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Research on the Blind Zone Positioning in Dual-satellite Passive Location System

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Abstract: Dual-satellite passive location system is a passive location method based on time difference of arrival and frequency difference of arrival. In order to improve the positioning accuracy, the position differential and pseudo-range differential method of satellite navigation system is used to correct the positioning error of this system, and the positioning accuracy after the correction is about 5 km. But there is one problem when we use the method. That is, basing on the result of positioning error distribution, positioning error in the band about ±100 km in the direction of the line between the two satellites using time difference of arrival and frequency difference of arrival positioning is very big, and positioning accuracy is very poor or the emitter can't be positioned in that area, which is called blind zone. In order to solve the difficult positioning problem in the blind zone, the reason for the positioning blind zone is given and a new method of multi-epoch time difference positioning is proposed. The results of solving method and simulation show that high positioning accuracy can be obtained by using the multi-epoch time difference method for the positioned emitter in the blind zone, which can effectively solve the problem of blind zone in positioning area.

Keywords: Time difference of arrival, Frequency difference of arrival, Multi-epoch, Time difference, Blind zone.

1. Introduction

Dual-satellite passive location system is based on joint positioning technology of time difference of arrival (TDOA) and frequency difference of arrival (FDOA), simultaneously the time difference and frequency difference information of the same emitter on the ground getting to the two satellites is measured to obtain the location of the signal source. The principle of dual-satellite passive location system basing on TDOA and FDOA is as shown in Fig. 1, where the emitter is T, the two satellites are S1 and S2, the receiving station is A.

Initially, time difference of arrival and direction measurement were used to achieve the positioning [1-2], then the time difference and the frequency difference of positioning technology was researched [3]. Domestic scholars have also carried out algorithm research of the time difference and the frequency difference dual-satellite passive location [4-7]. The positioning accuracy characteristics of the dual-satellite passive location system were also investigated, and positioning accuracy curve is obtained [8]. The influence of relative positions of dual satellites, measurement error of TDOA and FDOA, measurement error of satellite position and velocity on the geolocation accuracy of high and low orbit dual satellites is demonstrated [9].

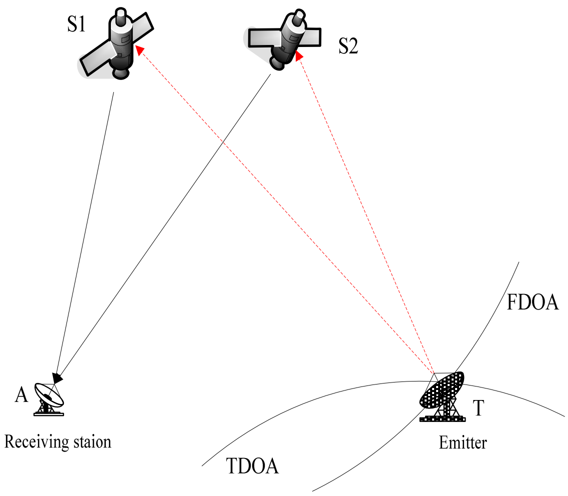

Fig. 1. The principle of dual-satellite passive location system basing on TDOA and FDOA.

Nowadays, positioning accuracy for dual-satellite passive location system can achieve 10 km or so by using current algorithm, which is relatively poor. Therefore differential method is applied to three satellites passive location by some scholars [10], but almost no scholars study differential techniques applying to dual-satellite passive location. The position differential technology of GPS positioning error correction method applied to positioning error correction technology of the dual-satellite passive location is researched for the first time [11]. But the accuracy is poor, and we can use the method unless the distance between the emitter and reference station is within hundreds of kilometer and the GDOP value of the emitter and reference station is close. So combining with pseudo-range differential in the application of GPS, the pseudo-range differential method in Search and Rescue with two satellites is also proposed innovatively [12], and its positioning accuracy is analysed, which has taken a critical step for the study of the passive location and also improves the passive positioning accuracy greatly, but the accuracy is not high enough, and there are some limitations in the application of this method, particularly, which can't be used for some area.

Moreover, basing on the result of positioning error distribution in dual-satellite passive location system, shown in Fig. 2(a) and Fig. 2(b), positioning error in the band about ±100 km in the direction of the line between the two satellites by using TDOA and FDOA positioning equation is so big, and positioning accuracy is very poor or emitter can't be located in that area, which is called blind zone, particularly at the inner sub-satellite point area. In order to ensure that there is no blind zone in the dual-satellite passive location system, it is necessary to solve the problem of positioning for blind zone effectively.

