Wavelets and triple difference as a mathematical method for filtering and mitigation of DGPS errors

Aly M. El-naggar

Transportation Department, Faculty of Engineering, Alexandria University, Egypt

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Abstract The accuracy of GPS position is primarily dependent on the satellite position, signal delay, and various environment noises such as ionospheric delay effects, ephemeris errors, satellite clock errors, multi-path distortion, tropospheric delay effects, and numerical errors. To overcome most of these errors the Differential Global Positioning System (DGPS) is used. Differential Global Positioning System is one of the most popular and reliable techniques for improving GPS accuracy by minimizing correlated errors between reference stations and rovers. The primary motivation of this paper is to improve GPS measurement accuracies by classifying errors in the frequency domain and subsequently separating, mitigating and decreasing them.

Wavelet spectral techniques can separate GPS signals into sub-bands where different errors can be separated and mitigated. The main goal of this paper was the development and implementation of DGPS error mitigation techniques using triple difference and wavelet. This paper studies, analyzes and provides new techniques that will help mitigate these errors in the frequency domain. The proposed technique applied to smooth noise for GPS receiver positioning data is based upon the analysis of wavelet transform (WT). The technique is applied using wavelet as a de-noising tool to tackle the high-frequency errors in the triple difference domain and to obtain a de-noised triple difference signal that can be used in a positioning calculation.

GPS accuracy is constrained by its susceptibility to many types of systematic and random errors. Some GPS errors, such as atmospheric errors, orbit errors and clock drifts are independent of local surroundings of the receiver, i.e. operational environment. The differential GPS technique (DGPS) reduces or even eliminates several errors of this type [2].

Orbital, satellite clock, and atmospheric errors can be reduced or even eliminated by differencing pseudorange measurements with a receiver at a known location (herein referred as DGPS) or by applying algorithms designed to model their effects. Some models are based on the parameters broadcast from the GPS constellation. The receiver clock error is usually

1. Introduction

Global Positioning System (GPS) measurements can be corrupted by several error sources. These errors are categorized as biases and random errors, i.e. ionosphere, troposphere, satellite clock, receiver clock offsets, receiver noise, and multipath. Differential GPS (DGPS) provides users with corrections to remove the correlated bias terms between receivers [1].

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included as an unknown parameter in single point and single difference GPS methods. Multipath is caused by multiple reflections of GPS signals interfering with the line-of-sight signal (LOS). It is environmentally dependent and thus cannot be mitigated by DGPS.

Another way to deal with these errors is to filter in the frequency domain, where all these errors have a different frequency spectrum component. Each error is characterized by a specific frequency band [3]. The wavelet-based trend extraction model is applied to triple difference signal to mitigate the errors to improve the DGPS static baseline solutions.

The paper is organized as follows. Section 2 discusses the wavelet. While the description of DGPS and various methods of differencing is presented in Section 3, and Numerical results and performance analysis are provided in Section 4. Conclusions are given in Section 5.

2. Wavelet spectral analysis

Everywhere around us are signals that can be analyzed. For example, there are seismic tremors, human speech, engine vibrations, medical images, financial data, music, and many other types of signals. Wavelet analysis is a new and promising set of tools and techniques for analyzing these signals.

The first wavelet was derived from the Haar base function found around 1910 by Haar. Morlet and Grossman created a large revolution in the wavelet world in the beginning of the 1980s when they introduced what is called the continuous wavelet transform. Their development was followed by the successful construction of an orthogonal wavelet with compromise of localization and undecimated in a multi-resolution representation to introduce a solid system to be used in signal analysis. Since then, the wavelet transform is a tool that represents data, functions or operators into different frequency components, essentially “cutting up” data. This tool is used to study each component with a resolution that matches its scale. In the last two decades wavelets have been used extensively in different research fields. It has many potential applications such as image processing, medical diagnostics, pattern recognition, geophysical signal processing, boundary value problems, and electromagnetic wave scattering.

Wavelet Toolbox™ software is a collection of functions built on the MATLAB® technical computing environment. It provides tools for the analysis and synthesis of signals and images, and tools for statistical applications, using wavelets and wavelet packets within the framework of MATLAB.

