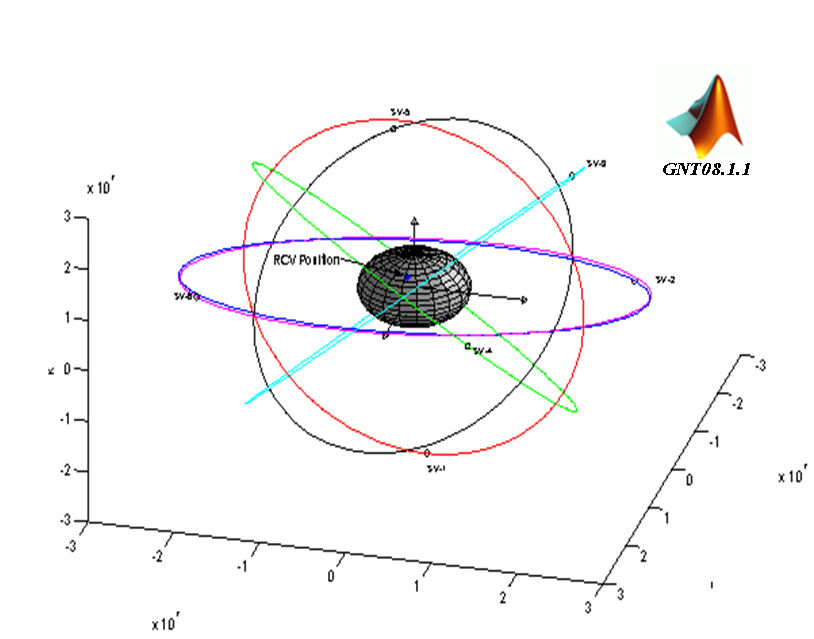
***Avionic & Navigation***

***Term Project***

**GPS Navigation Toolbox**

**GNT08.1.1**

****

**2**008

**By: Moein Mehartash**

Engineering and Computer Science

GPS Navigation Toolbox

Contents

[1. Introduction 4](#_Toc195947111)

[2. Principle of Radio Navigation 5](#_Toc195947112)

[3. GPS Ephemeris Parameter 8](#_Toc195947113)

[4. GPS Errors 10](#_Toc195947114)

[4.1 Ionospheric Error 11](#_Toc195947115)

[4.2 Troposphere Error 12](#_Toc195947116)

[4.3 Satellite Clock Error 13](#_Toc195947117)

[5. Simulation & GPS Toolbox 14](#_Toc195947118)

[5.1 Calculation of satellite position 20](#_Toc195947119)

[5.1.1 Mfile Simulation- SV\_Ephemeris\_Model 21](#_Toc195947120)

[5.2 Ionospheric Error 22](#_Toc195947121)

[5.2.1 Mfile Simulation -Error\_Ionospheric\_Klobuchar 23](#_Toc195947122)

[5.3 Tropospheric Error 24](#_Toc195947123)

[5.3.1 Mfile Simulation - Error\_Tropospheric\_Hopfield 25](#_Toc195947124)

[5.4 Satellite Clock Error 26](#_Toc195947125)

[5.4.1 Mfile Simulation - Error\_Satellite\_Clock\_Offset & Error\_Satellite\_Clock\_Relavastic 28](#_Toc195947126)

[5.5 Result Plot 29](#_Toc195947127)

[6. Reference 30](#_Toc195947128)

[7. Appendix 31](#_Toc195947129)

[7.1 Main Mfile 31](#_Toc195947130)

[7.2 Error\_Satellite\_Clock\_Offset 32](#_Toc195947131)

[7.3 Error\_Satellite\_Clock\_Relavastic 33](#_Toc195947132)

[7.4 Error\_Ionospheric\_Klobuchar 33](#_Toc195947133)

[7.5 Error\_Tropospheric\_Hopfield 35](#_Toc195947134)

[7.6 Gen\_G\_DX\_XYZ\_B 36](#_Toc195947135)

[7.7 plot\_Orbit 37](#_Toc195947136)

[7.8 Main 39](#_Toc195947137)

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Contents

[1. Introduction 4](#_Toc195947138)

[2. Principle of Radio Navigation 5](#_Toc195947139)

[3. GPS Ephemeris Parameter 8](#_Toc195947140)

[4. GPS Errors 10](#_Toc195947141)

[4.1 Ionospheric Error 11](#_Toc195947142)

[4.2 Troposphere Error 12](#_Toc195947143)

[4.3 Satellite Clock Error 13](#_Toc195947144)

[5. Simulation & GPS Toolbox 14](#_Toc195947145)

[5.1 Calculation of satellite position 20](#_Toc195947146)

[5.1.1 Mfile Simulation- SV\_Ephemeris\_Model 21](#_Toc195947147)

[5.2 Ionospheric Error 22](#_Toc195947148)

[5.2.1 Mfile Simulation -Error\_Ionospheric\_Klobuchar 23](#_Toc195947149)

[5.3 Tropospheric Error 24](#_Toc195947150)

[5.3.1 Mfile Simulation - Error\_Tropospheric\_Hopfield 25](#_Toc195947151)

[5.4 Satellite Clock Error 26](#_Toc195947152)

[5.4.1 Mfile Simulation - Error\_Satellite\_Clock\_Offset & Error\_Satellite\_Clock\_Relavastic 28](#_Toc195947153)

[5.5 Result Plot 29](#_Toc195947154)

[6. Reference 30](#_Toc195947155)

[7. Appendix 31](#_Toc195947156)

[7.1 Main Mfile 31](#_Toc195947157)

[7.2 Error\_Satellite\_Clock\_Offset 32](#_Toc195947158)

[7.3 Error\_Satellite\_Clock\_Relavastic 33](#_Toc195947159)

[7.4 Error\_Ionospheric\_Klobuchar 33](#_Toc195947160)

[7.5 Error\_Tropospheric\_Hopfield 35](#_Toc195947161)

[7.6 Gen\_G\_DX\_XYZ\_B 36](#_Toc195947162)

[7.7 plot\_Orbit 37](#_Toc195947163)

[7.8 Main 39](#_Toc195947164)

Figures List:

[Figure 1 Flowchart of Iterative Method for GPS Navigation 14](#_Toc195947165)

[Figure 2 GPS satellite & Receiver Position 15](#_Toc195947166)

[Figure 3 Iterative Method for GPS Navigation-Delta x 16](#_Toc195947167)

[Figure 4 Iterative Method for GPS Navigation in Finding Position 17](#_Toc195947168)

[Figure 5 Iterative Method for GPS Navigation –Norm Error 17](#_Toc195947169)

# Introduction

In the past several years compact radio navigation receivers have proliferated in the civilian market place, generally under the name of GPS or Global Positioning System. Appearing as handheld units or built into cars, mobile phones, and airplanes, these commercial applications originated from a Cold War military application. GPS is a worldwide radio-navigation system formed from a constellation of 24 satellites, each in its own orbit 11,000 nautical miles above the Earth, and five ground stations that make sure the satellites are working properly. The GPS satellites each take 12 hours to orbit the Earth. Each GPS satellite continuously broadcasts a Navigation Message at 50 [bit/s](http://en.wikipedia.org/wiki/Bitrate) giving the time-of-day, GPS week number and satellite health information (all transmitted in the first part of the message), an [ephemeris](http://en.wikipedia.org/wiki/Ephemeris) (transmitted in the second part of the message) and an almanac (later part of the message). The position calculated by a GPS receiver requires the current time, the position of the satellite and the measured delay of the received signal and then by using the triangulation rule the position of the receiver is determined. The large sources of error in GPS are produced by the atmospheric effect (ionospheric, tropospheric), clock errors of the satellite, multipath effect, satellite orbits errors and calculation-rounding errors. The errors of the GPS system are summarized in the following table. The individual values are no constant values, but are subject to variances. All numbers are approximate values [1]:

Table 1. Errors of GPS

|  |  |
| --- | --- |
| Error Source | Error |
| Ionospheric effects | ± 5 meter |
| Shifts in the satellite orbits | ± 2.5 meter |
| Clock errors of the satellites' clocks | ± 2 meter |
| Multipath effect | ± 1 meter |
| Tropospheric effects | ± 0.5 meter |
| Calculation- und rounding errors | ± 1 meter |

This report include the review of

* **Principle of Radio Navigation:** navigation base on trilateration has been investigated and the over determined Eq. for navigation has been solved.
* **GPS Ephemeris Data:** for GPS navigation, the position of GPS satellite is very important so the by receiving ephemeris data the position of the satellite is determined.
* **GPS Errors:** Three different sources of errors in GPS navigation has been investigated (Ionosphere, Troposphere and Satellite clock). Ionospheric Error model is generated base on Parkinson [1] and the Tropospheric Error Model based on Hopfiel model [2].
* **Simulation & GPS Toolbox:** One of the targets of this work is generating Matlab GPS Toolbox and in one case study the performance of generated toolbox will be verified.

