Application Of Probability Filter For Maintenance Of Air Objects

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Summary

The article considers the possibilities of increasing the accuracy of estimates of the parameters of the trajectory of the target with the provision of a given probability of stable support of the air object, in particular, during its maneuver. The aim of the work is to develop a filtration algorithm that provides a given probability of stable tracking of the air object by determining the regular components of filtration errors, in particular, when maneuvering the air object, and their compensation with appropriate correction of filter parameters and estimates of air object trajectory parameters.

Key words:
Kalman filter, air object tracking, filtering errors, air object.

1. Introduction

One of the problems in the theories of secondary processing of radar information is to ensure stable tracking of targets in conditions where the adopted model of target movement does not correspond to the real trajectory, in particular, when maneuvering the target. In this case, the dynamic errors of filtering marks (coordinate measurements) increase, and, accordingly, the probability of missing marks in the identification gate, the possibility of failure of the target from tracking.

Therefore, the problem of determining the current dynamic filtering errors and their use to correct the obtained estimates of the parameters of the target trajectory is relevant.

Literature analysis. To determine and correct the regular components of filtering errors, the current (average) values of the deviation of the parameters of the marks (measurements) from the extrapolated values of coordinates, in particular the values of the residuals or their quadratic forms [1,3, 6].

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When maneuvering the target devices (algorithms) for detecting the maneuver and determining its intensity (acceleration of the maneuver) with modification (change of structure) of the linear Kalman filter [2, 18-19].

The probability filter [4-7] provides an increase in the probability of stable target tracking by introducing current filtering errors into the filter feedback circuits.

The aim is to develop a filtering algorithm that provides a given probability of stable tracking of targets by determining the regular components of filtering errors, in particular, when maneuvering the target, and their compensation with appropriate correction of filter parameters and estimates of trajectory parameters of the air object.

2. Theoretical Consideration

To filter marks (coordinate measurements) x_i coming in each i-th cycle of tracking, and estimation of parameters of a trajectory of the purpose the linear Kalman filter which provides the minimum filtering errors for a linear trajectory which are defined by errors of measurements (in particular, variance σ_x^2) is usually used.

However, if the adopted model of motion of the target does not correspond to its real trajectory, in particular, when maneuvering the target, there are regular components of filtering errors, which are manifested in the values of residuals or their quadratic forms in the one-dimensional case (x coordinate):

$$z_i = x_i - x_{ei};$$

$$Q_i = z_i^2 / \sigma_x^2 \tag{1}$$

Where x_{ei} are the current extrapolated values of the trajectory parameter.
When maneuvering a target, a quadratic component appears in the expression for the trajectory of the target, which is determined by the acceleration of the maneuver g_M:

$$\Delta x_i = \frac{1}{2} g_M (t_i - t_M) \quad (2)$$

where t_M is the moment of the beginning of the maneuver.

Values determine the regular inconsistency component and additional errors in estimating target trajectory parameters.
If the mark does not hit the identification gate (maintenance) due to dynamic filtering errors, it is possible to reset the trajectory from the maintenance (in particular by the logic of S misses in a row).
The size of the support gate is selected under the conditions of ensuring a given probability of hitting the target mark in the gate.
In particular, the variance of the targeting error (extrapolated value) $\sigma^2_{(x_e)}$ should not exceed the specified value determined by the measurement errors:

$$\sigma^2_{(x_e)} \le \lambda^2 \sigma^2_x ,$$

where λ is a given constant.

At the same time, the size of the gate is limited by the requirements for the selective properties of the filter - the probability of getting into the gate of false marks, in particular, due to interference. For example, for a two-dimensional gate (in the coordinates x, y) the probability of correct selection of the target mark is defined as [5-12]:

$$P_c = 1 / 1 + 2\pi\nu\sigma_x\sigma_y ; \quad (3)$$

where ν is the intensity of the noise marks.
For the analysis of stable maintenance of the purpose it is expedient to use averaged (filtered or smoothed) values of discrepancies.

