Simulation Analysis of the Orientation Ability for Galileo in Asia-pacific Region

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***Abstract*—On the base of satellites' circulate rule, Galileo system simulation software is exploited and operated in the paper. The capability of Galileo navigation and positioning is analyzed and validated thought positioning precision in five different areas is computed. These demonstrates clear know about good capability of positioning all over the world.**

Keywords-galileo positioning system; navigation; positioning; simulation

I. INTRODUCTION

With the acceleration of European's Galileo system network, the world will have four satellite systems coexistence. The scholars had a large number of simulation study about the influencing factors of Galileo navigation and positioning and the combination of Global Positioning System (GPS), BDS and Galileo's.

In this paper, there is the simulation and analysis of Galileo positioning accuracy in different latitude regions in the Asia-pacific region, thus it can preliminary argued the positioning performance of this system in the Asia-pacific region.

II. SATELLITE CONSTELLATION SIMULATION PRINCIPLES

The simulation purpose was to get the satellite 3D coordinate of the fixed coordinate system. According to the Kepler's theorem, if the Kepler's six parameters are known, the satellite coordinates in the orbit coordinate system can be got. The mathematical models are as follow:

$$\begin{bmatrix} \xi_s \\ \eta_s \\ \zeta_s \end{bmatrix} = a_s \begin{bmatrix} (\cos E_s - e_s) \\ (1-e_s^2)^{1/2} \sin E_s \\ 0 \end{bmatrix} \quad (1)$$

(ξ_s, η_s, ζ_s) in the formula is the satellite coordinates in the orbit coordinate system, a_s is the semi-major axis of orbit, e_s is the orbital eccentricity, $\mathrm{E_s}$ is as the eccentric anomaly, M_s is the flat anomaly in a moment calculated by the next formula:

$$E_s = M_s + e_s \sin E_s$$

$$E_s = M_s + \left(180^\circ/\pi\right) e \sin E_s \quad (2)$$

$$M_s = n \times (t - t_0) \quad (3)$$

Here, t_0 is the simulation start time, t is observation time, and n is the average angular velocity for satellite movement. The mathematics transformation model to the satellite coordinate transformation for the solid coordinate is:

$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix} = R_3(GAST)R_3(-\Omega)R_1(-i)R_3(-\omega_S) \begin{bmatrix} \xi_S \\ \eta_S \\ \zeta_S \end{bmatrix} \quad (4)$$

Among them,

$$\mathrm{R}_3(-\Omega) = \begin{pmatrix} \cos\Omega & -\sin\Omega & 0 \\ \sin\Omega & \cos\Omega & 0 \\ 0 & 0 & 1 \end{pmatrix}$$

$$\mathrm{R}_1(-\mathrm{i}) = \begin{pmatrix} 1 & 0 & 0 \\ 0 & \cos\mathrm{i} & -\sin\mathrm{i} \\ 0 & \sin\mathrm{i} & \cos\mathrm{i} \end{pmatrix}$$

$$\mathrm{R}_3(-\omega_s) = \begin{pmatrix} \cos\omega_s & -\sin\omega_s & 0 \\ \sin\omega_s & \cos\omega_s & 0 \\ 0 & 0 & 1 \end{pmatrix}, R_3(GAST) = \begin{bmatrix} \cos(GAST) & \sin(GAST) & 0 \\ -\sin(GAST) & \cos(GAST) & 0 \\ 0 & 0 & 0 \end{bmatrix}$$

Among them, Ω is ascending node in red, i is the orbital inclination, and ω_s is perigee angular distance, $GAST$ is Greenwich sidereal time for vernal equinox. As a result, we get the satellite 3D coordinates under the ground fixed coordinate system.

III. SIMULATION AND ANALYSIS

In the process, it was assumed that the initial epoch observation is on April 30, 2014 (GTS time), there are three circular orbits, nine satellites distributed uniform each orbit and the flat anomaly of the starting time ($t_0 = 0$) of each first satellite. The basic parameters of simulation track are: semi-major axis α is 2993.707km, orbital inclination i is 56°, orbital eccentricity e_s is 0, Perigee angular distance ω is 0, scending node in red Ω is respectively 60°, 180°, 300°, flat anomaly M_s is 0° (the flat anomaly of the starting time ($t_0 = 0$) of each first satellite).

The city where the five representative to locate the simulation calculation had been chose in this paper. See the table below.

TABLE I. THE SIMULATION CITY LIST.

Area	City	Latitude E	Longitude N
Russia	Yakutsk	129°51′	62°01′
Mongolia	Ulan Bator	106°55′	47°58′
China	Chengdu	104°04′	30°40′
China	Hong Kong	114°06′	22°12′
Malaysia	Kuala Lumpur	101°41′	3°08′

A. Satellite Visible for Analysis

1) according to the principle of space geometry, $(\frac{2\times X_k^0}{a^2},\frac{2\times Y_k^0}{b^2},\frac{2\times Z_k^0}{c^2})$ is the tangent plane normal vector of receiver position as the point of tangency and tangent to the earth ellipsoid. Among them, (X_k^0,Y_k^0,Z_k^0) is the 3D coordinates of receiver in the ground fixed coordinate; a,b,c is the parameters of ellipsoid $\frac{x^2}{a^2}+\frac{y^2}{b^2}+\frac{z^2}{c^2}=1$, and $b=c$.