# Principle of Radio Navigation

The principle of radio navigation is remarkably simple. In a considerably simplified approach, each satellite is sending out signals with the following content: I am satellite X, my position is Y and this information was sent at time Z. In addition to its own position, each satellite sends data about the position of other satellites. These orbit data (ephemeris und almanac data) are stored by the GPS receiver for later calculations. For the determination of its position on earth, the GPS receiver compares the time when the signal was sent by the satellite with the time the signal was received. From this time difference the distance between receiver and satellite can be calculated. If data from other satellites are taken into account, the present position can be calculated by trilateration (meaning the determination of a distance from three points). This means that at least three satellites are required to determine the position of the GPS receiver on the earth surface. The calculation of a position from 3 satellite signals is called 2D-position fix (two-dimensional position determination). It is only two dimensional because the receiver has to assume that it is located on the earth surface (on a plane two-dimensional surface). By means of four or more satellites, an absolute position in a three dimensional space can be determined. A 3D-position fix also gives the height above the earth surface as a result.

To navigate successfully the receiver must first execute a series of actions. Initially, it must acquire a satellite in the correlation for tracking. From a cold start this may take several minutes per satellite. Next it must track the satellite with no bit errors for the 30 s length of one navigation message, which may take up to 1 min. For safety purposes many receivers obtain contiguous navigation messages and compare their contents to assure accurate data reception. At this point, from the code arrival time the receiver can estimate the pseudorange given by

 ()

Where  is the pseudorange and  is the real range. The pseudorange  contains two primary sources of error. The two error sources are: (a) errors in the inaccurate receiver clock (), called the receiver clock offset; and (b) errors in the inaccurate satellite receiving signal (). Note that an important property of  is that it is the same for all satellite signals and pseudoranges since it is a property of the receiver. The real range  is the distance from the ith satellite to the receiver. We will denote the satellite’s position as (Xi, Yi, Zi) and the receiver’s position as (X, Y, Z). Recall that the satellite position is calculated by the receiver from the ephemerides in the navigation message. While the right side of Eq. (1) contains the four unknowns of X, Y, Z, and .Hence, to solve for the four unknowns, a minimum of four satellites is required to yield four equations. Since Eq. (1) is nonlinear, typically this is done using the multidimensional Newton–Raphson method and a reasonable guess of the initial receiver position Parkinson [1]. A technique for solving Eq. (1) is the Newton– Raphson method. The initial guess is at (X0, Y0, Z0)



 ()

where X, Y, Z is the true ECEF solution and , , and  is the difference between the true solution and the initial guess. The initial guess at the receiver ECEF coordinates yields an initial guess for the true range. To correct the initial guess we need to calculate, , and in order to update X0, Y0, and Z0. This is done by a linear (first-order Taylor) expansion of  in the three spatial coordinates.

 ()

The solutions,, and  can be found using a minimum of four equations.

Defining,

 ()

Using these definitions, Eq. (4) becomes with solution. After solving,,  and. the corrected coordinates are updated to yield X, Y, and Z. This solution is, of course, an approximation so an iterative approach is required whereupon the most recent solution becomes the initial guess and the process above is repeated until the desired accuracy is obtained. If more than four satellites are being observed, the problem is over-determined and can be solved in a least squares sense to yield an optimal receiver location.

 ()

To calculate navigation errors, the ranging errors must be mapped to the navigation solution. This process is dependent on the satellite geometry as seen by the receiver. The factor mapping the ranging solution to the navigation solution is called dilution of precision (DOP). DOP is calculated from the design matrix containing the unit vectors A. The Q matrix is calculated from the design matrix as

 ()

The Q matrix maps the ranging covariance matrix into the navigation covariance matrix (see, for example, Parkinson et al., 1996, p. 195). In its simplest form it provides a scaling factor from the pseudorange errors to the navigational errors.

 ()

We are principally interested in the diagonal elements of Q.

 ()

In the following combinations

 ()

# GPS Ephemeris Parameter

The purely elliptical Kepler orbit is precise only for a simple two-body problem where the mutual gravitational attraction between the two bodies is the only force involved. In the actual GPS satellite orbit, there are many perturbations to the ideal orbit, including nonspherical Earth gravitational harmonics: lunar, solar gravitational attraction: and solar flux. Thus the GPS orbit is modeled as a modified elliptical orbit with correction terms to account for these perturbations:

1. *sin, cos* perturbations to the:
   1. Argument of latitude
   2. Orbit radius
   3. Angle of inclination
2. Rate of change of:
   1. Right ascension
   2. Inclination angle

Furthermore the parameters for this model are changed periodically to give a best fit to the actual satellite orbit. In normal operations, the fit interval is 4 hours. Following table shows ephemeris model parameters:

Table 2. Ephemeris Parameters &Units

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| No. | Parameter | Definition |  | Units |
| 1 | Crs | Amplitude of the Cosine Harmonic Correction Term to the Orbit Radius |  | meters |
| 2 | Δn | Mean Motion Difference From Computed Value |  | semi-circles/sec |
| 3 | M0 | Mean Anomaly at Reference Time |  | semi-circles |
| 4 | Cuc | Amplitude of the Sine Harmonic Correction Term to the Argument of Latitude |  | radians |
| 5 | e | Eccentricity |  | dimensionless |
| 6 | Cus | Amplitude of the Sine Harmonic Correction Term to the Argument of Latitude |  | radians |
| 7 |  | Square Root of the Semi-Major Axis |  |  |
| 8 | toe | Reference Time Ephemeris |  | seconds |
| 9 | Cic | Amplitude of the Cosine Harmonic Correction Term to the Angle of Inclination |  | radians |
| 10 | Ω0 | 2-31 |  | semi-circles |
| 11 | Cis | Amplitude of the Sine Harmonic Correction Term to the Angle of Inclination |  | radians |
| 12 | Crc | Amplitude of the Cosine Harmonic Correction Term to the Orbit Radius |  | semi-circles |
| 13 | ω | Argument of Perigee |  | meters |
| 14 |  | Rate of Right Ascension |  | semi-circles/sec |
| 15 | IDOT | Rate of Inclination Angle |  | semi-circles/sec |

By demodulating and extracting the navigation data, the user can calculate the satellite position vs. time. The following equations give the space vehicle antenna phase center position in WGS-84 Earth-centered Earth-fixed reference frame. The ECEF coordinate system is defined as WGS-84.

|  |  |
| --- | --- |
|  | Time from ephemeris reference epoch |
|  | Corrected mean motion |
|  | Mean anomaly |
|  | Kepler's Equation for Eccentric Anomaly (may be solved by iteration) (radians) |
|  | True Anomaly |
|  | Argument of Latitude |
|  | Second Harmonic Perturbations:  Argument of Latitude Correction  Radius Correction  Inclination Correction |
|  | Corrected Argument of Latitude  Corrected Inclination  Corrected Radius |
|  | Positions in orbital plane. |
|  | Corrected longitude of ascending node. |
|  | Earth-fixed coordinates. |
|  |  |

Note that it is the mean anomaly Mk that varies linearly with the time interval. However, the solution of the satellite position requires knowledge of the eccentric anomaly *Ek*, which does not vary linearly with time unless the eccentricity *e=0*. The eccentric anomaly *Ek* must be solved for by iterative calculation. In this project the Kepler’s Eq is solved by Matlab function fzero and initial condition *Ek0=Mk*. Also *t* is GPS time at time of transmission; i.e., GPS time corrected for transit time. Furthermore, *tk*shall be the actual total time difference between the time *t* and the epoch time *toe*and must account for beginning or end of week crossovers. That is, if *tk* is greater than302400 seconds, subtract 604800 seconds from *tk* . If *tk* is less than 302400 s, add 604800 s to *tk*.

# GPS Errors

The GPS system has been designed to be as nearly accurate as possible. However, there are still errors. Added together, these errors can cause a deviation of **± 50 -100** meters from the actual GPS receiver position. There are several sources for these errors, the most significant of which are discussed below:

* **Atmospheric Conditions**: The ionosphere and troposphere both refract the GPS signals. This causes the speed of the GPS signal in the ionosphere and troposphere to be different from the speed of the GPS signal in space. Therefore, the distance calculated from "Signal Speed x Time" will be different for the portion of the GPS signal path that passes through the ionosphere and troposphere and for the portion that passes through space.
* **Ephemeris Errors/Clock Drift/Measurement Noise:** As mentioned earlier, GPS signals contain information about ephemeris (orbital position) errors, and about the rate of clock drift for the broadcasting satellite. The data concerning ephemeris errors may not exactly model the true satellite motion or the exact rate of clock drift. Distortion of the signal by measurement noise can further increase positional error. The disparity in ephemeris data can introduce 1-5 meters of positional error, clock drift disparity can introduce 0-1.5 meters of positional error and measurement noise can introduce 0-10 meters of positional error.
* **Multipath:** A GPS signal bouncing off a reflective surface prior to reaching the GPS receiver antenna is referred to as multipath. Because it is difficult to completely correct multipath error, even in high precision GPS units, multipath error is a serious concern to the GPS user.

As mentioned before, Eq.1 states the main relation of GPS navigation, but true pseudorange is not directly an observable due to different source of errors, but instead must be observed with various perturbations. The measured pseudorange is equal to the true pseudorange plus various perturbing factors due to different error source, as shown below

 ()

Where:

: Troposphere error

: Ionosphere error

: Relativistic time correction

: Satellite bias clock error

In this report only Atmospheric Condition and Clock Drift has been investigated. Hopefully other error sources will be added. Atmospheric Condition and Clock Drift modeling are described more as following.

