stream.

The infrastructure used to generate the corrections includes a global network of reference stations (see Figure 2), redundant operations centers, each with redundant communications servers to ensure a high availability of the corrections service. Within each operations center a corrections processing server calculates orbit, clock and bias corrections for locations across the globe, to enable mobile receivers to correct for orbit, clock and atmospheric errors almost anywhere in the world, without the need for a local reference station.

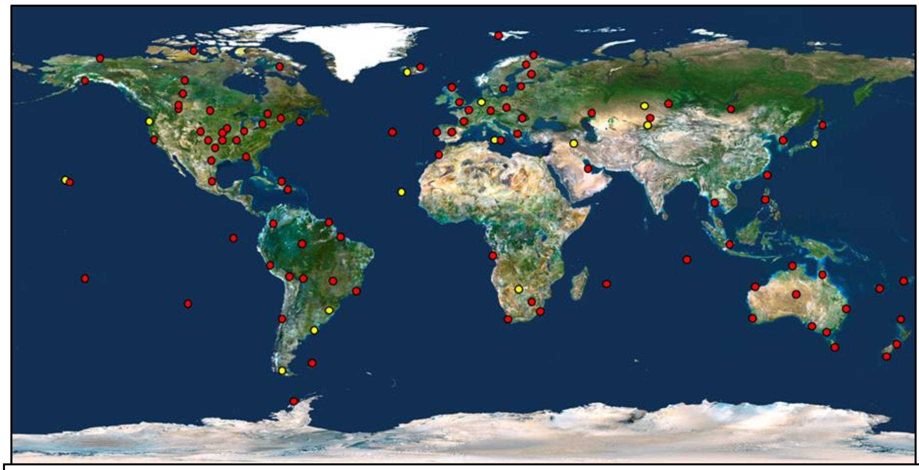
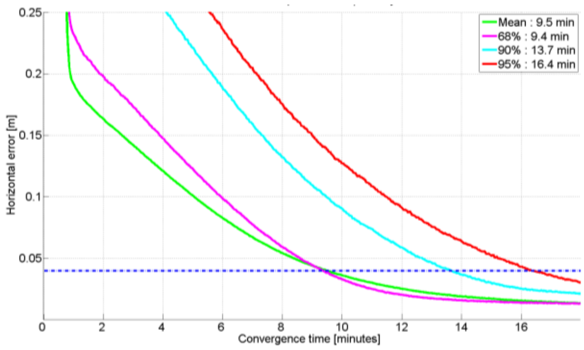


Figure 2: The global reference station network of over 120 receivers for the CenterPoint RTX service

5. RECENT ADVANCES

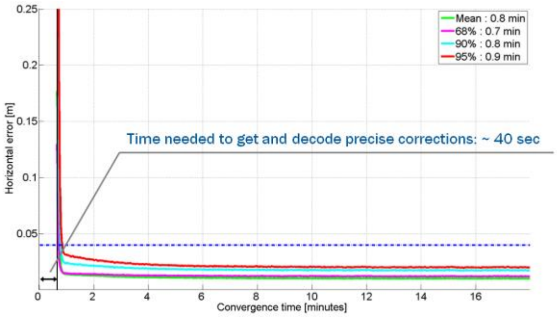


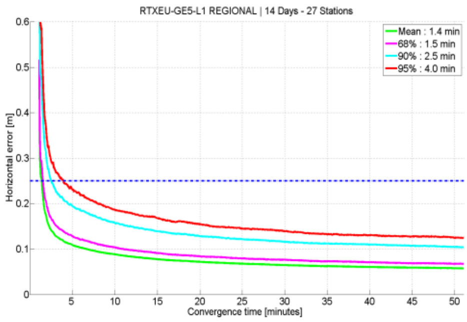
While the RTX service has been available for over 4 years providing sub 4 cm accuracy, the convergence time has limited the productive application to open sky environments such as the agricultural market, or GIS applications requiring sub foot accuracy. The longer convergence time to reach sub 4 cm accuracy using the global ionosphere and troposphere model has reduced the viability of the technology for the survey professional, for applications such as boundary definition, and for the highest accuracy GIS applications, such as recording the location of services.

To address these needs research was undertaken into the benefits of increasing the density of the reference station network to provide a regional ionosphere and troposphere model. Trimble established a network with 260 reference station across Europe, with reference station spacing on average of approximately 200 kilometers. Comparisons were then undertaken on the convergence time and accuracy using both single frequency and dual frequency receivers.

