Performance Evaluation of Global Differential GPS (GDGPS) for Single Frequency C/A Code Receivers

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BIOGRAPHY

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Lionel Garin is Director of Systems Architecture and Technology, SiRF Technology, Inc. He has over 25 years of experience in GPS and Telecommunication fields. Since 1998, his focus is on non traditional approaches to location technology, A-GPS, Distributed Server/Client Architecture, Indoor High Sensitivity operations and non GNSS location technologies. He holds several fundamental patents on this topic. Prior to SiRF, he worked at Ashtech/Magellan (now Thales Navigation) as head of Systems Engineering for Surveying GPS and GLONASS receivers. He holds an MSEE equivalent degree in Digital Communication, Systems Control and Estimation Theory for ENST Paris, France and a B.S. in Fundamental Physics from Pierre and Marie Curie University Paris, France.

ABSTRACT

Differential GPS is a technique that improves the accuracy of GPS. In its most common form, local differential GPS (LDGPS), high quality reference receivers are located at known, surveyed locations. These reference stations estimate the slowly varying error components of each satellite range measurement, form corrections and broadcast these corrections to local users within a range of 150 km (typical).

In this paper, we will analyze the performance one type of differential GPS referred to as Global Differential GPS (GDGPS) [1]. GDGPS, which is provided by NASA's Jet Propulsion Laboratory (JPL), differs from LDGPS in that the corrections are valid globally. The rationale for using GDGPS over LDGPS is that the corrections are available from a single source and are uniformly valid. This avoids the degradation of the quality of corrections with distance from reference receivers inherent in LDGPS.

GDGPS is primarily geared towards dual frequency receivers. In contrast, here, we will apply the corrections to a single frequency C/A code receiver. We will characterize the improvement in horizontal position accuracy obtained by using the GDGPS. In GDGPS, global corrections to the broadcast ephemeris and satellite clock corrections are computed using a global network of GPS reference sites, namely NASA's Global GPS Network (GGN) which is operated by JPL. For ionospheric delay corrections, we will use their database of global grid points of ionosphere electron density. For purposes of evaluation, these corrections were provided offline by JPL. They were then included in the measurements and post processed to evaluate the improvement in performance.

INTRODUCTION

Differential GPS is a well established technique to improve the accuracy of GPS [2]. The improvement in accuracy arises because certain sources of GPS errors vary slowly with time and are strongly correlated over distance. For instance, error components due to incorrect ephemeris data, satellite clock, ionosphere and troposphere can be accurately estimated and cancelled using a reference receiver at a known location.

However, even the nominally correlated errors lose that correlation if they are significantly delayed (temporally decorrelated) or are applied to a receiver significantly separated from the reference station (geographically/spatially decorrelated). The performance of local DGPS (LDGPS) receivers degrade with the distance from the reference receivers.

There are many DGPS techniques and applications. These include the LDGPS which uses a single reference station to develop a scalar correction to the code phase measurement for each satellite. Another alternative is the Wide Area Differential GPS (WADGPS) where a network of reference stations is used to form a vector correction for each satellite. The vector consists of individual corrections for the satellite clock, three components of the satellite ephemeris and parameters of an ionosphere delay model. The vector correction is valid over much greater geographical areas as compared to LDGPS corrections.

In this paper we will consider one form of WADGPS which is based on JPL's patented Global Differential GPS (GDGPS) architecture. The reader is referred to the links provided in reference [3] for a list of papers detailing the GDGPS architecture. GDGPS takes advantage of the network of reference receivers provided by NASA's Global GPS Network (GGN), which is operated and maintained by JPL. GPS observables from remote sites are compressed, packetized and transmitted over the internet to the processing centers. At the processing centers the global data is analyzed to produce precise GPS orbits and clocks. These are formatted as corrections to the GPS broadcast ephemerides, encoded, and are provided over a variety of communications channels to authorized users [1,3,4].

The fundamental tenet of GDGPS architecture is a state-space approach, where the orbits of the GPS satellites are precisely modeled, and the primary estimated parameters are the satellite state and clock [5]. The advantage of GDGPS over LDGPS is that the corrections are globally uniform and seamless. The corrections are provided as vector corrections independent of the user rather than as scalar pseudorange corrections. Users anywhere on the ground, in the air, or in near space can have access to the world's most precise differential corrections.

Robustness is achieved through redundancy. Multiple processing centers are operated in parallel and the corrections are transmitted through redundant communications channels including the internet.

