International Journal of Scientific Research in Civil Engineering
 | Volume 3 | Issue 4 | ISSN : 2456-6667

Satellite Coordinates from Ephemeris Data

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ABSTRACT

This research aims to illustrate the process of reading the orbital parameters and computing the satellite coordinates from navigation messages. The data gathered using smartphone Huawei p 10. A MATLAB software package for GPS ephemeris data processing and reading is presented in this paper. The ephemeris data processing and its theoretical background are introduced first. Then, the advantages and limitations of using ephemeris data to compute orbital parameters are identified. Finally, the software workflow is briefly explained.

Keywords: MATLAB, GPS, ephemeris data, ECEF, IGS, GNSS Service

I. INTRODUCTION

Since 1993, 24 satellites have been circling around the earth at a height of some 20000 km and, together with ground stations, form the global navigation system GPS, which is not only available to aircraft and ships but is now also used in motor vehicles and by hikers, mountaineers, hunters, etc.

Four satellites each have a common orbit, so there are six orbits in total. The tracks are all inclined at 55 ° to the equator and each offset by 60 ° along the equator to each other.

The arrangement of the lanes is chosen so that the satellites repeat their lanes on the earth's surface approximately every 24 hours (4 minutes earlier per day).[1]

On board, each satellite is three highly precise atomic clocks whose synchronization is constantly monitored by radio. The system's main control station is at Air Force Base (formerly Falcon AFB) in Colorado. The worldwide distributed control stations measure the time signals of the satellites, in the main control station from the exact orbits and the necessary time corrections for each satellite are calculated and uploaded.

All 24 satellites transmit coded radio signals at a frequency of 1.6 GHz (19 cm wavelength) after every one millisecond, which contain the current path parameters and the exact time of the signal transmission in addition to the identifier of the respective satellite.

There are principally two diverse orbital data, to be specific, broadcast ephemerides and IGS final ephemerides utilized in the GPS positioning. The broadcast ephemerides can be used to calculate positions in real time or in post-processing and can acquire through continuous broadcast from the USA GPS reference stations. On the other hand, final ephemeris users can download it from specific websites. In this paper, the process of reading the orbital parameters and computing the satellite coordinates from broadcast ephemerides. [2]

II. BROADCAST EPHEMERIDE

An easy way to comply with the conference paper formatting requirements is to use this document as a template and simply type your text into it.

Broadcast ephemeride include parameters for the GPS orbit. Which include the 6 parameters of Kepler, which characterize an idealized satellite's elliptical track only subject to the force of radially symmetrical geopotential. Two parameters of Kepler, a semimajor axis and e excentricity, describe the orbit's size and shape. The ECEF three parameters (i inclination angle, Ω athe rgument of perigee, ω longitude of the ascending node) describe the orbit orientation. The final Kepler parameter is M mean anomaly which specifies the satellite's position on the ellipse at the particular epoct$_{0e}$.[2, 3]

The other elements are correction terms.
The orbit elements used to compute the following:

1) The position and velocity of the satellite at epoch.
2) Solar radiation pressure coefficients and clock parameters for each satellite.

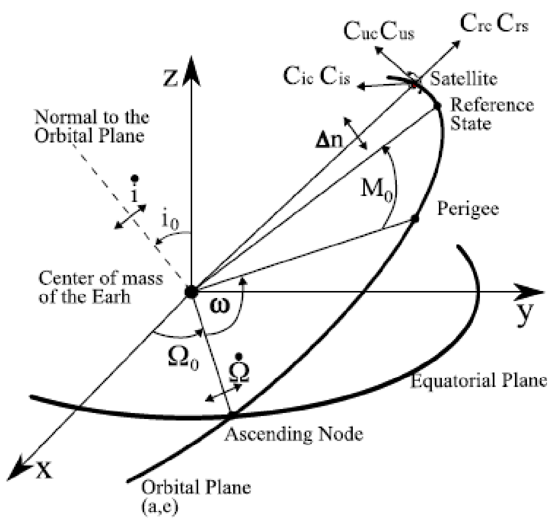

Figure 1. GPS ephemeris orbit elements.[3]

TABLE 1: GPS EPHEMERIS ORBIT ELEMENTS.[1, 4]

