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Experimental Differential GPS Reference Station Evaluation

Jay Farrell
Department of Electrical Engineering
University of California, Riverside
E-mail: farrell@ee.ucr.edu

Tony Givargis
Department of Computer Science
University of California, Riverside
E-mail: givargis@cs.ucr.edu

Abstract

Differential GPS operation (DGPS) uses a reference station at a known location to calculate and broadcast pseudorange corrections to local users, resulting in improved user position accuracy. DGPS accuracy is limited by the ability of the reference station to remove the effects of receiver measurement noise and multipath errors from the broadcast corrections. This article presents two new algorithms for DGPS reference station design. This article presents an experimental analysis of the accuracy of the algorithms. The single and two frequency reference station algorithms, respectively, achieve 6 dB and > 20 dB improvement relative to the raw corrections.

1 Introduction

GPS positioning accuracy[1] is limited by measurement errors that can be classified as either common mode or non-common mode. Common mode errors have nearly identical effects on all receivers operating in a limited geographic area (< 50 km). Non-common mode errors are distinct even for two receivers with minimal antenna separation. The common mode pseudorange errors have a typical standard deviation on the order of 25 meters for civilian receivers. The common mode errors are smooth, continuous signals with correlation times on the order of 300 seconds. The non-common mode errors are dominated by multipath and receiver noise. Code multipath (i.e., multipath errors on the pseudo-range derived from the pseudo-random noise code (PRN)) has a standard deviation of a few meters and correlation times for stationary receivers of a few minutes. Receiver measurement noise is predominantly high frequency and has a standard deviation between 0.2 m and 1.5 m depending on receiver technology.

GPS or GPS aided INS are candidate navigation systems for vehicle control applications in farming, aviation, rail, marine, mining, and dredging [1, 5]. For most control applications, the $\approx$ 100 m. standard GPS position accuracy is not sufficient. Differential GPS (DGPS) techniques can produce positioning accuracies at the 1 to 10 meter level [1]. These accuracies are sufficient to enable new automated vehicle control applications.

This article analyzes the experimental performance of two new algorithms for DGPS reference station implementation. Due to space limitations, the discussion of the algorithm herein is brief. A detailed discussion and theoretical performance analysis is presented in [3]. The main objectives in the design of these new algorithms is the removal of non-common mode errors (i.e., multipath and receiver noise) from the differential corrections. Algorithms for determining phase corrections are not discussed. Phase correction calculation algorithms are discussed, for example, in [1, 3]. In the remainder of this article, it will be assumed that all measurements are made simultaneously. This assumption may not be applicable to early generation receivers.

The specifications of the RTCM 104 standard [1] will serve as a basis for the design and discussion of this paper. In particular, atmospheric errors are included in the broadcast corrections, but reference station and satellite clock biases are removed from the broadcast corrections.

2 Background

This section presents background information necessary for the discussion of the reference station algorithm design and analysis. Throughout this article the notations x, $\hat{x}$, and $\tilde{x}$ will be used to denote the actual, computed, and measured values of a variable x, respectively.

2.1 Observables

The code pseudorange measured by a user receiver can be accurately modeled as [2, 3]

$$\begin{aligned}\tilde{\rho} &= \left((\hat{x}_{sv}-x)^2+(\hat{y}_{sv}-y)^2+(\hat{z}_{sv}-z)^2\right)^{0.5} \\ &\quad +c\Delta t_r(t)+MP(t)+\eta(t)+r_c(t)+c\Delta t_{ion}(t)\end{aligned} \tag{1}$$

where $r_c(t)=c\Delta t_{sv}(t)+SA(t)+E(t)+c\Delta t_{tr}(t)$, c is the speed of light, $\Delta t_r(t)$ is the receiver clock bias, Δt_{sv} is the satellite clock bias, $SA(t)$ is the selective availability error, $E(t)$ represents error in the calculated ephemeris, $\Delta t_{ion}(t)$ represents dispersive ionospheric errors, $\Delta t_{tr}(t)$ represents non-dispersive atmospheric errors, $MP(t)$ represents the multipath error, and $\eta(t)$ represents random measurement noise. The satellite position $(\hat{x}_{sv},\hat{y}_{sv},\hat{z}_{sv})$ is calculated based on the standard GPS equations [3, 5]. The last two terms in eqn. (1) represent the common mode errors.