The Wavelet Toolbox software includes a large number of wavelets that you can use for both continuous and discrete analyses. For discrete analysis, examples include orthogonal wavelets (Daubechies’ extremal phase and least asymmetric wavelets) and B-spline biorthogonal wavelets. For continuous analysis, the Wavelet Toolbox software includes Morlet, Meyer, derivative of Gaussian, and Paul wavelets.

The Wavelet toolbox is a collection of MatLab files for wavelet analysis, synthesis, and related processing algorithms.

2.1. Discrete wavelet transform

For easy computer implementation, the discrete wavelet transform (DWT) is implemented. Every one-dimensional signal \( S \) can be represented using wavelet base functions as follows.

\[
S(t) = \sum_{m \in \mathbb{R}} \sum_{n \in \mathbb{Z}} d_m^n \psi_{m,n}(t) \tag{1}
\]

where

\[
d_m^n(t) = \left( S(t), \psi_{m,n} \right) = \sum_n S(t) \psi_{m,n}(t) \tag{2}
\]

where \((R \text{ and } Z)\) represent the set of all integers and real numbers.

\[
\psi_{m,n}(t) = \lambda_n^{-m/2} \psi(\lambda_n^{-m} t - n) \tag{3}
\]

In Eq. (2) \( d_m^n \) is the detail coefficient, \( \psi_{m,n} \) is the wavelets function generated from the original mother wavelets \( \psi \in L^2(R) \), \( \lambda_n \) is the scale space parameter, \( t_n \) is the translation space parameter, \( m \) is the scale or level of decomposition, and \( n \) is the shifting or translation integer.

The scale and translation parameters form a wavelet’s frame where the signal is completely represented by its spectrum. The representation is on a dense grid for small scales and on a wide grid for large scale. For practical reasons, a dya-
dic frame is used with \( \lambda_0 = 2 \) and \( t_0 = 1 \) [3].

The discrete wavelet transform (DWT) coefficients \( \omega_{j,k} \) of a signal or a function \( f(x) \) are computed by the following inner product

\[
\omega_{j,k} = (f(x), \psi_{j,k}(x)) \tag{4}
\]

where \( \psi_{j,k} \) is the wavelet expansion function and both \( j \) and \( k \) are integer indices for the scale and translation of the wavelet function, respectively. The inverse wavelet transform is used for the reconstruction of the signal from the wavelet coefficients \( \omega_{j,k} \)

\[
f(x) = \sum_j \sum_k \omega_{j,k} \psi_{j,k}(x) \tag{5}
\]

Eqs. (4) and (5) are named as analysis and synthesis, respectively [5].

2.2. Continuous wavelet transform

The continuous Wavelet Transform (CWT) of a signal \( q(x) \) is defined as the inner product of the signal sequence with the family (analyzing) functions \( \psi(x) \) as

\[
Q_m(m, x_o) = \frac{1}{\sqrt{m}} \int_{-\infty}^{\infty} q(x) \psi \left( \frac{x - x_o}{m} \right) dx \tag{6}
\]

And the inverse CWT is as follows:

\[
q(x) = \frac{1}{C_\psi} \int_{-\infty}^{\infty} \int_{-\infty}^{\infty} Q_m(m, x_o) \psi \left( \frac{x - x_o}{m} \right) dx_o \frac{dm}{m^2} \tag{7}
\]

where \( m \) is the scale that determines the oscillating behavior of a particular daughter wavelet, \( x_o \) is the shifting of the mother wavelet or the daughter wavelet (important for having space localization information of the original signal), and \( C_\psi \) is the admissibility constant. The analyzing function \( \psi(x) \) is not limited to the complex exponential as is the case of the Fourier
transform. In fact, the only restriction on \( \psi(x) \) is that it must be short and oscillatory to guarantee the localization properties. This restriction ensures that the integral is finite and leads to the wavelet transform, and \( \psi(x) \) is named the mother wavelet. This mother wavelet dilates (or compresses) and translates simply as wavelets or daughter wavelets.

The definition of the CWT shows that the wavelet analysis is a measure of the similarity between the basis function (wavelets) and the signal itself. The calculated coefficients refer to the closeness of the signal to the wavelet of the current scale. The determination of the CWT coefficients of a signal starts by using the most compressed wavelet that can detect the highest frequencies existing in that signal. This starts by choosing a scale value that represents the original signal. Then, the wavelet is shifted by \( x_n \) along the space axis until the end of the signal. The next step is to increase the scale \( m \) by some amount (thus expanding the wavelet window to detect lower frequencies) and repeat the shifting procedure. The whole procedure is repeated for each value of \( m \) until some “maximum” desired value of \( m \) is reached.

