THE EFFECT OF MODIFIED UNBABC MAPPING FUNCTION ON THE IMPROVEMENT OF GLOBAL POSITIONING SYSTEM TROPOSPHERIC DELAY

Hamzah Sakidin[1], Tay Choo Chuan[2], Saedah Sakidin[3]

[1],[2]Faculty of Electrical Engineering,
Universiti Teknikal Malaysia Melaka,
Durian Tunggal Melaka,Malaysia

[3]Malaysian Maritime Academy,
Tanjung Dahan, Kuala Sg Baru, Melaka

Email: hamzahsakidin@utem.edu.my

ABSTRACT

Global Positioning System (GPS) tropospheric delay refers to the refraction of the GPS signal as it passes through the neutral atmosphere from the satellite to the earth, which causes longer distance traveled by the signal. The issue of atmospheric delay is investigated to minimize the positioning error due to tropospheric and ionospheric delay. The mathematical modeling on the tropospheric model should be revised and also modified to improve the delay. The zenith tropospheric delay can be amplified by a coefficient factor called mapping function to form total tropospheric delay. There are many mapping functions have been established to calculate the scale factor which can affect the total tropospheric delay. However, the mapping functions give large value when the elevation angles less than 5 degrees. The modification of the continued fractions by replacing sine function to cosine function in the popular mapping function called UNBabc has been proposed and tested to ensure the improvement of the result. The result of the modification, show a significant reduction of mapping function scale factor. The modified UNBabc mapping function has improved the tropospheric delay up to 19.1% at 2 degree elevation angle. This modified mapping function could be used as the alternative mapping function.

***KEYWORDS**: Global Positioning System, modeling, tropospheric, modification, zenith, delay.*

1.0 INTRODUCTION

The issue of atmospheric delay (error) is extensively investigated to minimize the positioning error due to tropospheric and ionospheric delay. Tropospheric delay refers to the refraction of the Global Positioning System (GPS) signal, as it passes through the neutral atmosphere from the satellite to the earth. The effect causes the distance traveled by the signal to be longer than the actual geometric distance between satellite and receiver on the earth. Tropospheric delay can be divided into hydrostatic (dry) delay and wet delay.

At zenith direction, tropospheric delay contributes about 2.5m (Ahn, 2005). Hydrostatic (dry) delay contributes about 90% and wet delay contributes about 10% of the tropospheric delay. This hydrostatic component has a smooth, slowly time-varying characteristic due to its dependence on variations in surface air pressure (weather cells). So this part can be modeled and removed with an accuracy of a few millimeters or better using a surface model (including pressure, temperature and humidity). It does not therefore create much of a problem as far as its effect on GPS signals. Although wet delay is much smaller than the hydrostatic component but the uncertainties in wet tropospheric delay modeling do place a great burden on high precision GPS applications. In this paper, section 2 contains the explanation about tropospheric delays, general information regarding mapping functions and also the details about UNBabc mapping functions for hydrostatics and non-hydrostatics. Section 3 states about the objectives of this study, while section 4 describes the methodology of the modification. Finally, sections 5 and 6 detail out the result and also the conclusion for this paper respectively.

2.0 TROPOSPHERIC DELAYS

The tropospheric delays (TD) at arbitrary elevation angles can be expressed in terms of the zenith delays and mapping functions. This representation allows the use of separate mapping functions for the hydrostatic and wet delay components (Schuler, 2001):

$$TD = ZHD.m_h(\varepsilon) + ZWD.m_w(\varepsilon) \tag{1}$$

where :

ZHD - zenith hydrostatic delay (m)
ZWD - zenith wet delay (m)
$m_h(\varepsilon)$ - hydrostatic mapping function (no unit)
$m_w(\varepsilon)$ - wet mapping function (no unit)

2.1 Mapping Function

Referring to Figure 1 below, the tropospheric delay is shortest in zenith direction (when the satellite at P) and it become larger with the increasing of zenith angle (at Q). Projection of zenith path delays into slant direction is performed by application of a mapping function or obliquity factor, m(z) that is defined as:

$$m(z) = \frac{TD}{ZD} \tag{2}$$

where :