$$\bar{z}_i = A \cdot \bar{z}_{i-1} + (1 - A) z_i \quad (4)$$

where A is the smoothing coefficient.
Dependence $\bar{z}_i$ from accelerating the maneuver of the entrusted object g_M is equal to [1-3, 13-15]:

$$\bar{z} = -\varphi_1 \, g_M T_i^2 / 12 \quad (5)$$

where

$$T_i = t_i - t_m \; ;$$

$$\varphi_1 = (1 - A)^2 \left[(i - A - 1)^2 + 1 - 2A^i \right] \cdot i^{-2} .$$

The variance of the smoothed residual is determined by the variance of the measurement errors σ^2_x:

$$\sigma^2_{(\bar{z})} = \varphi_2 \cdot \sigma^2_x ,$$

where

$$\varphi_2 = 1 - A / 1 + A + A^{2(i-1)} . \quad (6)$$

The proposed processing algorithm involves checking the probability of hitting the target marks in the support gate by comparing the current values of the smoothed residual from a certain value proportional to the size of the gate:

$$|\bar{z}| \le L \cdot \sigma_{(\bar{z})} \quad (7)$$

where L is the coefficient that determines the probability of hitting the mark in the gate (L = 2… 3).
When condition (7) is met, the current value is used to refine the elements of the correlation matrix of errors measurements R_i, extrapolation ψ_{ei}, filtration ψ_i and filter gain K_i.

For example, for the one-dimensional case (coordinates x) the variance of extrapolation errors will be determined as

$$\sigma^2_{(x_e)} = \sigma^2_x + \sigma^2_{\dot{x}} \tau^2 + 2K_{(x,\dot{x})} \cdot \tau + \frac{1}{4} \sigma^2_{(\bar{z})} \tau^4 ; \quad (8)$$

$$\sigma^2_{(\dot{x}_e)} = \sigma^2_{\dot{x}} + \sigma^2_{(\bar{z})} \cdot \tau^2 ,$$

where τ - extrapolation interval;
$\sigma^2_{\dot{x}}, \sigma^2_{\dot{x}_e}$ - according to the measurement variance and speed extrapolation.

The gain of the filter in the x coordinate:

$$K_i = \sigma^2_{(\dot{x}_{ei})} / \sigma^2_{(\dot{x}_{ei})} + \sigma^2_{x_i}$$

For the required response of the filter to the random scatter of the acceleration of the target with the dispersion σ^2_g filter gain K_i after the time of escort of the air object T_0 is limited (fixed) at the level K_0, where

$$T_0 = \sqrt[5]{144 \cdot T_c \cdot \sigma_x^2 \cdot \sigma_g^2} \qquad (9)$$

Where T_C - the period (cycle) of support.

Accordingly, the error (variance) of extrapolation due to measurement errors in the steady-state maintenance mode is defined as:

$$\sigma^2_{(x_e)} = K_0 / 1 - K_0 \cdot \sigma_x^2 \qquad (10)$$

If condition (7) is not fulfilled, in particular, when maneuvering the target, the current values are used to correct the current extrapolated values of the parameters (coordinates and speed):

$$\hat{x}_e = x_{ei} + \bar{z};$$

$$\hat{\dot{x}}_e = \dot{x}_{ei} - \frac{1}{2} g_M T_i \qquad (11)$$

The estimates of the target trajectory parameters are adjusted accordingly, in particular, for the x coordinates X:

$$\hat{x}_i = \hat{x}_{ei} + K_i(x_i - \hat{x}_{ei})$$

If the specified probability of hitting the mark in the maintenance gate is not provided and after correcting the current estimates of the parameters, a smaller value of the period (cycle) of maintenance is calculated T_c , under which this condition is met (by reducing extrapolation errors (targeting)).
For example [2]

$$T_{ci} = T_{ci=1} \cdot 1 / \sqrt{\bar{z} / \sigma_x}$$

Changing the target tracking period is possible for radar systems with electronic control of the pattern.

Conclusions

To ensure a given stability of the target tracking, in particular, during its maneuver, and to reduce errors in estimating the parameters of the trajectory, it is necessary to analyze the current dynamic filtering errors, to assess the probability of stable tracking of the air object.
Based on the obtained estimates of random and regular components of filtering errors, in particular, discrepancies, the elements of correlation error matrices and filter gain are refined, and extrapolated values and estimates of target trajectory parameters are corrected. If necessary, the maintenance period (cycle) is adjusted.

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