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Passive Track and Location Method with TDOA for Moving Target

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Abstract

Aiming at the problem of passive tracking of moving target, this paper establishes a mathematical model for the multi station time difference location and passive tracking of the moving radiation source and proposes a passive tracking algorithm based on extended Calman filter (Kalman Filter Extended, EKF). At first, the two order constant velocity motion model is established, the initial value and the initial co-variance of the Cal-man filter are used as the initial value and the initial co-variance of the system. The simulation results show that the extended Cal-man filter is used to achieve the real-time results of the time difference location. The positioning accuracy is greatly improved, and the target trajectory is more obvious. The tracking results can be approximate. Finally, the effectiveness of the proposed algorithm is verified by the engineering experiments.

Keywords*: Passive location; Time difference; Passive tracking; Extended Cal-man filter*

1. Introduction

With the continuous development of information technology, passive location system by passive surveillance collection target's radiation source signal target detection, recognition and positioning, the system itself does not radiate electromagnetic wave, electromagnetic concealment, survival ability strong and so on characteristics [1-5]. Multi station passive location system can obtain the target information in real time and accurately by using the passive detection information of multiple stations. With the development of the idea of "network centric warfare", the passive location system based on data link is becoming an important research direction of [6-8]. Time difference location is a very mature technology of multi station passive location method. The Difference of Arrival TDOA (Time) parameters are obtained by processing the [9,11] TDOA () parameters in the time series of the received signals from multiple stations. TDOA location technology is already quite mature technology, this article will not repeat them, the research emphasis of this thesis is to put in the passive tracking of moving targets. Passive target localization and tracking is a nonlinear filtering problem, which is derived from the nonlinear state equation and the nonlinear of the equation and the non - Gauss property of the correlation noise process. [12,13]. The classical Cal-man filter is mainly used to solve the linear model. In addition to the individual case, the optimal filter for nonlinear system has infinite number of dimensions, which is not practical in engineering. The extended Cal-man filter (Extended, Kalman Filter EKF) is used to describe the nonlinear problem of the local linearization of the nonlinear problem [14,15].

The actual tracking filter problem of EKF filtering method has irreplaceable advantage. It includes two aspects: first, the model is simple and easy to be accurately modeled in engineering practice. The filtering performance of the filter is often caused by the model error and the improvement of the performance of the filter is "drowned" in the error and noise, and the improvement of the performance is not significant [16-18]. Another reason

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is that the principle and calculation of EKF filtering method is simple, and can achieve real-time tracking of maneuvering targets.

2. Passive Tracking Algorithm for Moving Target

The target motion model is divided into two major categories: one is the non maneuvering target model, which is based on the two Velocity Constant (CV) model and the three order Acceleration CA (Constant) model; the other is the maneuvering target model [15,18]. In this paper, we establish the model of the target motion model, which is the most simple uniform linear motion model.

$$\mathbf{X}_{k+1} = \mathbf{\Phi}_{k+1,k}\mathbf{X}_k + \mathbf{\Gamma}\mathbf{v}_k \quad (1)$$

$$\mathbf{\Phi}_{k+1,k} = \begin{bmatrix} \mathbf{I}_3 & T\mathbf{I}_3 \\ 0 & \mathbf{I}_3 \end{bmatrix} \quad (2)$$

For the target state vector, $\mathbf{X}_k = \left[x_k, y_k, z_k, \dot{x}_k, \dot{y}_k, \dot{z}_k\right]^T$ the position coordinates of the radiation x_k, y_k, z_k $\dot{x}_k, \dot{y}_k, \dot{z}_k$ source are the components of the radiation source x_k, y_k, z_k in the direction of the axis, $\mathbf{\Phi}_{k+1,k}$ x, y, z and the state transfer matrix is a three-dimensional array, T is observing period, $\boldsymbol{\Gamma} = \begin{bmatrix} \dfrac{T^2}{2}\boldsymbol{I}_3 \\ T\boldsymbol{I}_3 \end{bmatrix}^T$ $\boldsymbol{v}_k = \left[v_{k1}, v_{k2}, v_{k,3}\right]^T$ which is the Gauss noise, v_{k1} v_{k2} v_{k3} which is independent of each other, $v_{ki} \sim \mathrm{N}\left(0, \sigma_v^2\right)$. The co-variance matrix of the state noise is expressed as

