Timing accuracy analysis using height as virtual satellite

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Abstract: There are two satellite navigation system is china, one is compass system, another is CAPS(China Area Position System). For satellite in these system are all GEO satellite, it's difficult to realize passive position. Height can be used as virtual satellite which would increase position accuracy substantially. But precise height measurement is expensive to realize.

At timing the distance between user and satellite must be computed to compensation the transmit delay. It is not necessary to get precise user coordinate. Height error is supposed and the position equation is listed. After resolve the equation we can see Z coordinate of user is much sensitive to height error and distance error cause by height error is much less. Timing error caused by 100m height error is less than 1us in most area of China. So height error is more tolerant when used for timing. In many cases a probable height can be suppose instead of precise height which need expensive device. Probable height can meet the requirement of us timing precise. It can used for many case of power system and telecom system.

Keywords: Compass, GPS, Passive position, Timing

I. Introduction

There are COMPASS and CAPS satellite navigation system in China. Satellites in these two systems are all GEO satellite which move slowly suitable for timing. But passive timing needs user coordinate to compute distance between satellite and user. GPS position is often adopted. Compass/GPS timing is often applied. At this method, GPS provide position to Compass timing. So GPS is also needed which increase cost of device.

Passive position can be carried out by three COMPASS and height which use height as virtual satellite to resolve position equation. Height is often measured by air pressure. Navigation data of CAPS system contain assistant information such as air pressure and temperature to increase precise height. Air pressure detect circuit is applied but add extra cost. The paper analyze timing error caused by height and reach a conclusion that time error caused by height is much less than position error. So passive timing by height can meet the requirement of most case of power system.

II. Passive timing principle

1. position using height as virtual satellite

The position equation can be described as follows:

$$\rho_1 = \sqrt{(x_1 - x_u)^2 + (y_1 - y_u)^2 + (z_1 - z_u)^2} - c \cdot \Delta t_u$$

$$\rho_2 = \sqrt{(x_2 - x_u)^2 + (y_2 - y_u)^2 + (z_2 - z_u)^2} - c \cdot \Delta t_u$$

$$\rho_3 = \sqrt{(x_3 - x_u)^2 + (y_3 - y_u)^2 + (z_3 - z_u)^2} - c \cdot \Delta t_u$$

$$x_u{}^2 + y_u{}^2 + z_u{}^2 = (R+h)^2 \tag{1}$$

At this equation, h means user height. (x_u, y_u, z_u) means user coordinate; $(x_i, y_i, z_i)(i=1,2,3)$ means satellite coordinator. Newton iterative method is often used to resolve the equation. Height used as virtual satellite can substantially increase GDOP factor and position precision.

