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Enhancing the Accuracy of Global Navigation Satellite Systems

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ABSTRACT

Fast and precise relative positioning for baselines can be achieved using dual-frequency Global Positioning System (GPS) receivers. While the Differential GPS (DGPS) technique enhances GNSS accuracy by mitigating certain errors, it cannot entirely eliminate orbital, ionospheric, and tropospheric errors. This study explores the application of accurate relative positioning for processing GPS data, discussing its advantages and limitations, and compares the outcomes with relative positioning results obtained using the Mecca permanent GPS observation network. The results and analysis of the integrated system are presented. The findings conclude that utilizing precise ephemeris from the International GPS Services (IGS) Network in combination with the Klobuchar ionospheric model and either the Hopfield or Saastamoinen tropospheric model significantly improves the accuracy of DGPS measurements.

1. INTRODUCTION

Our research is focused on improving the accuracy of differential GPS and Real Time Kinematic (RTK) observations using wide area GPS systems. GPS observations contain both systematic and random errors; Differential GPS (DGPS) and Real Time Kinematic (RTK) is an observation technique that can be used to remove or reduce the ionosphere effects arising in ordinary GPS (Alves 2004). In order to obtain precise coordinates for a point from GPS data, a number of nuisance parameters first need to be removed from the data. These may be classified as satellite errors, atmospheric errors, and receiver errors. Satellite errors include errors in the reported satellite coordinates and satellite clocks, atmospheric errors include signal delays due to the troposphere and ionosphere while receiver errors include receiver clock errors. Let us consider for a moment how each of these errors might be removed or mitigated.

Troposphere errors are largely removed by either applying a model which attempts to mathematically simulate the signal delay as in most commercial software or by estimating the signal troposphere delay along with the receiver coordinates (as in most research software). Ionosphere errors are removed by observing both GPS frequencies (L1 and L2) and combining the two observations to derive an ionosphere-free observation. Errors in satellite positions can be reduced by using precise satellite orbits available from the IGS and any remaining error (except multipath) largely cancels over short distances. That leaves satellite and receiver clock errors as the dominant errors to be death with and this is where relative positioning comes to the fore (Koba, 2003).

1.1. Precise Point Positioning

The vast majority of commercially available software utilizes the principles of relative positioning. However, in the late 1990s, the Jet Propulsion Laboratory (NASA) pioneered a new technique that did not require differencing to obtain precise position. The labeled it Precise Point

Positioning (PPP) and implemented it in their, GIPSY/OASIS II GPS processing software (Roulston, et al 2000). The largest difference between relative processing and PPP is how satellite and receiver clock errors are handled. Instead of between-receiver differencing to remove the satellite clock errors, PPP uses highly precise satellite clock estimates.

These satellite clock estimates are derived from a solution using data from a globally distributed network of GPS receivers. Instead of between – satellite differencing to remove receiver clock error, PPP estimates theses as part of the least squares solution for the coordinates. Consequently, precise absolute coordinates for a single receiver at an unknown location may be obtained without the need of a second receiver at a known location. A note of caution at this point is necessary. It may be possible to get PPP confused with another from a point positioning that many GPS users will be familiar with i.e, Single Point Positioning (SPP). SPP is different from PPP in two ways. Firstly SPP does not use precise satellite clock values and secondly, only the pseudo rage observations are used. PPP uses both the pseudo range and more precise carrier phase observations (Witchayangkoon, 2002).

The difference between these methods in terms of coordinate accuracy is larger; SPP producers coordinate accurate at the 1-3 m level while PPP can produce coordinates accurate at the 0.01 m level with 24hours observations. Consequently, PPP allows coordinate determination with a precision that is comparable to relative processing. Since no base station is required in PPP, a further question is:" what datum are the coordinates in?" For PPP, the datum is hidden in the satellite coordinates-the satellite reference frame (datum) will be the unknown ground site reference frame. This means that to obtain coordinates in a different reference frame the user needs to perform a usually straight forward coordinate transformation (Zhong-yi, etal. 2002).

2. OBSERVATIONS METHODOLOGY

This procedure involves four observables for each of the visible satellites in each epoch. The two pseudo range and carrier phase observables can be linearly combined, thus reducing the effects of the ionosphere refraction. The use of a troposphere model, together with parameterization techniques, can reduce the troposphere refraction effects. The IGS ephemerids supply satellite coordinates and clock errors, with accuracy in the order of 5cm and 0.3 ns, respectively, and are essential in PPP. However, variations due to geophysical phenomena should be removed using appropriate models. These corrections include Polarmotion (Koba et al 2000).