GDGPS is primarily geared towards the dual frequency users. Various performance studies have been carried out for dual frequency receivers [3]. However, relatively little analysis has been done on the improvement of GDGPS for single frequency C/A code receivers. In light of the above advantages, it is worthwhile to quantify the improvements for this class of receivers using GDGPS architecture.

For purposes of evaluation, GDGPS corrections were provided offline by JPL. They were then included in the measurements and post processed to evaluate the improvement in performance.

The measurement errors that were corrected using GDGPS corrections were

1) Ionosphere Delay
2) Satellite State (orbit + clock)

Below we describe in detail the above types of corrections that are provided by JPL using their GDGPS system.

SATELLITE STATE CORRECTIONS

Satellite State corrections include corrections to satellite orbit and satellite clock.

The satellite orbit corrections are provided in the form of more accurate satellite orbit vectors. These vectors are provided for all satellites at an interval of 1 minute. These accurate orbit vectors are differenced from the broadcast satellite position vectors at the corresponding times to obtain the errors in satellite orbits.

The satellite clock corrections are provided as broadcast clock corrections and the estimated clock corrections. The estimated value includes the corrections and is provided in km at an interval of 1 second. A "sigma" value which provides a formal error associated with the correction is also provided.

For evaluation purposes, the satellite orbit errors are converted to a pseudorange correction by projecting them onto the line of sight (LOS) from user to the satellite. They are then combined with the satellite clock corrections.

IONOSPHERIC DELAY CORRECTIONS

The GPS signals are delayed in proportion to the number of free electrons encountered. This delay is also dependent on the frequency. The ionosphere is usually reasonably well-behaved and stable in the temperate zones; near the equator or magnetic poles it can fluctuate considerably. Users need to correct the raw pseudoranges for this ionospheric delay.

The method below for removing ionospheric delay from single frequency GPS data is based on a database of global grid maps of ionosphere electron density. These maps are created in real time using input data from the

GDGPS network of GPS receivers. These maps were provided at 5 minute intervals

In the GDGPS implementation, the ionosphere is modeled as a spherical layer 450 km above the earth. The vertical total electron content of the ionosphere as a function of latitude and longitude is provided at 5 minute intervals. The data are presented on a 2 deg x 2 deg grid. The units are TECU. To obtain the correction for the GPS signal (at the L1 frequency) transmitted vertically, interpolate the grid to the desired latitude/longitude and multiply by the factor 0.162 meters/TECU.

For a non-vertical GPS ray path, we first determine where the receiver/satellite line-of-sight intersects the ionospheric layer (pierce points) and evaluate the vertical TEC (with appropriate interpolation). We then multiply this by an obliquity (which is a function of elevation angle) to account for the signal path length through the ionosphere as a function of elevation angle.

TROPOSPHERIC CORRECTIONS

For tropospheric corrections, the model as detailed in section A.4.2.4 reference [6] was used.

POSITION ACCURACY WITH AND WITHOUT GDGPS CORRECTIONS

Below we quantify the improvement in horizontal position accuracy using these GDGPS. It is assumed here that the measurements correspond to a single frequency (L1) C/A code measurement. The test locations are chosen to span a range of latitudes to provide a better understanding of ionosphere delay corrections. The test duration is 24 hours (January 12, 2005) at a sampling interval of 30 seconds.

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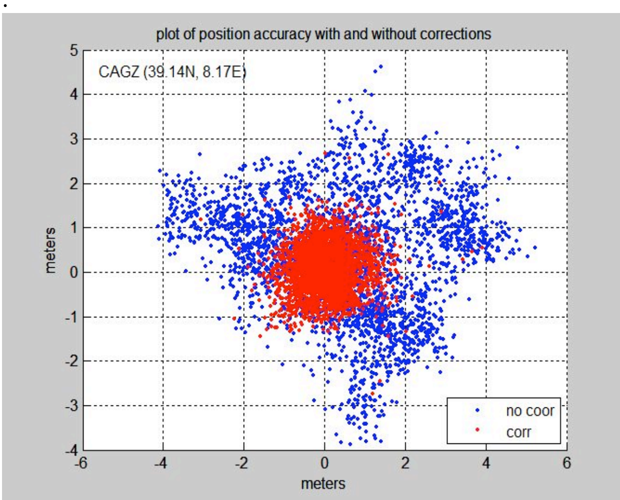

Figure 1: Plot of position accuracy with and without GDGPS corrections (CAGZ: 39.14 deg. N, 8.17 deg. E)

We compare the position accuracy obtained with GDGPS corrections against the position accuracy without these corrections. Figures 1 – 4 show the position accuracy with and without GDPGS corrections for various locations. Figure 5 quantifies the average improvement over these locations.