TD – total delay (slant neutral delay)
ZD – total zenith delay
z - zenith angle ($z = 90 - \varepsilon$)
ε - elevation angle (from ground to satellite)

TD can be separated into two components such as a hydrostatic component (zenith hydrostatic delay, ZHD) and a wet component (zenith wet delay, ZWD) with their mapping function, m(z) as stated in (1) and $ZD = ZHD + ZWD$. From Figure 1 below,

$$\frac{ZD}{TD} = \cos z \tag{3}$$

Substitution into (2) become,

$$m(z) = \frac{1}{\cos z} = \sec z \tag{4}$$

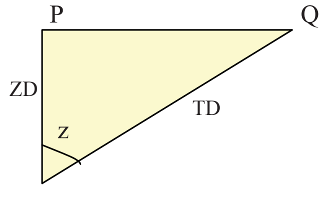

FIGURE 1
Illustration for obliquity factor (mapping function) between zenith and slant direction

Unfortunately, this secant model is only an approximation assuming a planar surface of the earth and not taking the curvature of the earth into account. Moreover, the temperature and water vapor distribution may cause deviations from this simple formula. Many mapping functions have been established to reduce the delay for arbitrary elevation angles. One of the mapping functions is Neill Mapping Function, which use continued fraction rather than the secant model.

2.2 UNBabc Mapping Function

UNBabc is a tropospheric mapping function established by (Guo *et.al.*, 2003) using ray tracing delay values, which has a 3-terms continued fraction form as shown in equation (5);

$$UNBabc_i(\varepsilon) = \frac{1 + \cfrac{a_i}{1 + \cfrac{b_i}{1 + c_i}}}{\sin\varepsilon + \cfrac{a_i}{\sin\varepsilon + \cfrac{b_i}{\sin\varepsilon + c_i}}} \tag{5}$$

where :

$i = h$ or nh

ε - elevation angle (90 – z)

$UNBabc_h$ - hydrostatic mapping function

$UNBabc_{nh}$ - non hydrostatic mapping function

From a series of analyses, parameter a_i is sensitive to the orthometric height, H and latitude, Q of the station whereas parameters b and c could be represented by constants. The least-squares estimated parameters for the hydrostatic function are:

a_h =(1.18972-0.026855H+0.10664cos Q)/1000

b_h = 0.0035716

c_h = 0.082456

and for the non-hydrostatic function:

a_{nh} =(0.61120-0.035348H-0.01526 cos Q)/1000
b_{nh} = 0.0018576
c_{nh} = 0.062741

3.0 OBJECTIVES

The objectives for this study as given below:

- To develop modified algorithms of mapping function for tropospheric delay (hydrostatic delay model and also wet delay model) based on UNBabc Mapping Function.
- To investigate the effectiveness of the modified mapping function by calculating its mapping function scale factor.

4.0 METHODOLOGY

4.1 Modification of UNB*abc* Mapping Function

Modification of UNB*abc* mapping function has been carried out by only focusing to the denominator of equation (5), while the rest of the mapping function will remain unchanged. The three sine terms (denominator) in equation (5) have been rearranged among the sine (s), cosine (c) and also tangent (t) for the hydrostatic and also non-hydrostatic mapping function. The UNB*abc* mapping function using sine, sine and sine (sss) as the denominator of the UNB*abc* mapping function. For an example, for scs, it is referring to the first term is s (sine), the second term is c (cos) and the third term s (sine).

Calculation of the mapping functions with different combination among sine, cosine and tangent have been carried out by using maple software. The purpose of the calculation is to find out which combination will give the smaller scale factor and at the same time to ensure that the value of the mapping function at 90 degrees elevation angle is unity. After calculating all combinations among sine, cosine and tangent for UNBabc_h and also UNBabc_{nh}, the combination of ssc has been selected for both components due to its smaller mapping function value compared to other combinations. This fact can be shown clearly when the elevation angle is less than 5 degree. The ssc combination of mapping function is called modified UNBabc_h mapping function for hydrostatic component (MUNB*abc*$_h$) and modified UNB*abc*$_{nh}$ mapping function for non hydrostatic component (MUNB*abc*$_{nh}$), which are based on UNB*abc* mapping function as given in equation (5). The modified UNB*abc* mapping function is given in equation (6).

$$MUNBabc_i(\varepsilon) = \frac{1+\dfrac{a_i}{1+\dfrac{b_i}{1+c_i}}}{\sin\varepsilon+\dfrac{a_i}{\sin\varepsilon+\dfrac{b_i}{\cos\varepsilon+c_i}}} \quad (6)$$

where

$i = h$ or nh
ε - elevation angle (90 – z)

The other parameters are unchanged as given in equation (5).