Time Parameters	
t_{0e}	Time of ephemerides parameters (reference time)
t_{0c}	clock parameter
a_0, a_1, a_2	SV Clock (offset, drift, drift rat)
$IODC$	Issue of Data, Clock
Keplerian Parameters (6 parameters of Kepler)	
$\sqrt{a}$	The square root of semimajor axis length
e	Eccentricity
i_0	Inclination angle at the reference time
$\Omega 0$	Longitude of the ascending node at the weekly epoch
ω	The argument of perigee at the reference time
$M0$	Mean anomaly at the reference time
$IODE$	Issue of Data, Ephemeris
Perturbation Parameters	
Δn	Mean motion difference from the computed value
$IDOT$	Rate of change for the inclination angle
$\dot{\Omega}$	Rate of change in ascending node right ascension
Cuc	The amplitude of cosine correction term for perigee argument
Cus	The amplitude of sine correction term for perigee argument
Crc	Amplitude of cosine correction term for geocentric distance
Crc	The amplitude of sine correction for geocentric distance
Cic	The amplitude of cosine correction term for the

	inclination angle
Cis	The amplitude of sine correction term for the inclination angle

III. Final ephemeris

Precise ephemerides and parameters of the clock depending on observations at worldwide dispersed monitor stations. Using high precision oscillators, satellite errors can be cleaned of station clock time errors. Currently, IGS (International GNSS Service) is the main source of final ephemerides and other GPS products. IGS is different from broadcast ephemerides, IGS depend on the rigorous global network which used to observe the phase. Figure 2 shows the worldwide distribution of IGS points.

Figure 2. IGS stations [5]

The satellite position is computed by the GPS orbit parameters as a function of time t. The position computed by the ollowing steps.

1) compute the corrected mean anomaly

$$M = M_0 + \left(\left(\frac{GM}{a^3}\right)^{1/2} + \Delta n\right) t$$

(1)

Where

GM = (3.986004418 ± 0.000000008) × 1014 m^3 s^{-2} is the Geocentric gravitational constant.

2) solve Kepler's equation by iteration (Newton-Raphson iteration)

$$E = M + e \sin E$$

(2)

Where the E_0 for the irst iteration $= M$

3) Compute the True anomaly

$$V = arctan2\left((1 - e^2)^{1/2} \sin E , \cos E - e\right)$$

(3)

4) Compute the correction terms

$$\emptyset = V + \omega$$

(4)

Correction of perigee

$$u = \emptyset + Cuc.cos\, 2\emptyset + Cus.sin\, 2\emptyset$$

(5)

Correction of Radial distance

$$r = a(1 - e.\cos E) + Crc.\cos 2\emptyset + Crs.\sin 2\emptyset$$

(6)

Correction of Inclination

$$i = i_0 + IDOT\,.t + Cic.\cos 2\emptyset + Cis.\sin 2\emptyset$$

(7)

Longitude for ascending node

$$\Omega = \Omega_0 + (\dot{\Omega} - rr)t - rr.t_{0e}$$

(8)

Where rr is the angular speed of Earth's rotation in inertial space = $7.2921151467.10^{-5}$

5) Compute the Satellite position in the orbital plane

$$\begin{bmatrix} \acute{X} \\ \acute{Y} \end{bmatrix} = \begin{bmatrix} \cos(u) & r \\ \sin(u) & r \end{bmatrix}$$

(9)

6) Compute the rotation matrix

$$m = \begin{bmatrix} \cos\Omega & -\cos i \sin\Omega \\ \sin\Omega & \cos i \cos\Omega \\ 0 & \sin i \end{bmatrix}$$

(10)

7) Compute the Satellite position in ECEF

$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix} = m \begin{bmatrix} \acute{X} \\ \acute{Y} \end{bmatrix}$$

(11)[6, 7]

IV. Result

A sample from RINX file is illustrated in the following Figure:

```
1 18 10 29 03 00 00.0  .000000000000D+00  .000000000000D+00  .000000000000D+00
     .250000000000D+02  .500000000000D+00 -.957182727646D-10  .161135933225D+01
    -.372529029846D-08  .899999996182D-02 -.372529029846D-08  .509901951408D+04
     .108000000000D+05  .186264514923D-08 -.903366543128D-04 -.186264514923D-08
     .959931088434D+00 -.500000000000D+00  .000000000000D+00 -.844285167866D-08
     .000000000000D+00  .200000000000D+01  .139900000000D+04  .000000000000D+00
     .000000000000D+00  .000000000000D+00  .000000000000D+00  .537000000000D+03
     .621600000000D+04  .000000000000D+00
```