In a practical implementation of the CWT, there will be redundant information, because the wavelet coefficients are calculated for every possible scale, which will, of course, lead to a large amount of work and yield a lot of redundancy. It will be necessary to use the most compressed wavelet that can detect the highest frequencies existing in that signal. This starts by choosing a scale value that represents the original signal. Then, the wavelet is shifted by \( x_n \) along the space axis until the end of the signal. The next step is to increase the scale \( m \) by some amount (thus expanding the wavelet window to detect lower frequencies) and repeat the shifting procedure. The whole procedure is repeated for each value of \( m \) until some “maximum” desired value of \( m \) is reached.

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3. Differential GPS (DGPS)

Differential GPS is used to reduce as much of the correlated errors as possible from the range measurements when tracking a satellite at the same time from two receivers. One of the receivers, whose precise position is well surveyed, is called the reference station while the other receivers are denoted ‘rovers’ or ‘remote’ stations. Since the reference station position is known, the ‘bias’ of its pseudorange can be calculated by differencing the pseudorange measurement and the satellite-to-reference station geometric distance [6].

Differencing of measurements (carrier or code) in the case of DGPS can be of three forms: single, double and triple differences:

(a) The traditional single differenced observable is formed from the difference between measurements obtained at two receivers from a single satellite (i.e. differencing across receivers). A single difference observable can also be generated across satellites.

(b) The double differenced observable is formed from the difference of two single differences i.e. one single difference is formed from two receivers and a satellite A while another single difference is formed from these two receivers and another satellite B. The double difference is then obtained by subtracting the two. This is referred to as differencing across receivers and satellites.

(c) The triple difference observable is formed from the difference of two double differences at two epochs. This is referred to as differencing across receivers, satellites and time [7].

The following will illustrate each type separately in detail.

3.1. Differencing techniques

3.1.1. Single differencing

The purpose of “single differencing” is to eliminate satellite clock bias. Consider the observation equations for two receivers, A and B observing same satellite, j:

\[
L'_A = \rho'_A + c\tau_A - c\tau_j + Z'_A - I'_A + B'_A
\]

\[
L'_B = \rho'_B + c\tau_B - c\tau_j + Z'_B - I'_B + B'_B
\]

where \( L'_A \) is the carrier phase, \( \rho'_A \) is the range from receiver A (at receive time) to the satellite j (at transmit time), \( \tau_A \) is the receiver clock bias, \( \tau_j \) is the satellite clock bias, \( Z'_j \) is the delay on the signal due to the troposphere, \( I'_A \) is the delay on the signal due to the ionosphere (the minus sign indicating that the phase velocity actually increases), and \( B'_A \) is the carrier phase bias.

The single difference phase is defined as the difference between these two:

\[
\Delta L'_{AB} = L'_A - L'_B
\]

\[
= (\rho'_A + c\tau_A - c\tau_j + Z'_A - I'_A + B'_A)
\]

\[
- (\rho'_B + c\tau_B - c\tau_j + Z'_B - I'_B + B'_B)
\]

\[
= (\rho'_A - \rho'_B) + (c\tau_A - c\tau_B) - (c\tau_j - c\tau_j) + (Z'_A - Z'_B) - (I'_A - I'_B) + (B'_A - B'_B)
\]

\[
= \Delta \rho'_{AB} + c\Delta \tau_{AB} + \Delta Z'_A - \Delta I'_A + \Delta B'_A
\]

Where we use the double-subscript to denote quantities identified with two receivers, and the triangular symbol as a mnemonic device, to emphasis that the difference is made between two points on the ground. The geometry of single differencing is illustrated in Fig. 1.

