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A Quick Location Method for High Dynamic GNSS Receiver Based on Time Assistance

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Abstract: Traditional A-GPS positioning method when quickly calculate a position, need a condition that the approximate position must not exceed 150km, otherwise the calculation will be very complex. This paper proposes a time-assisted fast positioning method for high dynamic GNSS receiver, effectively solving the problem of large search calculation in traditional method, even if exact position is unknown after the signal is recaptured. According to the known auxiliary time information and implied elevation information, this paper put forwards a custom coordinate system for building two-dimensional search space, which could reduce the number of search-dimensions. It proposes a search method based on receiver clock calculated by analyzing the influence of time auxiliary accuracy. By using GPS ephemeris data provided by the IGS, it builds a simulation environment and analyzes the influence of different preferred satellites based on the custom coordinate system on the calculation, and thus puts forward a principle for choosing the preferred satellites. Simulation examples show that through the rational combination of satellites to create a custom coordinate system, and when time auxiliary accuracy is less than 60us, the calculation can 100% guarantee to restore a complete satellite signal emission time and obtain an accurate position.
Keywords: Global Navigation Satellite System(GNSS), signal transmission time recovery, high dynamic, Time to First Fix(TTFF).

1 Introduction

Since the low speed of the message affects the speed of frame synchronization [1], the traditional non-auxiliary GPS receiver can not obtained the complete time of satellite signal emission instantly, which will affect TTFF (Time to First Fix). Take the GPS L1 as an example, from catching to accomplishing code phase synchronization of several satellites, ordinary receivers take one or two seconds to receive the time of satellite signal emission. But it takes about fifteen seconds to accomplish bit and frame synchronization by message, and receivers can not locate before frame synchronization completed. Through auxiliary methods [2, 3], before frame synchronization, receivers can recover the milliseconds of the signal emission to accelerate TTFF.

However, there are some conditions when using auxiliary GPS, that is only when the error of location estimation is not beyond 150km, can the receiver recover instantly the milliseconds of the satellite and calculate the exact position of the receiver [4–6]. When the receiver is in high dynamics, such that when the design speed reaches 900m/s, and when it lost the signal for a while, such that when the off power and loss of lock time is beyond 167s, the scope of the general location will be beyond 150km, which will increase the work of calculation. Literature [7, 8] proposes to reduce the calculation in searching through narrowing the searching area by visibility of satellite and through removing unreasonable values by calculation. But this method is still complex, for it is based on the calculation of the receiver's dimensional position and clock error, in which the dimensional search does not make use of information hidden on the surface of the earth. Literature [9–11] puts forward a kind of location by atomic clock assisted.

This paper puts forward a new idea that when calculating the general location, the four unknown numbers (the three dimensions and clock error) can be reduced to two (the two dimensions of the receiver on the earth), which is a combination of a custom coordinate system and the hidden information on the earth of the receiver. When calculating the two dimensions, there is new two-dimensional searching space and a searching method based on receiver clock calculated.

2 Building the Searching Space

With auxiliary time information and elevation information, search of the user's location is a search of the two dimensions in the horizontal level. To be convenient, the two dimensions in the horizontal level is redefined by the custom polar coordinate.

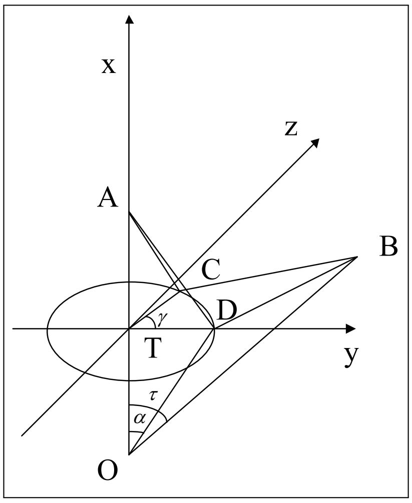

Figure 1: Custom coordinate system

As the graph shows, O represents the earth, with A and B two satellites. Satellite A And satellite B who build the custom coordinate system are called the preferred satellites for the convenience, while other satellites are called validate satellites.