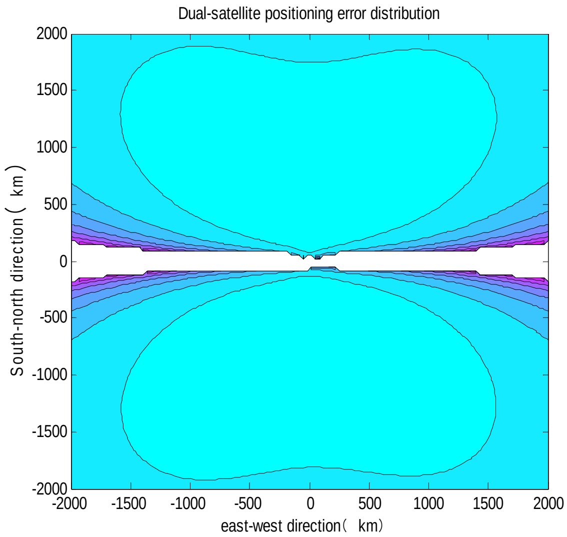

Fig. 2 (a). The result of positioning error distribution in dual-satellite passive location system.

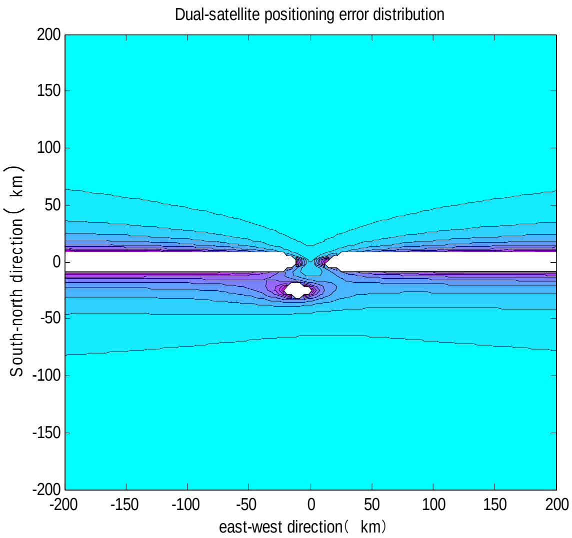

Fig. 2 (b). The result of positioning error distribution in dual-satellite passive location system.

Therefore, we found that the frequency difference error is very big, and it is not proper to use a separate frequency difference location system. While in the inner sub-satellite point area the positioning error caused by the time difference error is the smallest one and the time difference error in the blind zone is smaller than that of the non-blind-zone. A possibility is provided by these analyzes to solve the blind zone location problem by using the TDOA system.

2. The Principle of Multi-epoch Time Difference Positioning

As the satellite motion is continuous, a number of time difference measurements value can be obtained if measuring time difference of arrival of the measured emitter for several times continuously through the passive signal of dual-satellite. Orbit position of the satellites for several epochs can be determined at the same time by using satellite navigation receivers. Based on the principle of time difference measurement, the time difference equation for several epochs can be obtained, then position solution can be obtained, which is called the multi-epoch time difference method.

A set of three positioning equations about time difference can be obtained, assuming three successive epochs,

$$c\Delta t_1 = \sqrt{(x_1^{s1}-x)^2+(y_1^{s1}-y)^2+(z_1^{s1}-z)^2} - +\sqrt{(x_1^{s2}-x)^2+(y_1^{s2}-y)^2+(z_1^{s2}-z)^2} \quad (1)$$

$$c\Delta t_2 = \sqrt{(x_2^{s1}-x)^2+(y_2^{s1}-y)^2+(z_2^{s1}-z)^2} - \sqrt{(x_2^{s2}-x)^2+(y_2^{s2}-y)^2+(z_2^{s2}-z)^2} \quad (2)$$

$$c\Delta t_3 = \sqrt{(x_3^{s1}-x)^2+(y_3^{s1}-y)^2+(z_3^{s1}-z)^2} - \sqrt{(x_3^{s2}-x)^2+(y_3^{s2}-y)^2+(z_3^{s2}-z)^2} \quad (3)$$

In the above formula, superscript S1 and S2 represent the two satellites, the subscript 1, 2 and 3 represent the epoch.

