Evaluation of Tropospheric & Clock Errors for Precision GPS Positioning & Navigation

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Abstract: Positional inaccuracies in GPS are caused by several errors such as Ionospheric, Tropospheric, Satellite Clock, Receiver Clock etc., Instantaneous correction of these errors aids in precise navigation. In the present work Original Hopfield model is considered for the tropospheric correction. The instantaneous tropospheric correction results in more precise position using GPS. The decreasing order of components on basis of effect are Ionospheric delay, Tropospheric delay, Clock error, satellite bias error, Receiver error, multipath error, Ephemeris error, random errors etc. It is a time taken process to calculate the individual error separately. So in this paper we only concentrated on simulation and analysis the tropospheric delay, clock error, ephemeris error. We used Modified Hopfield model to analysis Tropospheric delay, receiver instrumental bias for analysis Clock error in between we eliminate Ephemeris error, after obtained results are compared with and without time correction in original Hopfield model.

Index Terms: Clock error, Ephemeris error, Global Positioning System (GPS), Original Hopfield model, Tropospheric delay

I. INTRODUCTION

Navigation is the art of directing a vehicle or a person from one point to another point. In early days various instruments like compass, clock, theodolite etc. are used for the navigation which is based on the movement of stars and sun. As technology developed we are using radio waves for navigation and positioning. Radio waves are the type of electromagnetic radiation with wavelength longer than infrared rays, travels at a speed of light. Frequency (30Hz – 300GHz), Wavelength (10,000kms -1mm). Radio waves are generated artificially by transmitters and receivers by radio receivers, using antennas and widely used in mobile radio communication, radar and other navigation systems. Due to matter present in between satellite and the ground base stations the properties of the signal are disturbed by various components.

II. METHODOLOGY

There are different files in RINEX format which gives raw data which includes no. of satellites are available from the individual receiver, health of satellite and huge data about satellite. They are Observation file, Navigation file, Meteorological file, Glonass navigation message file. Geostationary satellite data file, Satellite and Receiver clock data file. Among all we take raw data from Observation file and Navigation file. To obtain raw data programming is done in python language. From Observation file we achieve raw data for every one second for all visible satellites throughout the day. The parameters we get from file are L1, L2, D1, D2, S1, S2, C1, C2, P1, P2, Stec. From Navigation file we achieve raw data for every two hours for all visible satellites throughout the day. The parameters we get from file are a0, a1, a2, Toe, delta, Mo, ecc, roota, omega, ogamodat, IODT, IODC, TGD, SV health, Cus, Cuc, Crs, Crc, Cis, Cic, named as (C1,C2,C3,C4,C5,C6).

III. TROPOSPHERIC DELAY

Troposphere is the lower part of the atmosphere over the Earth’s surface, which mainly consists of nitrogen and oxygen, and a small amount of water vapour. The troposphere has the concentration of about 75% of the atmosphere quality and more than 90% of water quality. The average height of the troposphere is about 17 to 18 km, about 10 to 12 km at middle latitudes and about 8 to 9 km at the polar regions, which is higher in summer than in winter. According to different seasons we can assume that dry tropospheric delay will be more and wet tropospheric delay will be very less in summer and in the same way in winter we can observe wet troposphericdelay will be high and dry tropospheric delay will be low. The dielectric property of the troposphere changes with the time and space. Therefore, the propagation speed of the radio wave in troposphere is smaller than in vacuum, and the propagation path is bent. These changes coded the tropospheric refraction causes a delay that depends on the actual path of the radio wave. There are usually two major delay effects of the troposphere which cause a delay about 2.5m totally. The first and the larger effect is a Dry atmosphere excess delay caused by oxygen and nitrogen, which is about 2.3m accounting 80% -90% in total. The second effect -the Wet atmosphere is generally smaller 0.3m, about 10%-20%. The troposphere has obvious large-scale changes superposed with the local atmospheric turbulence usually. Because of the right irregular changes, it is very difficult to accurately forecast the tropospheric delay.
**IV. ORIGINAL HOPFIELD MODEL**

Several global tropospheric models such as the Saastamoinen model, Modified Hopfield model, Original Hopfield model, etc. have been empirically developed and employed in GPS correct for tropospheric delay. Troposphere delay corrections obtained from the original Hopfield model that use temperature, air pressure, water vapour pressure as input. We considered data on 17-mar-2017 in the summer at Machilipatnam weather station (Latitude: 16°21'36"11, Longitude: 81°17'13"88) is a town in Krishna district of the Andhra Pradesh state of India. The data from the station are processed and analyzed for every 2 hours time interval thought out a day. In troposphere atmospheric temperature decreases 6.5 degree centigrade for every 1 km. In the same way pressure, water vapour pressure decreases as altitude increases by 1 km each. The Original Hopfield model for calculation of tropospheric delay can be expressed as:

\[
\Delta S = \Delta Sd + \Delta Sw
\]