An assumption has been made, that the satellite clock bias \( \tau_j \) is effectively identical at the slightly different times that the signal was transmitted to A and to B. The difference in transmission time could be as much as a few milliseconds, either because the imperfect receiver clocks have drifted away from GPS time by that amount, or because the stations might be separated by 1000 km or more. Since selective availability is typically at the level of 10^{-9} (variation in frequency divided by nominal frequency), over a millisecond (10^{-3} s) the satellite clock error will differ by 10^{-12} s. This translates into a distance error of 10^{-12}c, or 0.3 mm, a negligible amount under typical

![Figure 1](image-url)
S/A conditions (however, it may not be negligible if the level of S/A was increased, but this effect could in principle be corrected if we used reference receivers to monitor S/A). Another point worth mentioning, is that the coordinates of the satellite at transmission time can easily be significantly different for receivers A and B, and this should be remembered when computing the term $\Delta \rho_{ijk}$. The atmospheric delay terms are now considerably reduced, and vanish in the limit that the receivers are standing side by side. The differential troposphere can usually be ignored for horizontal separations less than approximately 30 km, however differences in height should be modeled. The differential ionosphere can usually be ignored for separations of 1–30 km, depending on ionospheric conditions. Due to ionospheric uncertainty, it is wise to calibrate the ionosphere using dual-frequency receivers for distances greater than a few km. Although the single difference has the advantage that many error sources are eliminated or reduced, the disadvantage is that only relative position can be estimated (unless the network is global-scale). Moreover, the receiver clock bias is still unknown, and very unpredictable. This takes us to “double differencing” [8].

3.1.2. Double differencing
The purpose of “double differencing” is to eliminate receiver clock bias. Consider the single difference observation equations for two receivers A and B observing satellites j and k:

$$\Delta L_{iAB} = \Delta L_{iAB} + c \Delta \tau_{iAB} + \Delta Z_{iAB} - \Delta L_{jAB} + \Delta B_{iAB}$$  \hspace{1cm} (11)
$$\Delta L_{kAB} = \Delta L_{kAB} + c \Delta \tau_{kAB} + \Delta Z_{kAB} - \Delta L_{jAB} + \Delta B_{kAB}$$  \hspace{1cm} (12)

The double difference phase is defined as the difference between these two:

$$\nabla \Delta L_{iAB}^D = \Delta L_{iAB}^D - L_{iAB}^D$$

$$= (\Delta L_{iAB} + c \Delta \tau_{iAB} + \Delta Z_{iAB} - \Delta L_{jAB} + \Delta B_{iAB}) - (\Delta L_{kAB} + c \Delta \tau_{kAB} + \Delta Z_{kAB} - \Delta L_{jAB} + \Delta B_{kAB})$$
$$= (\Delta L_{iAB} - \Delta L_{kAB}) + (c \Delta \tau_{iAB} - c \Delta \tau_{kAB}) + (\Delta Z_{iAB} - \Delta Z_{kAB}) + (\Delta B_{iAB} - \Delta B_{kAB})$$
$$= \nabla \Delta L_{ijk}^D + \nabla \Delta Z_{ijk}^D + \nabla \Delta B_{ijk}^D$$  \hspace{1cm} (13)

Where we use the double-superscript to denote quantities identified with two satellites, and the upside-down triangular symbol as a mnemonic device, to emphasis that the difference is made between two points in the sky. Fig. 2 illustrates the geometry of double differencing. A point worth mentioning is that although the receiver clock error has been eliminated to first order, the residual effect due to “time tag bias” on the computation of the range term does not completely cancel, and still needs to be dealt with if the receiver separation is large. Any systematic effects due to unmodeled atmospheric errors are generally increased slightly by approximately 40% by double differencing as compared to single differencing. Similarly, random errors due to measurement noise and multipath are increased. Overall, random errors are effectively doubled as compared with the undifferenced observation equation. On the other hand, the motivation for double differencing is to remove clock bias, which would create much larger errors. One could process undifferenced or single differenced data, and estimate clock biases. In the limit that clock biases are estimated at every epoch, these methods become almost identical, provided a proper treatment is made of the data covariance [8].

3.1.3. Triple differencing
The receiver–satellite–time triple difference observable is the change in a receiver–satellite double difference from one epoch to the next [9].

Triple differencing is useful for preliminary baseline computations using carrier phase data and for cycle slip detection or repair [10].

