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Research on airborne infrared location technology based on orthogonal multi-station angle measurement method

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ABSTRACT

The passive location method based on angle measurement is studied, the low positioning accuracy and Geometric Dilution of Precision (GDOP) on some target azimuth of dual-station angle measurement location system are founded. Based on the structural characteristics of the airborne platform, an infrared passive angle measurement location method for the single plane is presented. According to the orthogonal method, four measuring stations are loaded onto the airborne platform, they are composed of two orthogonal angle measurement location systems. By choosing the location information of the two systems properly, the GDOP problem can be overcome effectively. Finally, the simulation results show that the method can effectively overcome the GDOP problem and improve the positioning accuracy.

1. Introduction

In modern warfare, anti-radiation missiles, stealth technology and electronic jamming challenge to survive of radar, while the passive infrared detection system with the characteristics of anti-electromagnetic interference and good concealment can take good advantages of passive location, and has become a hotspot [1]. Passive location receives the signal of the radiation source passively, the location of the radiation source is determined according to the time of arrival, bearing and other information of the signal of infrared radiation source [2–4]. The traditional passive location technologies include Time Difference of Arrival (TDOA), Frequency Difference of Arrival (FDOA) and the Angle Difference Location (ADL). Because of the poor direction finding accuracy of the early radar, ADL is seldom used. Along with the development of infrared detectors and the improvement of the direction finding accuracy, people pay more attention to the infrared location system based on angle measurement.

The basic infrared angle measurement location system uses two observation stations to measure the angle information of the target. So the triangulation location can be achieved by calculating the bearing of the target. But in the vicinity of 0° and 180°, the distance accuracy of the target will be severely weakened. This phenomenon is called the GDOP problem. The trinal-station and multi-station location mentioned in [5] solved the GDOP problem, but there are still some problems, such as a large amount of computation, complex data fusion and hard to realize. This paper studies the dual-station triangulation positioning principle, and analyzes the positioning accuracy and the GDOP problem. This method is applied to airborne infrared detection system. Combined with the characteristics of the airborne platform, an airborne orthogonal infrared passive location model is proposed for a single plane. The approximate model can simplify the calculation process, eliminate the GDOP problem, and improve the positioning accuracy; Because of the flexibility of the airborne platform, the poor mobility of the traditional fixed dual-station can be overcome.

2. Positioning principle of dual-station angle measurement

The traditional dual-station location uses two fixed observation stations. The azimuth of the target can be determined by measuring the angle information of the target. According to the positioning principle of human's eyes and the triangular relationship of the target and two observation stations, the distance of the target can be obtained. Its principle is shown in Fig. 1.

The target is located in T, the two infrared sensors are located in A and C respectively, the distance between T and A is R_1, and the distance between T and C is R_2. The middle point (B) of AC is the reference point, and the distance from T to B is R. Fig. 1 shows a variety of angular dependence. For ease of analysis, the following assumptions are made in this model:

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(1) The length of AC is L, and there is no error in the measurement of it;
(2) $\Delta\theta_1$ and $\Delta\theta_2$ are the errors of the infrared detectors in azimuth measurement, and they have been known;
(3) The difference between the horizontal path distance and slant path distance is ignored.

From Fig. 1, we can get:

$$\theta_3 = \theta_2 - \theta_1 = \theta_4 + \theta_5 \tag{1}$$

So:

$$\sin(\theta_2 - \theta_1) = \sin\theta_4 \cos\theta_5 + \cos\theta_4 \sin\theta_5 \tag{2}$$

It can be obtained by the triangle sine theorem:

$$\begin{cases} \dfrac{R}{\sin\theta_2} = \dfrac{L/2}{\sin\theta_4} \\ \dfrac{R}{\sin\theta_1} = \dfrac{L/2}{\sin\theta_5} \end{cases} \tag{3}$$

Then:

$$\sin(\theta_2 - \theta_1) = \frac{L}{2R}\left[\sin\theta_2\sqrt{1-\left(\frac{L}{2R}\sin\theta_1\right)^2} + \sin\theta_1\sqrt{1-\left(\frac{L}{2R}\sin\theta_2\right)^2}\right] \tag{4}$$

So:

$$R = \frac{L}{2}\left[\frac{\sin\theta_2\sqrt{1-\left(\frac{L}{2R}\sin\theta_1\right)^2} + \sin\theta_1\sqrt{1-\left(\frac{L}{2R}\sin\theta_2\right)^2}}{\sin(\theta_2-\theta_1)}\right] \tag{5}$$

R can be obtained by the formula (5) [6].The position of the target can be easily determined by the distance R, the measured azimuth angle and the position of the carrier craft.