## Ionospheric Error

As GPS satellite signals traverse the ionosphere, they are delayed by an amount proportional to the number of free ions encountered. The ion density is a function of the local time, magnetic latitude, sunspot cycle and other factors.

Klobuchar[1] developed a simple analytical model for ionospheric time delay, which we have used for ionospheric correction model. This form of GPS user ionospheric correction algorithm requires the user’s approximate geodetic latitude, longitude, elevation angle E and azimuth A to each GPS satellite. The calculation proceeds as follows

1. Calculate the Earth-centered angle 

 ()

1. Compute the subinospheric latitude, 

 ()

If , then . If, then.

1. Compute the subionospheric longitude

 ()

1. Find the geomagnetic latitude, , of the subionospheric location looking toward each GPS satellite. It is found by

 ()

1. Find the local time, t, at the subionospheric point

 ()

If t>86400, use t=t-86400. If t<0, add 86400.

1. To convert to slant time delay, compute the slant factor, F

 ()

1. Compute the ionospheric time delay Tiono by first computing x

 ()

If PER< 72000 then PER=72000.

1. If  then

 ()

Otherwise

 ()

## Troposphere Error

The primary purpose of the tropospheric analysis system is to estimate wet tropospheric delays that can be converted into integrated water vapor and thereby serve as a valuable input into numerical weather and climate models. For this reason, Hopfield model is devoted to tropospheric delay modeling and estimation. Hopfield splits the troposphere delay into two parts: a contribution of the “Dry” and a contribution of the “Wet” atmosphere. The zenith delay of the dry component is given by

 ()

Where  is ambient temperature and  is ambient air pressure. The zenith delay of the wet component is given by

 ()

Multiply the zenith delay’s with their mapping functions to correct for elevations lower than 90 Deg. And add the components to obtain the SV’s tropospheric delay correction

 ()

Where El is the SV’s elevation in Rad.

## Satellite Clock Error

The user receiver needs to correct the GPS satellite clock errors. The user receiver must have an accurate representation of GPS system time at the time of transmission for GPS signal it receiving from satellite i. the satellite clock correction  is obtained using coefficients broadcast from the satellite after being uploaded by the GPS control segment. The control segment actually uploads several different sets of coefficient to the satellite, of which each set is valid over a given time period. The data sets are then transmitted in the downlink DataStream to the users in the appropriate time intervals. These corrections represent a second order polynomial in time.

The GPS time needed to solve for user position is  where the SV pseudorandom noise code phase is time at the time of transmission and is easily determined by the GPS receiver. The satellite clock correction term is approximated by a polynomial

 ()

Where, and  are the polynomial correction coefficient corresponding to phase error, frequency error, and rate of change of frequency error; the relativistic correction is ;  is a reference time for clock correction and  is group delay.

Relativistic correction must be computed by the user. A first order effect described in the GPS gives the relativistic correction for an Earth-centered, Earth-fixed (ECEF) observer and a GPS satellite of eccentricity e. this relativistic correction varies as the *sine* of the satellite eccentric anomaly Ek as follows:

 ()

Where

F:-4.442807633E-10s/m.

Ek: eccentric anomaly of the satellite orbit

A: semi major axis of the satellite orbit

# Simulation & GPS Toolbox

In this chapter the numerical simulation and the functions of ***GNT08.11*** result will be shown. First the algorithm of computation is derived and then the position of GPS receiver is determined. In the next part of the chapter, Matlab functions are presented.

The following flowchart shows the data relation and the algorithm for estimation the position of GPS receiver. The first step for GPS navigation is using Ephemeris data to estimate the position of satellite, the simulation result for GPS satellite position are shown in Table 3 and Figure 2 shows the graphical result.

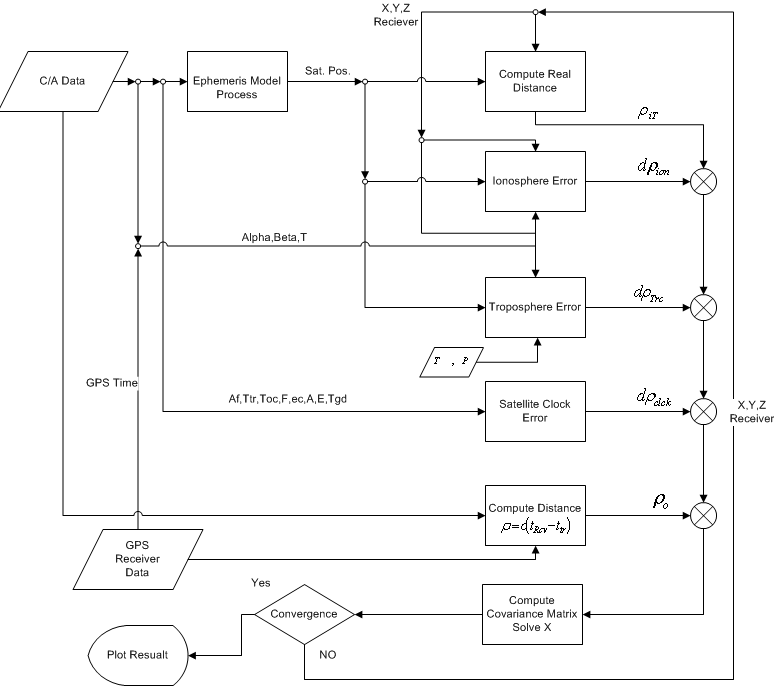


Figure Flowchart of Iterative Method for GPS Navigation

Table . Satellite Position

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
|  | Satellite 1 | Satellite 2 | Satellite 3 | Satellite4 | Satellite 5 | Satellite 6 | Unit |
| X | 1.6127e+007 | 1.2604e+007 | 2.5942e+007 | 2.1059e+007 | 1.0073e+007 | 1.5934e+007 | meters |
| Y | -1.5548e+007 | 1.2117e+007 | -4.7596e+006 | 1.6302e+007 | 2.1064e+007 | -4.8197e+006 | meters |
| Z | 1.4384e+007 | 2.0032e+007 | 4.3389e+006 | 2.2840e+006 | 1.3011e+007 | 2.0534e+007 | meters |



Figure 2 GPS satellite & Receiver Position

For Iterative algorithm, the convergence condition is defined as the norm of, and for the simulation the convergence condition is set to ***1meter***. The condition of convergence happened after 5 iteration and the results are shown in the following table.

Table . Iterative Solving for delta x

|  |  |  |  |
| --- | --- | --- | --- |
| Iteration |  |  |  |
| 1 | 4.8017e+006 | 4.2249e+005 | 6.1371e+006 |
| 2 | -8.6674e+005 | -9.6971e+004 | -1.0668e+006 |
| 3 | -4.0708e+004 | -6.5404e+003 | -4.5982e+004 |
| 4 | -8.0702e+001 | -1.5564e+001 | -8.6632e+001 |
| 5 | -2.7517e-004 | -8.0973e-005 | -3.3180e-004 |

Table . Iterative position for GPS receiver

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Iteration |  |  |  | Bias |
| 0 | 0 | 0 | 0 | 0 |
| 1 | 4.8017e+006 | 4.2249e+005 | 6.1371e+006 | 1.4686e+006 |
| 2 | 3.9350e+006 | 3.2552e+005 | 5.0703e+006 | 6.5428e+004 |
| 3 | 3.8943e+006 | 3.1898e+005 | 5.0244e+006 | 1.0646e+002 |
| 4 | 3.8942e+006 | 3.1896e+005 | 5.0243e+006 | -1.8454e+001 |
| 5 | 3.8942e+006 | 3.1896e+005 | 5.0243e+006 | -1.8454e+001 |

Iterative process is show in the following diagram. In following figure the solution to covariance matrix is shown. In Figure 4 the convergence of receiver position from initial [0 0 0] to real position is shown. In Figure 5 the norm of  is shown, which states the convergence of algorithm.



Figure Iterative Method for GPS Navigation-Delta x



Figure Iterative Method for GPS Navigation in Finding Position



Figure Iterative Method for GPS Navigation –Norm Error

The important parameter from covariance matrix are shown in following table

Table . Important parameter from covariance matrix

|  |  |
| --- | --- |
| Parameter | Value |
| GDOP | 3.46 |
| PDOP | 2.45 |
| HDOP | 2.14 |
| VDOP | 1.54 |
| TDOP | 2.45 |

The source of error and the amount is shown in the following tables.