2) $(X^j-X_k^0,Y^j-Y_k^0,Z^j-Z_k^0)$ is the direction vector computed of satellite and receiver. Among them, (X^j,Y^j,Z^j) is the 3D coordinates of satellite in the ground fixed coordinate;

3) The angle between the direction and the above normal vector is computed. Because the receiver can only receive the satellite signal that angle is greater than 15 degree, so the angle must be less than 75 degree.

According to the above principle, we had got the satellite visible situation of these five cities in one day as shown in Tab. 3.

TABLE II. THE ANALYSIS OF VISIBLE SATELLITE NUMBER OF CITIES (%).

Area	City	Visible satellite number			
		6	7	8	9
Russia	Yakutsk	6%	78%	16%	0%
Mongolia	Ulan Bator	78%	22%	0%	0%
Sichuan, China	Chengdu	49%	35%	16%	0%
Hong Kong special administrative region	Hong Kong	0%	30%	66%	4%
Malaysia	Kuala Lumpur	0%	0%	60%	40%

From Tab. 3, the number of satellites in low latitudes than in high latitudes and mid-latitude regions, especially most number in equatorial regions. And there are the same distributions of high and middle latitude regions.

B. PDOP Analysis

The basic principle formula of satellite positioning is:

$$R_k^j=\sqrt{(X^j-X_k^0)^2+(Y^j-Y_k^0)^2+(Z^j-Z_k^0)^2} \quad (5)$$

R_k^j is the distance between the satellite and receiver k in j moment. Based on least squares principle, the power inverse matrix could be got from eq. 5.

$$Q_{xx}=(A^TA)^{-1}=\begin{bmatrix} Q_{11} & Q_{12} & Q_{13} & Q_{14} \\ Q_{21} & Q_{22} & Q_{23} & Q_{24} \\ Q_{31} & Q_{32} & Q_{33} & Q_{34} \\ Q_{41} & Q_{42} & Q_{43} & Q_{44} \end{bmatrix} \quad (6)$$

So PDOP was got:

$$PDOP=\sqrt{Q_{11}+Q_{22}+Q_{33}} \quad (7)$$

According to the above formula, PDOP value distribution of each city in a day is shown in Fig. 1.

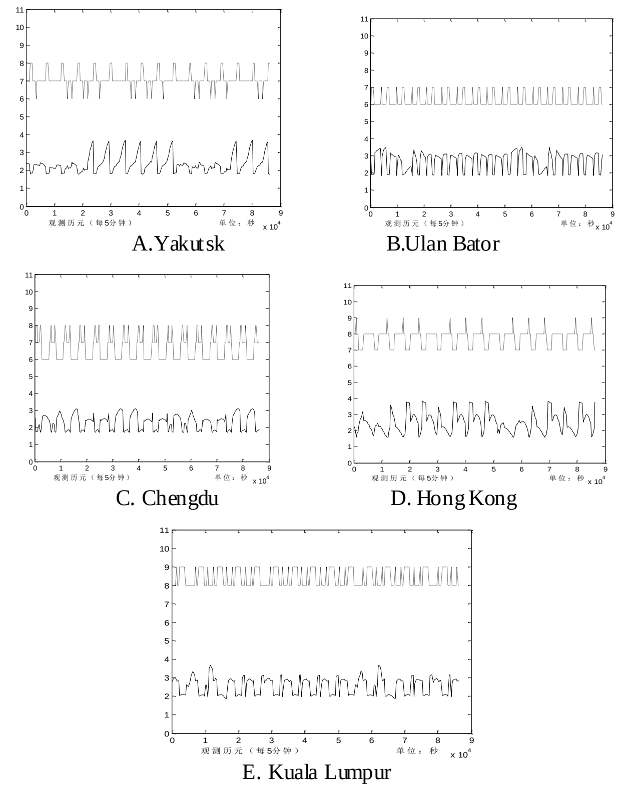

FIGURE I. THE PDOP VALUE DISTRIBUTION IN ONE DAY IN GIVEN AREAS (NOTE: SOLID LINE REPRESENTS PDOP, DOTTED LINE REPRESENTS NUMBER OF SATELLITE OF IN SOME MOMENT)

From Fig. 1, we can see the PDOP value distribution of the different areas in one day is roughly the same. PDOP value is about 2.0. It indicates that Galileo system in Asia-pacific region has a great navigation and positioning performance.

IV. CONCLUSIONS

Through the simulation comparison of Galileo system, we find that Galileo system has a great positioning performance. But now Galileo system is assembling, many problems which need be studied will be verified after the system built.

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