$$\mathbf{Q}_k = \mathrm{E}\left[\mathbf{\Gamma}\mathbf{v}_k\mathbf{v}_k^T\mathbf{\Gamma}^T\right] = \mathbf{\Gamma}\sigma_v^2\mathbf{\Gamma}^T = \begin{bmatrix} \frac{1}{4}T^4\mathbf{I}_3 & \frac{1}{2}T^3\mathbf{I}_3 \\ \frac{1}{2}T^3\mathbf{I}_3 & T^2\mathbf{I}_3 \end{bmatrix}\sigma_v^2 \quad (3)$$

The observation equation is

$$\mathbf{Z}_k = \mathrm{G}\left(\mathbf{X}_k\right) + \mathbf{N}_k \quad (4)$$

Among them, $\mathbf{Z}_k$ the measurement is the dimension of the measurement m noise is independent of the Gauss white noise $\mathbf{N}_k$, $\mathbf{G}\left(\mathbf{X}_k\right)$ which is a nonlinear function vector $\mathbf{R}_k = diag\left[\sigma_{k1}^2, \sigma_{k2}^2, \cdots, \sigma_{km}^2\right]$.

The filtering equation of EKF algorithm is as follows:

Forecast equation

$$\mathbf{X}_{k/k-1} = \mathbf{\Phi}\mathbf{X}_{k-1} \quad (5)$$

Forecast co-variance

$$\mathbf{P}_{k/k-1} = \mathbf{\Phi}\mathbf{P}_{k-1/k-1}\mathbf{\Phi}^T \quad (6)$$

Kalman gain for

$$\mathbf{K}_k = \mathbf{P}_{k/k-1}\mathbf{H}_k^T\left[\mathbf{H}_k\mathbf{P}_{k/k-1}\mathbf{H}_k^T + \mathbf{R}_k\right]^{-1} \quad (7)$$

Filtering equation for

$$\mathbf{X}_k = \mathbf{X}_{k/k-1} + \mathbf{K}_k\left(\mathbf{Z}_k - \mathrm{G}\left(\mathbf{X}_{k/k-1}\right)\right) \quad (8)$$

Filtering co-variance

$$\mathbf{P}_k = \left[\mathbf{I} - \mathbf{K}_k\mathbf{H}_k\right]\mathbf{P}_{k/k-1}\left[\mathbf{I} - \mathbf{K}_k\mathbf{H}_k\right]^T + \mathbf{K}_k\mathbf{R}\mathbf{K}_k^T \quad (9)$$

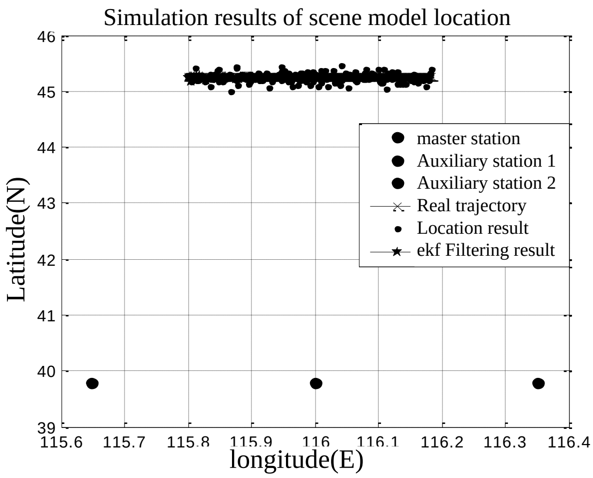
In the formula: $\mathbf{H}_k = \left.\frac{\partial \mathbf{G}(\mathbf{X})}{\partial \mathbf{X}}\right|_{\mathbf{X}=\mathbf{X}_{k/k-1}}$ for measurement of jacobian matrix of the equation in the forecasting point $\mathbf{X}_{k/k-1}$.

$\mathbf{X}_0, \mathbf{P}_0$ Multi station time difference locating results can be used as the initial value of the tracking process, and the real-time tracking of moving target can be realized by recursive procedure.

