

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

VC.VishnuVardhan Reddy, M.Manohar Reddy, G.Akshitha, K.S.Ramesh, R.Revathi

**Abstract:** Positional inaccuracies in GPS are caused by several errors such as Ionospheric, Tropospheric, Satellite Clock, Receiver Clock etc., Instantaneous correction of these error 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.

**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 6 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.

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\* Correspondence Author

**VC.VishnuVardhan Reddy\***, Student, Electronics and Communication Department, Koneru Lakshmaiah Education Foundation, Vaddeswaram, Guntur District, India.

**M.Manohar Reddy**, Student, Electronics and Communication Department, Koneru Lakshmaiah Education Foundation, Vaddeswaram, Guntur District, India.

**G.Akshitha**, Student, Electronics and Communication Department, Koneru Lakshmaiah Education Foundation, Vaddeswaram, Guntur District, India.

**Dr.K.S.Ramesh**, professor, Electronics and Communication Department, Faculty of Engineering, Koneru Lakshmaiah Education Foundation, Vaddeswaram, Guntur District, India.

**Dr.R.Revathi**, associate professor, Electronics and Communication Department, Faculty of Engineering, Koneru Lakshmaiah Education Foundation, Vaddeswaram, Guntur District, India.

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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 af0, af1, af2, Toe, delta, Mo, ecc, roota, omega, omegadot, 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 at low latitudes, 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 tropospheric delay 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°21'36.111", Longitude: 81°17'13.888") 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 throughout 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:

$$\Delta S = \Delta S_d + \Delta S_w$$

Where  $\Delta S$  is Total Tropospheric delay

$\Delta S_d$  is Dry Tropospheric delay

$\Delta S_w$  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. Before get into Hopfield model, Elevation angle of satellite (E), Temperature of the station (T) [Kelvin], Atmospheric Pressure (P) [millibars], Water Vapour Pressure (e) [millibars], Earth's radius (Re) [meters] should be obtained.

Early days evaluation and analysis is done at only once a month by this we can't achieve correct delay because parameters like temperature, pressure, water vapour pressure varies continuously at particular day in continuous time. By here we achieve only 1 delay time for complete month. Hence exact delay occurred by tropospheric layer can't be accurate throughout the month. So we came with a new approach that, evaluate at every second throughout the day, continued to end of the month. Therefore, we can achieve Total Tropospheric delay accurately. To obtain Tropospheric delay we consider Original Hopfield model. It is not we proposed model, it is being used from long time and the research till now is done by considering parameters with time interval of 3 hours or once a day at particular time for a month. So we came with a new proposal that to use 1 sec data parameters which helps to find.

Elevation angle of the satellite to get this we found ECEF co-ordinates then converted to local co-ordinates or East North Up (ENU) system and considering parameters for every 2 hours in Original Hopfield model to obtain accuracy Tropospheric time delay for continuous time interval of every 2 hours throughout the day. By this we found Total Tropospheric delay. 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 ENU coordinates are used to calculate Elevation angle of the satellite. Till here we use 1 sec raw data parameters (observation file and navigation file) to calculate Elevation angle. From here we taken parameters (Temperature, Pressure, Water vapour pressure) from Machilipatnam weather station. We have taken these parameters at a interval of 2 hours because there are two reasons one is we can't get parameters for every second and other is for every 2 hours or 3 hours there will be no major changes in the environment parameters.

(4) And finally by obtaining all time values for 1 sec and parameters for 2 hours time interval for all 8 visible satellites calculated Total Tropospheric delay by Original Hopfield Model.

