ESTIMATING THE GNSS BROADCAST EPHEMERIS ERROR

Sebastian CIUBAN[1]

Scientific Coordinator: Vlad Gabriel OLTEANU[1]

[1]University of Agronomic Sciences and Veterinary Medicine of Bucharest, Faculty of Land Reclamation and Enviornmental Engineering, 59 Mărăşti Blvd, District 1, 011464, Bucharest, Romania, Phone: +4021.318.25.64, Fax: + 4021.318.25.67, Email: ciuban.sebastian@gmail.com

Corresponding author email: ciuban.sebastian@gmail.com

Abstract

The aim of this paper is to compare the position of a certain GNSS satellite with respect to an ECEF (Earth Centered Earth Fixed) frame, obtained from broadcast ephemeris and precise post-processed orbits. To accomplish this, RINEX (Reciever Independent Exchange Format) and SP3 (Standard Product) files were downloaded from the International GNSS Service (IGS) corresponding to the same day.
Furthermore, in order to assess the error of the broadcast ephemeris, several routines were developed under MATLAB environment, with the aim of importing the data, comparing the orbits and plotting the results.

Key words: GNSS, precise orbits, ephemerides.

INTRODUCTION

Satellite PNT (positioning, navigation and timing) was born during the XX_{th} century. At the beginning, GNSS (Global Navigation Satellite Systems) were developed for military purposes, but now have various uses for the civil segment. Domains such as aerial, naval and terrestrial navigation benefited the most becoming dependent because of the efficient solutions that the satellite technology provides.

To obtain the right position and find the solution for the navigation problem is mandatory to know (with certain accuracty) the position of the GNSS satellites which may be obtained with the aid of the broadcasted ephemeris and the clock corrections transmitted by the system. These data is part of the navigation message. Any error in the GNSS satellites coordinates or satellite clock will affect the positioning accuracy.

COMPUTING THE SATELLITE ORBIT

To compute a GNSS satellite orbit or position at a certain moment with respect to an ECEF frame, the data from a RINEX (Reciever INdependent EXchange format) navigation file (baia0710.13n) has been used (Figure 1).

Figure 1. RINEX data block for satellite 1

The data blocks of the RINEX file have the required parameters that define an orbit:
a) Keplerian parameters (Figure 2)
- $\sqrt{a}$ – square root of the semi-major axis;
- e – orbit eccentricity;
- i_0 – initial inclination;
- M_0 – mean anomaly;
- Ω - longitude of ascending node ;
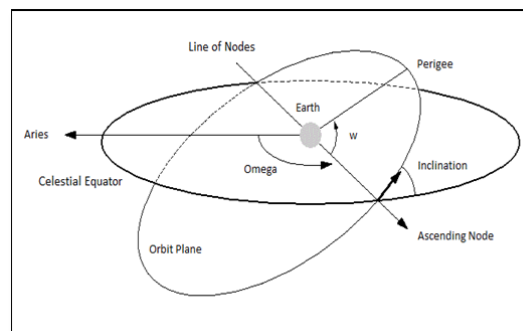- ω - argument of perigee.

Figure 2. Keplerian elements
(satelliteorbitdetermination.com)

b) Perturbation parameters
- Ω_{dot} – rate of change of right ascension;
- Δn – delta n;
- i_{dot} – rate of change of inclination;
- C_{uc}, C_{us}, C_{rc}, C_{rs}, C_{ic}, C_{is} – correction coefficients to the argument of perigee, orbit radius and inclination.

(http://spaceflight.nasa.gov/realdata/elements/)

To obtain the GNSS satellite coordinates from the navigation message the following algorithms must be respected :
- Compute the time t_k from the ephemerides reference epoch t_{oe}:
$$t_k = t - t_k$$
- Compute the mean anomaly at t_k:
$$M_k = M_0 + \left(\frac{\sqrt{\mu}}{\sqrt{a^3}} + \Delta n \right) t_k$$
μ = gravitational constant
- Solve (iteratively) the eccentric anomaly
$$M_k = E_k - e \sin E_k$$
- Compute the true anomaly v_k:
$$v_k = \arctan \left(\frac{\sqrt{1 - e^2} \sin E_k}{\cos E_k - e} \right)$$
- Compute the argument of latitude u_k:
$$u_k = \omega + v_k + C_{uc} \cos 2(\omega + v_k) + C_{us} \sin 2(\omega + v_k)$$
- Compute the radial distance r_k:
$$r_k = a(1 - e \cos E_k) + C_{rc} \cos 2(\omega + v_k) + C_{rs} \sin 2(\omega + v_k)$$
- Compute the longitude of the ascending node λ_k:
$$\lambda_k = \Omega_0 + (\Omega_{dot} - \omega_E) t_k - \omega_E t_{oe}$$
ω_E = earth's angular velocity
- Compute the coordinates in the ECEF frame:
$$\begin{bmatrix} X_k \\ Y_k \\ Z_k \end{bmatrix} = R_3(-\lambda_k) \, R_1(-i_k) \, R_3(-u_k) \begin{bmatrix} r_k \\ 0 \\ 0 \end{bmatrix}$$
R_1 and R_3 are rotation matrices

After these steps, the results will be compared with corresponding data from the precise post-processed orbits contained in the SP3 (Standard Product) file (igs17312.sp3).