Figure 3. RINEX data block for SV 1

The above data used to calculate the satellite position

```
GM = 3.986008e14; %% Earth
gravitational constant
rr = 7.2921151467e-5; %% Earth
rotation rate in rad/s
s_L=299792458;%% speed of light
clockbias=.000000000000D+00 ;
clockdrift=.000000000000D+00;
clockdriftrate=.000000000000D+00;
IODE=.250000000000D+02; %% IODE rate
of change of inclination with time
Crs=.500000000000D+00;%% amplitude of
harmonic correction terms for the
computed orbit radius
Del_n=-.957182727646D-
10 ;%%correction to the computed mean
motion
M0=.161135933225D+01;%%mean anomaly
at the reference time
Cuc=-.372529029846D-08;%% amplitude
of harmonic correction terms for the
computed argument of latitude
e=.899999996182D-02;%% eccentricity
Cus=-.372529029846D-08;%%amplitude of
harmonic correction terms for the
computed argument of latitude
aro=.509901951408D+04;%% square root
of the semi-major axis
TOE= .108000000000D+05;%% ephemeris
reference time (second)
Cic=.186264514923D-08;%%amplitude of
harmonic correction terms for the
computed inclination angle
omega0=-.903366543128D-04;%%
longitude of the ascending node at
the beginning of the GPS week
Cis=-.186264514923D-08;%%amplitude of
harmonic correction terms for the
computed inclination angle
i0 = .959931088434D+00;%%
iniclination angle at the reference
time
Crc=-.500000000000D+00;%%amplitude of
harmonic correction terms for the
computed orbit radius
omega=.000000000000D+00;%%argument of
perigee
omega_dot=-.844285167866D-08;%%rate
of change of RAAN with time
IDOT= .000000000000D+00;%%rate of
change of inclination with time
TGD=.000000000000D+00;  %%
IODC=.537000000000D+03;%% Issue of
Data, Clock
transit_time =0.0654272844884243;
receipt_time =611056;
tt=receipt_time-transit_time;

%%
~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~
%%            Satellite coordinate
calculation
%%
~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~
a = aro ^2;
%% Time elapsed since toe
t=tt-TOE;%% tt=transmit time
%% Format the time
 if t >  302400,
     t= t-604800;
 elseif t < -302400,
     t = t+604800;
 end
 %% Mean anomaly time t
ma= M0+(sqrt(GM /a^3)+Del_n)*t
%% Iteration for E
E = ma;
itr=0;
while(1)
   itr=itr+1;
   E_br = E;
   E =ma+e*sin(E);
   dE = E-E_br;
   if abs(dE) < 1e-13,
      break;
   end
end
%% True anomaly
v=  atan2(sqrt(1-e^2)*sin(E),  cos(E)-e)
%% omega+fj
fay = v+omega
%% Argument of perigee
w=fay+ Cuc*cos(2*fay)+Cus*sin(2*fay)
%% Radial distance
r=a*(1-
e*cos(E))+Crc*cos(2*fay)+Crs*sin(2*fa
y)
%% Inclination
i=i0+IDOT*t+Cic*cos(2*fay)+Cis*sin(2*
fay)
%% Longitude for ascending node
omega = omega0+(omega_dot-rr)*t-
rr*TOE
%% Rotation matrix
m=[cos(omega)      -
cos(i)*sin(omega); ...
                    sin(omega)
cos(i)*cos(omega);...
                    0
sin(i)  ];
%% Satellite position in ECEF in
meters
```

```
Sat_XYZ=m*[cos(w)*r; sin(w)*r]
```

And the calculated position is:

Sat_XYZ =

18946882.0507969
4059859.65971154
17126587.7760477

V. CONCLUSION

In this paper, we presented a program to estimate GPS satellite position using broadcast ephemerides.

In the GNSS market survey and mapping sector, reliable, consistent positioning accuracy has always driven new product development. It should not be forgotten that the precision of the location estimated from the data on the broadcast is influenced by knowledge on the gravity field and by troposphere and ionosphere factors.

The paper's initial objective was to develop a set of programs to display the status of the GPS Space Segment in real time with the data provided by the GPS receivers. With the many applications developed, this goal has been achieved. They are standalone programs that can display the data collected by the receiver in real time.

VI. REFERENCES

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Cite this article as :

Tariq N. Ataiwe, Abbas Z. Khalaf, I H Mohammed, "Satellite Coordinates from Ephemeris Data", International Journal of Scientific Research in Civil Engineering (IJSRCE), ISSN : 2456-6667, Volume 3 Issue 4, pp. 15-19, July-August 2019. URL : http://ijsrce.com/IJSRCE19335