The purpose of “triple differencing” is to eliminate the integer ambiguity. Consider two successive epochs ($i, i + 1$) of double differenced data from receivers A and B observing satellites j and k:

$$\nabla \Delta L_{iAB}^k(i) = \nabla \Delta L_{iAB}^k(i) + \nabla \Delta Z_{iAB}^k(i) - \nabla \Delta B_{iAB}^k(i) - \lambda_o \nabla \Delta N_{iAB}^k$$  \hspace{1cm} (14)

$$\nabla \Delta L_{iAB}^k(i + 1) = \nabla \Delta L_{iAB}^k(i + 1) + \nabla \Delta Z_{iAB}^k(i + 1) - \nabla \Delta B_{iAB}^k(i + 1) - \lambda_o \nabla \Delta N_{iAB}^k$$  \hspace{1cm} (15)

The triple difference phase is defined as the difference between these two:

$$\delta(i, i + 1) \nabla \Delta L_{iAB}^k = \nabla \Delta L_{iAB}^k(i + 1) - \nabla \Delta L_{iAB}^k(i) = \delta(i, i + 1) \nabla \Delta L_{iAB}^k(i) + \delta(i, i + 1) \nabla \Delta L_{iAB}^k(i)$$  \hspace{1cm} (16)

where we use the delta symbol to indicate the operator that differences data between epochs. Fig. 3 illustrates triple differenc-
ing geometry. The triple difference only removes the ambiguity if it has not changed during the time interval between epochs. Any cycle slips will appear as outliers, and can easily be removed by conventional techniques. This is unlike the situation with double differencing, where cycle slips appear as step functions in the time series of data. On the other hand, it is a very useful method for obtaining better nominal parameters for double differencing, and it is a robust method, due to the ease with which cycle slips can be identified and removed. It can be shown that triple difference solution is identical to the double differenced solution, provided just one epoch double differenced equation is included for the first point in a data arc, along with the triple differences, and provided the full data covariance matrix is used to compute the weight matrix [8].

The main advantage of the triple difference method is its robust nature. When a loss of lock is encountered only data at a single epoch will be edited and processing will continue. In fact, numerous losses of lock can be handled with ease. For this reason, hundreds of baselines can be processed in (unattended) batch mode. If the receiver oscillators are synchronized and tuned, and if the station 1 coordinates are sufficiently well known, then as few as three parameters need to be estimated (namely, the coordinates of station 2). The main disadvantages of this scheme are as follows: (1) The correlated weight matrix is more complicated and (2) as with delta single differences, one cannot exploit the integer nature of the integer ambiguities [11].

4. Experimental analysis and results

To evaluate the performance of proposed method, an experimental study is implemented. The data used in this paper are from observation on two known coordinates GPS points, where the baseline length is approximately 1600 m.

In this experiment, two receivers, named as GPS base station and rover station, were taken to acquire original observables. GPS base and rover stations are located at the open surroundings, in other words, no obstacle affects GPS signal transmission and the site stations have excellent satellite visibility and minimal multipath sources.

The focus of these experiments was to investigate correlated errors between two GPS stations by using the triple difference and wavelet which is the critical step for building the necessary procedures for mitigation of the correlated errors.

The triple difference errors have low (coarse-gain) and/or high frequency (fine-gain) fluctuations. Fortunately, the high

<table>
<thead>
<tr>
<th>Table 1</th>
<th>Reference known rover coordinates.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>X</td>
</tr>
<tr>
<td></td>
<td>4732331.678</td>
</tr>
</tbody>
</table>

Figure 4 Decomposition the triple difference signal of L1 of satellite #2.
frequency aspect is relatively easy to remove if the proper denoising threshold is applied.
4.1. Applying triple difference and wavelet model

The first step is applying triple difference between base and rover station, after this step we have noised signal which suffers from correlated errors. Preprocessing data were conducted based on the wavelet analysis. The procedure of the wavelet analysis is as follows.

A basic wavelet de-noising algorithm consists of three steps:

(1) Decompose the noisy signal (triple difference GPS signals) using a wavelet multi-resolution analysis. The signal is decomposed into n layers wavelet based on multiscale analysis.

(2) De-noise the details’ wavelets coefficients, which contain the high-frequency portion of the signal.

(3) Reconstruct the de-noised signal by applying the inverse wavelet transform to de-noised coefficients.

Wavelet adaptive filtering was conducted using MATLAB and the decomposition scale was specified for triple difference signal of L1 of satellite #2, for example, as shown in Fig. 4. It shows that observation noise dominantly distributes in the layers of d1, d2, d3 and d4 corresponding to this experiment. The triple difference for L1 of sat #2, for example, is shown in Fig. 5. The figure shows that the signal has low and high frequency fluctuations.