In the custom right-angle coordinate system, O is origin, $\overrightarrow{OA}$ is axis Z, axis Y is vertical toward plat $\overrightarrow{OAB}$, and axis X is vertical toward plat $\overrightarrow{OYZ}$ and on the left hand of YZ. The unit vector $\vec{e}_x$, $\vec{e}_y$, $\vec{e}_z$ of X, Y, Z can be stated as $\vec{e}_x = \frac{\vec{e}_y \times \vec{e}_z}{|\vec{e}_y \times \vec{e}_z|}, \vec{e}_y = \frac{\overrightarrow{OA} \times \overrightarrow{OB}}{\left|\overrightarrow{OA} \times \overrightarrow{OB}\right|}, \vec{e}_z = \frac{\overrightarrow{OA}}{\left|\overrightarrow{OA}\right|}$. "×" represents outer calculation of the vector. Therefore, the arbitrary point C can be represented as $\left(\overrightarrow{OC} \cdot \vec{e}_x, \overrightarrow{OC} \cdot \vec{e}_y, \overrightarrow{OC} \cdot \vec{e}_z\right)$ in the system.

Suppose satellite A arrives at the receiver signal $\overline{AC}$, whose intersection with plat XY is D. Then the physical meaning of the circle $\overline{CTD}$ they form is a collection of the same transmission time delay of the satellite signal when it arrives at the earth. $\overline{BD}$ represents the shortest distance when satellite B arrives at the receiver, on the condition that time delay of satellite A is in certainty. Then the problem of satellite B's obscure time delay is to calculate the length of $\overline{BD}$. R is the distance between the satellite and the earth center, such as $\overline{OA}$. τ is the intersection angle of two satellites against the earth center. r is the distance between the receiver and the earth center, such as $\overline{OD}$, $\overline{OC}$. The result is a combination of the radius of the earth semi-major and the elevation the receiver estimates.

We can see that when r is known by the estimated elevation, the receiver in the horizontal level is decided by angle α and angle γ. It will be clearer when we cite the polar coordinate in three-dimension. The referential value is the length between the point and O. The first referential angle is the intersection angle α of $\overline{AOD}$, and the second referential angle is the intersection angle γ of $\overline{CTD}$ against the surface of circular cross-section. Then the coordinates of A, B, C in the space can be presented as $A:(R,0,0)$, $B:(R\cos\tau, R\sin\tau, 0)$, $C:(r\cos\alpha, r\sin\alpha\cos\gamma, r\sin\alpha\sin\gamma)$. Then:

$$\overline{AC}=\sqrt{R^2+r^2-2rR\cos\alpha},\quad \overline{BC}=\sqrt{R^2+r^2-2rR\cos\alpha\cos\tau-2rR\sin\alpha\sin\tau\cos\gamma}$$