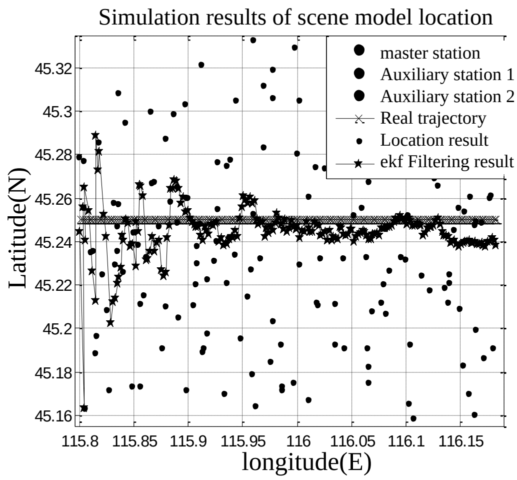
3. Digital Simulation and Analysis

In this section, we analyze the performance of moving target tracking by using EKF filtering algorithm.

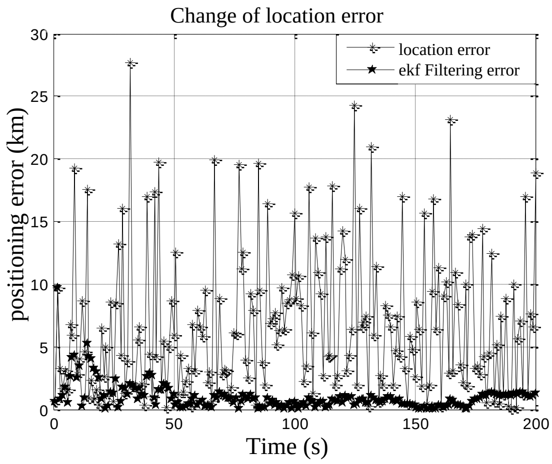
If the three observation stations are a type of station, the baseline length of the station is 30km, the target radiation source is uniform and linear motion, the velocity is 300m/s, the distance of the target distance is about 600km. Time difference measurement error standard deviation is 50ns, observation station absolute error of 15m, standing between relative error is 5m, target altitude 5 km, 1 km of altitude error, observation time is 100s. The target is to carry on the three station time difference location, and then the target track is more obvious and the tracking effect is achieved by EKF filtering. The location and location results are shown in Figure 1.



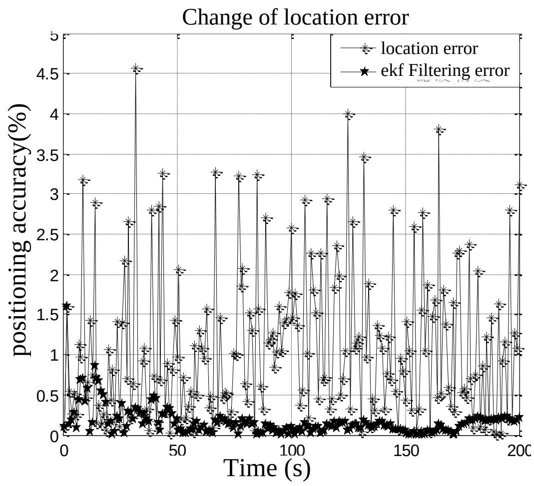
(a) Simulation scenarios and positioning results



(b) Localization results in local amplification



(c) Positioning and filtering errors



(d) Positioning and filtering accuracy

Figure 1. Simulation Scene Location and Filtering Results

From Figure 1 (b), it can be known that due to the random distribution of the error of time difference measurement, the instantaneous location results are randomly distributed around the true value. After the EKF filter, the target tracking is more clear. By (c), (d), the instantaneous position error is about 10km, the positioning accuracy is about 1.5%, and the tracking error is stable in 3km after filtering 10s, tracking precision is within 0.5%.

On the motion scene it was repeated 200 times Monte Carlo simulation, which was the target of the tracking error curve as shown below.