Fig. 6 shows the residuals. High-frequency noise is relatively easier to remove; on the other hand, it is difficult to distinguish between real signal and low-frequency noise. Multiresolution analysis was used as a tool for mitigation of the noise in the signal.

After denoising the L1 signal, for example, the denoised signal is reconstructed by using the wavelet transform and the denoising signal for L1 of sat. #2 is shown in Fig. 7.

Fig. 8a–c shows the noised triple difference, residuals and denoised triple difference for C1 signal of sat. #2.

Fig. 9a and b shows the noised triple difference, residuals and denoised triple difference for L2 signal of sat. #2.

Fig. 10a and b shows the noised triple difference, residuals and denoised triple difference for P2 signal of sat. #2.

Figure 9 (a) Noised triple difference for L2 signal of sat. #2. (b) Residuals for L2 signal of sat. #2.

Figure 10 (a) Noised triple difference for P2 signal of sat. #2. (b) Residuals for P2 signal of sat. #2.
The triple difference and applying one-dimensional wavelet model were performed to other five satellites. To compare and analyze the results, discrepancies between the calculated and “ground truth” coordinates of the rover stations were computed using spectrum survey office software. The root mean square (RMS) of the coordinates for each component and baseline in two cases before and after applying wavelet model are shown in Table 2.

Table 2  Calculated differences of baseline components before and after applying wavelet model.

<table>
<thead>
<tr>
<th>Calculated difference of baseline components</th>
<th>ΔX (m)</th>
<th>ΔY (m)</th>
<th>ΔZ (m)</th>
<th>RMS (ΔX) (m)</th>
<th>RMS (ΔY) (m)</th>
<th>RMS (ΔZ) (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Before applying wavelet</td>
<td>–1055.201</td>
<td>+819.950</td>
<td>+847.762</td>
<td>0.001</td>
<td>0.002</td>
<td>0.004</td>
</tr>
<tr>
<td>After applying wavelet</td>
<td>–1055.209</td>
<td>+819.953</td>
<td>+847.765</td>
<td>0.001</td>
<td>0.002</td>
<td>0.004</td>
</tr>
</tbody>
</table>

Table 3 shows the calculated coordinate of the GPS station in two cases before and after applying wavelet model and differences between known and calculated rover GPS station. Results show that there is matching of the reference coordinates within 4–6 mm.

Table 3  Reference and calculated rover coordinates in two cases before and after applying wavelet model.

<table>
<thead>
<tr>
<th>Reference known rover coordinates (C) (m)</th>
<th>4732331.678</th>
<th>2723847.897</th>
<th>3285478.329</th>
</tr>
</thead>
<tbody>
<tr>
<td>Calculated rover coordinates before applying wavelet (C1) (m)</td>
<td>4732331.686</td>
<td>2723847.888</td>
<td>3285478.321</td>
</tr>
<tr>
<td>Calculated rover coordinates after applying wavelet (C2) (m)</td>
<td>4732331.682</td>
<td>2723847.891</td>
<td>3285478.324</td>
</tr>
<tr>
<td>Difference between (C) and (C1) (m)</td>
<td>0.008</td>
<td>–0.009</td>
<td>–0.008</td>
</tr>
<tr>
<td>Difference between (C) and (C2) (m)</td>
<td>0.004</td>
<td>–0.006</td>
<td>–0.005</td>
</tr>
<tr>
<td>Value of enhancement (m)</td>
<td>0.004</td>
<td>0.003</td>
<td>0.003</td>
</tr>
</tbody>
</table>

5. Conclusion

The main goal of this paper was the development and implementation of DGPS error mitigation techniques using triple difference and wavelet.

The technique is applied using wavelet as a de-noising tool to tackle the high-frequency errors in the triple difference domain and to obtain a de-noised triple difference signal that can be used in a positioning calculation.

Based on the experimental results obtained so far, the following conclusions can be drawn:
- An alternative methodology has been proposed to mitigate the correlated GPS errors.
- The experimental results indicate that there is an enhancement of calculation of rover GPS coordinates.
- The experimental results on measurement data demonstrate the effectiveness of the proposed method; so that the enhancement of calculation of rover coordinates is 4 mm in X direction, 3 mm in Y direction and 3 mm in Z direction.

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