Frontiers in Signal Processing, Vol. 4, No. 1, January 2020
https://dx.doi.org/10.22606/fsp.2020.41008

A Distance Azimuth Tracking Algorithm Based on Alpha-beta Filtering

HE Yong-qing[1], PENG Liang-fu[1*], LING Yun-song[2] and QUAN Yu[1]

[1] College of Electrical Information Engineering, Southwest Minzu University, China
[2] College of Automation, University of Electronic Science and Technology of China, China
Email: 1377994955@qq.com

Abstract. When monitoring and tracking the relative distance and the azimuth angle between the host and the target aircraft, a traffic collision avoidance system (TCAS) needs to filter observed relative distance and azimuth angle using a Kalman filter. For the target of uniformly moving aircraft, the α-β filter algorithm is employed in general. In order to improve the filtering effect of α-β filtering algorithm, an improved filtering algorithm is presented in this paper. The algorithm not only considers the residual in direction of range, but also considers the residual in orthogonal direction of range. The calculation formula of range azimuth tracking filtering algorithm is derived according to the azimuth angle and the relative distance between the host and target aircraft, by projecting under rectangular coordinate system, considering both the residuals in direction of range and the orthogonal direction of range. The filtering effect of the algorithm has been verified by the Monte Carlo simulation carried out in MATLAB. The experiment results show that, in comparison with α-β filtering algorithm, this algorithm retains the advantage of lower computation cost of α-β filtering, and meanwhile achieves smaller estimate errors and better filtering effect.

Keywords: target tracking, alpha-beta filtering, direction residual, distance azimuth tracking filter, matlab simulation.

1 Introduction

In the collision avoidance logic of the traffic collision avoidance system (TCAS), it is necessary to monitor and track the target aircraft [1]. The main observation for monitoring and tracking the target aircraft is the relative distance and azimuth angle between the aircraft and the target aircraft. By processing the observed values of the relative distance and azimuth angle of the target aircraft, the track information of the target aircraft is formed, so as to achieve the tracking of the target aircraft [2-3]. Therefore, relative distance and azimuth angle need to be filtered in engineering, and the commonly used filter is kalman filter [4-5]. Due to the large amount of work in calculating the gain matrix in kalman filter, in order to reduce the calculation amount of the gain matrix, alpha-beta filtering is generally adopted for the uniform motion (CV) model [6]. In order to improve the filtering effect and reduce the filtering error, a range azimuth tracking filtering algorithm based on alpha beta filtering is proposed.

For the measurement of the filter system in polar coordinate system, when constructing the filter equation, the state vector can take either rectangular coordinate vector or polar coordinate vector. The former will face the nonlinear problem of measurement equation and the latter will face the nonlinear problem of state equation. After extended kalman filter, the estimation accuracy of the two methods is basically the same [7]. In rectangular coordinate system, measurement errors are coupled with each other. If decoupling filter in x and y direction is used instead of coupling filter, tracking accuracy will be reduced. However, in practical engineering applications, rectangular coordinate system is often decoupled and the resulting error can be ignored [8]. Therefore, the range-azimuth tracking filter proposed in this paper adopts rectangular coordinate system. Firstly, the measured values in the polar coordinate system are converted into cartesian coordinate system, and the relative distance and azimuth are directly projected onto the x and y directions respectively. Then kalman filter is used to filter the data after coordinate transformation.

2 Alpha-beta Filtering Algorithm

α-β filter is a constant gain filter for the target uniform velocity motion model (CV) [9]. In general, the following assumptions are made: the target is moving at a uniform speed and the noise is observed smoothly. Let x and $\dot{x}$ be the position vector and velocity vector of the moving target respectively. At this time, the state vector is $X = [x, \dot{x}]^T$, then the state equation of the target is:

$$\hat{X}_{k+1} = A\hat{X}_k + Cu_k \tag{1}$$

where, $\hat{X}_{k+1}$ represents the estimated value of system state X_{k+1} obtained by α-β filter at k+1.