According to Salam et al. (2002), it is possible to obtain precision of a few millimeters and a few centimeters in the horizontal and vertical components, respectively. Such levels of accuracy can be obtained for static point position, using a period of 24 hours of data. Once the coordinates for all stations are daily estimated, a solution for a specific epoch can be obtained. As there is no correlation between the coordinates of different stations, such a solution may be obtained independently for each station [Shen, 2002].

2.1. *Observation Sites and used Instruments*

The location for the proposed GPS network is shown in Figure (1). A pilot network has been established over the Holly Mecca. The system involves permanently running GPS reference stations, at spacing up to 30 km, then feeding GPS data to a central processing computer. Five LEICA GPS SR530 dual frequency receivers collected the GPS data on 12 th February 2006, where point (G182) was used as reference point. At first, the static observations with rate in legal two seconds are performed. Four receiver of the same LEICA type is setup at the other points for more than 24 hours. The Reference Stations are designed to support high- precision positioning over a wide area.

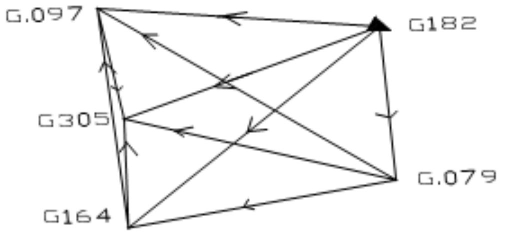


Figure (1): The shape of *Mecca* network

The weighted average position of points obtained from the solution of points in code_ phase solution with Hopfield troposphere model, Klobucher Ionosphere model, precise orbit and mask angle 15˚. This value is to be adopted as the position to be used as a reference to test the accuracy and precision in all subsequent investigations.

Table (1): Two reference solutions, namely Code solution and Code-Phase solution

point	Code solution			Code_ phase solution (adopted value)			The difference		
	East (m)	North(m)	Ht.(m)	East(m)	North(m)	Ht.(m)	ΔE(m)	ΔN(m)	ΔH(m)
G-079	604847.109	2358799.827	344.232	604847.605	2358799.313	344.1557	-0.4975	0.5137	0.0758
G-097	581954.337	2379143.209	265.318	581954.305	2379142.648	264.7447	0.0319	0.5618	0.5729
G-164	584332.702	2353111.952	222.583	584333.051	2353112.241	222.2416	-0.3488	-0.2893	0.3416
G-182 reference	603577.634	2377008.347	418.155	603577.634	2377008.347	418.1548	0	0	0
M-305	584002.934	2366022.109	273.465	584003.240	2366022.323	273.1244	-0.3053	-0.2142	0.341

3. OBSERVATIONS ANALYSIS

Leica Geostationary Office programme (LGO) is used for data analysis. The software is particularly well suited for the rapid processing of small-size single and dual frequency surveys, permanent network processing, ambiguity resolution on long baselines, ionosphere and troposphere modeling, clock estimation and time transfer, combination of different receiver types, simulation studies, orbit determination and estimation of Earth rotation parameters and the generation of so –called free network solutions. The results and analysis of observations will be introduced into three steps as following:

3.1. Orbital errors

To study the effect of satellite position on the solution, the processing of Mecca network Code-Phase observations was done twice. Every run utilized the same processing parameters except that the first run used the broadcast ephemeris, and the second run used the precise ephemeris as produced by International GPS Service "IGS". The results is presented in table (2) below. From table (2), the horizontal Position coordinates varies in a wide range from 0.13 mm to 0.71 mm. The range for height varies from 0.83 mm to 1.94 mm. As a closing remark for this section, one can easy detect the contribution of precise ephemeris in improving the solution against the broadcast solution.

Table (2): The differences between the default code- phase solution and the code-phase solution by replacing the orbit model ***to precise model*** at Mecca network

Point	ΔE(mm)	ΔN(mm)	ΔH(mm)
G-079	0.23	0.51	1.4
G-097	0.13	0.45	0.83
G-164	0.52	0.54	0.98
G-182	0	0	0
M-305	0.71	0.69	1.94

3.2. Ionosphere errors

To study the effect of ionosphere error on the solution, the processing of Mecca network Code-Phase observations was done several times in this observation using klobucher ionosphere model with the adopted values [Witchayangkoon, 2002]. Every run utilized the same processing parameters except that the first run utilized an ionosphere model from the following models:

- ○ Computed Model
- ○ Standard
- ○ Global/Regional

Table (3): The differences between the default solution and the solution by replacing the ionosphere model to ***computed model*** at Mecca network.

point	ΔE(mm)	ΔN(mm)	ΔH(mm)
G-079	0	0	0.01
G-097	0. 01	0	-0. 03
G-164	0	0	0
G-182	0	0	0
M-305	0. 11	-0. 11	0. 04