5.0 RESULT

5.1 Calculation of Tropospheric Delay Using UNB*abc* Mapping Function

The improvement of troposheric delay can be shown by comparing both of the mapping function values. The reduction of the mapping function values will reflect the improvement of the new tropospheric delay compared to the current tropospheric delay.

According to equation [1], tropospheric delay (TD) can be obtained by the multiplication between ZHD with mapping function. The value of ZHD (2.31m) and ZWD (0.25m) will be used in the calculation. The ZHD and ZWD are calculated from Saastamoinen model (Saastamoinen, 1972) using Maple software.

5.1.1 Tropospheric Delay using UNB*abc* mapping function

The UNB*abc*$_h$ value from equation (5) should be multiplied by the zenith hydrostatic delay, ZHD value (2.31m) to obtain the hydrostatic component (A). while for obtaining non hydrostatic component (B), UNB*abc*$_{nh}$ from equation (5) should be multiplied by the zenith wet delay, ZWD value (0.25m) as shown in Table 1.

TABLE 1
Tropospheric Delay (TD) using UNBabc mapping function

Elevation angle, E (^{o})	A = $UNBabc_h$ x ZHD	B = $UNBabc_{nh}$ x ZWD	Current TD=A+B (meter)
2	42.72	5.53	48.25
3	33.88	4.16	38.04
4	27.80	3.31	31.11
5	23.43	2.73	26.16
10	12.84	1.44	14.28
45	3.27	0.36	3.63
90	2.31	0.25	2.56

5.1.2 Tropospheric Delay Using Modified UNBabc Mapping Function

The hydrostatic component (C) can be obtained when MUNBabc_h from equation (6) multiplies the ZHD value (2.31m) and the non hydrostatic component (D) can be obtained when MUNBabc_{nh} from equation (6) multiplies the ZWD value (0.25m) as shown in Table 2.

TABLE 2
New Tropospheric Delay (TD) using Modified UNBabc mapping function

Elevation angle, E (^{o})	C = $MUNBabc_h$ x ZHD	D = $MUNBabc_{nh}$ x ZWD	New TD = C + D (meter)
2	34.08	4.97	39.05
3	30.87	4.01	34.88
4	26.61	3.25	29.86
5	22.9	2.71	25.61
10	12.81	1.44	14.25
45	3.27	0.36	3.63
90	2.31	0.25	2.56

5.1.3 Improvement of Tropospheric Delay (TD)

The improvement of tropospheric delay can be shown by comparing between modified UNBabc mapping function and UNBabc mapping function. As coefficient to the zenith delay, the improvement in mapping function will directly effect the total tropospheric delay. The current TD is calculated using UNBabc mapping function and the new TD is calculated using modified UNBabc mapping function. The improvement of the tropospheric delay can be shown in Table 3 below:

TABLE 3
Percentage improvement for the tropospheric delay (TD)

Elevation angle, E (^{0})	Current TD (meter)	New TD (meter)	Improvement (%)
2	48.2	39.0	19.1
3	38.0	34.9	8.3
4	31.1	29.9	4.0
5	26.2	25.6	2.1
90	2.6	2.6	0.0

6.0 CONCLUSION

The study shows that the combination of sine, sine and cosine (ssc) is a suitable choice to be an alternative for the mapping function. For the elevation angles less than 5 degrees, the reduction percentage of the scale factor is very obvious. On the other hand, the reduction shows the significant improvement of the mapping function, either for hydrostatic or non hydrostatic mapping functions. As the coefficient to the zenith tropospheric delay, the improvement of mapping function can directly reduce the total tropospheric delay of the GPS signal. Modified UNBabc mapping function contributes up to 19.1 percent to the tropospheric delay improvement at two degree elevation angle.

7.0 REFERENCES

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