Furthermore, as the SP3 file provides satellite positions at a 15 minutes rate, for other epochs, an interpolation process is necesessary. A 10th order polynomial interpolation was used as this is sufficient to provide centimeter accuracy (Sanz Subirana & Juan Zornoza, 2013).

$$P_n(x) = \sum_{i=1}^{n} y_i \, \frac{\prod j \neq i \, (x - x_j)}{\prod j \neq i \, (x_i - x_j)}$$

ROUTINES DEVELOPED UNDER MATLAB

MATLAB is a high-level programming language for numerical computation, and visualization. Using this environment, tasks such as analyzing data, developing functions, plotting results, and many other applications are successfully completed (mathworks.com).

In order to accomplish the purpose of this paper, several functions, described below, were developed:
- readRINEXnav.m – imports the data from the RINEX navigation file (baia0710.13n) and it returns a matrix containing the broadcasted ephemerides.
- extr.m – it receives as input data, a matrix with broadcasted ephemerides, and the PRN number of the GNSS satellite for which the orbit will be computed. And it will return the ephemerides only for that satellite
- satdata.m – this function will compute the GNSS satellite orbit with respect to an ECEF frame
- plot_orbit.m – is an improved function which uses satdata.m Its inputs are: the matrix with extracted ephemerides, the period of interest (t_{oe1}, t_{oe2}- time of ephemeris) in seconds, and the increment.
- readSP3.m – which will return the ECEF coordinates in km (X, Y, Z) and the corresponding time in seconds of the current day for the GNSS satellite in cause from the SP3 file (igs17312.sp3)
- extract_sp3.m – will return the ECEF coordinates and corresponding time for a certain satellite.
- interpolare.m – the function will interpolate the track of the satellite in its orbit at a given time.

A general script, namely the s_orbit.m file, involving all the functions described above, computes and plots the orbit from the RINEX navigation file and from the SP3 file.

RESULTS AND DISCUSSIONS

The data files (RINEX and SP3) used to accomplish the purpose of this paper were downloaded from the International GNSS Service (http://igs.bkg.bund.de) corresponding to the same day (11.03.2013).
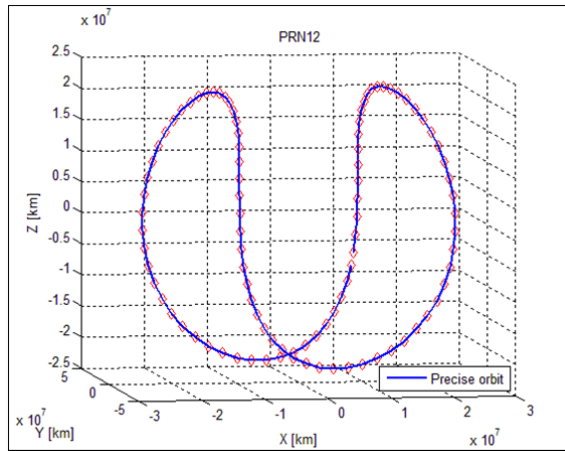As inputs, the GPS SV 12 broadcast ephemeris and post-processed orbits were used.

Figure 3. Complete precise orbit

The first result was the complete precise orbit of the satellite obtained from the SP3 file. Its position was computed every 15 minutes (Figure 3). This will be used as reference data and it will be compared with the positions obtained from the broadcast ephemeris.
The next phase involved the computation of the partial orbit from the navigation message with respect to ECEF frame according to the algorithm presented before. The GPS satellite position was calculated for 8 epochs, from t_{oe1}=252000 (seconds of GPS week) to t_{oe2}=258300, every 15 minutes (Table 1).