Table (4): The differences between the default solution and the solution by replacing the ionosphere model to ***standard model*** at Mecca network

point	ΔE(mm)	ΔN(mm)	ΔH(mm)
G-079	0	0	-0. 01
G-097	0	0	0. 01
G-164	0.01	-0. 03	-0. 1
G-182	0	0	0
M-305	-0. 22	0. 04	-0. 11

Table (5): The differences between the default solution and the solution by replacing the ionosphere model to ***global model*** at Mecca network

point	ΔE(mm)	ΔN(mm)	ΔH(mm)
G-079	0	0	0
G-097	0	0	0. 01
G-164	0	0	0
G-182	0	0	0
M-305	0. 34	0. 14	0. 13

As it is indicated in tables (3, 4and 5), the coordinates vary in a clear range from sub millimeter with respect to all types of Ionosphere models.

3.3. Troposphere errors

To study the effect of tropophere error on the solution, a process of Mecca Code-Phase observations was carried out several times. Every run utilized the same processing parameters except that the first run utilized a troposphere model from the following models:

- ○ Simplified Hopfiled Model
- ○ Saastimoinen Model
- ○ Essen & Froome Model
- ○ No Troposphere Model

The differences between the resulted coordinates for each troposphere model used and the original values are depicted in tables (6) to (9) .

Table (6): The differences between the default code- phase solution and the code-phase solution by replacing the troposphere model with ***simplified Hopfield*** at Mecca network

point	ΔE(mm)	ΔN(mm)	ΔH(mm)
G-079	-1	0.4	9.6
G-097	0.2	0.5	20.3
G-164	0.1	1	26.3
G-182	0	0	0
M-305	0.2	0.6	19.1

As it is shown tables in (6), the differences between the Simplified Hopfield troposphere model values and the computed values ranging between -0.1mm and -0.2mm in east component, 0.5mm to 1.0 mm in north component and ranging between 9.6 to 26.3 mm in height component. By changing the troposphere model to Saastamoinen model the difference to phase solution is shown in table (7).

Table (7): The differences between the default code- phase solution and the code-phase solution by replacing the troposphere model ***to Saastamoinen model*** at Mecca network

point	ΔE(mm)	ΔN(mm)	ΔH(mm)
G-079	-0.1	0	0.3
G-097	0.1	0.1	0.7
G-164	0.1	0.1	1
G-182	0	0	0
M-305	0	0.1	0.7

The differences between the Saastimoinen troposphere model values and the computed values ranging between 0.3mm and 1.0 mm in height component and 0.1mm differences in east and north component. By changing the troposphere model to Essen and Froome model the difference to phase solution is shown in table (8).

Table (8): The differences between the default code- phase solution and the code-phase solution by replacing the troposphere model to ***Essen and Froome*** model at Mecca network

point	ΔE(mm)	ΔN(mm)	ΔH(mm)
G-079	0	-0.2	-7.4
G-097	0.1	-0. 3	-16.2
G-164	0.1	-0. 6	-21.1

G-182	0	0	0
M-305	0. 2	-0. 3	-15.6

The differences between the Essen & Froome troposphere model values and the computed values ranging between 0.1mm and 0.2mm in east component, -0.2 mm to -0.6 mm in north component and ranging between -0.7 to -21.1 mm in height component. By changing the troposphere model to No Troposphere model the difference to code-phase solution is shown in table (9).

Table (9): The differences between the default code- phase solution and the code- phase solution by replacing the troposphere model ***to no troposphere model*** at Mecca network

point	ΔE(mm)	ΔN(mm)	ΔH(mm)
G-079	-13.6	25.9	-83.4
G-097	13.5	-5.6	-143.7
G-164	4.5	20.2	-217.8
G-182	0	0	0
M-305	16.7	20.0	-132.9

The differences between the computed values and the values, which no troposphere model used, ranging between -13.6mm and 16.7mm in east component and -5.6 mm to 25.9 mm on north component and in height component ranging between -83.4 to -217.8 mm.

Finally, it is revealing that troposphere models have higher effect on the height component than on the east and north components. The difference between the troposphere models was very small but it higher if no troposphere model used, so the use of any troposphere model is better than when no model used.

3.4. Kinematic code & phase solution.

In this mode, there are two processing categories based on the number of the references stations. The first processing category is performed based on using one single reference station while the second category is based on using three reference stations. The results of both categories are outlined and analyzed in the following section.