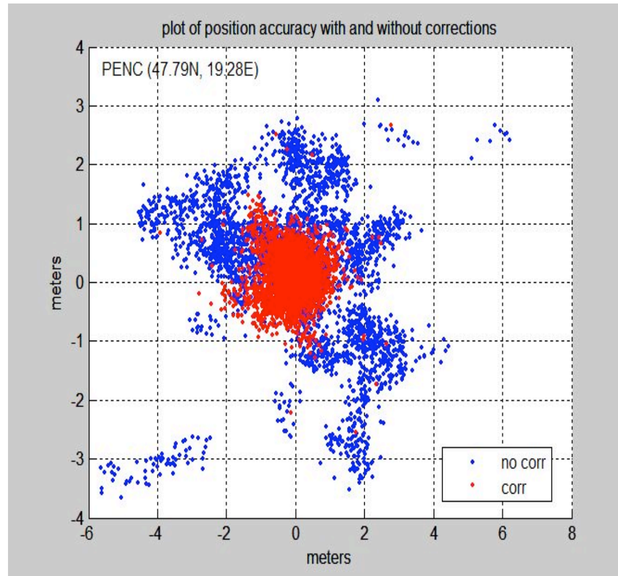

Figure 2: Plot of position accuracy with and without GDGPS corrections (PENC 47.79 deg. N, 19.28 deg. E)

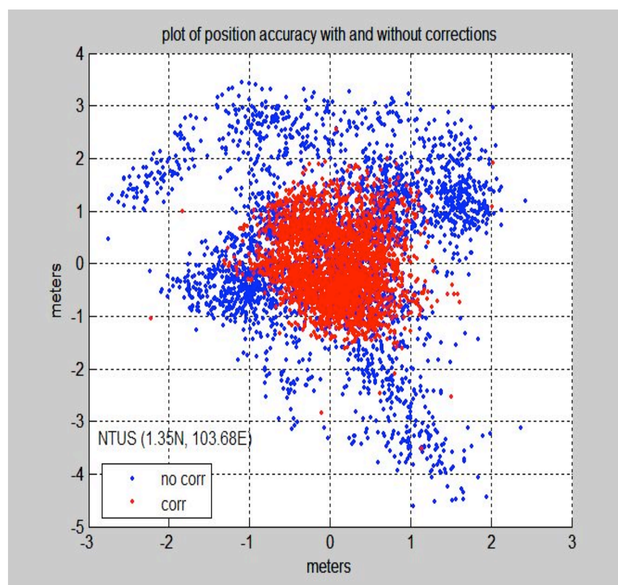

Figure 3: Plot of position accuracy with and without GDGPS corrections (NTUS 1.345 deg. N, 103.67 deg. E)

TEMPORAL CORRELATION OF GDGPS CORRECTIONS

The GDGPS satellite state corrections (orbit, clock) are provided every minute and the ionosphere corrections are provided every 5 minutes. It is desirable to quantify the

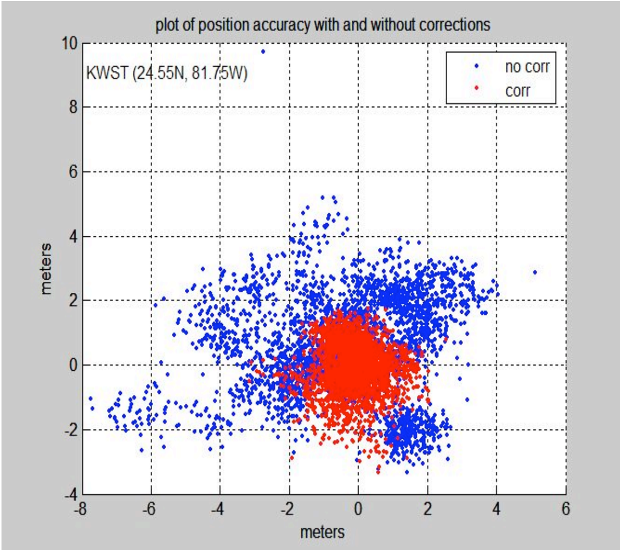

Figure 4: Plot of position accuracy with and without GDGPS corrections (KWST 24.55 deg. N, 81.75 deg. W)

