Ionospheric Parameters Estimation for Accurate GPS Navigation Solution

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Abstract- Satellite navigation system plays an increasing role in modern society. Various satellite navigation systems are in operation and being currently developed including global positioning system (GPS), global navigation satellite system (GLONASS), and Galileo. Thus, there is an increasing need for the research and development in various areas such as signal generation, signal reception, precise positioning, high-precision geodesy and survey. The satellite system transmits the navigation message signal to the earth station (or) directly to GPS users .The errors due to transmitter end, receiver end and due to atmosphere, the signal is degraded and sometimes it may be lost in space ,which in turn causes errors in accuracy of navigation solution. The errors that effect the navigation solution accuracy are: Atmospheric errors, Satellite clock errors, Ephemeris errors, Receiver noise error and error due to Multipath.

Among various kinds of error factors, the GNSS signal delay by the ionosphere is the greatest after the elimination of selective availability. The total electron content present in the ionosphere causes refraction to the GPS signal, due to this delay occurs in the GPS signal during its journey to the ground receivers which results in range delay and This delay can be estimated using single frequency receivers and as well as using dual frequency receivers. This delay due to the Ionospheric refraction is estimated around 14m-20m in range, Hence to obtain the precise navigation solution, it is necessary to estimate the ionospheric parameters such as TEC and delay. With available different modeling methods we can reduce the error in range. Hence in this paper, TEC as well as ionospheric delay are estimated for precise computation of the navigation solution.

Keywords: Total Electron Content, Pseudo Random Codes, Global Positioning System

I. INTRODUCTION

Satellite navigation system plays an increasing role in modern society. Various satellite navigation systems are in operation and being currently developed including global positioning system (GPS), global navigation satellite system (GLONASS), and Galileo. Among all other GNSS systems GPS is the most widely used service it was originally developed by the US army and is still monitored by the U.S. Department of Defense (DOD). However, today, GPS is managed by the National Space-Based Positioning, Navigation, and Timing (PNT) Executive Committee to provide user with his position, velocity and time. GPS comprises of three functional segments they are Space segment, Control segment and User segment. GPS Space segment constellation consists of 32 operational satellites placed in 6 orbital planes in the medium earth orbit (MEO) which is at a height of 20,200km above the surface of the earth that provides users with continuous, worldwide positioning capability using the data transmitted in the GPS navigation message.

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GPS Provides service to unlimited number of users since the user receivers operate passively. The system utilizes the concept of one-way time of arrival (TOA) of the GPS signal[1].

GPS signal consists of 3 components they are PRN ranging codes, navigation message and carrier frequencies. The satellites broadcast PRN ranging codes and navigation data on two carrier frequencies i.e. L1 (1575.42MHz) and L2 (1227.6MHz) using Code Division Multiple Access (CDMA). Each Satellite generates a unique PRN sequence which is randomly generated binary sequence which is different from other satellites which allows all the satellites to share the same frequency signals. The PRN codes are selected in such a way that they have low cross-correlation properties with respect to each one another. Each satellite generates a short code called as Coarse/Acquisition or C/A code which has a bit rate of 1.023 Mbps and a long code denoted as Precision or P code with a bit rate of 10.23Mbps. The navigation data provides the means for the receiver to determine the location of the satellite at the time of signal transmission and the ranging codes enable the receiver to determine the transit time. Based on the satellite position and the transit time, Receiver location can be computed at any instant of Time.

II. GPS OBSERVABLES

They are two types of observables in GPS measurements. i.e. code range measurements and carrier phase measurements. As the code range measurements are less prone to noise, in this paper we are considering the code range measurements for TEC estimation

Carrier phase measurements

The carrier phase measurement is the difference in phase between the carrier wave from the satellite and the receiver oscillator signal at a specified epoch. The range is simply the sum of the total number of full carrier cycles between the receiver and the satellite multiplied by the carrier wavelength. The ranges determined by the carriers are more accurate than those obtained by the codes, but in carrier phase measurements the carrier signals are highly influenced by noise as compared to the pseudo random codes. So, we are estimating the range using code range measurements other than carrier phase measurements