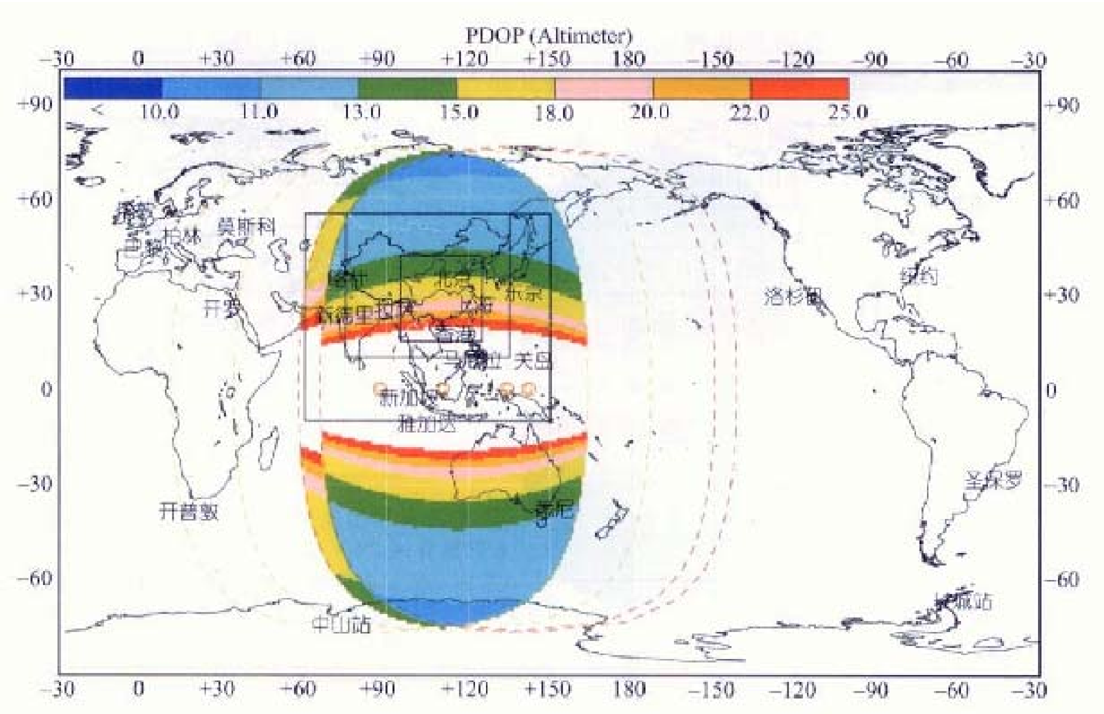

Fig.1 same PDOP distribution based on height and 4 GEO satellite

Figure.1 shows the PDOP equate distribution while position by 4 CAPS satellite and height. It can be conclude that the PDOP factor would increase gradually with the fall of latitude. For main area of China is locate at semitropical district, position can be realized. CAPS receiver can realize 20 meter position precision and 100ns timing accuracy with coarse code.[1]

2. Passive timing principle

GEO satellite navigation system can realize passive timing while user position is fixed. The principle can be explained as Fig.2. Groundstation generate navigation data and transfer to satellite, then satellite transmit data to receiver.

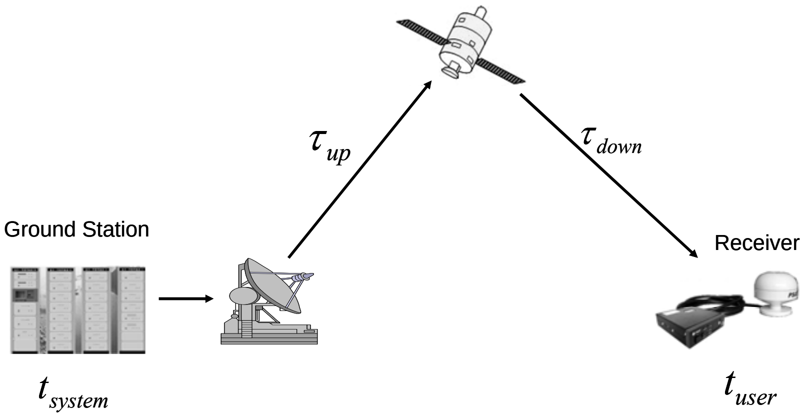

Fig.2. The principle of GEO navigation satellite timing

Receiver get the navigation data, compute the satellite coordinate and transmit delay. Then correct local time and synchronize to satellite. The timing schedule is shown as Fig.3. t_{sys} is the transfer time of satellite signal, t_{rcv0} is the corresponding receiver time. t_{rcv1} is time receiver gets the signal. To receiver, t_{rcv0}, t_{rcv1} are known, if total delay τ_{delay} is computed, time modify error can be gotten, so synchronization can be realized. So it is shown from figure

$$\tau_{delay} = \tau_{up} + \tau_{down} + \tau_{other}$$

$$\tau_{delay} = \tau_{up} + \tau_{down} + \tau_{other} \quad (2)$$

τ_{up} : transmit delay from ground station to satellite, often can be gotten from navigation data;