3 Search Method on the Basis of Clock Error

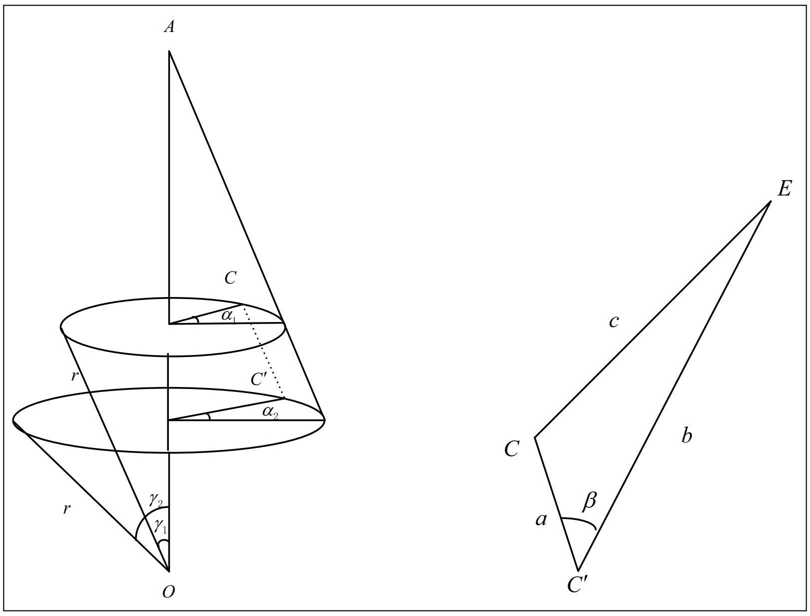

Figure 2: Influence on receiver position by time bias

As the graph shows, C is the real location of the receiver, with coordinate $(r,\ \alpha_1,\ \gamma_1)$. $C\prime$ is the deviated location caused by clock error, with coordinate $(r,\ \alpha_2,\ \gamma_2)$. According to the custom coordinate system, coordinate values of C and $C\prime$ in the space are:

$$C:(r\cos\alpha_2, r\sin\alpha_2\cos\gamma_2, r\sin\alpha_2\sin\gamma_2),\quad C\prime:(r\cos\alpha_1, r\sin\alpha_1\cos\gamma_1, r\sin\alpha_1\sin\gamma_1).$$

Suppose $\Delta\alpha=\alpha_2-\alpha_1$, $\Delta\gamma=\gamma_2-\gamma_1$, local time error is Δb, error of the direction vector $\overrightarrow{C\prime C}$ is

$$\begin{cases}\vec{x}=\dfrac{\cos\gamma_1\,|AC|}{R\tan\alpha_1}\Delta b-\dfrac{|AC|}{R\sin\tau}\left(1-\dfrac{|AC|}{|BC|}\cos\tau+\dfrac{|AC|}{|BC|}\cot\alpha_1\sin\tau\cos\gamma_1\right)\Delta b\\ \vec{y}=\dfrac{\sin\gamma_1\,|AC|}{R\tan\alpha_1}\Delta b+\dfrac{|AC|}{R\sin\tau\tan\gamma_1}\left(1-\dfrac{|AC|}{|BC|}\cos\tau+\dfrac{|AC|}{|BC|}\cot\alpha_1\sin\tau\cos\gamma_1\right)\Delta b\\ \vec{z}=-\dfrac{|AC|}{R}\Delta b\end{cases}$$

Namely, $\overrightarrow{C\prime C}$ is the only value that corresponds Δb, so it can be presented as $\overrightarrow{C\prime C}=f(\Delta b)$.

From the validate satellite E, we can search for packs in the space according to the geometric relations and determine the vectors $\overrightarrow{C\prime C}$ and $\overrightarrow{EC\prime}$ as well as the included angle β, thus working out $\overrightarrow{EC}$. Assuming that these vectors are a, b, c, then we have the following expression:

$$\begin{cases} a = |CC\prime| = f(\Delta b) \\ b = |EC\prime| = c + \Delta b \\ c = \sqrt{a^2 + b^2 - 2ab\cos\beta} \end{cases}$$

The only unknown in the equation set Δb can be solved by simultaneous equation. After working out the Δb, we can compute the variance of clock error packs and make the minimum variance as the truth value due to the uniformity of Δb of different validate satellites.

4 Experiment and Analysis

For the experiment, GPS constellation of IGS ephemeris is selected, the time being 25 December 2011. When the receiver is at a position of N28.2°E112.9°, a total of ten satellites are visible and their distribution and position are as follows:

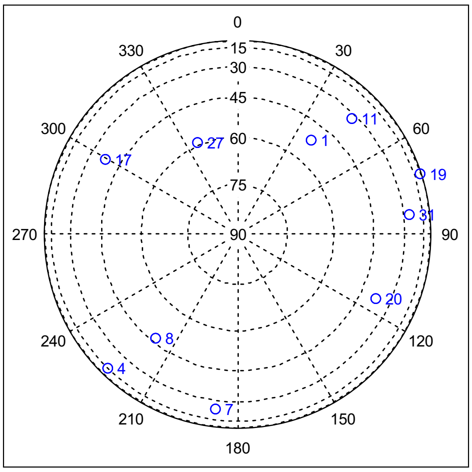

Figure 3: Sky charts of visual satellites

The chosen sphere of movement of the receiver is 10°N~30°N, 120°E~140°E. Simulation test imitates the movement of the receiver within this sphere at a pace of 1° per movement. Height precision error is set at no more than 10km, time auxiliary error at 0~200us. In order to illustrate the impact on the calculation by the two satellites, we select two pacts: the first pact is of No. 1 and No. 4 satellites, and the second pact No. 8 and No. 20.