Table . Important parameter from covariance matrix

|  |  |  |
| --- | --- | --- |
| Offset Error | | |
| SV | dTclck(Sec) | Distance Error(m) |
| 1 | 3.1532e-005 | 9.4529e+003 |
| 2 | 1.2003e-004 | 3.5983e+004 |
| 3 | -2.7334e-007 | -8.1946e+001 |
| 4 | -1.6363e-005 | -4.9054e+003 |
| 5 | 7.8390e-004 | 2.3501e+005 |
| 6 | -6.8825e-006 | -2.0633e+003 |

Relativistic Error

Table . Important parameter from covariance matrix

|  |  |  |
| --- | --- | --- |
| Relativistic Error | | |
| SV | dTclck(Sec) | Distance Error(m) |
| 1 | 6.2697e-009 | 1.8796 |
| 2 | -3.1723e-009 | -.95 |
| 3 | -7.2228e-009 | -2.1653 |
| 4 | -1.0670e-008 | -3.1988 |
| 5 | -9.7982e-009 | -2.9374 |
| 6 | 6.0348e-010 | .18092 |

Ionosphere Error

Table . Important parameter from covariance matrix

|  |  |  |
| --- | --- | --- |
| Ionosphere Error | | |
| SV | dTclck(Sec) | Distance Error(m) |
| 1 | 4.6554e-008 | 1.3957e+001 |
| 2 | 4.4740e-008 | 1.3413e+001 |
| 3 | 4.6864e-008 | 1.4049e+001 |
| 4 | 4.7241e-008 | 1.4162e+001 |
| 5 | 4.7072e-008 | 1.4112e+001 |
| 6 | 4.2179e-008 | 1.2645e+001 |

Troposphere Error

Table . Important parameter from covariance matrix

|  |  |
| --- | --- |
| Troposphere Error | |
| SV | Distance Error(m) |
| 1 | 3.7468e+000 |
| 2 | 2.8173e+000 |
| 3 | 4.2665e+000 |
| 4 | 6.1694e+000 |
| 5 | 4.9369e+000 |
| 6 | 2.5032e+000 |

For simulation of GPS navigation some Matlab functions have been generated, in the following table the functions and field of usage are described then the operation of functions will be explained more in next part.

Table 11. Functions Generate for GPS Simulation

|  |  |
| --- | --- |
| Definition | Used Matlab Function |
| Covariance Matrix & solution | **Gen\_G\_DX\_XYZ\_B** |
| Calculation of Satellite position | SV\_Ephemeris\_Model  Kepler\_Eq |
| Satellite Clock Error | **Error\_Satellite\_Clock\_Offset**  **Error\_Satellite\_Clock\_Relavastic** |
| Ionosphere Error | **Error\_Ionospheric\_Klobuchar**  **Calc\_Azimuth\_Elevation**  **ECEF2GPS** |
| Troposphere Error | **Error\_Tropospheric\_Hopfield**  **Calc\_Azimuth\_Elevation** |
| Result Plot | **plot\_Orbit** |

## Calculation of satellite position

The position of satellite is calculating base on Ephemeris model, so the function SV\_Ephemeris\_Model computes the satellite position base on theory of ephemeris model . The following tables show the function inputs and outputs. The source of function is printed in Appendix.

Function [Output1,Output2]=SV\_Ephemeris\_Model(Input1, Input2):

Input1 (): GPS User Time (Sec)

Input2 (): Ephemeris Matrix with following format

Output1 (N): xyz position in ECEF

Output2 (): Orbit parameter

N: Number of Satellite

Table 12. Function input format for SV\_Ephemeris\_Model

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Function Input Format | | | | |
| Satellite 1 | Satellite 2 | ..... | Satellite n | Units |
| Crs | Crs |  | Crs | meters |
| Δn | Δn |  | Δn | semi-circles/sec |
| M0 | M0 |  | M0 | semi-circles |
| Cuc | Cuc |  | Cuc | radians |
| e | e |  | e | dimensionless |
| Cus | Cus |  | Cus | radians |
|  |  |  |  |  |
| toe | toe |  | toe | seconds |
| Cic | Cic |  | Cic | radians |
| Ω0 | Ω0 |  | Ω0 | semi-circles |
| Cis | Cis |  | Cis | radians |
| Crc | Crc |  | Crc | semi-circles |
| ω | ω |  | ω | meters |
|  |  |  |  | semi-circles/sec |
| IDOT | IDOT |  | IDOT | semi-circles/sec |

Table 13. Function output format for SV\_Ephemeris\_Model

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| |  |  |  |  |  | | --- | --- | --- | --- | --- | | Function Ouput1 Format | | | |  | | Satellite 1 | Satellite 2 | ..... | Satellite n | Unit | | Xpos | Xpos |  | Xpos | meters | | Ypos | Ypos |  | Ypos | meters | | Zpos | Zpos |  | Zpos | meters | | |  |  |  |  |  | | --- | --- | --- | --- | --- | | Function Oupu2 Format | | | |  | | Satellite 1 | Satellite 2 | ..... | Satellite n | Units | | M | M |  | M | radians | | E | E |  | E | radians | |  |  |  |  | radians | |  |  |  |  | radians | |  |  |  |  | radians | |  |  |  |  | meters | |  |  |  |  | radians | |  |  |  |  | radians | | A | A |  | A | meters | |  |  |  |  | - | |

### Mfile Simulation- SV\_Ephemeris\_Model

One case study has been investigated; the following ephemeris data from six satellites has been used as input for the function SV\_Ephemeris\_Model.

Table 14. Function input1 format for SV\_Ephemeris\_Model

|  |
| --- |
| GPS Receiver Time |
| 247080 |

Table 15. Function input2 format for SV\_Ephemeris\_Model

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| |  |  |  |  |  |  |  |  | | --- | --- | --- | --- | --- | --- | --- | --- | |  |  | | Function Input2 Format | | | | | | Satellite 1 | Satellite 2 | Satellite 3 | | Satellite4 | Satellite 5 | Satellite 6 | Units | | -5.9875e+001 | 6.5281e+001 | -8.5656e+001 | | 4.6969e+001 | 6.2500e-002 | 5.4563e+001 | meters | | 1.5294e-009 | 1.6692e-009 | 1.4644e-009 | | 1.4919e-009 | 1.1192e-009 | 1.6494e-009 | semi-circles/sec | | -4.8401e-001 | -8.7179e-001 | -8.8417e-001 | | -8.8899e-001 | -9.7589e-001 | 1.1990e-001 | semi-circles | | -2.9840e-006 | 3.3509e-006 | -4.5337e-006 | | 2.4196e-006 | 1.3784e-007 | 2.8610e-006 | radians | | 3.7472e-003 | 1.1916e-003 | 6.8008e-003 | | 6.7628e-003 | 7.8766e-003 | 5.0219e-003 | dimensionless | | 7.8715e-006 | 3.3546e-006 | 6.5677e-006 | | 1.1941e-005 | 1.1863e-005 | 3.4180e-006 | radians | | 5.1536e+003 | 5.1535e+003 | 5.1537e+003 | | 5.1537e+003 | 5.1538e+003 | 5.1537e+003 |  | | 2.5198e+005 | 2.5200e+005 | 2.5200e+005 | | 2.5200e+005 | 2.5200e+005 | 2.5200e+005 | seconds | | -2.2352e-008 | -5.0291e-008 | -4.4703e-008 | | -1.2852e-007 | 7.2643e-008 | -1.6764e-008 | radians | | 6.4108e-001 | -7.0909e-001 | -3.5952e-001 | | 9.6454e-001 | -2.7200e-002 | -7.0123e-001 | semi-circles | | 1.3039e-007 | 4.0978e-008 | -1.2480e-007 | | -9.1270e-008 | -6.8918e-008 | 6.8918e-008 | radians | | 3.0394e-001 | 3.0031e-001 | 3.0513e-001 | | 3.0066e-001 | 3.1381e-001 | 3.0266e-001 | semi-circles | | 2.2494e+002 | 3.0363e+002 | 2.5019e+002 | | 1.4213e+002 | 1.6128e+002 | 3.0716e+002 | Meters | | -5.1669e-001 | -2.8071e-001 | -8.2533e-001 | | 8.2234e-002 | -6.0022e-001 | 5.1312e-001 | semi-circles/sec | | -2.5994e-009 | -2.7268e-009 | -2.5919e-009 | | -2.5278e-009 | -2.3444e-009 | -2.7663e-009 | semi-circles/sec | |

The outputs of the SV\_Ephemeris\_Model due to case study data are:

Table 16. Function Output1 format for SV\_Ephemeris\_Model

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Function Ouput1 Format | | | | | | |
| Satellite 1 | Satellite 2 | Satellite 3 | Satellite4 | Satellite 5 | Satellite 6 | Unit |
| 1.6127e+007 | 1.2604e+007 | 2.5942e+007 | 2.1059e+007 | 1.0073e+007 | 1.5934e+007 | meters |
| -1.5548e+007 | 1.2117e+007 | -4.7596e+006 | 1.6302e+007 | 2.1064e+007 | -4.8197e+006 | meters |
| 1.4384e+007 | 2.0032e+007 | 4.3389e+006 | 2.2840e+006 | 1.3011e+007 | 2.0534e+007 | meters |

Table 17. Function output2 format for SV\_Ephemeris\_Model

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Function Oupu2 Format | | | | | | |
| Satellite 1 | Satellite 2 | Satellite 3 | Satellite4 | Satellite 5 | Satellite 6 | Units |
| -7.1171e-001 | -1.1002e+000 | -1.1126e+000 | -1.1174e+000 | -1.2043e+000 | -1.0852e-001 | radians |
| -2.2388e+000 | -3.4561e+000 | -3.4930e+000 | -3.5080e+000 | -3.7788e+000 | -3.4263e-001 | radians |
| 4.0414e+000 | 2.8274e+000 | 2.7925e+000 | 2.7776e+000 | 2.5091e+000 | 5.9389e+000 | radians |
| 2.4182e+000 | 1.9456e+000 | 1.9967e-001 | 3.0359e+000 | 6.2344e-001 | 7.5509e+000 | radians |
| 2.4182e+000 | 1.9456e+000 | 1.9967e-001 | 3.0359e+000 | 6.2345e-001 | 7.5509e+000 | radians |
| 2.6621e+007 | 2.6589e+007 | 2.6730e+007 | 2.6729e+007 | 2.6729e+007 | 2.6435e+007 | meters |
| 9.5484e-001 | 9.4345e-001 | 9.5860e-001 | 9.4454e-001 | 9.8588e-001 | 9.5084e-001 | radians |
| -1.6003e+001 | -2.0245e+001 | -1.9147e+001 | -1.4987e+001 | -1.8103e+001 | -2.0220e+001 | radians |
| 2.6559e+007 | 2.6559e+007 | 2.6560e+007 | 2.6561e+007 | 2.6561e+007 | 2.6560e+007 | meters |
| 3.7472e-003 | 1.1916e-003 | 6.8008e-003 | 6.7628e-003 | 7.8766e-003 | 5.0219e-003 | - |

## Ionospheric Error

The ionosphere error of GPS is calculating base on Kbobuchar model, so the Matlab function named Error\_Ionospheric\_Klobuchar and computes time error due to delay in Ionospere. The following tables show the function inputs and outputs. The source of function is printed in Appendix.