Where \(\Delta S\) is Total Tropospheric delay

\(\Delta Sd\) is Dry Tropospheric delay

\(\Delta Sw\) is Wet Tropospheric delay

To obtain Total Tropospheric delay, we calculated Dry Tropospheric delay and Wet Tropospheric delay separately by using Machilipatnam weather station parameters data. Tropospheric time delay for continuous time interval of every 2 hours thought out the day. By this we found Total Tropospheric delay and from this output we analyzed how much delay and when will be Dry and Wet Tropospheric delay occurs. To obtain Total Tropospheric delay we followed accordingly.

1. Extraction of satellite ephemeris and time parameters,
2. Satellite position estimation,
3. Computation of elevation angle, For computation of elevation angle Earth Centered Earth Fixed (ECEF) coordinates are extracted from the rinex data and it is converted into local coordinates also called East North Up (ENU) coordinates.

The Important steps of algorithm to find ECEF co-ordinates; Semi-major axis,

\[a = (\sqrt[3]{a^3}) + \Delta n.\]

Time from ephemeris motion,

\[tk = t-\text{toe}\]

Mean anomaly,

\[Ma = M0 + n(tk)\]

Eccentric anomaly (must be solved iteratively for \(Ea\)),

\[Ma = Ea - \text{esin}Ea\]

True anomaly,

\[\sin(i) = ((\sqrt{1-e^2})\sin(Ea))/(1-\cos(Ea))\]

\[\cos i = \cos Ea - e\cos(E)\]

Argument of latitude,

\[m = i + \text{smallomega}\]

Argument of latitude correction,

\[n = C1\sin(2m) + C2\cos(2m)\]

Radius correction,

\[\text{lambdac} = C5\sin(2m) + C6\cos(2m)\]

Incline correction,

\[\text{lambdap} = C3\sin(2m) + C4\cos(2m)\]

Corrected argument of latitude,

\[q = m + n\]

Corrected radius,

\[p = a(1-\text{ecos}Ea) + \text{lambdac}\]

Corrected inclination,

\[z = i0 + (\text{di}/\text{dt})*tk + \text{lambdac}\]

Corrected longitude of node,

\[\text{lambdac} = \omega0 + (\omega + \text{etoe})(tk) - \text{etoe}\]

First convert ECEF coordinate to local coordinates also called ENU (East North Up),

\[\text{ENU} = \text{R}*[X, Y, Z]\]

Where, \(la\) = latitude of the satellite

\(lo\) = longitude of the satellite.

Finally, we calculated Total Tropospheric delay and observed time varying

Continuously.
V. RESULTS & ANALYSIS

Fig 1: Tropospheric Delay correction for 1st secs data for 8 different satellites.

Fig 2: Tropospheric Delay correction for 2nd secs data for 8 different satellites.

Fig 3: Tropospheric Delay correction for 3rd sec data for 8 different satellites.

Fig 4: Tropospheric Delay correction for 4th sec data for 8 different satellites.

Fig 5: Tropospheric Delay correction for 5th sec data for 8 different satellites.

Fig 6: Tropospheric Delay correction for first 10 secs average data.

Fig 7: Tropospheric Delay correction for 15 secs average data.

VI. CLOCK ERROR

Start with correction of GPS system time help out to determine mathematically left over errors with more accurate and simple. Early research has different models to correct GPS time. Till now all other research papers eliminates errors and delays by calculate errors and delays separately and followed elimination process to achieve corrected GPS time. Here we followed a method which eliminates few errors like clock error, ephemeris error, transit time.
At first we achieved two different times at user side (receiver). one time is that the time at which the signal is received by receiver (tobs) and second time is that the time taken to travel message signal from satellite to the receiver located at base station, which is equal to the pseudo-range divided by the speed of the light (p/c). To obtain GPS system time and Clock Error we followed accordingly.