The full carrier phase measured by a user receiver can be accurately modeled as [2, 3]

$$\begin{aligned}\tilde{\phi}\lambda &= \left((\hat{x}_{sv}-x)^2+(\hat{y}_{sv}-y)^2+(\hat{z}_{sv}-z)^2\right)^{0.5} \\ &\quad +c\Delta t_r(t)+mp(t)+\zeta(t)+N\lambda+r_c(t)-c\Delta t_{ion}(t)\end{aligned} \tag{2}$$

where $\lambda=\frac{c}{f}$ is the wavelength corresponding to the carrier frequency f, mp represents phase multipath, and ζ represents phase measurement noise. Phase multipath error has a typical magnitude on the order of a centimeter. Phase measurement noise has a standard deviation on the order of a millimeter (i.e., 1% of the wavelength). The variable N is a constant integer that represents the

[1] Discussion of GPS terminology and positioning algorithms can be found, for example, in [3, 5].

whole number of carrier cycles between the satellite and receiver at an initial measurement time. This integer bias is unknown. The full carrier phase measurement cannot be used as a pseudo-range measurement unless the *integer ambiguity* N is determined [4].

The ionospheric effects are dependent on the carrier frequency and can be modeled to first order as

$$c\Delta t_{ion}(t) = \frac{A}{f^2} TEC \qquad (3)$$

where TEC is the total electron count in a fixed cross sectional area along the actual path traversed by the signal between the satellite and receiver. The GPS system currently uses two carrier frequencies ($f_1 = 1575.42$ M Hz and $f_2 = 12227.60$ M Hz). It is convenient for the analysis that follows to define the quantity $I_a = \frac{A}{f_1 f_2} TEC$. With this definition, the ionospheric delay affecting the pseudo-range measurements derived from the f_1 and f_2 carrier signals can be represented as

$$c\Delta t_{ion_1}(t) = \frac{f_2}{f_1} I_a \quad \text{and} \quad c\Delta t_{ion_2}(t) = \frac{f_1}{f_2} I_a. \qquad (4)$$

Note that the dispersive ionospheric effects affect the code and phase measurements in opposite senses (i.e., code is delayed while phase is advanced [4]).

2.2 Differential Corrections

The objective of the DGPS reference station is to accurately estimate and broadcast real-time corrections that enable a GPS user to eliminate the effects of the common mode errors from the positioning solution. The extent to which this objective is achieved will depend on the ability of the reference station to separate the common mode and non-common mode errors. Carrier phase information can be used advantageously in this separation process.

A reference receiver at an accurately calibrated location (x_o, y_o, z_o) can calculate the reference-to-satellite range as

$$\hat{R}_o = \left((\hat{x}_{sv} - x_o)^2 + (\hat{y}_{sv} - y_o)^2 + (\hat{z}_{sv} - z_o)^2\right)^{0.5}.$$

The basic range space differential correction (per satellite) is determined by differencing the calculated and measured reference-to-satellite ranges:

$$\begin{aligned} \hat{\Delta}_{DGPS}(t) &= \hat{R}_o - \tilde{\rho} && (5) \\ &= -(c\Delta t_o(t) + c\Delta t_{sv} \\ &\quad + r_c(t) + c\Delta t_a(t) + MP(t) + \eta(t)) && (6) \end{aligned}$$

where Δt_o represents the bias in the reference receiver clock. Based on the RTCM specification list, the broadcast corrections should be corrected to remove the reference receiver and satellite clock errors. Therefore, the broadcast corrections will take the form

$$\begin{aligned} \hat{\Delta}_{GPS}(t) &= \hat{R}_o + c\Delta\hat{t}_o(t) + c\Delta\hat{t}_{sv}(t) - \tilde{\rho} && (7) \\ &= -(r_c + c\Delta t_a(t) + MP(t) + \eta(t)) && (8) \end{aligned}$$

where the residual reference receiver and satellite clock errors have been included in r_c. The residual satellite clock error is small and common to all receivers using the same set of ephemeris data to calculate the satellite clock corrections. Therefore it will be removed through differential operation. The calculation of $c\delta t_o$ is addressed in [1] and Section 7.5.2 in [3].