Function [Output]=Error\_Ionospheric\_Klobuchar(Inp1,Inp2,Inp3,Inp4,Inp5)

Input1 (3): XYZ position of receiver (Meter)

Input2 (3): XYZ matrix position of GPS satellites (Meter)

Input3 (1): The coefficients of a cubic equation representing the amplitude of the delay (Alpha)

Input4 (1): The coefficients of a cubic equation representing the period of the model (Beta)

Input5 (1): Time of Week (sec)

Output (N: Time Delay of Ionosphere (Second)

Table . Function input format for Error\_Ionospheric\_Klobuchar

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| |  |  | | --- | --- | | Function Input1 Format | | | Receiver Position | Unit | | Xpos | meters | | Ypos | meters | | Zpos | meters | | |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | | |  |  |  |  |  | | --- | --- | --- | --- | --- | | Function Input2 Format | | | |  | | Satellite 1 | Satellite 2 | ..... | Satellite n | Unit | | Xpos | Xpos |  | Xpos | meters | | Ypos | Ypos |  | Ypos | meters | | Zpos | Zpos |  | Zpos | meters | | |

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| |  | | --- | | Function Input3 Format | |  | |  | |  | |  | |  | | |  | | --- | | Function Input4 Format | |  | |  | |  | |  | |  | | |  | | --- | | Function Input5 Format | |  | |

Table . Function Output format for Error\_Ionospheric\_Klobuchar

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Function Output Format | | | |  |
| Satellite 1 | Satellite 2 | ..... | Satellite n | Unit |
| Tion1 | Tion2 |  | Tionn | Sec |

### Mfile Simulation -Error\_Ionospheric\_Klobuchar

One case study has been investigated; the following data from six satellites and GPS receiver have been used as input for the function Error\_Ionospheric\_Klobuchar.

Table . Function input format for Error\_Ionospheric\_Klobuchar

|  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| |  |  | | --- | --- | | Function Input1 Format | | | Receiver Position | Unit | | 3.8942e+006 | meters | | 3.1896e+005 | meters | | 5.0243e+006 | meters |  |  | | --- | |  | |
| |  |  |  |  |  |  |  | | --- | --- | --- | --- | --- | --- | --- | | Function Input2 Format | | | | | | | | Satellite 1 | Satellite 2 | Satellite 3 | Satellite4 | Satellite 5 | Satellite 6 | Unit | | 1.6127e+007 | 1.2604e+007 | 2.5942e+007 | 2.1059e+007 | 1.0073e+007 | 1.5934e+007 | meters | | -1.5548e+007 | 1.2117e+007 | -4.7596e+006 | 1.6302e+007 | 2.1064e+007 | -4.8197e+006 | meters | | 1.4384e+007 | 2.0032e+007 | 4.3389e+006 | 2.2840e+006 | 1.3011e+007 | 2.0534e+007 | meters | |

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| |  | | --- | | Function Input3 Format | |  | | 1.2107e-008 | | -7.4506e-009 | | -1.1921e-007 | | 5.9605e-008 | | |  | | --- | | Function Input4 Format | |  | | 9.6256e+004 | | -3.2768e+004 | | -1.9661e+005 | | 1.9661e+005 | | |  | | --- | | Function Input5 Format | | 247080 | |

The outputs of the Error\_Ionospheric\_Klobuchar due to case study data are:

Table . Function Output format for Error\_Ionospheric\_Klobuchar

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Function Output Format | | | | | | |
| Satellite 1 | Satellite 2 | Satellite 3 | Satellite 4 | Satellite 5 | Satellite 6 | Unit |
| 4.6554e-008 | 4.4740e-008 | 4.6864e-008 | 4.7241e-008 | 4.7072e-008 | 4.2179e-008 | Sec |

## Tropospheric Error

The Troposphere error of GPS is calculating base on Hopfiled model, so the Matlab function named Error\_Tropospheric\_Hopfield and computes distance error due to delay in troposphere. The following tables show the function inputs and outputs. The source of function is printed in Appendix.

Function [Output]=Error\_Tropospheric\_Hopfield(Inp1,Inp2,Inp3,Inp4,Inp5)

Input1 (1): Temprature at reciever antenna location (‘C)

Input2 (1): Pressure at reciever antenna location (‘kPa)

Input3 (1): Vapour Pressure at reciever antenna location (‘kPa)

Input4 (3): XYZ position of receiver (Meter)

Input5 (3): XYZ matrix position of GPS satellites (Meter)

Output (N: Distance error of troposphere (Meter)

Table . Function Input format for Error\_Tropospheric\_Hopfield

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| |  | | --- | | Function Input1 Format | | Tamb | | |  | | --- | | Function Input2 Format | | Pamb | | |  | | --- | | Function Input3 Format | | Pvap | | |  |  | | --- | --- | | Function Input4 Format | | | Receiver Position | Unit | | Xpos | meters | | Ypos | meters | | Zpos | meters | |
| |  |  |  |  |  | | --- | --- | --- | --- | --- | | Function Input5 Format | | | |  | | Satellite 1 | Satellite 2 | ..... | Satellite n | Unit | | Xpos | Xpos |  | Xpos | meters | | Ypos | Ypos |  | Ypos | meters | | Zpos | Zpos |  | Zpos | meters | | | | |

Table . Function Output format for Error\_Tropospheric\_Hopfield

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Function Output Format | | | |  |
| Satellite 1 | Satellite 2 | ..... | Satellite n | Unit |
| dRTro1 | dRTro2 |  | dRTron | Meter |

### Mfile Simulation - Error\_Tropospheric\_Hopfield

One case study has been investigated; the following data from six satellites, GPS receiver and antenna condition have been used as input for the function Error\_Tropospheric\_Hopfield.

Table . Function Input format for Error\_Tropospheric\_Hopfield

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| |  | | --- | | Function Input1 Format | | 15 | | |  | | --- | | Function Input2 Format | | 101.325 | | |  | | --- | | Function Input3 Format | | 0.85 | | |  |  | | --- | --- | | Function Input4 Format | | | Receiver Position | Unit | | 3.8942e+006 | meters | | 3.1896e+005 | meters | | 5.0243e+006 | meters | |
| |  |  |  |  |  |  |  | | --- | --- | --- | --- | --- | --- | --- | | Function Input5 Format | | | | | | | | Satellite 1 | Satellite 2 | Satellite 3 | Satellite4 | Satellite 5 | Satellite 6 | Unit | | 1.6127e+007 | 1.2604e+007 | 2.5942e+007 | 2.1059e+007 | 1.0073e+007 | 1.5934e+007 | meters | | -1.5548e+007 | 1.2117e+007 | -4.7596e+006 | 1.6302e+007 | 2.1064e+007 | -4.8197e+006 | meters | | 1.4384e+007 | 2.0032e+007 | 4.3389e+006 | 2.2840e+006 | 1.3011e+007 | 2.0534e+007 | meters | | | | |

The outputs of the Error Error\_Tropospheric\_Hopfield due to case study data are errors of troposphere:

Table . Function Output format for Error\_Tropospheric\_Hopfield

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
|  |  | Function Output Format | | | |  |
| Satellite 1 | Satellite 2 | Satellite 3 | Satellite 4 | Satellite 5 | Satellite 6 | Unit |
| 3.7468 | 2.8173 | 4.2665 | 6.1694 | 4.9369 | 2.5032 | Meter |

## Satellite Clock Error

The satellite clock error of GPS includes two type of error: Offset error and Relativistic error, so two functions are generated to model these sources of error. The Matlab functions are named Error\_Satellite\_Clock\_Offset and Error\_Satellite\_Clock\_Relavastic.The following tables shows the function inputs and outputs. The source of function is printed in Appendix.