In order to illustrate the impact of different pacts of satellites on algorithms, we compare two pacts to show the success rate distribution of both ways of calculation when there are 2, 4, 6 and 8 satellites involved. The results are as follows:

The above result shows that:

1. Using auxiliary time information, the two pacts can both lead to the launching time of the satellite correctly. But the success rate, as it is subject to the precision of the time auxiliary, is more or less reduced as the error increases.

2. Normally, the more the validate satellites the higher success rate. In reality, however, the success rate of pacts of two satellites is remarkably lower than those of pacts of more than

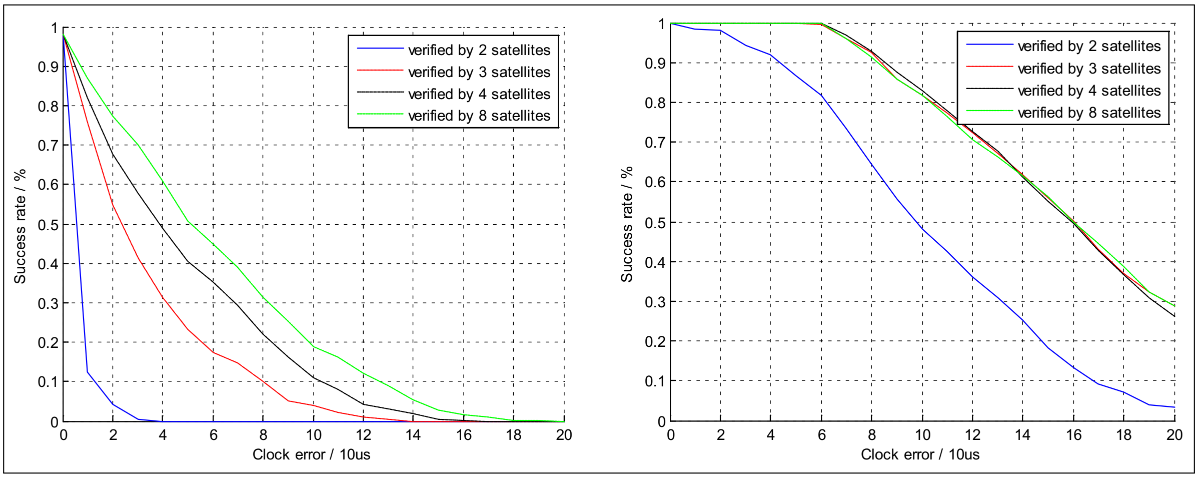

Figure 4: Success rate of algorithm in different conditions

two satellites. It means that when the number of validate satellites is more than two, an increase in the number of validate satellites does not lead to an obvious increase in success rate.

3. The algorithm of the first pact of first choice satellites does not guarantee a success rate of 100%. Even if the clock error is 0, the success rate is only as high as 98%. As the clock error increases, the success rate drops quickly enough to render the result virtually useless.

4. The second pact of first choice satellites can yield a success rate of 100% when the clock error is below 60us. When the error increases, the success rate drops at a lower rate than with the first pact. Therefore, it can be applied to cases of a wider range of time errors.

5 Conclusion

To sum up, to safeguard the success rate of algorithm, we can determine the principle of first choice satellite selection. In other words, when selecting preferred satellites, we must work out the area where the receiver can capture the signal of all the satellites according to the distribution of visible satellites. The selection principle is:

1. Select pacts on the same side on the verge of the area. Make sure that the line connecting the first choice satellites is nowhere near the top of the receiver.

2. Under the above principle, select pacts of satellites with greater distances.

The first principle can overcome the situation when PDOP value is infinite. The Second principle is conducive to further reducing PDOP value and increasing the application scope of local time auxiliary precision. It is also good for reducing scope of searching space and reducing calculation load.

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