Equation (7) shows the actual reference station calculation. Equation (8) shows the remaining error sources in the calculated signal.

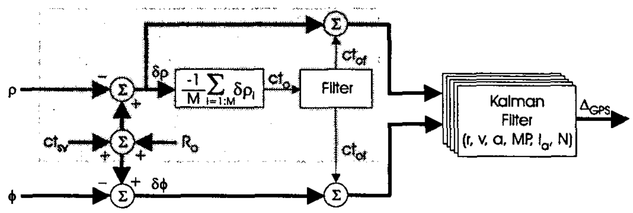

Figure 1: Single Frequency Reference Station Design with Correction Filtering. Wide lines represent vector variables where $v = \dot{r}$, and $a = \ddot{r}$.

Note that the Δ_{DGPS} signal contains the desired common mode error sources, which will cancel the corresponding errors in the user's position calculation. It also contains the multipath and measurement noise terms. Since these errors can be as large as several meters, it is beneficial to filter the $\hat{\Delta}_{GPS}$ signal to remove the non-common mode errors prior to broadcast.

The basic reference station is shown in the shaded (upper left) portion of Figure 1. The shaded portion of the figure incorporates the principles described above to produce range corrections for each in-view satellite which are corrected for satellite clock error and filtered reference station clock bias. The resultant differential corrections from this basic algorithm are those of eqn. (7). The corrections are corrupted by the reference station multipath and receiver noise. Algorithms to attenuate the affects of these non-common mode errors on the broadcast corrections are the topic of the remainder of this article.

2.3 Existing Algorithms

Differential reference station algorithms have been previously presented [6, 7]. Both reference station algorithms can be represented by a block diagram similar to Figure 1, where the basic corrections for each satellite (outputs of the shaded box) are filtered before being broadcast to users. The purpose of the filtering is to reduce the non-common mode multipath error and receiver measurement noise. In addition, the filters generate the rate of change of the correction which is useful for correcting Doppler measurements and for propagating latent corrections to the time of applicability [1].

All the algorithms in [6, 7] and discussed herein are designed using the Kalman filtering methodology [2]. The existing algorithms and those proposed in subsequent sections are distinguished from each other by the filter model and the measurements that the filter incorporates.

The algorithm of [7] calculates reference station corrections by passing the basic correction of eqn. (7) through a three state Kalman filter with $\mathbf{x} = [c, v, a]$ where c is the filtered correction (i.e., pseudorange error), v is the rate of change of the correction, a is the acceleration of the correction. The Kalman filter is driven by the basic differential correction of eqn. (7). The resulting filter is suboptimal, since it neglects the correlation in the multipath errors, which have been modeled as white measurement noise. The article shows that the difference between the corrections of two reference stations using separate antennas but identically software had standard deviations of approximately 3.6 m and peak values of approximately 10 meters. Therefore, the standard deviation of a single reference station specified in [7] would be about 2.5 m.

The algorithm of [6] is based on a four state filter $\mathbf{x} = [c, v, a, e]^T$ where c, v, and a are as defined above, and e represents the difference between the rates of change of the code and carrier pseudorange corrections. This fourth state is used to allow the filter to account for the fact that changes in the ionospheric error affect the code and phase measurements in opposite senses. The filter uses the measurement of equation (7) and a Doppler correction as observables. This algorithm does not model the code multipath as a separate state, instead including the code multipath in the η term. Therefore, the η term has significant time correlation violating the standard Kalman filter assumptions. Article [6] also discussed issues related to integrity management, filter health, and data reasonableness checking. These issues will not be discussed herein.

The filter presented in [7] is able to decrease the effect of the high frequency random receiver noise, but cannot substantially decrease the effects of multipath since the the frequency content of the corrections and the multipath error are very similar. Both have correlation times on the order of minutes. The filter presented in [6] uses Doppler measurements to smooth the code corrections. This requires one additional state, but gives the filter a greater ability to reject multipath errors. Performance statistics are not presented in [6], but can be inferred (using a PDOP $\approx$ 3) to be at the 1.6-2.6 m level based on the 5-8 m position accuracies stated in the conclusion of that article.