3. Analysis of the dual-station positioning accuracy

It can be known from formula (5) that R/L is a function of the azimuth angle θ_1 and θ_2, so the expression of distance sensitivity can be obtained:

$$\frac{\Delta R}{R} = f_1(\theta_1, \theta_2)\Delta\theta_1 + f_2(\theta_1, \theta_2)\Delta\theta_2 \tag{6}$$

According to [6], the standardized variation of R can be obtained:

$$\left(\frac{\Delta R}{R}\frac{1}{\Delta\theta}\right) = \left\{\frac{\sqrt{1-\left(\frac{L}{2R}\sin\theta_2\right)^2}[\cos\theta_1 + \sin\theta_1\cot(\theta_2-\theta_1)] + \sin\theta_2\sqrt{1-\left(\frac{L}{2R}\sin\theta_1\right)^2}\left[\cot(\theta_2-\theta_1) - \frac{\left(\frac{L}{2R}\right)^2\sin\theta_1\cos\theta_2}{1-\left(\frac{L}{2R}\sin\theta_1\right)^2}\right]}{\sin\theta_2\sqrt{1-\left(\frac{L}{2R}\sin\theta_1\right)^2} + \sin\theta_1\sqrt{1-\left(\frac{L}{2R}\sin\theta_2\right)^2}}\right\} \bullet \gamma_1 + \left\{\frac{\sqrt{1-\left(\frac{L}{2R}\sin\theta_1\right)^2}[\cos\theta_2 - \sin\theta_2\cot(\theta_2-\theta_1)] - \sin\theta_1\sqrt{1-\left(\frac{L}{2R}\sin\theta_2\right)^2}\left[\cot(\theta_2-\theta_1) + \frac{\left(\frac{L}{2R}\right)^2\sin\theta_2\cos\theta_2}{1-\left(\frac{L}{2R}\sin\theta_2\right)^2}\right]}{\sin\theta_2\sqrt{1-\left(\frac{L}{2R}\sin\theta_1\right)^2} + \sin\theta_1\sqrt{1-\left(\frac{L}{2R}\sin\theta_2\right)^2}}\right\} \bullet \gamma_2 \bullet \alpha \tag{7}$$

This is the standardized distance sensitivity formula, γ_1 and γ_2 are independent random variables with the same standard deviation, and their means are zero; α represents the ratio of root mean squares of $\Delta\theta_1$ and $\Delta\theta_2$. According to [7], a conservative approximation analysis method is used: $\left|\frac{\Delta R}{R}\frac{1}{\Delta\theta}\right|$ represents the distance accuracy. $\left|\frac{\Delta R}{R}\frac{1}{\Delta\theta}\right| = \sqrt{m^2+n^2}$, m represents the sensitivity coefficient of γ_1, and n represents the sensitivity coefficient of γ_2. Assume that $\Delta\theta_1$ is equal to $\Delta\theta_2$, so α is equal to 1. Take R/L as 10, 100 and 1000 respectively, then the ranging sensitivity curves can be obtained as shown in Fig. 2 by using MATLAB.It can be seen from Fig. 2 that the distance sensitivity is the highest in the vicinity of 0° and 180°, so the location error caused by angle measurement in the two azimuths is the largest, this is the GDOP problem. The farther the distance between the target and the line which two sensors located in, the larger the error of the distance measurement, and the lower the positioning accuracy. In a certain range, the farther the distance between the two stations, the higher the positioning accuracy.

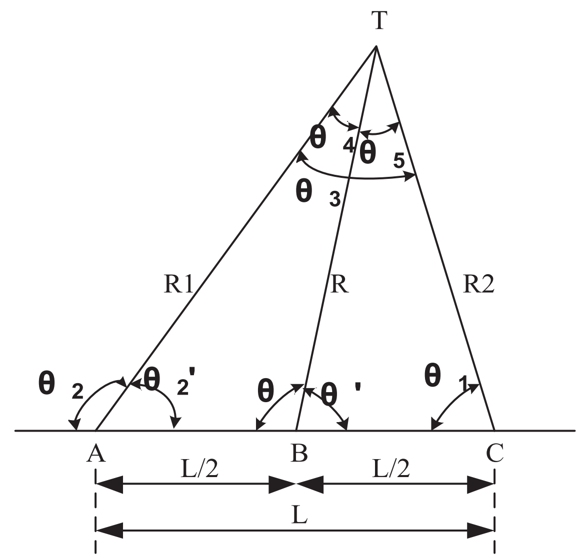

Fig. 1. Positioning principle of dual-station angle measurement.

4. Location model of airborne orthogonal multi-station infrared angle measurement for a single plane

In order to solve the GDOP problem of the dual-station location model, the most direct method is to use multi-station angle measurement data fusion. Ref. [5] mentioned the method of isosceles trinal-station for the ground and shipborne observation stations. Considering the characteristics of aircraft platform, the location model of airborne infrared detectors based on orthogonal quadri-station angle measurement is given, as shown in Fig. 3.