Table 1. ECEF coordinates of GPS satellite 12 at different epochs

| No. | t_{oe}(sec) | 1.0e+07* | | |
		X[km]	Y[km]	Z[km]
1	252000	1.1286	1.9896	1.3650
2	252900	1.1340	2.1322	1.1267
3	253800	1.1418	2.2466	0.8691
4	254700	1.1482	2.3315	0.5967
5	255600	1.1491	2.3863	0.3142
6	256500	1.1407	2.4111	0.0263
7	254700	1.1191	2.4074	-0.2620
8	258300	1.0811	2.3769	-0.5458

The plotted values describe the broadcasted partial orbit (Figure 4).
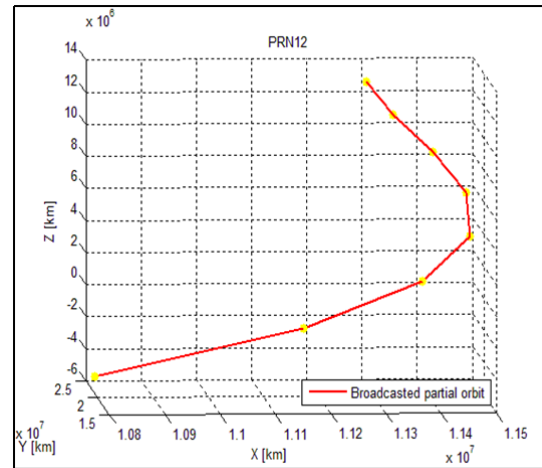

Figure 4. Broadcasted partial orbit

As we expected , the coordinates obtained from RINEX navigation message compared with those from SP3 file contain errors, which are presented in Table 2.

Table 2. Errors between RINEX-SP3

No.	t_{oe}(sec)	Δx[m]	Δy[m]	Δz[m]
1	252000	0.5190	-0.7292	0.5721
2	252900	0.4597	-0.5377	0.5169
3	253800	0.4168	-0.4159	0.4562
4	254700	0.3620	-0.3355	0.3818
5	255600	0.2644	-0.2653	0.2736
6	256500	0.1003	-0.1867	0.1086
7	254700	-0.1434	-0.0985	-0.1374
8	258300	-0.4617	-0.0276	-0.4804

For a better understanding the evolution of errors over time, the linear error have been computed (Table 3) and plotted (Figure 5).

Table 3. Spatial distance (RINEX vs SP3)

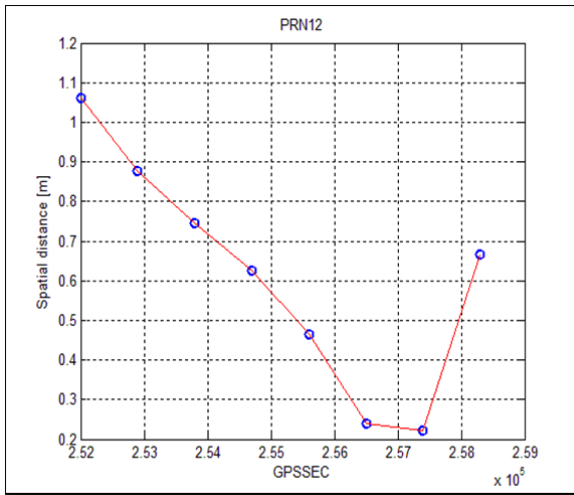| t_{oe} (sec)	Spatial dist. [m]
252000	1.0623
252900	0.8762
253800	0.7449
254700	0.6240
255600	0.4638
256500	0.2382
254700	0.2217
258300	0.6668

Figure 5. Linear error over time

Also, a comparison has been made between the precise orbit computed every 15 minutes and interpolated orbit computed every 5 seconds, both belonging to the same period of time (Figure 6).
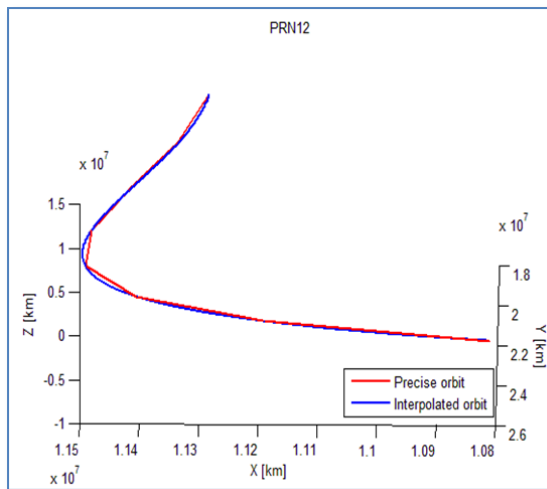

Figure 6. Precise orbit vs Interpolated orbit

CONCLUSIONS

Satellite based positioning and navigation are affected by various errors that occur during these processes. The differences between broadcasted and post-processed orbits are small enough for real time navigation and positioning. This represents the basic concept for GNSS measurements in real time.

REFERENCES

European Space Agency, 2013, GNSS Data Processing Book: Volume I and Volume II.
Online documentation:
[http://igs.bkg.bund.de/]
[http://spaceflight.nasa.gov/realdata/elements]
[http://www.mathworks.com]
[http://satelliteorbitdetermination.com]