1. Raw time (Tc) is calculated by subtracting the transit time from the time of receiving.
   \[ T_c = T_{obs} - \left( \frac{\text{pseudo-range}}{\text{speed of the light}} \right) \]

2. Time of ephemeris (Toe) is one of the GPS error data, which is to be remove from raw time (Tc).
   \[ T_k = T_c - T_{oe} \]
   Tk is the actual total time difference between the time Tc and the ephemeris time Toe, and must account for the beginning or end of the week crossovers. This is, following adjustment must be made on Tk.

3. We have to take only absolute value from the Tk. [let it be Tk1].

   - For i = 1:8
     - If Tk1 > 302400
       \[ T_{k2} = T_{k1} - 604800; \]
     - Else Tk1 < 302400
       \[ T_{k2} = T_{k1} + 604800; \]

   Finally Tk = Tk2.

4. To find overall time correction, we calculated \( \Delta t \) which includes \( \Delta tr \) (Relativistic correction), M (Mean anomaly), E (Eccentric anomaly), n (Mean motion), Tgd (Estimated group delay differential). The information obtained from the GPS satellite is the mean anomaly (M). From this value, the true anomaly must be obtained because the true anomaly (v) is used to find the position of the satellite which we used in troposphere delay calculation. The first step is to obtain the eccentric anomaly E from the mean anomaly (M). Equation E is format as \( E = M + e \times \sin(E) \) appears very simple, it is nonlinear one; therefore, it is difficult to solve analytically. Where e is eccentricity of the satellite orbit, and M can be obtained from navigation file only unknown is E. One way to find E is iteration method. Here a new E value is obtained from a previous one. Iteration formatted as \( E_{i+1} = M + e \times \sin(E_i) \), where \( E_{i+1} \) is the present value, \( E_i \) is the previous value. We should consider \( E_0 \) initial value as M (E0 = M)
   
   Either one can define a error signal as \( \text{Err} = (E_{i+1}) - E_i \) and end the iteration when the Err is less than a predetermined value.

5. Mean motion,
   \[ n = \sqrt{\frac{\mu}{a^3}} \]

6. Mean anomaly,
   \[ M = M_0 + (n \times t_k) \]
   \[ M_1 = \text{rem}(M+(2\times\pi)/2\times\pi) \]
   \( E_1 = M_1 \)

7. \( E = M + e \times \sin(E) \) Iteration method to find E.
   For \( j = 1:10 \)
   \[ E_{old}(j) = E_1(i); \]
   \[ E_1(j) = M(i) + ec(i) \times \sin(E_1(i)); \]
   \[ dE_k(j) = \text{rem}(E_1(i) - E_{old}(j), 2 \times \pi); \]
   If abs(dE_k(i)) < 1.e-12
   Break;
   end

8. \( E_2 = \text{rem}(E_1 + (2\times\pi)/2\times\pi) \)
   Eccentric anomaly, \( E = E_2 \)

9. \( \Delta tr = F \times e \times (\sqrt{a}) \times \sin(E) \)

10. \( \Delta t = af0 + af1(tk2) + af2(tk2) + \Delta tr - Tgd \)
    From \( \Delta t \) we obtained overall time correction. To get more accuracy the GPS time at time of transmission can be corrected again,

11. \( T = t_c - \Delta t \)

We calculated T for 1Sec time for 8 satellites; These 8 satellites are visible in 1 Sec data of both observation file and navigation file.

**VII. RESULTS & ANALYSIS**

GPS data of visible satellites for one day is analyzed for the position of satellite, with reference to the receiver, the transit time of visible satellite is calculated and the overall time correction is also calculated. Time correction of eight different satellites (14,27,24,20,15,29,21,28) for one second, five second and ten second as shown in fig 1, fig 2 and fig 3.
In GPS data, for every instant of time 8 to 9 satellites are visible. In the calculation of pseudo range if the same transit time is considered for all visible satellites at any instantaneous time may lead to an erroneous position estimation. The present work focuses on satellite time correction leads to different transit time for all visible satellite at any instantaneous time. A nearest approximation of this transit time for calculation of pseudo range will lead to precise positioning in GPS real time application.

**VIII. CONCLUSION**

In this paper we presented the Clock error and Tropospheric delay analysis for different satellites by considering transit time with reference to the GPS receiver over a baseline is consider for precise positioning of a receiver. The time correction for eight satellites of one second, five second, ten second data is calculated. The analysis of transit time for each satellite using position of satellite method can correct the time correction for precise navigation. Using Original Hopfield model we analyzed the Tropospheric Delay for visible satellites using 1 second data. Considering the Machilipatnam weather station parameters on 17th March, 2017 we estimated the delay in meters.

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