By changing the troposphere model to simplified Hopfield, as an example for the common troposphere model, the difference in phase - code solution is shown in figure (2). Figure (2) shows the differences between the Simplified Hopfield troposphere model and the computed values. The difference in east component varies in ranges between -0.8mm and 1.4 mm, the mean differences equal 0.12 mm and the standard deviation 0.47 mm. The difference in north component varies in ranges between -1.4mm and 1.6 mm, the mean differences equal

0.30 mm and the standard deviation 0.60 mm. The difference in height component varies in ranges between 11.4 mm and 32.2 mm, the mean differences equal 18.77mm and the standard deviation 4.4 mm.

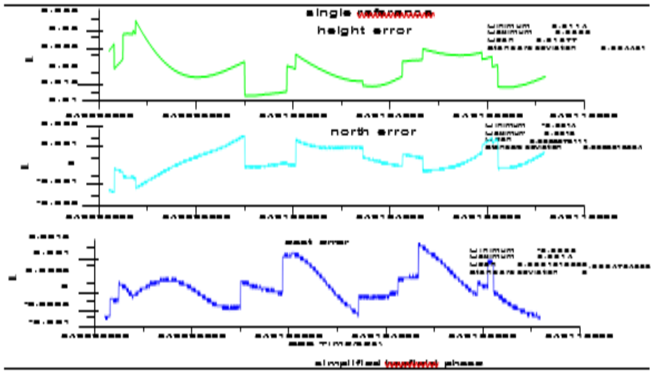


Figure 2: The differences between the default code-phase solution and the code-phase solution by replacing the troposphere model to ***Simplified Hopfield*** at Mecca network.

By changing the troposphere model to no troposphere model the difference in code-phase solution is shown in figure (3). Figure (3) shows the differences between the no troposphere model used and the computed values. The difference in east component varies in ranges between 13.3mm and 37.5 mm, the mean differences equal 21.47 mm and the standard deviation 6.44 mm. The difference in north component varies in ranges between -2.2mm and 5 mm, the mean difference equal 9.66mm and standard deviation 5.51mm.

The difference in height component varies in ranges between -72.3 mm and -189 mm, the mean differences equal -110.5 mm and the standard deviation 21.8 mm.

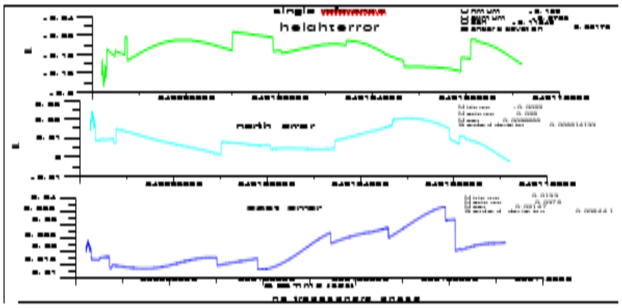
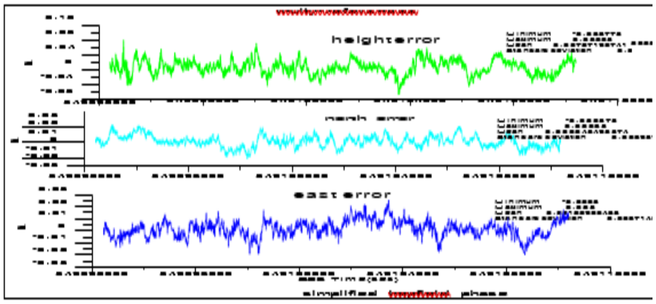


Figure 3: The differences between the default code-phase solution and the code-phase solution by replacing the troposphere model ***to no troposphere model*** at Mecca network

By performing the second run using Code-Phase only, with multi references, we use the main default parameters with code-Phase observations and Hopfield model for troposphere. In the following processes the troposphere model is replaced only, with fixing all other processing parameters. By changing the troposphere model to simplified Hopfield the difference to code- phase solution is shown in figure (4).



The differences between the default code- phase solution and the code-phase solution by replacing the troposphere model to ***Simplified Hopfield*** at Mecca network for multi references.

4. CONCLUSIONS

In this research 5 stations of Holly Mecca were processed with Leica Geostationary Office software (LGO) and compare the result with those obtain in ITRF2000. The result shows the general agreement. Solution is better than 40mm for daily solutions, and the repeatability is about 20mm, 35mm, 45mm for N,E,H components. The difference between the coordinates and those obtain in relative mode in ITRF 2000 are due to the ambiguity resolution and combination of solution in software. The difference between baseline computed and relative mode is better than 30 mm. The use of precice ephemeris rather than broadcast ephemeris, Klobucher ionosphere model**,** andHopfield or saastimoinen troposphere model would give an apperciable improvement for all baselines. Also, The troposphere models have the same effect on the all observation teqniques, the Hopfield model give the same results with the Saastimoinen model as addition of midel result values between the Simplified Hopfield model and Essen & Froome model.

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