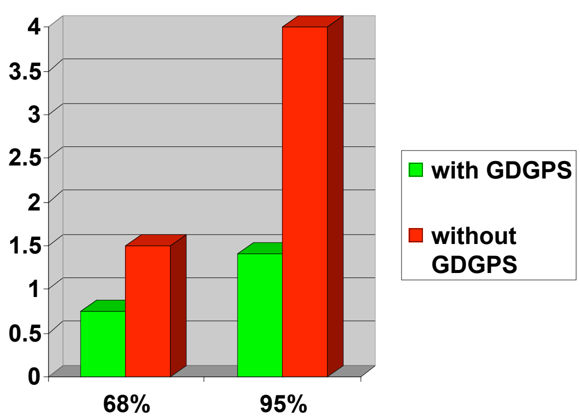

Figure 5: Plot of position accuracy with and without GDGPS

performance degradation when the corrections are available less frequently. This would enable us to understand the tradeoff of performance with transmission bandwidths. Figure 6 shows the relative degradation in horizontal position accuracy with infrequent updating. Here, the one minute satellite state updates (5 minutes for ionosphere delay updates) are used as reference.

SPATIAL CORRELATION OF GDGPS CORRECTIONS

The effectiveness of these corrections in the presence of uncertainty in the user position was also studied. Here the user position was deliberately offset by about 130 km from the true position. The LOS projection of the satellite orbit corrections and the ionosphere delay corrections are affected by this uncertainty in user position.

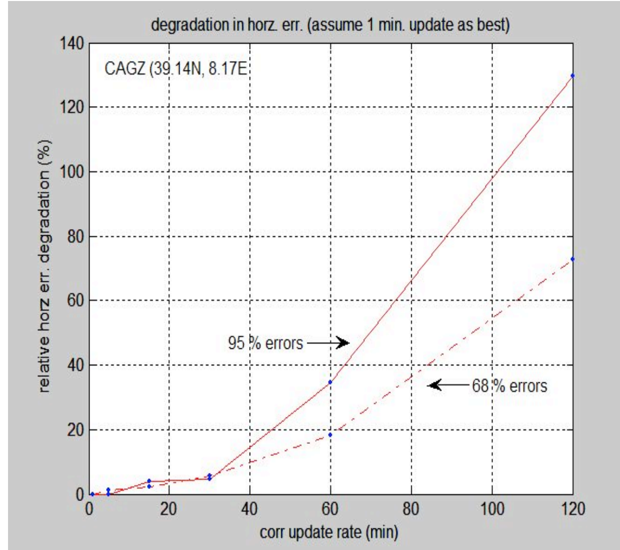

Figure 6: Plot of horizontal position accuracy degradation vs. update rate (CAGZ: 39.14 deg. N, 8.17 deg. E)

Table 1 below summarizes the degradation in horizontal position accuracy due to this offset.. The test duration was 24 hours (January 12, 2005) at a sampling interval of 30 seconds.

location	Accuracy (68%) m		Accuracy (95%) m	
	No offset	130 km offset	No offset	130 km offset
PENC	0.71	0.74	1.36	1.44
NTUS	0.84	0.89	1.41	1.47

Table 1: Spatial correlation of GDGPS corrections for (NTUS 1.345 deg. N, 103.67 deg. E and PENC 47.79 deg. N, 19.28 deg. E)

CONCLUSIONS

The improvements in horizontal position accuracy using GDGPS corrections for a single frequency C/A code measurement under open sky conditions were quantified for various locations. The degradation of these improvements with increasing uncertainty in the user position was quantified. It is also shown that the relaxing the update rate of the corrections to 15 minutes results in only a small performance degradation.

Unlike LDGPS, the corrections are available from a single source and are valid worldwide. There is no necessity to acquire, track and decode SBAS satellites which could be at a low elevation for users in several geographical regions.

It should be emphasized here that these improvements were quantified under an open sky scenario. In applications where the receiver will be operated in dense urban canyons and/or indoors, multipath errors will dominate significantly and improvements with GDGPS corrections will not be obvious to the user. The urban canyon/indoor scenarios necessitate effective multipath cancellation in parallel with GDGPS.

The application of GDGPS to Assisted GPS (A-GPS) has several distinct advantages. These include the simplicity of the correction data collection and the data dissemination to the end user. Furthermore, the horizontal accuracy can be brought less than 1 meter (one sigma) even when the reference network is not very dense.

ACKNOWLEDGMENTS

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