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Rate of Phase Difference Change Estimation in Single Airborne Passive Locating System

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Abstract

As an important parameter in the single airborne passive locating system, the rate of phase difference change contains range information of the radio emitter. Taking single carrier sine pulse signals as an example, this article illustrates the principle of passive location through measurement of rates of phase difference change and analyzes the structure of measurement errors. On the basis of the Cramér-Rao lower bound (CRLB), an algorithm associated with time-chips is proposed to determine the rates of phase difference change. In the measurement of the rates of phase difference change, phase discrimination in the frequency domain outperforms that in the time domain when signal noise rate (SNR) is lower. Multi-chip processing can significantly reduce variance of the measurement of rates of phase difference change. Simulations demonstrate the validity and accuracy of the proposed algorithm. The simulations carried out on the typical single airborne passive location have proved its adaptability to dynamic measurements. The proposed algorithm to determine the rates of phase difference change proves simple and easy to implement with less computation workload.

Keywords: location; rate of phase difference change; Cramér-Rao lower bound; phase discrimination; multi-chip processing

1. Introduction

Passive location is a technique that locates the target emitter through receiving its radio wave without emitting any radio signals during operation. It is characterized by long effective distance, electromagnetic silence, and undetectable possibility. It has long been an indispensable part of an integrated air defense system and long distance airborne warning system either on land or on sea. Meanwhile, it is a key means to develop marine, aeronautic, astronautic, detection, tracking, and geographical sciences and technologies.

It is required to acquire parameters carrying the location information of the target emitter from the received signals by means of the kinematics-based passive locating and tracking algorithm[1]. Ref.[2] put forward a method to locate a single station through arriving time and direction of a signal as well as its changing rate. Ref.[3] presented a method on the ground of Doppler rate of change. Refs.[4-7] studied passive locating techniques using rates of phase difference change and analyzed the accuracy in determining the rates of phase difference change. All the above methods focused the attention on the full utilization of the information involved in radio signals about the position of the target emitter so as to quickly and accurately locate the emitter itself. This makes accurate acquisition of parameters one of the key techniques in passive locating system.

Ref.[8] suggested two methods: One is to measure the integer ambiguity during a fixed length of time, and the other is to measure the phase difference of dual-channel signals and obtain the rate of phase difference change through further frequency estimation. The former needs a time length of about 10 s and its accuracy is quite poor. The latter requires high consistency among the dual-channel signals and there exists phase ambiguity. Ref.[5] pointed out that the narrow width of the pulse and the extra-low value of the rate of phase difference change are the main reasons for the

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difficulty in measurement, and he suggested to use orthogonal phase shift to transform the received signal into the complex signal and then determine it by maximum likelihood (ML). Although the variance of estimation reaches the Cramér-Rao lower bound (CRLB), it is not practicable to implement owing to the large computational workload. After comparing the existing methods to measure the rates of phase difference change, Ref.[9] pointed out that the basic assumption they were based on is too ideal to be applied in engineering implementation. This article, after analyzing CRLB of rates of phase difference change, develops a multi-chip method based on multiple observations with full exploitation of phase coherence. This method proves to have high accuracy and less computational complexity as well as practical feasibility.

2. Principles of Single Airborne Passive Location

2.1. Principles of single airborne passive location based on rates of phase difference change

When there is a relative motion existing between observation platforms, i.e. the airborne vehicle and the target emitter, the angles of a received signal to be measured are steadily changing variables, which comprise the information about the range from the emitter to the airborne receiver. To simplify the exposition of the principles, the sine law can be used in 2D plane.

Assume that the position of a target emitter is fixed, the airborne observer moves in a straight line at a constant speed, v, and the azimuth of the emitter is β. After a length of time, dt, the measured azimuth is β+dβ, and the distance between the emitter and the airborne observer is R (see Fig.1).

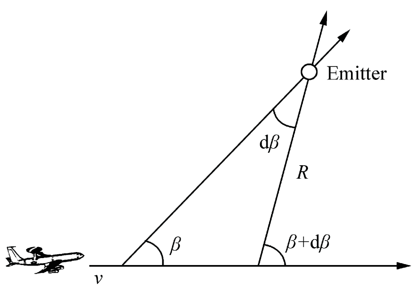

Fig.1 Rate of angle change in terms of geometrics.

From the sine law, the following can be achieved[8]

$$\frac{R}{\sin\beta}=\frac{v\mathrm{d}t}{\sin \mathrm{d}\beta} \tag{1}$$

Eq.(1) can be rewritten as

$$R=\frac{v\sin\beta}{\sin \mathrm{d}\beta/\mathrm{d}t}\approx\frac{v\sin\beta}{\mathrm{d}\beta/\mathrm{d}t}=\frac{v\sin\beta}{\dot{\beta}} \tag{2}$$

From Eq.(2), it can be understood that the distance R can be obtained given the speed of the airborne observer v, the azimuth of the emitted radio signals β, and the rate of azimuth change $\dot{\beta}$. Thus, with the distance R and the azimuth β known, the location of the target emitter is realized. Here, $\dot{\beta}$ is the key parameter. Several methods are available to acquire azimuth β, the typical one is called the instant locating method. It is a through measurement of the phase difference of the received signal using an interferometer. In this case, the measurement of azimuth is converted into determination of phase differences, and the rate of azimuth change into the rate of phase difference change.

In Fig.2, E_a and E_b are two antennas of the airborne interferometer, $\phi(t)$ is the phase difference of the received signal, then

$$\phi(t)=\omega_T\Delta t=\frac{2\pi d}{c}f_T\cos\beta(t) \tag{3}$$

where ω_T is the angular frequency of the signal, Δt the time difference of the signal arriving at both antennas, d the length of the base line of the interferometer, c the light speed, f_T the signal frequency, and $\beta(t)$ the azimuth of the radio wave, it is a time-varying parameter.

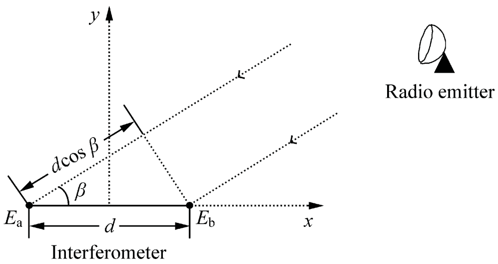

Fig.2 From azimuth difference to phase difference.

The derivative of Eq.(3) is

$$\dot{\phi}(t)=-\frac{2\pi d}{c}f_T\sin\beta(t)\cdot\dot{\beta}(t) \tag{4}$$

where

$$\dot{\phi}(t)=\frac{\mathrm{d}\phi(t)}{\mathrm{d}t}$$

$$\dot{\beta}(t)=\frac{\mathrm{d}\beta(t)}{\mathrm{d}t}$$

Let $k=-\frac{2\pi d}{c}$, then Eq.(3) is simplified into

$$\dot{\phi}(t)=kf_T\sin\beta(t)\cdot\dot{\beta}(t) \tag{5}$$

Obviously, Eq.(5) can easily be transformed into

$$\dot{\beta}(t)=\frac{\dot{\phi}(t)}{kf_T\sin\beta(t)} \tag{6}$$

Substituting Eq.(6) into Eq.(2), we can obtain

$$R=\frac{kvf_T\sin^2\beta(t)}{\dot{\phi}(t)} \tag{7}$$

From Eq.(7), it can be concluded that given the informative parameters of the moving airborne observer, the passive location of the target emitter can be accomplished with the measured values of β, $\dot{\phi}$, and f_T.