For the above three formulas, partial derivatives on x, y, z respectively, 9 partial derivatives can be obtained, composing of the Jacobian matrix F_x, denote as respectively

$$F_X = \begin{bmatrix} F_{1x} & F_{1y} & F_{1z} \\ F_{2x} & F_{2y} & F_{2z} \\ F_{3x} & F_{3y} & F_{3z} \end{bmatrix}$$

Then,

$$F_{1x} = \frac{x-x_1^{s1}}{r_{11}} - \frac{x-x_1^{s2}}{r_{21}} \quad (4)$$

$$F_{1y} = \frac{y-y_1^{s1}}{r_{11}} - \frac{y-y_1^{s2}}{r_{21}} \quad (5)$$

$$F_{1z} = \frac{z-z_1^{s1}}{r_{11}} - \frac{z-z_2^{s2}}{r_{21}} \quad (6)$$

$$F_{2x} = \frac{x-x_2^{s1}}{r_{12}} - \frac{x-x_2^{s2}}{r_{22}} \quad (7)$$

$$F_{2y} = \frac{y-y_2^{s1}}{r_{12}} - \frac{y-y_2^{s2}}{r_{22}} \quad (8)$$

$$F_{2z} = \frac{z-z_2^{s1}}{r_{12}} - \frac{z-z_2^{s2}}{r_{22}} \quad (9)$$

$$F_{3x} = \frac{x-x_3^{s1}}{r_{13}} - \frac{x-x_3^{s2}}{r_{23}} \quad (10)$$

$$F_{3y} = \frac{y-y_3^{s1}}{r_{13}} - \frac{y-y_3^{s2}}{r_{23}} \quad (11)$$

$$F_{3z} = \frac{z-z_3^{s1}}{r_{13}} - \frac{z-z_3^{s2}}{r_{23}} \quad (12)$$

In the above formula, subscript k of r_{ki} denotes the corresponding satellite k = 1, 2, and the subscript i denotes the corresponding epoch. Its composition matrix is

$$F_x = \begin{bmatrix} F_{1x} & F_{1y} & F_{1z} \\ F_{2x} & F_{2y} & F_{2z} \\ F_{3x} & F_{3y} & F_{3z} \end{bmatrix}$$

Assuming the time difference measured is σ_1, σ_2, σ_3. According to this multi-epoch time difference method, the position of the emitter can be obtained by using the classical Newton iterative method in the Cartesian coordinate system.

3. Experiment Results

Effective satellite orbit data are used for this experiment, three simulation experiments results are given as following:

Simulation experiment 1: Let the satellite height be H, H is less than 1000 km, x_{11}=125, y_{11}=30.1. The distance between x_{i2} and x_{i1} is about 100 km, the distance between y_{i2} and y_{i1} is about 300 m, i=1, 2, 3. Every two epochs are more than 200 km, corresponding satellite orbit of two satellites and the resulting positioning error of emitter for three time epoch as follows:

Epoch i: sat1(i)=[x_{i1} y_{i1} H];

sat2(i)=[x_{i2} y_{i2} H]; $i = 1,2,3$.

The positioning error of the emitter after solution Δx_1 Δy_1 Δz_1 can be obtained.

Simulation experiment 2: Let the satellite height be H, H is less than 1000 km, x_{11}=125, y_{11}=30.1. The distance between x_{i2} and x_{i1} is about 200 m, the distance between y_{i2} and y_{i1} is about 300 m i=1, 2, 3. Every two epochs are less than 100 km, corresponding satellite orbit of two satellites and the resulting positioning error of emitter for three time epochs is similar with experiment simulation 2.

The positioning error of the emitter after solution:

$\Delta x_1 < \Delta x_2 < 1$ km
$\Delta y_1 < \Delta y_2 < 1$ km
$\Delta z_1 < \Delta z_2 < 1$ km

Simulation experiment 3: Let the satellite height be *H*, *H* is less than 1000 km, the satellite ephemeris error is 10 m (accuracy or orbit accuracy measured from the onboard navigation receiver), the two satellites orbit are the same with simulation experiment 2. The resulting positioning error of emitter for three time epoch as follows:

$\Delta x_1 \langle \Delta x_3 \langle \Delta x_2 \langle 1\text{km}$
$\Delta y_1 \langle \Delta y_3 \langle \Delta y_2 \langle 1\text{km}$
$\Delta z_3 \langle \Delta z_1 \langle \Delta z_2 \langle 1\text{km}$

From the above simulation experiments can be shown:

1) The multi-epoch the time difference method can solve the localization problem for the blind zone under the satellite, and the positioning accuracy is high.

2) The time space between epoch chosen should be longer appropriately, positioning effect will be better.

To describe the positioning error distribution, the above equations are transformed by using the geographic coordinate system. In the geographical coordinate system, the position of the emitter can be set to $(x, y, 0)$, the subscript (e, n, u) denotes the north-east-day coordinate system of the geographic coordinate system, and the coordinates of the satellite can be set as $(x_{ei}^k, y_{ni}^k, H), (k=1,2, i=1,2)$, k is the satellite number and i is the epoch number. In the geographical coordinate system, assuming that the satellite height is *H*, since there are only two unknowns, only two epochs are needed to determine the position of the emitter.