Function [Output]= Error\_Satellite\_Clock\_Offset(Inp1,Inp2,Inp3)

Input1 (3): Matrix of Coefficients for satellite clock offset

Input2 (1): Time of transmission (Sec)

Input3 (1): Satellite Clock reference time (Sec)

Output (1:offset satellite clock error due to PRN (Sec)

Table . Function Input format for Error\_Satellite\_Clock\_Offset

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| |  |  |  |  | | --- | --- | --- | --- | | Function Input1 Format | | | | | Satellite 1 | Satellite 2 | ..... | Satellite n | | Af0 | Af0 |  | Af0 | | Af1 | Af1 |  | Af1 | | Af2 | Af2 |  | Af2 | | |  |  |  |  |  | | --- | --- | --- | --- | --- | | Function Input2 Format | | | |  | | Satellite 1 | Satellite 2 | ..... | Satellite n | Unit | | Ttr | Ttr |  | Ttr | Sec | |
| |  |  |  |  |  | | --- | --- | --- | --- | --- | | Function Input3 Format | | | |  | | Satellite 1 | Satellite 2 | ..... | Satellite n | Unit | | Toc | Toc |  | Toc | Sec | |  |

Table . Function Output format for Error\_Satellite\_Clock\_Offset

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Function Output Format | | | |  |
| Satellite 1 | Satellite 2 | ..... | Satellite n | Unit |
| dTclc | dTclc |  | dTclc | Sec |

Function [Output]=Error\_Satellite\_Clock\_Relavastic(Inp1,Inp2,Inp3,Inp4,Inp5)

Input1 (1): Rel correction constant equals to -4.4428076633E-10

Input2 (1): Ecentricity

Input3 (1): Orbit Semi major axis(Meter)

Input4 (1): Orbit Eccentric Anomaly

Input5 (1): Group Delay (Sec.)

Output (1: Relativistic satellite clock error (Sec)

Table . Function Input format for Error\_Satellite\_Clock\_Relavastic

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| |  |  |  |  | | --- | --- | --- | --- | | Function Input2 Format | | | | | Satellite 1 | Satellite 2 | ..... | Satellite n | | Ec1 | Ec2 |  | Ecn | | |  |  |  |  |  | | --- | --- | --- | --- | --- | | Function Input3 Format | | | |  | | Satellite 1 | Satellite 2 | ..... | Satellite n | Unit | | A1 | A2 |  | An | meter | |
| |  |  |  |  |  | | --- | --- | --- | --- | --- | | Function Input4 Format | | | |  | | Satellite 1 | Satellite 2 | ..... | Satellite n | Unit | | Ek1 | Ek2 |  | Ekn | Rad | | |  |  |  |  |  | | --- | --- | --- | --- | --- | | Function Input5 Format | | | |  | | Satellite 1 | Satellite 2 | ..... | Satellite n | Unit | | Tgd1 | Tgd2 |  | Tgdn | Rad | |

Table . Function Output format for Error Error\_Satellite\_Clock\_Relavastic

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Function Output Format | | | |  |
| Satellite 1 | Satellite 2 | ..... | Satellite n | Unit |
| dTrel1 | dTrel2 |  | dTreln | Sec |

### Mfile Simulation - Error\_Satellite\_Clock\_Offset & Error\_Satellite\_Clock\_Relavastic

Table . Function Input format for Error\_Satellite\_Clock\_Offset

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| |  |  |  |  |  |  | | --- | --- | --- | --- | --- | --- | | Function Input1 Format | | | | | | | Satellite 1 | Satellite 2 | Satellite 3 | Satellite 4 | Satellite5 | Satellite 6 | | | 3.1536e-005 | 1.2004e-004 | -2.7334e-007 | -1.6370e-005 | 7.8391e-004 | -6.8936e-006 | | | 7.9581e-013 | 1.7053e-012 | 0 | -1.4779e-012 | 3.1832e-012 | -2.2737e-012 | | | 0 | 0 | 0 | 0 | 0 | 0 | | |
| |  |  |  |  |  |  |  | | --- | --- | --- | --- | --- | --- | --- | | Function Input2 Format | | | | | | | | Satellite 1 | Satellite 2 | Satellite 3 | Satellite 4 | Satellite 5 | Satellite 6 | Unit | | 251984 | 252000 | 252000 | 252000 | 252000 | 252000 | Sec | |

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Function Input3 Format | | | | | | |
| Satellite 1 | Satellite 2 | Satellite 3 | Satellite 4 | Satellite 5 | Satellite 6 | Unit |
| 2.4708e+005 | 2.4708e+005 | 2.4708e+005 | 2.4708e+005 | 2.4708e+005 | 2.4708e+005 | Sec |

Table . Function Output format for Error\_Satellite\_Clock\_Offset

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Function Output Format | | | | | | |
| Satellite 1 | Satellite 2 | Satellite 3 | Satellite 4 | Satellite 5 | Satellite 6 | Unit |
| 3.1532e-005 | 1.2003e-004 | -2.7334e-007 | -1.6363e-005 | 7.8390e-004 | -6.8825e-006 | Sec |

Table . Function Input format for Error\_Satellite\_Clock\_Relavastic

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| |  |  |  |  |  |  | | --- | --- | --- | --- | --- | --- | |  |  | Function Input2 Format | | | | | Satellite 1 | Satellite 2 | Satellite 3 | Satellite 4 | Satellite 5 | Satellite 6 | | 3.7472e-003 | 1.1916e-003 | 6.8008e-003 | 6.7628e-003 | 7.8766e-003 | 5.0219e-003 |  |  |  |  |  |  |  |  | | --- | --- | --- | --- | --- | --- | --- | |  |  | Function Input3 Format | | | |  | | Satellite 1 | Satellite 2 | Satellite 3 | Satellite 4 | Satellite 5 | Satellite 6 | Unit | | 2.6559e+007 | 2.6559e+007 | 2.6560e+007 | 2.6561e+007 | 2.6561e+007 | 2.6560e+007 | meter |  |  |  |  |  |  |  |  | | --- | --- | --- | --- | --- | --- | --- | |  |  | Function Input4 Format | | | |  | | Satellite 1 | Satellite 2 | Satellite 3 | Satellite 4 | Satellite 5 | Satellite 6 | Unit | | -2.2388 | -3.4561 | -3.493 | -3.508 | -3.7788 | -3.4263e-001 | Rad |  |  |  |  |  |  |  |  | | --- | --- | --- | --- | --- | --- | --- | |  |  | Function Input5 Format | | | |  | | Satellite 1 | Satellite 2 | Satellite 3 | Satellite 4 | Satellite 5 | Satellite 6 | Unit | | 4.6566e-010 | 2.3283e-009 | 1.8626e-009 | 5.1223e-009 | -9.3132e-010 | 3.2596e-009 | sec | |

Table . Function Output format for Error Error\_Satellite\_Clock\_Relavastic

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
|  |  | Function Input5 Format | | | |  |
| Satellite 1 | Satellite 2 | Satellite 3 | Satellite 4 | Satellite 5 | Satellite 6 | Unit |
| 6.2697e-009 | -3.1723e-009 | -7.2228e-009 | -1.0670e-008 | -9.7982e-009 | 6.0348e-010 | Sec |

## Result Plot

The Matlab function plot\_Orbit is generetaed shoe the position of GPS satellites and their orbits. The following tables show the function inputs and outputs. The source of function is printed in Appendix.

Function plot\_Orbit(Input1,Input2)

Input1:

%A:(m) =>semi-major orbit axis

%ec: =>eccentricity

%Inc:(Rad) =>Inclination angle

%Omega:(Rad) =>Longitude of Ascending Node

%v:(Rad) =>True Anomaly

Input2:

%Color:(string) =>The color of orbit in plot resualt



# Reference

[1] Bradford W. Parkinson, James J. Spilker, “Global Positioning System: Theory and Applications”, AIAA series, Vol.164

[2] Eingereicht von, “On Ground-Based GPS Tropospheric Delay Estimation”, Dissertation wurde der Universität der Bundeswehr München, 2001

# Appendix

Matlab Mfiles

## Main Mfile

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

%Main Part of The Program, Which asemble diffrent Matlab Function

clc

format long e

clear

close all

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

%Initial Constant

C=299792458;

F=-4.442807633\*10^(-10);

T\_amb=20;

P\_amb=101;

P\_vap=.86;

color=['r','b','c','g','k','m'];

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

%Load Data and Difinition

load project\_data.mat

GPS\_Time=iono(1);Alpha=iono(2:5);

Beta=iono(6:9);

af=[eph(21,:);eph(20,:);eph(19,:)]';

Toc=[eph(18,:)];

Ttr=GPS\_Time-pr./C;

ec=[eph(5,:)];

A=[eph(7,:)].^2;

Tgd=[eph(17,:)];

Rho\_0=pr;

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

%Compute satellite position and corrected orbit value

[Pos\_xyz\_Mat,Orbit\_parameter]=SV\_Ephemeris\_Model(iono(1,1),eph);

Pos\_SV=Pos\_xyz\_Mat;

E=Orbit\_parameter(2,:);

A=Orbit\_parameter(9,:);

Ec=Orbit\_parameter(10,:);

Inc=Orbit\_parameter(7,:);

Omega=Orbit\_parameter(8,:);

v=Orbit\_parameter(3,:);

Dim=size(Pos\_SV);

n=Dim(1);

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

%%%%%%%%%%%%%%%%%%%%%%%Plot The Geometry%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

plot\_Orbit(Orbit\_parameter,color)

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

%Initial GPS Position

Xu=0;Yu=0;Zu=0;Pos\_Rcv=[Xu Yu Zu];

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

%Start Iteration

%Initialization Parameter

Iter=1;