Code range measurements

The PRN codes transmitted by a satellite are used to determine the pseudo range or distance between the satellite antenna and the antenna of the GPS receiver the receiver can make this measurement by replicating the code being generated by the satellite and determine the time offset between the arrival of a particular transition in the code and the same transmission in the code replica. The ranging equation of the arrived GPS signal can be given as[2]

$$p = \rho + c(dt - dT) + d_{ion} + d_{tro} + \varepsilon$$

--Eq.1

Where
'p' is measured pseudo range
'ρ' is geometric or true range
'c' represents speed of light
dt and dT are offsets of satellite and receiver clocks
'd_{ion}','d_{tro}' are delays due to ionosphere and troposphere
'ε' represent effects of multipath and receiver measurement noise

Here the delay due to d_{tro}, $c(dt-dT)$, ε are negligible when compared to d_{ion} ,so neglecting those three errors, Eq.1 is reduced to Eq.2 as shown below

$$p = \rho + d_{ion} \quad \text{--Eq.2}$$

Navigation solution accuracy of the GPS system is dependent on the accuracy of the measured GPS ranging signals[3]. But, the GPS signals are degraded due to several factors such as atmospheric refraction, multipath, receiver clock bias, satellite clock bias and satellite-receiver geometry[4]. Table 1 represents the typical error value for each of the error source

Table 1 GPS ERROR BUDGET

Error Type	Error (meters)	Segment
Ephemeris	3.0	Signal-In-Space
Clock	3.0	Signal-In-Space
Ionosphere	4.0	Atmosphere
Troposphere	0.7	Atmosphere
Multipath	1.4	Receiver
Receiver	0.8	Receiver

From Table 1, it is clear that, error due to ionospheric refraction is more(≈4m) than the other errors[3]. Hence to obtain the precise navigation solution, it is necessary to estimate the ionospheric delay.

III. ESTIMATION OF IONOSPHERIC DELAY

The satellite which is the heart of the GPS navigation system, is placed in space. The signal transmitted from satellite passes through different layers of the atmosphere such as ionosphere and troposphere while reaching the receiver placed on the ground. Due to the refraction of these atmospheric layers, GPS signal is delayed before it reaches the receiver. The atmospheric layers are full of charged particals and the delay of the GPS signal is a function of these charged particales. To represent these charged particles, we use a term called Total Electron Content (or)Count(TEC).TEC is the total number of electrons present along a path between satellite and GPS receiver TEC is most important in determining the scintillation and group delay of the radio waves through a medium and TEC is strongly affected by solar activity .

If range measurements are available on two separate frequencies it allows the calculation of the absolute TEC The formula for calculating the TEC is given below

$$TEC = \frac{1}{40.3}\left[\frac{1}{f_1^{\,2}} - \frac{1}{f_2^{\,2}}\right]^{-1} |(pr_1 - pr_2)| \quad (\text{Units in } el/m^2)$$

-- Eq.3

'f_1' Represents the L_1 frequency = 1575.42 MHz
'f_2' Represents the L_2 frequency = 1227.60 MHz

'pr_1'And 'pr_2' Are the Pseudo Random Noise (PRN) codes (C/A and P codes)

TEC Values are often represented in terms of Total Electron Content Units (TECU)

Where $1TECU = 10^{16} el/m^2$

$$\text{Ionosphere Delay Error} = \left(\frac{40.3}{f^{\,2}}\right) TEC \quad (\text{units in mts})$$

--Eq.4

Using TEC ,Ionosphere Range Delay for L1 and L2 frequencien be estimated using Eq.4

Ionosphere Delay Error For L_1

$$= \left(\frac{40.3}{f_1^{\,2}}\right) TEC \text{ (units in mts)} \quad \text{--Eq.5}$$

Ionosphere Delay Error For L_2

$$= \left(\frac{40.3}{f_2^{\,2}}\right) TEC \text{ (units in mts)} \quad \text{--Eq.6}$$