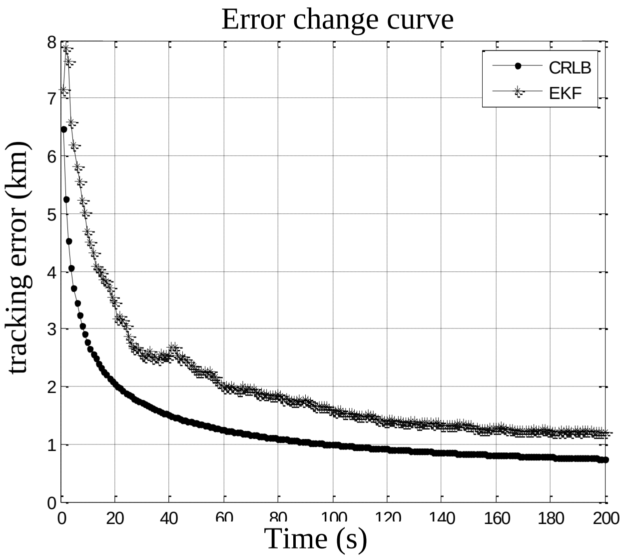


Figure 2. Monte Carlo Simulation 200 Times the Tracking Error Curve

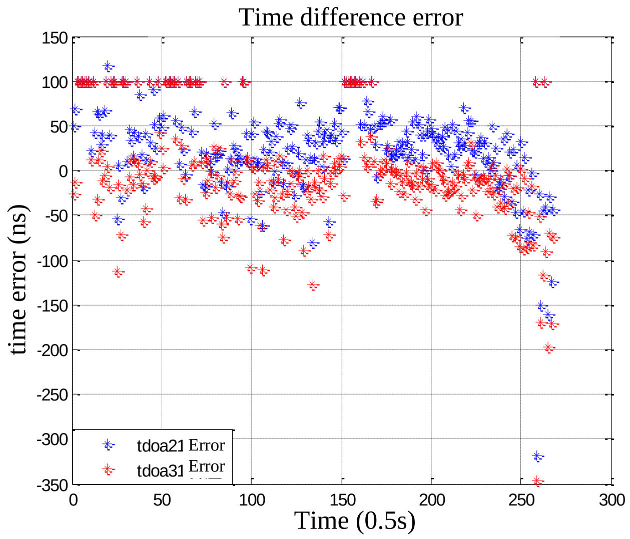
By Figure2, it can be traced in the scene after10 seconds after tracking error can reach 3km, and finally stable at around 1km. With the increase of the observation time, the tracking curve can be close to the tracking error of CRLB.

4. Engineering Test Verification

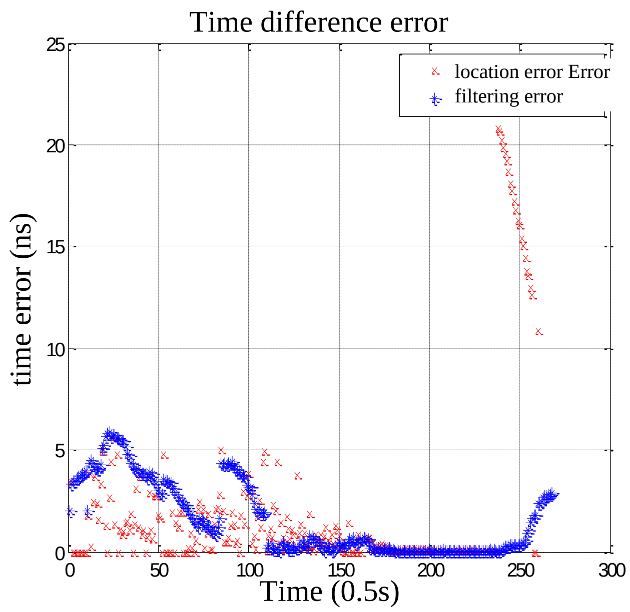
In order to further verify the effectiveness of the proposed algorithm, the engineering application value of the algorithm is tested, and the actual observation data of the three station time difference location system is processed by using the method.

The experimental scene is three ground observation station to carry on the observation and positioning of the airborne moving source. In the experiment, the target radiation source is narrow beam fan and the sweeping angle range is $-30^{\circ} \sim 30^{\circ}$. The three stations are located in a triangular configuration, $(39.7504^{\circ}\text{N},116.1214^{\circ}\text{E})$ and the two stations are located at the position of the station $(39.7818^{\circ}\text{N},116.1320^{\circ}\text{E})$ $(39.7839^{\circ}\text{N},116.1676^{\circ}\text{E})$. The altitude of observation station is about 55m, the line length are 3.6km 5.4km, the target height is 1.37km, the target is from far and near to the subjective test station. The target trajectory can be provided by the airport cooperation unit after the experiment, and it is easy to be processed and analyzed afterwards. The test data observation time is about 2 minutes, the source of the subjective measurement station about 11.66km~1.38km.