τ_{down} : transmit delay from satellite to receiver. Suppose satellite position (X_{SV}, Y_{SV}, Z_{SV}) , user position (X_u, Y_u, Z_u) , so $\tau_{down} = \sqrt{(X_u - X_{SV})^2 + (Y_u - Y_{SV})^2 + (Z_u - Z_{SV})^2} / c$

τ_{other} : other delay; $\tau_{other} = \varepsilon + a_0 + t_b$, ε is the modify of transmit, can be calculate from radio transmit model parameter; a_0 is total delay of receive and transmit of device; t_b is unilateralism delay of receiver.

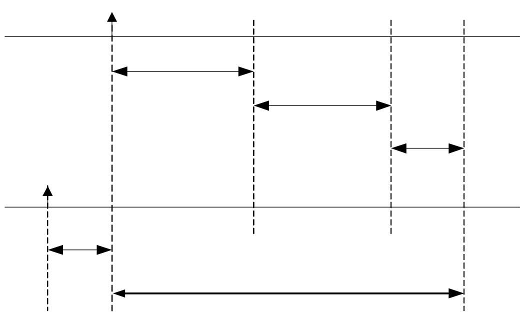

Fig.3. Receiver timing schedule

III. Height error to timing accuracy

At passive timing application, coordinate is used to calculate the distance between satellite and user to get the transfer delay. So for timing user coordinate is not necessary.

For precise height need temperature and humidity sensor which increase cost. Height error which cause error of distance computation, is main factor of timing accuracy. So analysis is carried out.

Suppose 3 GEO navigation satellite is applied which locate in 0 latitude. Satellite A locate at East longitude 80°, B locate at 110 and°C locate at 140°. So position of SV can be calculated as follow

$$\begin{cases} x = (R_N + h)\cos\varphi\cos\lambda \\ y = (R_N + h)\cos\varphi\sin\lambda \\ z = [R_N(1-f)^2 + h]\sin\varphi \end{cases} \quad (3)$$

While R_N is radius of equator, h is distance between SV and surface of earth, φ is latitude, λ is longtitude.

Suppose $R_N = 6378KM$, $h = 35786KM$,for GEO SV locate at equator, so $\varphi = 0$. $R_N + h = 42164Km$ 。

So coordinate of 3 SV can be calculated.

$$\begin{cases} x_A = 7321701; \\ y_B = 41523434; \\ z_B = 0; \end{cases} \quad \begin{cases} x_B = -14420937; \\ y_B = 39621200; \\ z_B = 0; \end{cases} \quad \begin{cases} x_C = -32299478; \\ y_C = 27102498; \\ z_C = 0; \end{cases}$$

We suppose predefine position, so pseudorange ρ_1, ρ_2, ρ_3 ,distance D1,D2,D3 can all be calculated. Certain Error is added to height, then resolve the position equation. So we can get user coordinate and D1,D2,D3.

The predefine position is

$$\begin{cases} x_u = -2818609 \\ y_u = 5502736 \\ z_u = 1740395 \end{cases} \quad \begin{cases} D_1 = 37461253; \\ D_2 = 36079253; \\ D_3 = 36588253; \end{cases}$$

Then height error is simulated to calculate user position and distance D1,D2,D3. the result is shown as Tab.1 while 100~900 meter error introduced. So we can see coordinate Z is most sensitive to height error while distance D1,D2,D3 are much less sensitive.

From equation (1), height error affect clock error t_u first. t_u play same effect to D1,D2,D3. from Tab.1, 100 meter height error cause 15 meter error to distance. When height error >500, distance error caused is less than 300m and time error caused is less than 1us while error of coordinate Z is more than 2000 meter.

From Fig.4 we can see timing is much less sensitive to height than position. So we can reach a conclusion that the method using height as virtual satellite to position can be applied to timing.