The subsequent section of this article will present an eight state two frequency reference station filter. This filter will utilize both code and phase pseudorange measurements. The filter is analyzed analytically in [3] and experimentally herein to determine the filter performance.

3 Single and Two Frequency Reference Station Design

This section briefly presents the algorithm for single and two frequency reference stations driven by code and phase pseudo-range measurements. Due to the different effect that ionospheric effects have on the two measurements, the ionospheric effects will need to be modeled separately from the remaining forms of common mode error. For this purpose, let the desired differential correction for the f_1 code pseudorange be

$$y_1(t) = \Delta_{DGPS}(t) = -r_c(t) - \frac{f_2}{f_1} I_a(t). \tag{9}$$

Since the differential correction calculated at the reference station is corrupted by multipath and receiver noise, the measured correction is modeled as

$$\begin{aligned} \tilde{z}_1(t) &= \hat{R}_o(t) + c\Delta\hat{t}_{sv}(t) + c\Delta t_{of}(t) - \tilde{\rho}_{o1}(t) \\ &= -r_c(t) - \frac{f_2}{f_1} I_a(t) - MP_1(t) - \eta_1(t) \end{aligned} \tag{10}$$

Let z_2 denote a similarly processed version of the measured f_1 carrier phase range correction (measured in cycles) at the reference station, then

$$\begin{aligned} \tilde{z}_2(t) &= (\hat{R}_o(t) + c\Delta\hat{t}_{sv}(t) + c\Delta t_{of}(t))/\lambda_1 - \tilde{\phi}_{o1}(t) \\ &= \frac{-1}{\lambda_1} r_c(t) + \frac{1}{\lambda_2} I_a(t) - N_1 - mp_1(t) - \nu_1(t) \end{aligned} \tag{11}$$

where the subscripts in the right hand side of the equation indicate to which carrier frequency the subscripted variable refers. The measurements corresponding to f_2 are

$$\tilde{z}_3 = \hat{R}_o(t) + c\Delta\hat{t}_{sv}(t) + c\Delta\hat{t}_{of}(t) - \tilde{\rho}_{o2}(t) \tag{12}$$

$$= -r_c(t) - MP_2(t) - \frac{f_1}{f_2} I_a(t) - \eta_2(t) \tag{13}$$

$$\tilde{z}_4 = (\hat{R}_o(t) + c\Delta\hat{t}_{sv}(t) + c\Delta\hat{t}_{of}(t))/\lambda_2 - \tilde{\phi}_{o2}(t) \tag{14}$$

$$= \frac{-1}{\lambda_2} r_c(t) + \frac{1}{\lambda_1} I_a(t) - N_2 - \nu_2(t). \tag{15}$$

Use of both the code and phase measures to drive the filter will therefore require the state to be defined as $\mathbf{x} = [r_c, \dot{r}_c, \ddot{r}_c, MP_1, MP_2, I_a, N_1, N_2]^T$ for a filter using two frequency measurements. The first three state variables represent the range correction and its first two derivatives, excluding ionospheric effects. The MP_i states represent code multipath, which is to be removed. The I_a state represents ionospheric effects, which are modeled separately to properly account for their different effects on the code and carrier observables. The N_i states account for the carrier integer ambiguity, which will be estimated as a real variable. The measurement models corresponding to the observable variables are

$$\begin{aligned} z_1(t) &= \mathbf{H}_1\mathbf{x}(t), & \mathbf{H}_1 &= [-1,0,0,-1,0,-\tfrac{f_2}{f_1},0,0], \\ z_2(t) &= \mathbf{H}_2\mathbf{x}(t), & \mathbf{H}_2 &= [\tfrac{-1}{\lambda_1},0,0,0,0,\tfrac{1}{\lambda_2},-1,0], \\ z_3(t) &= \mathbf{H}_3\mathbf{x}(t), & \mathbf{H}_3 &= [-1,0,0,0,-1,-\tfrac{f_1}{f_2},0,0], \\ z_4(t) &= \mathbf{H}_4\mathbf{x}(t), & \mathbf{H}_4 &= [-\tfrac{1}{\lambda_2},0,0,0,0,\tfrac{1}{\lambda_1},0,-1]. \end{aligned}$$