The difference between the 1 and the main station, the difference of the time difference between the secondary station2 and the main station are-21.31ns and 18.23ns respectively, and the difference is 44.54ns and 41.7ns respectively. Two way time difference error curves are shown in Figure 3 (a). The time difference error is recorded as 100ns in the graph. The positioning and tracking error curves are shown in Figure 3 (b).



(a) Two way time difference error



(b) Positioning and tracking error curve

Figure 3. Two-way Difference Error and Positioning, Tracking Error Curve

From Figure 3 (b) it can be seen after the use of EKF filter tracking precision is obviously due to the instantaneous positioning accuracy, tracking results more smooth and continuous. Tracking the beginning of poor positioning effect, most of the tracking error of about tracking accuracy of about 30%, after 100 packet data (packet data every 0.5s) track the performance becomes better, the tracking error is reduced to a few hundred meters or tens of meters tracking accuracy of about 1%.

According to the test station configuration cloth, using time difference measurement error in the test digital simulation, get the positioning error distribution as shown in Figure 4.

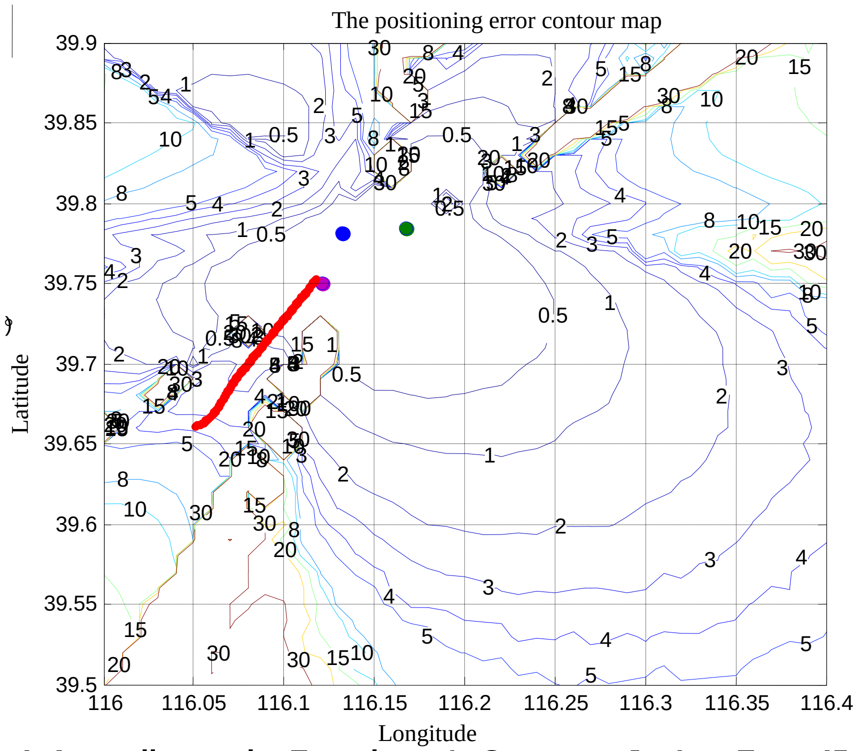


Figure 4. According to the Experiment's Geometry Jet Lag Error 45 ns and 40 ns Respectively Under the Condition of Positioning Error Distribution

From Experimental results and simulations from four comparison chart, what you can see in the simulation target's trajectory is about the most distant position error 4km, it also about 4km observation data processing based on the positioning error, the error is caused by differences in random jitters time difference. With the objective observation station movement toward positioning errors are gradually reduced, consistent test results and simulation results.

5. Conclusion

This paper studies the multi-station TDOA Location tracking some of the key technologies in this typically passive positioning technology. The establishment of a multi-station time difference moving emitter location and tracking of a mathematical model, the EKF filtering algorithm are applied to passive tracking moving objects, and the sports scene simulation and Monte Carlo simulation, so as to form analysis of the tracking features EKF algorithm. Finally, through the engineering test data analysis, it verifies the effectiveness of the proposed algorithm.

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