Pos\_Rcv\_N{Iter}=[Pos\_Rcv];

%Constrain for convergence

B1=1;

END\_LOOP=100;

while (END\_LOOP > B1)

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

## Error\_Satellite\_Clock\_Offset

%This Function calculate Satellite Offest Clock Error Base on GPS Theory \*

%and application . edited by B. Parkinson,J. Spilker, P.Enge, AIAA,1996 \*

%CopyRight By Moein Mehrtash

%\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*

% Written by Moein Mehrtash, Concordia University, 3/23/2008 \*

% Email: moeinmehrtash@yahoo.com \*

%\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*

% Reference:"GPS Theory and application",edited by B.Parkinson,J.Spilker, \*

%\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*

%Ofset Model: \*

%dTclk\_Ofset=af0+af1\*(T-Toc)+af2\*(T-Toc)^2+..... \*

%af :(1/Sec^i) =>Matrix of Coeeficient for satellite offset \*

%Ttr:(Sec) => Time of transmission \*

%Toc:(Sec) => Sv Clock refernce time \*

%dTclk\_Ofset:(Sec)=> Sv Clock offset time \*

%\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*

function dTclk\_Offset=Error\_Satellite\_Clock\_Offset(af,Ttr,Toc);

Dim1=size(af);

Order\_Coef=Dim1(2);

No\_SV=length(Toc);

for j=1:No\_SV

dTclk\_Ofset=0;

T(j)=Ttr(j)-Toc(j);

if T(j)>302400

T(j)=T(j)-604800;

else if T(j)<-302400

T(j)=T(j)+604800;

end

end

for i=1:Order\_Coef

dTclk\_Ofset=dTclk\_Ofset+af(j,i)\*T(j)^(i-1);

end

dTclk\_Offset(j)=dTclk\_Ofset;

end

## Error\_Satellite\_Clock\_Relavastic

%This Function calculate Satellite Clock Error Base on

%application . edited by B. Parkinson,J. Spilker, P.Enge, AIAA,1996

%CopyRight By Moein Mehrtash

%\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*

% Written by Moein Mehrtash, Concordia University, 3/23/2008 \*

% Email: moeinmehrtash@yahoo.com \*

%\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*

% Reference:"GPS Theory and application",edited by B.Parkinson,J.Spilker, \*

%\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*

%Relativistic Error

%dTclk\_Rel=F\*ec\*sqrt(A)\*sin(E)-Tgd (Sec)

%F : =>Rel correction constant

%ec:(Meter) =>Ecentricity

%A:(Meter) =>Orbit Semi major axis

%E:(Rad) =>Orbit Eccentric Anomaly

%Tgd:(Sec) =>Group Delay

%\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*

function dTclk\_Rel=Error\_Satellite\_Clock\_Relavastic(F,ec,A,E,Tgd);

No\_SV=length(A);

for i=1:No\_SV

dTclk\_Rel(i)=F\*ec(i)\*sqrt(A(i))\*sin(E(i))-Tgd(i);

end

## Error\_Ionospheric\_Klobuchar

%This Function approximate Ionospheric Group Delay

%CopyRight By Moein Mehrtash

%\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*

% Written by Moein Mehrtash, Concordia University, 3/21/2008 \*

% Email: moeinmehrtash@yahoo.com \*

%\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*

% \*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*

% Function for computing an Ionospheric range correction for the \*

% GPS L1 frequency from the parameters broadcasted in the GPS \*

% Navigation Message. \*

% ==================================================================

% References: \*

% Klobuchar, J.A., (1996) "Ionosphercic Effects on GPS", in \*

% Parkinson, Spilker (ed), "Global Positioning System Theory and \*

% Applications, pp.513-514. \*

% ICD-GPS-200, Rev. C, (1997), pp. 125-128 \*

% NATO, (1991), "Technical Characteristics of the NAVSTAR GPS", \*

% pp. A-6-31 - A-6-33 \*

% ==================================================================

% Input : \*

% Pos\_Rcv : XYZ position of reciever (Meter) \*

% Pos\_SV : XYZ matrix position of GPS satellites (Meter) \*

% GPS\_Time : Time of Week (sec) \*

% Alfa(4) : The coefficients of a cubic equation \*

% representing the amplitude of the vertical \*

% dalay (4 coefficients - 8 bits each) \*

% Beta(4) : The coefficients of a cubic equation \*

% representing the period of the model \*

% (4 coefficients - 8 bits each) \*

% Output: \*

% Delta\_I : Ionospheric slant range correction for \*

% the L1 frequency (Sec) \*

% ==================================================================

function [Delta\_I]=Error\_Ionospheric\_Klobuchar(Pos\_Rcv,Pos\_SV,Alpha,Beta,GPS\_Time)

GPS\_Rcv = ECEF2GPS(Pos\_Rcv);

Lat=GPS\_Rcv(1)/pi;Lon=GPS\_Rcv(2)/pi; % semicircles unit Lattitdue and Longitude

S=size(Pos\_SV);

m=S(1);n=S(2);

for i=1:m

[El,A0]=Calc\_Azimuth\_Elevation(Pos\_Rcv,Pos\_SV(i,:));

E(i)=El/pi; %SemiCircle Elevation

A(i)=A0; %SemiCircle Azimoth

% Calculate the Earth-Centered angle, Psi

Psi(i)=0.0137/(E(i)+.11)-0.022; %SemiCircle

%Compute the Subionospheric lattitude, Phi\_L

Phi\_L(i)=Lat+Psi(i)\*cos(A(i)); %SemiCircle

if Phi\_L(i)>0.416

Phi\_L(i)=0.416;

elseif Phi\_L(i)<-0.416

Phi\_L(i)=-0.416;

end

%Compute the subionospheric longitude, Lambda\_L

Lambda\_L(i)=Lon+(Psi(i)\*sin(A(i))/cos(Phi\_L(i)\*pi)); %SemiCircle

%Find the geomagnetic lattitude ,Phi\_m, of the subionospheric location

%looking toward each GPS satellite:

Phi\_m(i)=Phi\_L(i)+0.064\*cos((Lambda\_L(i)-1.617)\*pi);

%Find the Local Time ,t, at the subionospheric point

t(i)=4.23\*10^4\*Lambda\_L(i)+GPS\_Time; %GPS\_Time(Sec)

if t(i)>86400

t(i)=t(i)-86400;

elseif t(i)<0

t(i)=t(i)+86400;

end

%Convert Slant time delay, Compute the Slant Factor,F

F(i)=1+16\*(.53-E(i)^3);

%Compute the ionospheric time delay T\_iono by first computing x

Per(i)=Beta(1)+Beta(2)\*Phi\_m(i)+Beta(3)\*Phi\_m(i)^2+Beta(4)\*Phi\_m(i)^3;

if Per(i) <72000 %Period

Per(i)=72000;

end

x(i)=2\*pi\*(t(i)-50400)/Per(i); %Rad

AMP(i)=Alpha(1)+Alpha(2)\*Phi\_m(i)+Alpha(3)\*Phi\_m(i)^2+Alpha(4)\*Phi\_m(i)^3;

if AMP(i)<0

AMP(i)=0

end

if abs(x(i))>1.57

T\_iono(i)=F(i)\*5\*10^(-9);

else

T\_iono(i)=F(i)\*(5\*10^(-9)+AMP(i)\*(1-x(i)^2/2+x(i)^4/4));

end

end%for

Delta\_I=T\_iono;

## Error\_Tropospheric\_Hopfield

%This Function approximate Troposspheric Group Delay Base on

%application . edited by B. Parkinson,J. Spilker, P.Enge, AIAA,1996

%CopyRight By Moein Mehrtash

%\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*

% Written by Moein Mehrtash, Concordia University, 3/21/2008 \*

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%\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*

% Reference:"GPS Theory and application",edited by B.Parkinson,J.Spilker, \*

%\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*

%Input

% T\_amb:'C =>At reciever antenna location

% P\_amb:hPa =>At reciever antenna location

% P\_vap:hPa =>Water vapore pressure at reciever antenna location

% Pos\_Rcv : XYZ position of reciever (Meter)

% Pos\_SV : XYZ matrix position of GPS satellites (Meter)

%Output:

% Delta\_R\_Trop: m =>Tropospheric Error Correction

%\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*

function Delta\_R\_Trop=Error\_Tropospheric\_Hopfield(T\_amb,P\_amb,P\_vap,Pos\_Rcv,Pos\_SV)

S=size(Pos\_SV);

m=S(1);n=S(2);

for i=1:m

[E,A0]=Calc\_Azimuth\_Elevation(Pos\_Rcv,Pos\_SV(i,:));

El(i)=E; %Elevation Rad

A(i)=A0; %Azimoth Rad

end

%Zenith Hydrostatic Delay

Kd=1.55208\*10^(-4)\*P\_amb\*(40136+148.72\*T\_amb)/(T\_amb+273.16);

%Zenith Wet Delay

Kw=-.282\*P\_vap/(T\_amb+273.16)+8307.2\*P\_vap/(T\_amb+273.16)^2;

for i=1:m

Denom1(i)=sin(sqrt(El(i)^2+1.904\*10^-3));

Denom2(i)=sin(sqrt(El(i)^2+.6854\*10^-3));