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

$$a = (\sqrt{a})^2.$$

Corrected mean motion,

$$n = (\sqrt{\mu/a^3}) + \Delta n.$$

Time from ephemeris motion,

$$tk = t - toe$$

Mean anomaly,

$$Ma = M_0 + n(tk)$$

Eccentric anomaly (must be solved iteratively for

$$Ea), Ma = Ea - e \sin Ea$$

True anomaly,

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

$$\cos i = \cos Ea - e / 1 - e \cos Ea$$

Argument of latitude,

$$m = i + \text{smallomega}$$

Argument of latitude correction,

$$n = C_1 \sin(2m) + C_2 \cos(2m)$$

Radius correction,

$$\text{lamdap} = C_3 \sin(2m) + C_4 \cos(2m)$$

Inclination correction,

$$\text{lamdaz} = C_5 \sin(2m) + C_6 \cos(2m)$$

Corrected argument of latitude,

$$q = m + n$$

Corrected radius,

$$p = a(1 - e \cos Ea) + \text{lamdap}$$

Corrected inclination,

$$z = i_0 + (di/dt) * tk + \text{lamdaz}$$

Corrected longitude of node,

$$\text{lamdac} = \Omega_0 + (\Omega + \Omega_e)(t_k) - \Omega_e t_{oe}$$

In-plane x-position,  
 $a = p \cos q$   
 In-plane y-position,  
 $b = p \sin(q)$   
 $X = a \cdot \cos(\text{lamdac}) - b \cdot \cos(z) \cdot \sin(\text{lamdac})$   
 $Y = a \cdot \sin(\text{lamdac}) + b \cdot \cos(z) \cdot \cos(\text{lamdac})$   
 $Z = b \cdot \sin(z)$

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

$$[R] = [-\sin(la) \cos(lo) \ 0; \\ -\cos(la) \sin(lo) \ \sin(la) \sin(lo) \ \cos(lo); \\ \cos(la) \cos(lo) \ \sin(la) \cos(lo) \ \sin(lo)]$$

Where,  $la$  = latitude of the satellite

$Lo$  = longitude of the satellite.

$$[ENU] = [R] \cdot [X, Y, Z]$$

secondly find Elevation angle of the satellite, Elevation angle =  $\arctan(U/\sqrt{N^2 + \sqrt{E^2}})$

Finally, we calculated Total Tropospheric delay and observed time varying Continuously.

### V. RESULTS & ANALYSIS

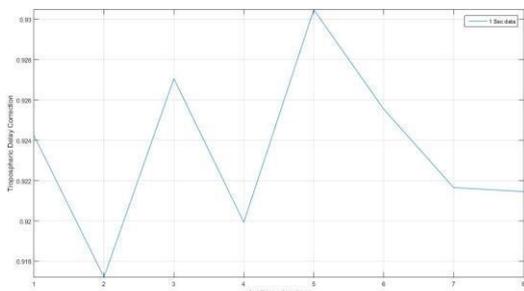


Fig 1: Tropospheric Delay correction for 1st secs data for 8 different satellites.

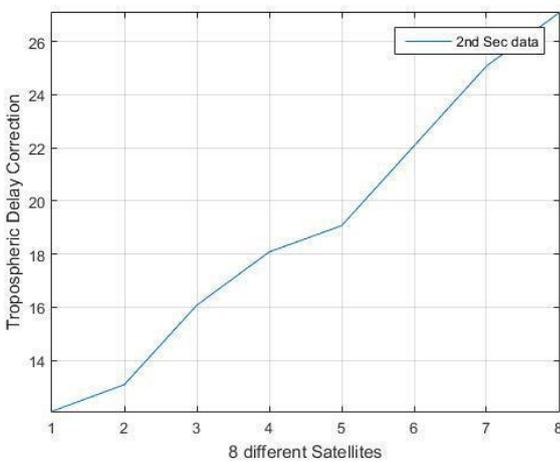


Fig 2: Tropospheric Delay correction for 2nd secs data for 8 different satellites.

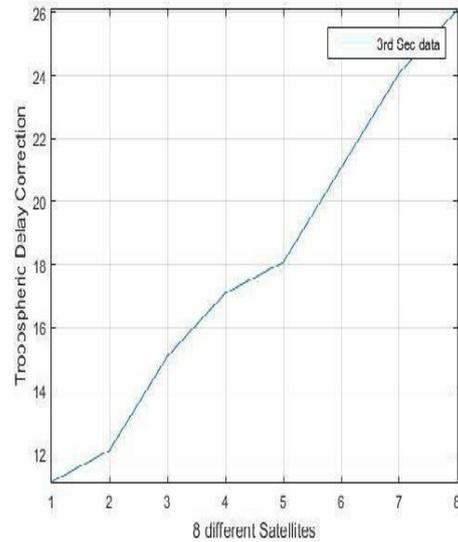


Fig 3: Tropospheric Delay correction for 3rd sec data for 8 different satellites.

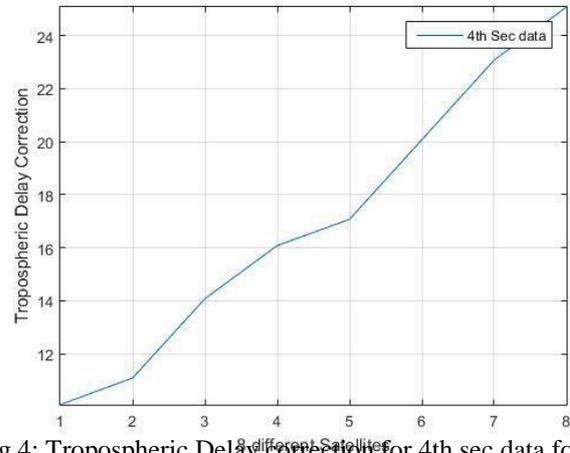


Fig 4: Tropospheric Delay correction for 4th sec data for 8 different satellites.