State transition matrix $A = \begin{bmatrix} 1 & T \\ 0 & 1 \end{bmatrix}$. Input relation matrix $C = \begin{bmatrix} T^2/2 \\ T \end{bmatrix}$. Process noise u_k is gaussian white noise with variance $Q = E\left[u(k)u(k)^T\right]$ and mean zero. The expression of the observation equation is:

$$Z_k = DX_k + v_k \tag{2}$$

where: Z_k represents the position observation quantity of the system at moment k. Measurement matrix $D = \begin{bmatrix} 1 & 0 \end{bmatrix}$. Measurement noise v_k is white gaussian noise with mean zero and variance $O = E\left[v(k)v(k)^T\right]$. The filtering equation is:

$$\hat{X}\left(k/k\right) = \hat{X}\left(k/k-1\right) + H\left[Z\left(k\right) - D\hat{X}\left(k/k-1\right)\right] \tag{3}$$

$$\hat{X}\left(k/k-1\right) = A\hat{X}\left[\left(k-1\right)/\left(k-1\right)\right] \tag{4}$$

$$H = \left[\alpha, \beta/T\right]^T \tag{5}$$

where H is the gain matrix.

Since the selection of Q and O will affect the accuracy of the filter, and α and β are directly related to Q and O, the selection of alpha and beta must take into account Q and O, namely noise characteristics and dynamic performance. Meanwhile, according to various optimization rules, the following formula is commonly used as the parameters of α and β in engineering practice [10].

$$\alpha\left(k\right) = \frac{2\left(2k-1\right)}{k\left(k+1\right)}, \quad \beta\left(k\right) = \frac{6}{k\left(k+1\right)} \tag{6}$$

3 Range Azimuth Tracking Filter Algorithm

The range azimuth tracking filter algorithm is based on the α-β filter. In the rectangular coordinate system, relative distance R is projected on the x and y directions according to the azimuth Angle, and then the x and y directions are filtered respectively, so as to achieve the tracking of moving targets.

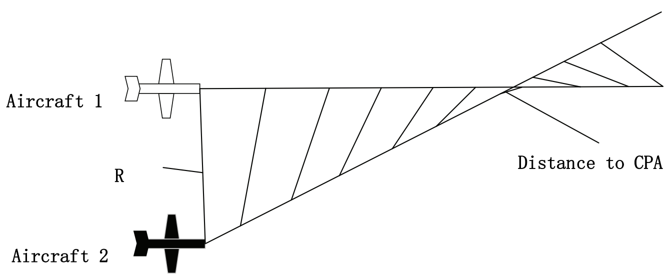


Figure 1. The closest distance between two points

In TCAS, the closest distance between two aircraft is the relative diagonal distance when the two aircraft reach the closest point. As shown in figure 1, the relative distance R between the two aircraft is located on an inclined plane connecting the two aircraft. According to the azimuth Angle between the two aircraft, the relative distance is projected on the x and y directions on the inclined plane, thus turning the collision avoidance problem of three-dimensional space aircraft into that of two-dimensional inclined plane [11]. Set up a rectangular coordinate system with the origin of aircraft 1 on the inclined plane, as shown in figure 2.

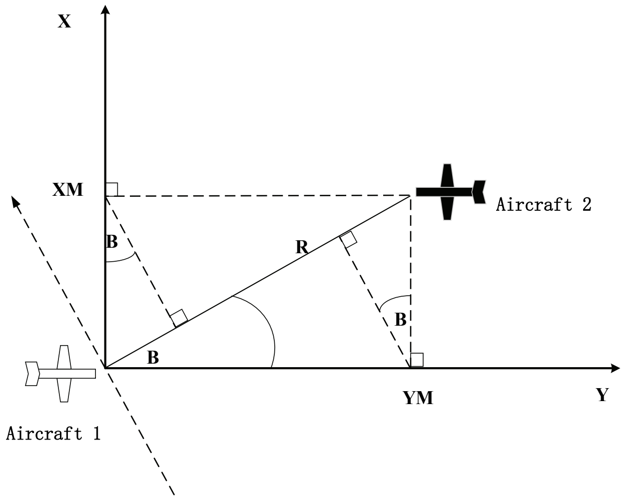


Figure 2. Projection diagram of distance azimuth target tracking

In figure 2, aircraft 1 is used as the observation point. Aircraft 2 as target. R is the relative distance between the observation point and the target. B is the observed azimuth angle. According to the echo data of target motion, the target is known to do uniform acceleration motion, and then the system model is established.

First, the system model is used to predict the target at time k, and coordinate transformation is carried out to project the position of the target onto the x and y directions in the rectangular coordinate system. If the distance predicted at time k is $R=\sqrt{X_k^2+Y_k^2}$, then it is $X_k=R\times\sin B$, $Y_k=R\times\cos B$, where, X_k and Y_k represent the measured distance at time k projected to the x and y directions, respectively.