Fig.1 error result of position and distance at same height error

Tab 1.The relation between Altitude error and the calculate result of position

Seq	Height error(m)	X error	Y error	Z error	D1 error	D2 error	D3 error
1	100	-1.1421	2.2365	360.09	14.89	14.89	14.89
2	200	-3.4263	6.7095	1080.1	44.67	44.67	44.67
3	300	-6.8528	13.419	2159.5	89.342	89.342	89.342
4	400	-11.422	22.366	3597.8	148.91	148.91	148.91
5	500	-17.133	33.551	5394.2	223.37	223.37	223.37
6	600	-23.988	46.973	7547.5	312.73	312.73	312.73
7	700	-31.985	62.634	10057	417	417	417
8	800	-41.126	80.535	12920	536.18	536.18	536.18
9	900	-51.411	100.68	16137	670.27	670.27	670.27

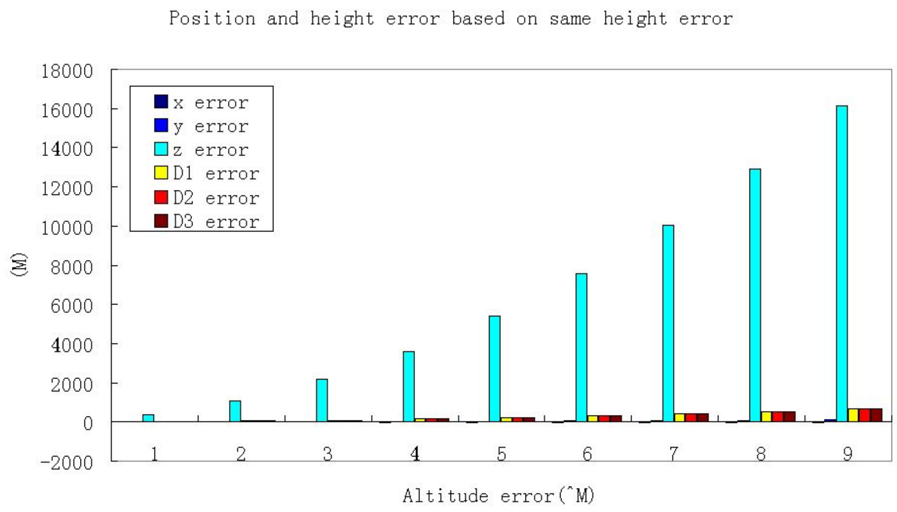

Fig.4 Position and height error based on same height error

We carried out same calculation at five city which distribute over mainland of China as BeiJing,ShangHai, SanYa, LaSa, KaShen, Harbin. The result is shown as Tab.2.

Tab.2 Calculation result of five city

location	Height error	Xerror	Yerror	Zerror	D1error	D2error	D3error
BeiJing	100	2.1241	-1.7036	-448	14.907	14.907	14.907
ShangHai	100	-1.1291	0.1694	115.1	15.0095	15.0095	15.0095
SanYa	100	-1.8052	1.0642	206.8	14.9908	14.9908	14.9908
Harbin	100	0.2014	1.8131	150.2	14.9209	14.9209	14.9209
LaSa	100	1.3646	1.8896	-2221	15.1339	15.1339	15.1339