%Troposhpheric Delay Correctoion

Delta\_R\_Trop(i)=Kd/Denom1(i)+Kw/Denom2(i); % Meter

end

## Gen\_G\_DX\_XYZ\_B

%This Function use Ephemeris Data and Calculate satellite Position

%CopyRight By Moein Mehrtash

%\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*

% Written by Moein Mehrtash, Concordia University, 3/28/2008 \*

% Email: moeinmehrtash@yahoo.com \*

%\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*

%\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*

% Satellite Position By Ephemeris Model

%Function's Inputs:

%Pos\_SV(m):Satellite Position Matrix

%Pos\_Rcv(m):GPS reciever Position

%Rho(m):Pseudo Range

%Function's Outputs:

%G:

%Delta\_X:

%Pos\_RCV\_N:

%B:

%\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*

%\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*

function [G,Delta\_X,Pos\_Rcv\_n,B]=Gen\_G\_DX\_XYZ\_B(Pos\_SV,Pos\_Rcv,Rho);

[m,n]=size(Pos\_SV);

d=Distance(Pos\_SV,Pos\_Rcv);

for i=1:m

dif=Pos\_SV(i,:)-Pos\_Rcv;

unit=dif./d(i);

for j=1:n

Unit\_Mtrix(i,j)=unit(j);

end

end

G=[-Unit\_Mtrix ones(m,1)];

Delta\_Rho=(Rho-d');

Delta\_X=inv(G'\*G)\*G'\*Delta\_Rho;

Pos\_Rcv\_n=(Pos\_Rcv'+Delta\_X(1:3))';

B=Delta\_X(4);

## plot\_Orbit

%This Function show the satellite and its orbit+Earth geometry

%CopyRight By Moein Mehrtash

%\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*

% Written by Moein Mehrtash, Concordia University, 3/28/2008 \*

% Email: moeinmehrtash@yahoo.com \*

%\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*

%\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*

%Plot Orbit+Erath

%Function's Inputs:

%A:(m) =>semi-major orbit axis

%ec: =>eccentricity

%Inc:(Rad) =>Inclination angle

%Omega:(Rad) =>Longitude of Ascending Node

%v:(Rad) =>True Anomaly

%Color:(string) =>The color of orbit

%Name:(string) =>Name of satellite

%Function's Output:

%Plot Orbit $ Satellite

%Plot Earth

%\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*

function plot\_Orbit(Orbit\_parameter,color)

[m,n]=size(Orbit\_parameter);

E=Orbit\_parameter(2,:);

A=Orbit\_parameter(9,:);

ec=Orbit\_parameter(10,:);

Inc=Orbit\_parameter(7,:);

Omega=Orbit\_parameter(8,:);

v=Orbit\_parameter(3,:);

for i=1:n

ii=num2str(i);

Name\_SV=strcat('SV-',ii);

Nu=0:2\*pi/100:2\*pi;

r=A(i)\*(1-ec(i)^2)./(1+ec(i).\*cos(Nu));

x = r.\*cos(Nu);

y = r.\*sin(Nu);

xs=x.\*cos(Omega(i))-y.\*cos(Inc(i)).\*sin(Omega(i));

ys=x.\*sin(Omega(i))+y.\*cos(Inc(i)).\*cos(Omega(i));

zs=y.\*sin(Inc(i));

plot3(xs,ys,zs,color(i),'Linestyle','-')

hold on

xlabel('Xaxis')

ylabel('Yaxis')

zlabel('Zaxis')

r0=A(i)\*(1-ec(i)^2)/(1+ec(i)\*cos(v(i)));

x0 = r0\*cos(v(i));

y0 = r0\*sin(v(i));

xp=x0\*cos(Omega(i))-y0\*cos(Inc(i))\*sin(Omega(i));

yp=x0\*sin(Omega(i))+y0\*cos(Inc(i))\*cos(Omega(i));

zp=y0\*sin(Inc(i));

plot3(xp,yp,zp,'blacko','Linewidth',2); % plot true anomaly

text(xp+.1\*xp,yp+.1\*yp,zp+.1\*zp,Name\_SV);

axis\_data = get(gca);

xmin = axis\_data.XLim(1);

xmax = axis\_data.XLim(2);

ymin = axis\_data.YLim(1);

ymax = axis\_data.YLim(2);

zmin = axis\_data.ZLim(1);

zmax = axis\_data.ZLim(2);

% I, J ,K vectors

R=6399592;

plot3([0,2\*R],[0 0],[0 0],'black','Linewidth',2); plot3(2\*R,0,0,'black>','Linewidth',2.5);

plot3([0 0],[0,2\*R],[0 0],'black','Linewidth',2); plot3(0,2\*R,0,'black>','Linewidth',2.5);

plot3([0 0],[0 0],[0,2\*R],'black','Linewidth',2); plot3(0,0,2\*R,'black^','Linewidth',2.5);

% right ascending node line plot

xomega\_max = xmax\*cos(Omega(i)\*pi/180);

xomega\_min = xmin\*cos(Omega(i)\*pi/180);

yomega\_max = ymax\*sin(Omega(i)\*pi/180);

yomega\_min = ymin\*sin(Omega(i)\*pi/180);

xlabel('I');

ylabel('J');

zlabel('K');

R=6399592;

[x,y,z] = ellipsoid(0,0,0,R,R,R,20);

surfl(x, y, z)

shading faceted %interp

colormap(gray);

hold on

az = 120;

el = 30;

view(az, el);

end

## Main

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

%Main Part of The Program, Which asemble diffrent Matlab Function

clc

format long e

clear

close all

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

%Initial Constant

C=299792458;

F=-4.442807633\*10^(-10);

T\_amb=20;

P\_amb=101;

P\_vap=.86;

color=['r','b','c','g','k','m'];

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

%Load Data and Difinition

load project\_data.mat

GPS\_Time=iono(1);Alpha=iono(2:5);

Beta=iono(6:9);

af=[eph(21,:);eph(20,:);eph(19,:)]';

Toc=[eph(18,:)];

Ttr=GPS\_Time-pr./C;

ec=[eph(5,:)];

A=[eph(7,:)].^2;

Tgd=[eph(17,:)];

Rho\_0=pr;

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

%Compute satellite position and corrected orbit value

[Pos\_xyz\_Mat,Orbit\_parameter]=SV\_Ephemeris\_Model(iono(1,1),eph);

Pos\_SV=Pos\_xyz\_Mat;

E=Orbit\_parameter(2,:);

A=Orbit\_parameter(9,:);

Ec=Orbit\_parameter(10,:);

Inc=Orbit\_parameter(7,:);

Omega=Orbit\_parameter(8,:);

v=Orbit\_parameter(3,:);

Dim=size(Pos\_SV);

n=Dim(1);

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

%%%%%%%%%%%%%%%%%%%%%%%Plot The Geometry%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

plot\_Orbit(Orbit\_parameter,color)

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

%Initial GPS Position

Xu=0;Yu=0;Zu=0;Pos\_Rcv=[Xu Yu Zu];

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

%Start Iteration

%Initialization Parameter

Iter=1;

Pos\_Rcv\_N{Iter}=[Pos\_Rcv];

%Constrain for convergence

B1=1;

END\_LOOP=100;

while (END\_LOOP > B1)

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

%%%%%%%%%%%%%%%%%Compute Satellite Pseudo Range%%%%%%%%%%%%%%%%%%%%%%%%%%%%

%Rho=Rho\_0+Delta\_I+Delta\_T+Delta\_Rel+Delta\_Off

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

%A.Compute Satellite Offset Clock Error

dTclk\_Offset=Error\_Satellite\_Clock\_Offset(af,Ttr,Toc); %(Sec)

dR\_Error\_Satellite\_Clock\_Offset=C\*dTclk\_Offset; %(Meter)

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

%B.Compute Satellite Relavistic Clock Error

dTclk\_Rel=Error\_Satellite\_Clock\_Relavastic(F,ec,A,E,Tgd); %(Sec)

dR\_Error\_Satellite\_Clock\_Rel=C\*dTclk\_Rel; %(Meter)

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

%C.Compute IonoSphere Error

dT\_Ion=Error\_Ionospheric\_Klobuchar(Pos\_Rcv\_N{Iter},Pos\_SV,Alpha,Beta,GPS\_Time);%(Sec)

dR\_Error\_Ionsphere=C\*dT\_Ion; %(Meter)

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

%D.Compute Tropospheric Error

Delta\_R\_Trop=Error\_Tropospheric\_Hopfield(T\_amb,P\_amb,P\_vap,Pos\_Rcv\_N{Iter},Pos\_SV);

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

%Compute Pseudo Range

Rho=Rho\_0'+dR\_Error\_Satellite\_Clock\_Offset'+dR\_Error\_Satellite\_Clock\_Rel';

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

%Compute Covariance Matrix,deltax

[G0,Delta\_X0,Pos\_Rcv\_N0,B0]=Gen\_G\_DX\_XYZ\_B(Pos\_SV,Pos\_Rcv\_N{Iter},Rho);

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

Iter=Iter+1

G{Iter}=G0;

Delta\_X{Iter}=Delta\_X0;

B(Iter)=B0;

Pos\_Rcv\_N{Iter}=Pos\_Rcv\_N0;

END\_LOOP=norm(Delta\_X0(1:3));

end %End of While

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%