The desired f_1 differential range correction can be calculated from the filter state as

$$y_1(t) = \mathbf{L}_1\mathbf{x}(t), \quad \mathbf{L}_1 = [-1,0,0,0,0,-\frac{f_2}{f_1},0,0]$$

for the two frequency filter. The output y_1 represents the range correction including ionospheric error, but processed to remove multipath, code measurement noise, reference station clock error, and predicted space vehicle clock error. Theoretical (covariance) analysis and specification of the state transition matrix are presented in [3]. Experimental results for this reference station algorithm are presented in Section 4. The single frequency filter is defined similarly, but does not require states 5 nor 8 and uses only z_1 and z_2.

4 Experimental Analysis

To experimentally determine the reference station performance, two reference stations with identical software were run simultaneously. Each reference station receiver was connected to its own antenna. The antennas were located on a building roof edge approximately 5 m. above the earth surface. The earth surface adjacent to the building was a large parking lot. The differential separation of the antennas is $(n,e,h) = (-3.28, -1.62, .29)m$. The data presented is the difference between the corrections generated by the two reference stations. The mean of the difference (across all available satellites at both bases) at each sampling instant is also removed, as the mean will only affect the user clock estimate not the user position. This is the same experimental set-up and procedure as described relative to Figure 8 of [7].

The hardware for each reference station includes an Ashtech Z-XII receiver and antenna, and an 486 equivalent PC. The antenna used a ground plane, but did not use a choke ring. Each reference station

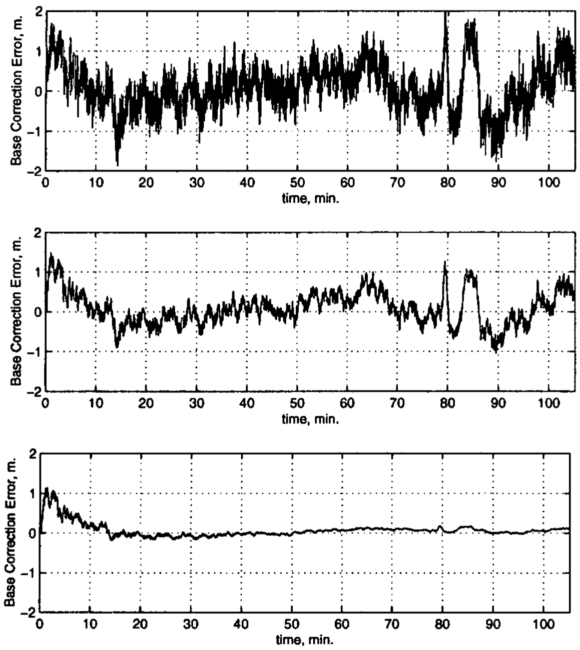

Figure 2: Reference Station Correction Difference for PRN 4. (a) Top–Unfiltered. (b) Middle–Single Frequency Filter. (c) Bottom–Two Frequency Filter.

calculated and stored time stamped corrections to disk for analysis later. The reference station software simultaneously calculated the basic differential corrections, the single frequency corrections, and the two frequency corrections for all available satellites in real-time. Therefore, the results of the unfiltered, single frequency and two frequency filters are directly comparable and based on identical receiver measurements. Due to space limitations, the graphical data is only presented for a single satellite (PRN 4). The experimental results for a set of five satellites is summarized in Table 1. The presented data was collected the morning of June 9, 1998 for the satellites with PRN's: 4, 5, 8, 9, and 24.

Figure 2a shows the difference between the basic unfiltered corrections. The data is stored at a 1.0 Hz rate. Therefore, the plot represents about 6000 samples. The difference between the corrections of the two bases has considerable high and low frequency variation. The low frequency variations are attributed predominantly to multipath. Figure 2b shows the difference in the reference station corrections as generated by the single frequency reference station. The single frequency reference station algorithm is able to decrease the affects of receiver noise, but cannot significantly reduce the effects of multipath. Although slight improvements in performance are possible through additional filter tuning, dramatic increases in performance cannot be expected. The single frequency reference station algorithm is not able to accurately observe the ionospheric state I_a. Since this state is very slowly changing, the filter has difficulty discriminating the integer ambiguity N_1. Therefore, the phase measurement cannot be used as a pseudorange signal by the filter to directly estimate r_c. The filter instead uses the change in the phase measurement to accurately and rapidly ($t < .1$ minute) estimate the velocity and acceleration of the correction. The single frequency reference station algorithm uses the phase measurement to smooth the corrections (i.e., accurate rate), but cannot accurately discriminate the correction from the multipath. The single frequency reference station therefore yields performance very similar to, but slightly better than, that that would result from a reference station filter using code pseudorange and Doppler as presented in [6].