Set X_{k-1}, $\hat{X}_{k-1}$ and $\tilde{X}_{k-1}$ as target position, estimated value and estimated error respectively at $k-1$, and the estimated error is $\tilde{X}_{k-1}=X_{k-1}-\hat{X}_{k-1}$. At this time, the error covariance is predicted by the system model. Prediction covariance $P_{k,k-1}$ (prediction error variance matrix $PCOV$) satisfies the prediction error formula of kalman filter:

$$P_{k,k-1}=\Phi_{k,k-1}P_{k-1}\Phi_{k,k-1}^T+\Gamma_{k,k-1}Q_{k-1}\Gamma_{k,k-1}^T \tag{7}$$

State transition matrix $\Phi_{k,k-1}=\begin{pmatrix}1 & T\\ 0 & 1\end{pmatrix}$. Input relation matrix $\Gamma_{k,k-1}=\begin{pmatrix}\frac{1}{2}T^2\\ T\end{pmatrix}$. The variance matrix of the estimated error is $P_{k-1}=E[\tilde{X}_{k-1}\tilde{X}_{k-1}^T]$. Is the process noise variance matrix Q_{k-1}. Substitute into the above formula as follows.

$$\begin{pmatrix}PCOV_{11} & PCOV_{12}\\ PCOV_{21} & PCOV_{22}\end{pmatrix}=\begin{pmatrix}1 & T\\ 0 & 1\end{pmatrix}\times P_{k-1}\times\begin{pmatrix}1 & 0\\ T & 1\end{pmatrix}+\begin{pmatrix}\frac{1}{2}T^2\\ T\end{pmatrix}\times Q_{k-1}\times\begin{pmatrix}\frac{1}{2}T^2 & T\end{pmatrix} \tag{8}$$

The relationship between the prediction covariance matrix and α/β and the smoothing parameter ($W1/W2$) of the position/velocity in the distance orthogonal direction is as follows, where $VAR=R^2\times 7.569\times 10^{-3}$ is the measurement variance in the orthogonal direction of distance.

$$\alpha=\frac{PCOV_{11}}{PCOV_{11}+VAR},\quad \beta=\frac{T\times PCOV_{12}}{PCOV_{11}+VAR} \tag{9}$$

$$W1 = \frac{PCOV_{11}}{PCOV_{11} + VAR}, \ W2 = \frac{PCOV_{12}}{PCOV_{11} + VAR} \tag{10}$$

Then calculate the residual of the distance direction of x and y and the residual of the orthogonal direction of the distance, as follows:

$$RESID_R = R - (X_k \times \sin B + Y_k \times \cos B), \ RESID_{CR} = X_k \times \cos B - Y_k \times \sin B \tag{11}$$

The residual $RESID_R$ in the distance direction and the residual $RESID_{CR}$ in the distance orthogonal direction are projected onto the x and y directions to obtain the estimated value of the state:

$$\begin{pmatrix} X_k \\ \dot{X}_k \end{pmatrix} = \begin{pmatrix} X_{k-1} \\ \dot{X}_{k-1} \end{pmatrix} + \begin{pmatrix} \alpha \\ \beta / T \end{pmatrix} \times RESID_R \times \sin B - \begin{pmatrix} W1 \\ W2 \end{pmatrix} \times RESID_{CR} \times \cos B \tag{12}$$