IV. RESULTS

The results are based on the data due to the dual frequency GPS receiver located at Hyderabad (Hyde:Long/Lat: 17°24'39"N 78°33'4"E). The data of the typical day i.e August 1st 2012, is collected and sampled at an interval of 30 seconds,in order to carry out the thesis work. Visibility of the satellites for complete 24 hours of the typical day is shown in Fig.1

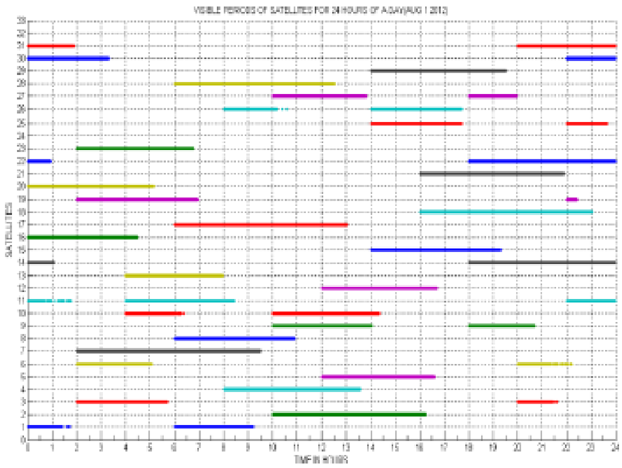


Fig.1 Visibility of the satellites for the entire day of 1st August, 2012

As an illustration, satellite positions computed at 12:00Hrs of the typical day is listed in Table 1. It is observed that total of 9 satellites are visible at 12:00Hrs of the typical day and along with the satellite positions, azimuth and elevation angles are also calculated. As an illustration TEC plots of SVPRN 7, SVPRN 13, SVPRN 16 and SVPRN 23 are shown in Fig.2 For SVPRN 7, maximum TEC observed is 102TECU at 9:49Hrs and minimum TEC observed is 20TECU at 2:00Hrs. For SVPRN 13, maximum TEC observed is 83TECU at 7:56Hrs and minimum TEC observed is 18 TECU at 4:00Hrs. For SVPRN 16, maximum TEC observed is 62TECU at 4:48Hrs and minimum TEC observed is 19 TECU at 2:00Hrs. For SVPRN 23, maximum TEC observed is 65 TECU at 6:45Hrs and minimum TEC observed is 15 TECU at 4:00Hrs.

Table 2 Positions of the Satellites visible at 12th hour of 1st August, 2012

Satellite Numbers	Satellites Position				
	X(meters)	Y(meters)	Z(meters)	Azimuth Angle (degrees)	Elevation angle (degrees)
SVPRN02	10019240.17	21155786.87	13155765.51	315.71	67.29
SVPRN04	-3537621.475	16562814.87	20134218.98	24.86	42.01
SVPRN05	3123095.717	23974946.87	-10863581.62	174.48	37.16
SVPRN09	20815348.78	16241484.35	2008506.276	256.66	37.10
SVPRN10	-9297463.088	24006088.7	5349521.989	95.65	48.77
SVPRN12	12483113.55	9669915.706	21373798.44	328.49	30.07
SVPRN17	-17903474.09	14691563.38	12965568.63	65.93	19.31
SVPRN27	20223406.23	17562591.53	-1162898.688	245.47	37.00
SVPRN28	-11901875.82	21481052.21	-9272867.77	132.17	21.99