Figure 2c shows the difference in the reference station corrections as generated by the two frequency reference station. After a brief ($\approx$ 10 minute) transient period, the two frequency reference station correction difference is significantly less than that of the basic or single frequency reference station algorithms. The improved performance of the two frequency reference station algorithm is due to the increased observability of the ionospheric state I_a. The observability of I_a allows both integers to be estimated rather accurately so that the phase measurements can be used directly as pseudorange estimates in the estimation of r_c. Therefore, multipath errors can be accurately discriminated from the ionosphere and r_c states. Note that multipath errors are essentially eliminated after a 10 minute transient period. This 10 minute transient period corresponds well with the transient predicted via the covariance simulations.

Figure 3a shows the correlation function of the reference station differences for the satellite with PRN 4 for time shifts of 0 through 300 seconds. The correlation functions were generate using the correction differences only for $t \geq 30min.$ to ensure that the filter was operating in steady state. The correlation functions for all three reference stations are shown on the same graph. The correlation function for the two frequency reference station is difficult to distinguish from the time axis, but is relatively constant at approximately $0.01m^2$.

Figure 3b shows the power spectral density of the reference station correction differences for the three reference station algorithms for frequencies between 0.001 and 0.5 Hz. The single frequency filtering gives a roughly 6 dB improvement over the basic unfiltered corrections at all frequencies. The two frequency filtering gives better that 20 dB improvement over the basic unfiltered corrections at all frequencies.

Table 1 shows statistics of the reference station correction differences for all five satellites that were available for the entire duration of the experiment. The first column shows the satellite identity by means of its PRN. The remainder of the table is subdivided into four sets of columns. The column headings 'u', '1', and '2' in each section of the table indicates that the column of data is for the unfiltered, single frequency, and two frequency reference station algorithms, respectively. The four subsections of the table indicate the maximum value of the correction difference and the standard deviation of the correction difference for the entire experiment and the steady state portion of the experiment. The factor of ten improvement is easily noticed in all four statistics for satellites 4, 5, and 9. For satellites 8 and 9, significant multipath error at the start of the experiment caused the correction difference to still be decaying towards zero at t = 1000 sec. This affects both the maximum value and the standard deviation, but the effect decays steadily with time. All the data in the table is for the reference station correction differences. To estimate the standard deviation of the error for a single base, the presented standard deviation should be divided by $\sqrt{2}$.

5 Conclusions

This article has presented and analyzed two new algorithms for the design of reference stations for differential GPS implementations. The algorithms incorporate both code and phase pseudorange data for DGPS correction estimation. Experimental analysis is presented herein. The analysis shows that the single frequency reference station is not capable of accurately removing multipath errors from the broadcast corrections. Alternatively, the two frequency reference station is able to accurately estimate and remove the effects of multipath from the broadcast corrections. The single frequency and two frequency reference station algorithms improved the accuracy of the basic corrections by 6 dB and 20 dB, respectively.

All DGPS reference station algorithms have some transient period. The algorithms presented herein have approximately 10 minute transient periods between satellite acquisition and steady state filter operation. This length of time corresponds to the first $\frac{1}{36}$ of a satellites 6 hour fly-by or approximately 5 degrees of elevation change. Since most users ignore satellites below a threshold elevation of 5 to 10 degrees, the reference station corrections would be in steady state before the corrections began to be used.