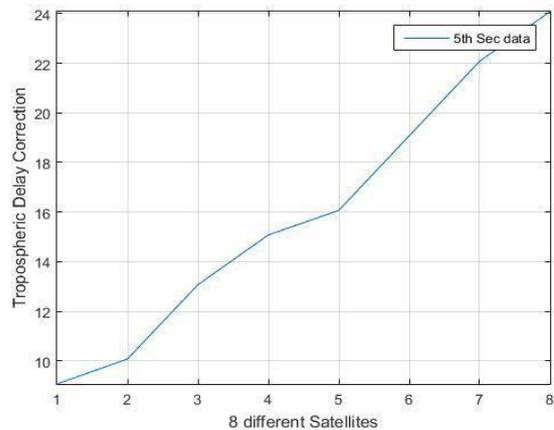


Fig 5: Tropospheric Delay correction for 5th sec data for 8 different satellites.

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

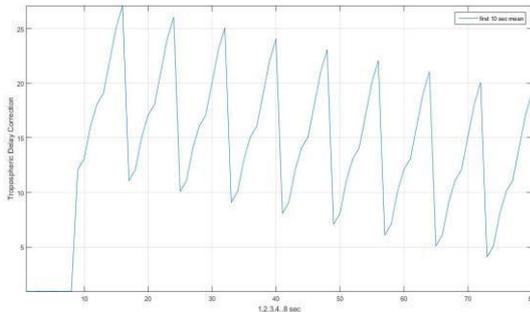


Fig 6: Tropospheric Delay correction for first 10 secs average data.

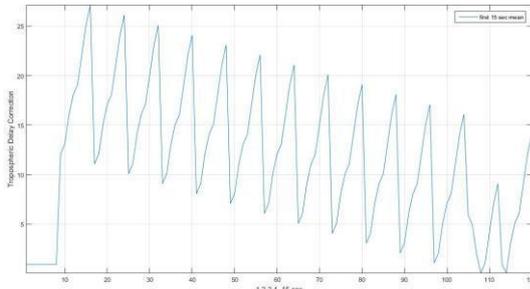


Fig 7: Tropospheric Delay correction for 15 secs average data.

### 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.

$$T_c = T_{obs} - (\text{pseudo-range}/\text{speed of the light}).$$

(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  $Tk1 > 302400$ 

$$Tk2 = Tk1 - 604800;$$
  - Else  $Tk1 < 302400$ 

$$Tk2 = Tk1 + 604800;$$

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  $E = M + es * (\sin * E)$  appears very simple, it is nonlinear one; therefore, it is difficult to solve analytically. Where es is eccentricity of the satellite orbit, es 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  $E_{i+1} = M + es * (\sin * E_i)$ , where  $E_{i+1}$  is the present value,  $E_i$  is the previous value. We should consider  $E_0$  initial value as  $M$  ( $E_0 = M$ )

Either one can define a error signal as  $Err = (E_{i+1}) - E_i$  and end the iteration when the Err is less than a predetermined value.

(5) Mean motion,

$$n = \frac{\sqrt{\mu}}{a^3} * \Delta n$$

(6) Mean anomaly,

$$M = M_0 + (n * tk)$$

$$M1 = \text{rem}(M + (2 * \pi) / 2 * \pi)$$

{remainder after  $M + (2 * \pi)$  divided by  $2 * \pi$ }

$$E1 = M1$$

(7)  $E = M + es * (\sin * E)$  Iteration method to find E.