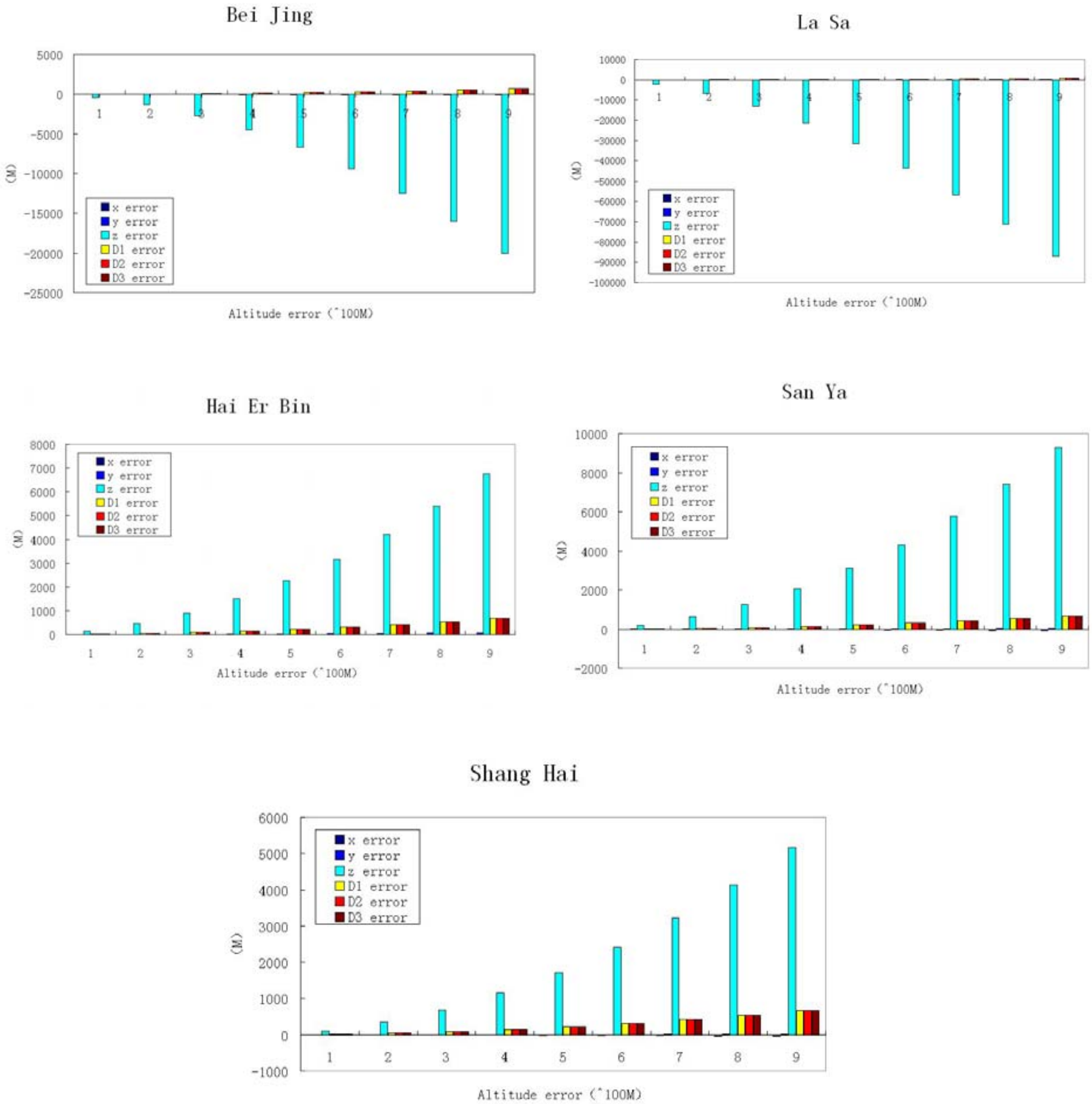

Fig.5. Calculation result of BeiJing,ShangHai,SanYa,LaSa ,Haerbin

IV. Conclusion

Time synchronize is becoming more and more important with development of information industry. Passive timing is most valuable of GEO satellite service for its user number is unlimited. When using height as virtual satellite to position, timing error is much less than position error at same height error. From analysis of paper we can see timing error caused by 100m height error is less than 50ns. So precise height is not necessary at most case and expensive devices are not needed.

V. References

[1]Ai G X. Positioning system based satellite communication and Chinese area positioning system (CAPS). Science in China, J Astron Astrophys，2008，8（6）：611-635．