Two epochs are used by monitoring the emitter during satellite motion, let

$$r_i^k = \sqrt{(x - x_{ei}^k)^2 + (y - y_{ni}^k)^2 + H^2}$$
k=1, 2, *i*=1, 2

The positioning equation of multi-epoch time difference method is expressed as

$$c\Delta t_1 = \sqrt{(x - x_{e1}^2)^2 + (y - y_{n1}^2)^2 + H^2} - \sqrt{(x - x_{e1}^1)^2 + (y - y_{n1}^1)^2 + H^2}, \quad (13)$$

$$c\Delta t_2 = \sqrt{(x - x_{e2}^2)^2 + (y - y_{n2}^2)^2 + H^2} - \sqrt{(x - x_{e2}^1)^2 + (y - y_{n2}^1)^2 + H^2}, \quad (14)$$

For the above equation, the classical Newton iterative method is used to solve it here. The solving equation is as follows

$$F_1 = \sqrt{(x - x_{e1}^2)^2 + (y - y_{n1}^2)^2 + H^2} - \sqrt{(x - x_{e1}^1)^2 + (y - y_{n1}^1)^2 + H^2} - c\Delta t_1 \quad (15)$$

$$F_2 = \sqrt{(x - x_{e2}^2)^2 + (y - y_{n2}^2)^2 + H^2} - \sqrt{(x - x_{e2}^1)^2 + (y - y_{n2}^1)^2 + H^2} - c\Delta t_2 \quad (16)$$

For the above two expressions, the partial derivative on *x*, *y*. The subscript (e, n, u) represents the North-east-day coordinate system of the geographic coordinate system. Four partial derivatives can be derived from the procedure, composing of the Jacobian matrix F_x, denoting as respectively.

$$F_{1x} = \frac{x - x_{e1}^2}{r_1^2} - \frac{x - x_{e1}^1}{r_1^1} \quad (17)$$

$$F_{1y} = \frac{y - y_{n1}^2}{r_1^2} - \frac{y - y_{n1}^1}{r_1^1} \quad (18)$$

$$F_{2x} = \frac{x - x_{e2}^2}{r_2^2} - \frac{x - x_{e2}^1}{r_2^1} \quad (19)$$

$$F_{2y} = \frac{y - y_{n2}^2}{r_2^2} - \frac{y - y_{n2}^1}{r_2^1} \quad (20)$$

Matrix

$$F_x = \begin{bmatrix} F_{1x} & F_{1y} \\ F_{2x} & F_{2y} \end{bmatrix}$$

Assuming the time difference measured is σ_{t1}, σ_{t2}.

The position solution of the emitter can be obtained by the classical Newton Iteration method.

The simulation results for the blind zone are shown in Fig. 3(a) and Fig. 3(b).

From the above figure, high positioning accuracy can be obtained for the blind zone by using multi-epoch time difference method, which can solve the problem of positioning in blind zone. For practical applications, angle of arrival in the passive direction given by the signal can be used to determine roughly whether the emitter is located in the region which can't be located, which can also be determined by the threshold of the GDOP value. If it is the region which can't be located, using multi-epoch time difference location method, otherwise, using time difference frequency and time difference location method.

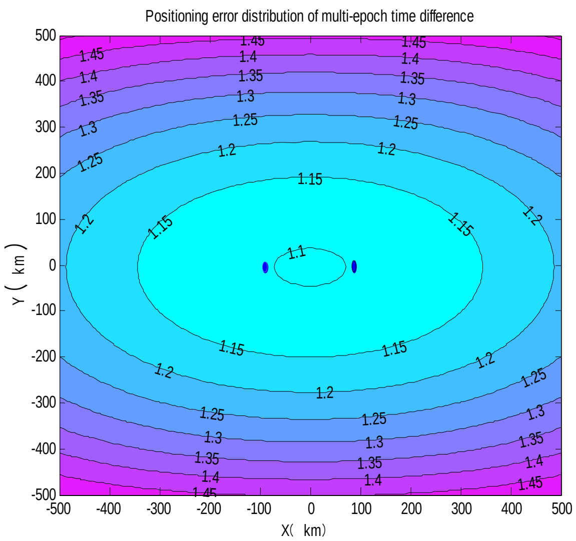

Fig. 3 (a). The positioning error distribution of blind zone by multi-epoch time difference method.