For  $j = 1:10$

$$E_{old}(j) = E1(i);$$

$$E1(j) = M(i) + ec(i) * \sin E1(i);$$

$$dEk(j) = \text{rem}(E1(i) - E_{old}(j), 2 * \pi);$$

$$\text{If } \text{abs}(dEk(i)) < 1.e-12;$$

Break;

end

(8)  $E2 = \text{rem}(E1 + (2 * \pi) / 2 * \pi)$

{remainder after  $E1 + (2 * \pi)$  divided by  $2 * \pi$ }

$$\text{Eccentric anomaly, } E = E2$$

(9)  $\Delta tr = F * es * (\sqrt{a}) * \sin E$

(10)  $\Delta t = af_0 + af_1(tk_2) + af_2(tk_2) + \Delta tr - Tgd$

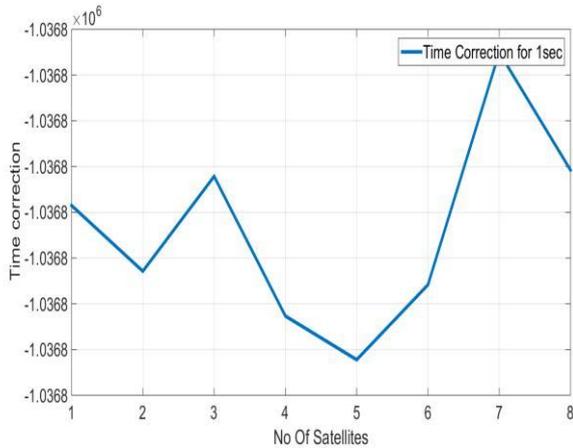
From  $\Delta t$  we obtained overall time correction. To get more accuracy the GPS time at time of transmission can be corrected again,

(11)  $T = tc - \Delta t$

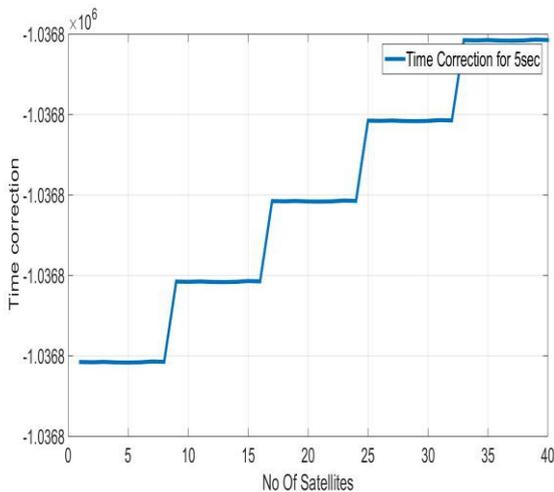
We calculated T for 1Sec time for 8 satellites; These 8 satellites are visible in 1 Sec data of both observation file and navigation file.

**VII. RESULTS & ANALYSIS**

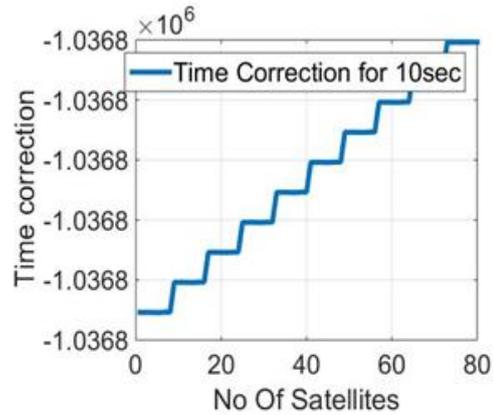
GPS data of visible satellites for one day is analyzed for the position of satellite. with reference to the receiver, the transit time of visible satellite is calculated and the overall time correction is also calculated. Time correction of eight different satellites (14,27,24,20,15,29,21,28) for one second, five second and ten second as shown in fig 1, fig 2 and fig 3.



**Fig 1: Time correction for eight different satellite one second data.**



**Fig 2: Time correction for eight different satellite five second data.**



**Fig 3: Time correction for eight different satellite ten second data.**

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 considered 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 17<sup>th</sup> March, 2017 we estimated the delay in meters.

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## AUTHORS PROFILE



**VC. Vishnu Vardhan Reddy** is a student of B.Tech studying fourth year in Electronics and Communication Engineering (ECE) from Koneru Lakshmaiah Education Foundation, Vaddeswaram, Vijayawada, India. Interested to do research in satellite communication.



**M. Manohar Reddy** is a student of B.Tech studying fourth year in Electronics & Communication Engineering (ECE) from Koneru Lakshmaiah Education Foundation, Vaddeswaram, Vijayawada, India. Interested to do research in satellite communication.



**G. Akshitha** is a student of B.Tech studying fourth year in Electronics and Communication Engineering (ECE) from Koneru Lakshmaiah Education Foundation, Vaddeswaram, Vijayawada, India. Interested to do research in satellite communication.



**Dr. K.S. Ramesh** working as professor in Electronics and communication engineering. His work mainly focus on satellite navigation and augmentation studies. He also work on application of signal processing techniques for prognostic studies on earthquake using GPS. He handling three government funding projects from DST and MoES government of India.