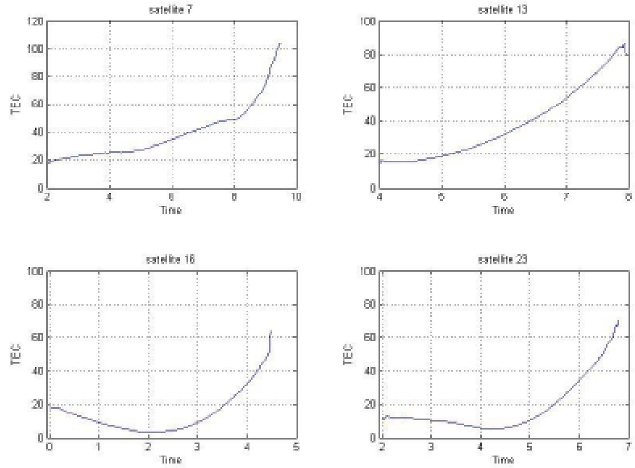


Fig.2 Estimated TEC for the satellites SVPRN 7, SVPRN 13, SVPRN 16 and SVPRN 23

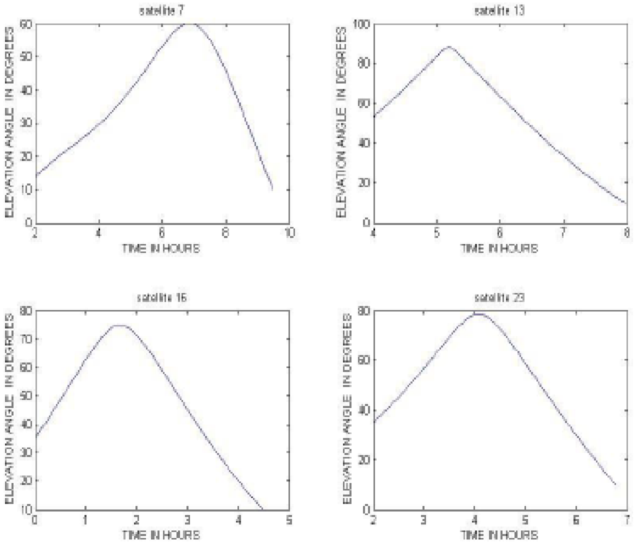


Fig.3 Elevation for the satellites SVPRN 7, SVPRN 13, SVPRN 16 and SVPRN 23

As the TEC is a function of elevation angle of the satellite, each of these satellites elevation angle w.r.t to time is also plotted and shown in Fig.3 Range of elevation angle for SVPRN 7 is 15^0 to 60^0 during the visibility period of 2:00Hrs to 9:40Hrs.For SVPRN 13,range of elevation angle is 21^0 to 90^0 during the visibility period of 4:00Hrs to 8:00Hrs.

Range of elevation angle for SVPRN16 is 10^0 to 75^0 during the visibility period of 0:00Hrs to 4:30Hrs.For SVPRN 23,the range of elevation angle for is from 17^0 to 80^0 during the visibility period of 2:00Hrs to 6:56Hrs. It can be obsefrved from Fig.3 that TEC is maximum as the elevation angle is minimum . As an illustration for SVPRN 13, minimum elevation angle is 21^0 and the corresponding TEC is 82TECU

TEC is estimated for all the satellites visible during the entire day on 1st August 2012.In order to estimate the TEC over the entire day, moving average filter is used so that any outliers can be filtered out. The TEC estimated over the entire day of 1st August 2012 is shown in Fig.4. The maximum value (57TECU) is observed at 10:00Hrs (UTC) and minimum value(11.4TECU)is observed at 1:00Hrs(UTC).