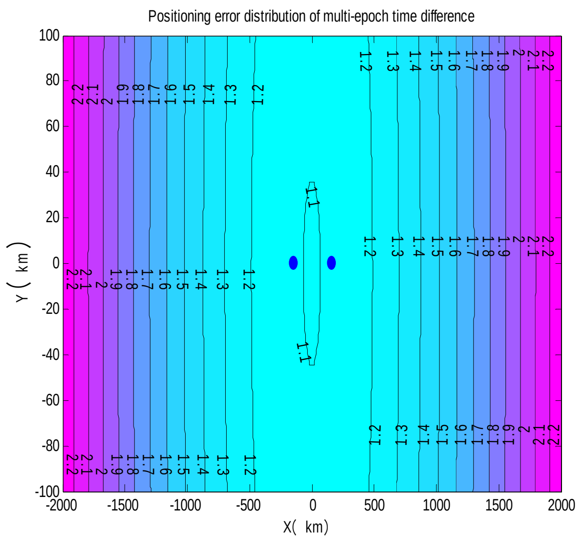

Fig. 3 (b). The positioning error distribution of blind zone by multi-epoch time difference method.

4. Conclusions

In this paper, the cause of blind zone generating is analyzed. In order to solve the problem of positioning in blind zone, a new method of multi-epoch time difference method is put forward to solve the problem of blind zone localization and make up for the defect of TDOA and FDOA location system. The results of resolution and simulation show that high positioning accuracy can be obtained for the blind zone by using multi-epoch time difference method, which can effectively solve the problem of blind zone in the location area.

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References

[1]. Wegner L. H., On the accuracy analysis of airborne techniques for passively locating electromagnetic emitters, Report R-722-PR, *Rand Corp., National Technical Information Service as ASTIA D.C. AD* 729 767, 1971.

[2]. Torrieri D. J., Statistical theory of passive location systems, *IEEE Transactions on Aerospace and Electronic Systems*, Vol. AES-20, Issue 2, 1984, pp. 183-198.

[3]. Ho K. C., Chan Y. T., Geolocation of a known altitude object from TDOA and FDOA measurements, *IEEE Transactions on Aerospace and Electronic Systems*, Vol. 33, Issue 3, 1997, pp. 770-783.

[4]. Zhang Y., Sheng W. D., Guo F. C., *et al.*, Low orbit dual-satellites location algorithm and its precision analysis, *Journal of Chinese Inertial Technology*, Vol. 15, Issue 2, 2007, pp. 188-192.

[5]. Guo F. C., Fan Y., A method of Dual-Satellites geolocation using TDOA and FDOA and its precision analysis, *Journal of Astronautics*, Vol. 29, Issue 4, 2008, pp. 1381-1386.

[6]. Guo F. C., Fan Y., Analysis of dual-satellites geo-location method using TDOA and FDOA, *Aerospace Electron Confront*, Vol. 6, 2006, pp. 20-23.

[7]. Sun G. L., Shen S. T., Ding Z. M., *et al.*, An integration method for passive RDSS and DNS, *Acta Aeronautica et Astronautica Sinica*, Vol. 27, Issue 4, 2006, pp. 682-686.

[8]. Liu Yang, Liu Xiaobo, Analysis of Location Precision in Dual-satellite Passive Location System Based on GDOP, *Journal of Nanchang Hangkong University*, Vol. 31, Issue 4, 2017, pp. 7-13.

[9]. Di Hui, Pan Jinbo, Zhang Guoqiang, Zhao Qinguang, Geolocation Accuracy of High and Low Orbit Satellite by using TDOA and FDOA, *Aerospace Shanghai*, Vol. 35, Issue 8, 2018, pp. 54-59.

[10]. Liu J. Y., Kang G. H., Yue Y. Z., *et al.*, Integrated navigation system of three-star passive Beidou /SINS based on pseudo-range difference, *Journal of Chinese Inertial Technology*, Vol. 15, Issue 4, 2007, pp. 445-448.

[11]. Yanrong Xue, Xiaohui Li, Longxia Xu, *et al.*, Research on Position Differential Method of Dual-satellites TDOA and FDOA in Passive Location System, in *Proceedings of the IEEE International Frequency Control Symposium Proceedings*, Baltimore, USA, 21-24 May 2012, pp. 481-485.

[12]. Yanrong Xue, ShaoJun Feng, Washington Yotto Ochieng, *et al.*, The Improvement of the Positioning Accuracy in Search and Rescue with Two Satellites, in *Proceedings of the 7th China Satellite Navigation Conference (CSNC'16)*, Chang Sha, China, 18-20 May 2016, pp. 255-261.

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