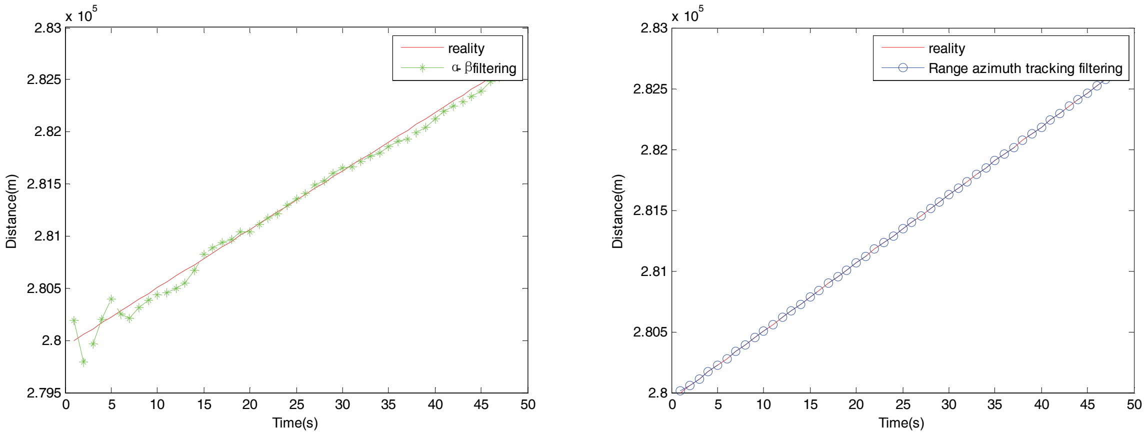
$$\begin{pmatrix} Y_k \\ \dot{Y}_k \end{pmatrix} = \begin{pmatrix} Y_{k-1} \\ \dot{Y}_{k-1} \end{pmatrix} + \begin{pmatrix} \alpha \\ \beta / T \end{pmatrix} \times RESID_R \times \cos B + \begin{pmatrix} W1 \\ W2 \end{pmatrix} \times RESID_{CR} \times \sin B \tag{13}$$

x and y direction filters are kalman filters. After projecting relative distance R and azimuth Angle B to x and y directions, kalman filters are used for filtering. After filtering, the x and y direction data are resynthesized into range and azimuth Angle, thus completing the filtering of range and azimuth Angle.

4 Simulation Results and Analysis

To verify the performance of the range-azimuth tracking filter algorithm, it is compared with the results of conventional alpha-beta filtering in the x and y directions. The two filtering algorithms are also simulated in monte carlo for 200 times [12]. The parameters of the computer simulation are as follows: assume that two aircraft are flying in the same direction, with the target aircraft in front and the aircraft behind. Initial velocity *Vb0* = 900km/h. Initial velocity *Va0* =700 km/h. The azimuth of the target aircraft relative to the aircraft is equal to 30°. The observation period is *T*=1s. Simulation time *t*=500s. The relative distance between the two aircraft *R*=280km. The change of observation target position (relative distance) *Navr*=100m.

Computer simulation using MATLAB programming. The simulation results are shown in figure 3, where figure (a) and figure (b) are respectively the comparison between the real trajectory of the moving target and the observed trajectory after the α-β filtering, and after the range-azimuth tracking filtering. Figure 4 shows the error of the observed target position. Figure 5 is a comparison of the estimated errors of the α-β filter and the range azimuth tracking filter.



(a)Alpha-beta filtering (b) Range azimuth tracking filtering

Figure 3. Comparison of alpha-beta filtering and range azimuth tracking filtering for moving target trajectories

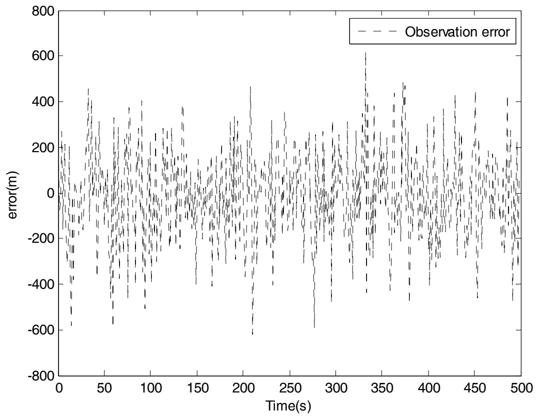


Figure 4. The error of observation target

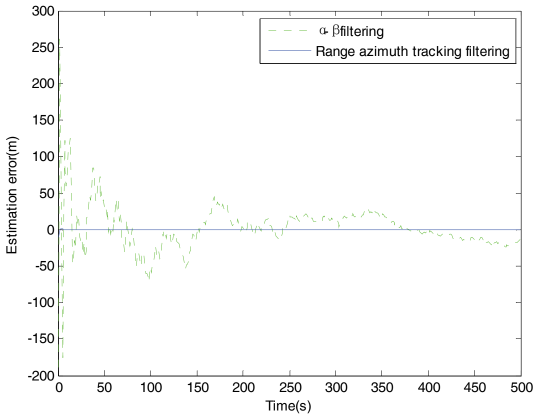


Figure 5. Comparison of the estimation errors between alpha-beta filtering and range azimuth tracking filtering

From the simulation results in figure 3, it can be clearly seen that the observed track is closer to the real value after the range-azimuth tracking filter than after the α-β filter. It can be seen from figure 4 and 5 that the observation error has always existed in the whole observation process, but the estimated error after filtering is gradually approaching to zero, and the filtering effect is very good. In figure 5, it is clear that the estimation error generated by the range-azimuth tracking filter tends to zero faster than that of the α-β filter, and the fluctuation is small.