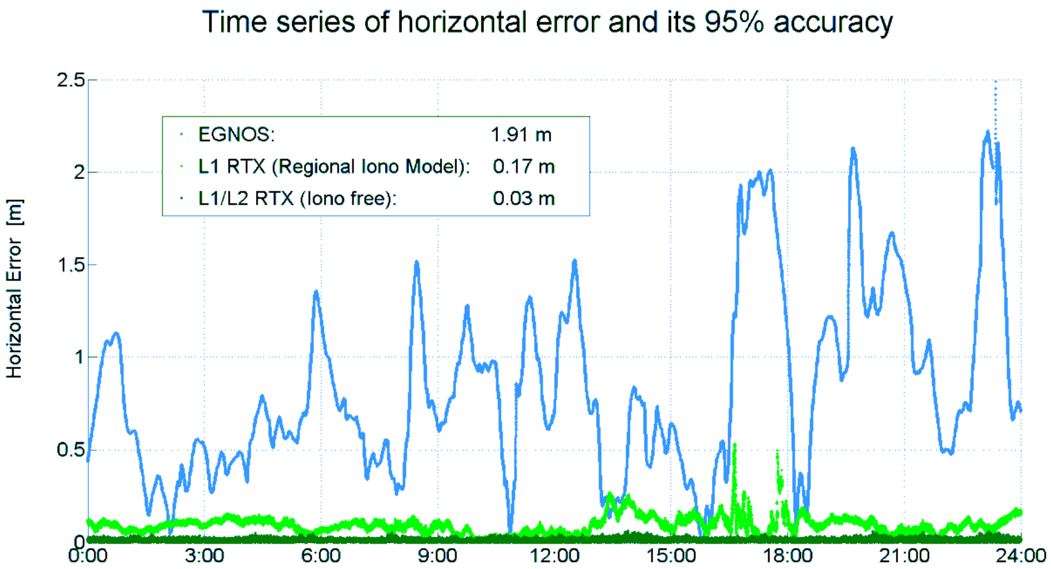
For the dual frequency receiver, test data was collected over a 14 day period analyzing approximately 23,000 convergence runs using data from 35 static stations in Europe. During the same period data for approximately 8,000 convergence runs was collected from 27 single frequency static stations. The results clearly demonstrated significant gains in performance with convergence times and horizontal accuracies similar to those obtained using VRS services and approach the accuracies of short baseline RTK. The results also highlighted the benefit of using dual frequency receivers over single frequency receivers for survey level of performance and accuracy, with the dual frequency receivers converging to <4cm horizontal at a 95% level in under 1 minute. At these accuracies the technology is suitable for rural cadastral surveys and many topographical survey applications.

In contrast, to analyze the single frequency receivers against potential automotive applications a target of converging to the lesser accuracy of <25cm horizontal was set. Convergence to sub lane level (1.5m) took less than 1 minute, and the <25 cm level accuracy was achieved in 4 minutes at a 95% level.





Finally as a part of the comparison three survey grade receivers were connected to a geodetic antenna to compare the performance of similar receivers when using EGNOS, operating as a single frequency receiver with RTX corrections and operating as a dual frequency receiver with RTX corrections. After allowing the solutions to converge data was collected over a 24 hour period to provide a comparison of accuracies.



6. SUMMARY

While it has been shown at a research level that centimeter accuracy can be achieved using the technology in current smartphones, significant technical and economic challenges remain to be overcome. Until then viable solutions for centimeter accuracy will require the use of dual frequency technology, higher quality dual frequency antennas together with either VRS or satellite delivered correction services with regional ionosphere and troposphere models.

The test results have clearly shown the benefit of dual frequency receivers over single frequency receivers in terms of convergence time and accuracy. The benefits of increasing the density of reference station network are improved productivity gained through significantly faster convergence times.

The CenterPoint RTX satellite delivered correction services can provide horizontal positioning accuracies suitable for many cadastral/land administration tasks, together with a range of high accuracy GIS applications, with an unprecedented ease of use.

It has been shown that with the availability of a network with a reference station spacing of approximately 200km providing regional models for ionosphere and troposphere corrections and the use of a high quality antenna, single frequency performance using the RTX corrections can meet the requirements for automotive applications at the sub lane level in open sky environments. However the most robust solution with fastest availability of high accuracy positioning remains the multi frequency receiver using all available observables.

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