The implementation of the two frequency reference station requires an eight state Kalman filter for each satellite and a single reference station clock correction filter. The calculations required for this implementation do not impose a significant computational burden for state of the art computers. In fact, the experiments presented herein implemented the clock filter and the single and the two frequency reference station Kalman filters for at least eight satellites with writing of data to the hard disk at a 1.0 Hz rate on a IBM compatible 66 M Hz 486 computer. If desired, the computational load could be significantly decreased by either curve fitting the optimal filter gains or using stored gains for the steady state portion of the operation (i.e., $t > 10$ minutes).

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References

[1] *RTCM Recommended Standards for Differential Navstar GPS Service*, Version 2.1, RTCM Special Committee No. 104, January 3, 1994.

[2] Brown, R., Y. Hwang, *Introduction to Random Signals and Applied Kalman Filtering*, 2nd ed. New York : J. Wiley, c1992.

[3] Farrell, J. A., and M. Barth, *The Global Positioning System and Inertial Navigation*, McGraw-Hill, ISBN-0-07-022045-X, 1999.

[4] Hatch, R., "The Synergism of GPS Code and Carrier Measurements," Proc. 3rd Int. Geodetic Symposium on Sat. Doppler Pos., 1982, Las Cruces, NM.

[5] Kaplan, E., ed., *Understanding GPS: Principles and Applications* Boston : Artech House, c1996.

[6] Loomis, P., G. Kremer, and J. Reynolds, "Correction Algorithms for Differential GPS Reference Stations," *Navigation: Journal of the Institute of Navigation*, Vol. 36 (2), Summer 1989, pp. 91-106.

[7] Vallot, L., S. Snyder, B. Schipper, N. Parker, and C. Spitzer, "Design and Flight Test of a Differential GPS/Inertial Navigation System for Approach/Landing Guidance," *Navigation: Journal of the Institute of Navigation*, Vol. 38 (2), Summer 1991, pp. 321-340.

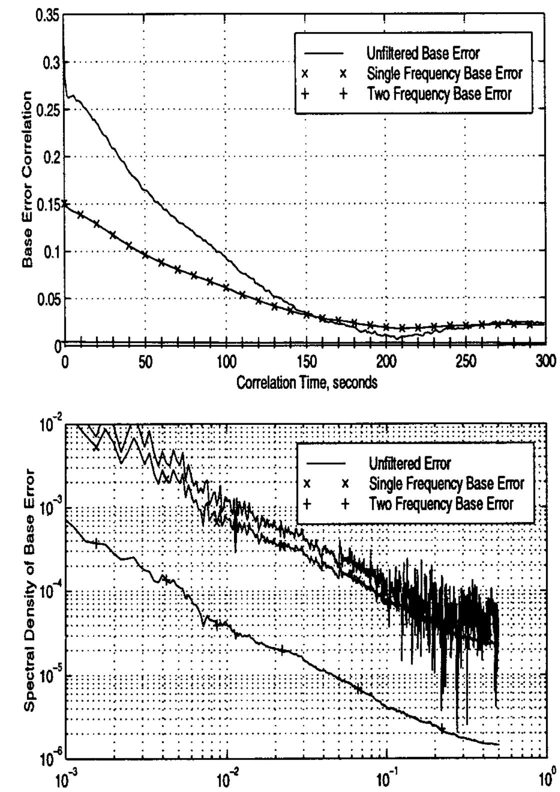

Figure 3: (a) Top–Time correlation for the unfiltered, single frequency and two frequency filtered range station correction differences. (b) Bottom–Power spectral density of the unfiltered, single frequency and two frequency filtered corrections. Experimental data for $t \geq 30$ for PRN 4.

	Max for $t > 0$			Max for $t > 1000$			Std. for $t > 0$			Std. for $t > 1000$		
PRN	u	1	2	u	1	2	u	1	2	u	1	2
4	2.1	1.5	1.1	2.1	1.3	.19	.57	.41	.18	.55	.38	.07
5	2.0	1.5	.99	2.0	1.2	.23	.54	.35	.12	.50	.31	.06
8	2.2	1.6	1.0	1.8	1.1	.61	.52	.35	.18	.47	.29	.12
9	2.1	1.1	.36	2.1	1.1	.16	.39	.23	.05	.39	.23	.03
24	2.0	1.3	.82	2.0	1.2	.67	.49	.34	.15	.47	.32	.12

Table 1: Various Statistics Related to the Reference Station Correction Differences