It can be seen from the above computer simulation results that the estimated error of the range azimuth tracking filter proposed in this paper is significantly less than that of the conventional α-β filtering algorithm when tracking a target moving at a uniform speed. This shows that the range-azimuth tracking filtering algorithm is superior to the conventional α-β filtering algorithm in tracking performance. The improved filtering algorithm is suitable for tracking the moving target with uniform speed, and the tracking effect is good.

5 Conclusion

In this paper, an improved range-azimuth tracking filtering algorithm is proposed based on the conventional alpha-beta filtering algorithm. This algorithm introduces the idea of coordinate projection. The relative distance between the two aircraft is projected on the inclined plane according to the azimuth in the x and y directions. The problem of collision avoidance of three-dimensional space aircraft is changed to that of aircraft on two-dimensional inclined plane. The prediction results are modified by using the residuals of distance direction and distance orthogonal direction, which improves the filtering accuracy of the algorithm. The computer simulation results show that the improved algorithm not only maintains the advantages of less calculation of the α-β algorithm, but also has a better tracking effect on the moving target. It is suitable for monitoring and tracking the moving target of airborne anti-collision system. Due to the limitation of space, this paper only discusses the target moving at a uniform speed, and the azimuth tracking filter algorithm for the target moving at a uniform speed will be discussed in another paper.

Acknowledgements. The work of this paper is supported by the Southwest Minzu University Graduate Innovative Research Project (Master Program CX2018SZ92). A special acknowledgement should give to Southwest Minzu University for its experimental conditions and technical support.

Reference

1. Simon, “Security guard: mid-air collision avoidance system,” *Large Aircraft*, no. 5, pp. 101-102, 2014.
2. QIAO Shao-jie, HAN Nan and ZHU Xin-wen, “A Dynamic Trajectory Prediction Algorithm Based on Kalman Filter,” *ACTA ELECTRONICA SINICA*, vol. 46, no. 2, pp. 418-423, 2018.
3. WU Y, LIM J and YANG M H, “Object tracking benchmark,” in *IEEE Transactions on Pattern Analysis and and Machine Intelligence*, on. IEEE, 2015, pp. 1834-1848.
4. YU Geng, WANG Han and ZHAO Long, “Analysis on ground based augmentation system position domain integrity monitoring based on Kalman filtering,” *Science Technology and Engineering*, vol. 18, no. 26, pp. 243-247, 2018.
5. JING Zhan-rong and YANG Yan, “Signal detection and estimation,” in *Beijing: Chemical Engineering Press*, 2004, pp. 310-313.
6. LI Xiao-mao, WAND Wen-tao and KE Jun, “Research on α-β filter in the course angle navigation of unmanned surface vehicle,” *Chinese Journal of Scientific Instrument*, vol. 38, no. 7, pp. 1747-1755, 2017.
7. PAN Quan, LIANG Yan and YANG Feng, “Modern target tracking and information fusion,” in *Beijing: National Defense Industry Press*, 2009, pp. 287.
8. HE You, XIU Jian-juan and ZHANG Jing-wei, “Radar data processing and application,” in *Beijing: Electronic Industry Press*, 2009, pp. 31-51, 71-80.
9. LI Shu-jun and LI Kai-duan, “Algorithm research of targets tracking based on adaptive α-β filter,” *Science Technology and Engineering*, vol. 12, no. 34, pp. 9367-9369, 2012.
10. HE Li-wen, LI Yan-peng and FAN Bo, “An improved alpha beta filter algorithm,” *Modern electronic technology*, vol. 35, no. 21, pp. 28-30, 2012.
11. LIN Yun-song, PENG Liang-fu and TONG Ling, “Mathematics model for collision avoidance in Traffic Alert and Collision Avoidance System,” *Journal of University of Electronic Science and Technology of China*, vol. 37, no. 4, pp. 552-555, 2008.
12. Boguslaw B, “Application of stochastic approach based on Monte Carlo (MC) simulation for life cycle inventory (LCI) to the steel process chain: Case study,” *Science of the Total Environment*, vol. 481, no. 10, pp. 649-655, 2014.