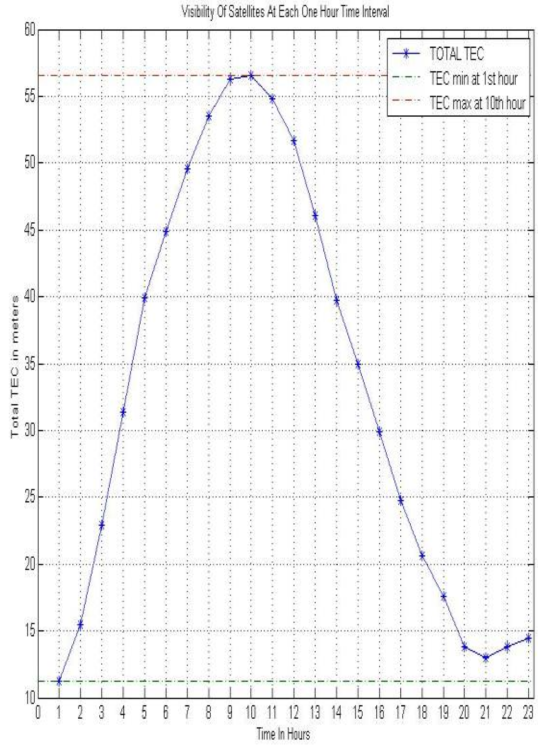
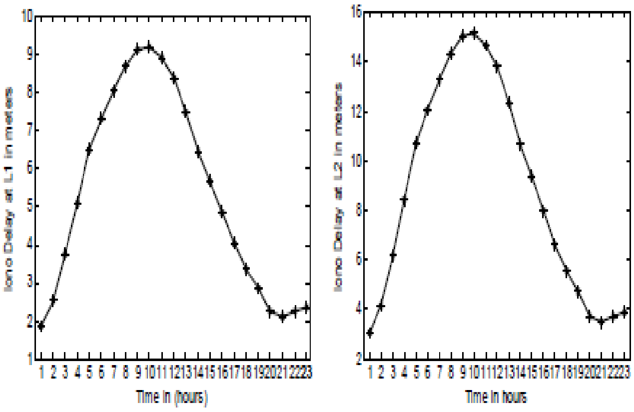


Fig.4 TEC estimated over the entire day of 1st August, 2012

Ionospheric delay is also calculated for the enter day of 1st August, 2012 on both L1(1575.42MHz) and L2(1227.60MHz) frequencies. It is observed that minimum value of ionospheric delay(1.8m on L1 and 3m on L2) is obtained at 1:00Hrs(UTC) and maximum value of the ionospheric delay is obtained at 10:00Hrs(UTC).Fig. 4.a and Fig.4.b shows the ionospheric delay calculated on L1 and L2 frequencies respectively.

The Ionospheric parameters computed on the typical day of 1st August 2012 are listed in Table 3



a. On L1 Frequency b. On L2 frequency

Fig.5 Ionospheric estimated over the entire day of 1st August, 2012

Table 3 Ionospheric parameters estimated on typical day of 1st August, 2012

1 hour duration	TOTAL TEC (TECU)	Ionospheric delay on L1 (meters)	Ionosperic delay on L2 (meters)
1	11.23317908	1.82395878	3.00395878
2	15.49888591	2.516592039	4.144687277
3	22.91792168	3.721239035	6.128673956
4	31.41098045	5.100277775	8.399874147
5	39.92964848	6.483474752	10.67792272
6	44.91952817	7.29369373	12.01230837
7	49.52220015	8.041040844	13.24314755
8	53.54278035	8.693872293	14.31832467
9	56.27544685	9.13758204	15.04908998
10	56.55012298	9.182181875	15.12254343
11	54.81543242	8.900515924	14.65865525
12	51.64574379	8.385845822	13.81102219
13	46.03620584	7.475011416	12.31092852
14	39.68977698	6.444526229	10.61377667
15	34.9220223	5.670374233	9.33879134
16	29.89625506	4.854328106	7.994808706
17	24.71367395	4.012819727	6.608891155
18	20.60556324	3.345775736	5.51030676
19	17.54416684	2.84868931	4.691633033
20	13.82137993	2.244211288	3.696091313
21	12.97267754	2.106405402	3.469132675
22	13.80142224	2.240970708	3.690754258
23	14.41545984	2.340673496	3.854959211

V. CONCLUSIONS

In this paper, by collecting the data of the dual frequency GPS receiver located at Hyderabad (Hyde :Long/Lat: 17°24'39"N 78°33'4"E) , TEC and Ionospheric delay are estimated for the entire day of 1st August 2012.. Estimation of the ionospheric delay is important as it causes a delay in ranging measurements which in turn cause an error in navigation solution. It is observed that the maximum delay of 9.18m on L1 and 15.12m on L2 is obtained at 10:00Hrs of the day. This work can be extended further by eliminating the ionospheric dalay from the ranging information, with which it is possible to obtain more precise navigation solution

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