ANALYSIS OF SENSITIVITY OF TARGET TRACKING SYSTEMS TO EXTERNAL INTERFERENCE IN MULTICHANNEL RADARS WITH FIXED PARAMETERS

Abstract. The multichannel and fixed parameters radars for tracking targets with the phased array antennas are widely used in modern military surveillance systems. The modular integration of a phased antenna array with digital processors allows to realize the command and control functions of antenna patterns for tracking multiple targets in the time resolution modes. Tracking of the air targets in range, radial speed and angular coordinates of evaluations and azimuth is provided by means of the multichannel radars without adaptation modes to the characteristics of external influences. Thus, adjusting the algorithms of tracking systems to the maximum maneuverability of the air targets can lead to a significant reduction in the accuracy of surveillance in comparison with the potentially achievable accuracy for such radars of tracking the linear flight targets in the long duration of time. In the case of adjusting the algorithms of tracking systems to either low intensity of flying targets, or lack of the aircraft maneuvering, it is possible to significantly increase the error of the aircraft flying information, and as a result to have a disruption of tracking the air targets. The increase in the parameters of the tracking error in relation to the influence of external interference were obtained as a result of the study. As a result of research, it is possible to assess the feasibility of adapting to certain characteristics of external influences, and provide recommendations for selecting and fixing the parameters of algorithms of tracking systems to ensure their versatility to surveillance targets with both high maneuverability, and implementing the stealth technology.

Keywords: automatic tracking system; extrapolation error variance; range; radar with fixed parameters.

Introduction

The problem of achieving sustainable tracking of maneuverable targets is a tackle in complex and expensive adaptive radar systems for tracking the air targets. Analysis of possible errors in tracking accuracy under the influence of external interference in radars with fixed parameters is presented in the article. In practice, it often happens that the regulation of the parameters of the tracking system does not meet the requirement of stable tracking of targets when exposed to external interference, which is considered in the article.

This publication analyzes possible losses in tracking accuracy in systems with fixed parameters, if the settings of the algorithms of tracking systems do not match the characteristics of external interference.

The influence of parameters of the target movement stochastic models with both exponentially correlated values of targets acceleration, and observations on potential accuracy of radio tracking system by range is investigated, and also in case of fixing of parameters dependences of relative increase of tracking error are received.

It is known that the synthesis of the tracking systems is based on the model of both target movement characteristics, and the measurements of corresponding flight coordinates.

Therefore, it is quite natural that the closer these models are to real practical conditions, the higher the accuracy of the tracking systems.

However, the characteristics of external influences change in the real condition, and therefore it is necessary to find out, the change in characteristics affects the potential accuracy of the optimal system. If the system parameters of radars do not meet the characteristics of the external influences, the radars will determine the decrease in the accuracy of tracking the air targets.

The obtained results make it possible to evaluate the feasibility of designing the tracking systems that are adaptable to certain characteristics of external influences.

If adaptation is impractical, it allows you to select fixed values of the parameters of the radar at which the system best meets its purpose.

Thus, the analysis of the sensitivity of the targets tracking systems under the influence of external interference in the multichannel radars with fixed parameters is presented in the article.

Research and publications analysis. The potential effectiveness of the airspace surveillance depends on the accuracy of tracking air targets by means of radars. The main parameters of the radar include sensitivity of the receiver devices, the signal-to-noise ratio and the discriminator characteristics [1-3].

Adjusting the parameters of the tracking algorithm to the worst conditions, for example, the signal-to-noise ratio is minimal, maneuverability is maximum, leads to a relative deterioration in the accuracy of tracking the air targets to compare with the optimal setting of the characteristics to the best conditions of surveillance, for example, when the signal-to-noise ratio is very high and the targets fly at the strait path without maneuvering.

The choice of parameters of the air targets tracking algorithm for the radars with fixed parameters design for the best conditions.

If the influence of external interference increases, it will lead to a deterioration in the accuracy of tracking targets by a radar with fixed parameters.

Thus, the correct choice of characteristics of the target's maneuverable flight model and the tracking
The purpose of the article is to analyze the sensitivity of the receiving module of the tracking system to the choice of the parameters of the model of the target’s maneuverable flight of the to the surveillance modes of the multichannel radars with fixed parameters under the influence of the external interference. The estimation of possible decrease in sensitivity in case of mismatch of the radar parameters with the characteristics of external interference is carried out.

Research results

Let us consider a model in which the maneuverable flight of a aircraft is described by a stochastic mathematical model with exponentially correlated components of the target acceleration vectors. The target acceleration vectors are used to describe the motion of a maneuvering target along the tracked coordinates [1].

\[ \mathbf{x}(t_n + T_n) = \Phi(T_n)\mathbf{x}(t_n) + B\xi(t_n), \]

where \( \mathbf{x}(t_n) = (x(t_n), \dot{x}(t_n), \ddot{x}(t_n))^T \) – the state vector, the components of which are the coordinate of the target, its first and second derivatives;

\[ \Phi(T_n) = \begin{pmatrix} 1 & T_n & T_n^2/2 \\ 0 & 1 & T_n \\ 0 & 0 & \rho \end{pmatrix} \]

the transition state matrix;

\[ B = (0 \ 0 \ 1)^T \]

the excitation matrix;

\( T_n \) – the observation time interval;

\( \xi(t_n) \) – discrete sequence of white excitation noise with variance, which is described by the expression:

\[ v^2_\xi(T_n) = \sigma^2_\xi(1 - \rho^2); \]

\[ \rho = e^{-T_n/T_u} \]

parameters describing the correlation of the components of the target acceleration vector in the observation interval;

\( T_u \) – the time constant of the correlation of the components of the targets acceleration vector;

\( \sigma_\xi \) – the standard deviation of the values of the components of the targets acceleration vector.

As shown in [1], with the small interval of observations \( T_n < 1s \) the matrix element \( \varphi_{13} \) of the matrix \( \Phi(T_n) \) can be taken equal to zero:

\[ \Phi(T_n) = \begin{pmatrix} 1 & T_n & 0 \\ 0 & 1 & T_n \\ 0 & 0 & \rho \end{pmatrix}. \]

In the synthesis of linear systems, the model of observations is represented by the following equation:

\[ y(t_n) = H\mathbf{v}_e(t_n) + f(t_n), \]

where \( H = (100) \) – matrix of observations; \( f(t_n) \) – discrete white sequence of observation noise with zero mean and variance \( v_f(t_n) \).

In these models, the parameters to be fixed are: \( \epsilon, \sigma_\xi, T_u, v_f \). There are two parameters determined by the maneuverability of the monitored targets, and the latter is determined by the value of the signal-to-noise ratio and the characteristics of the discriminator.

In addition, when the target’s observation is organized within the criterion of the sufficient accuracy [8], the variable parameter may be the interval of observations \( T_n \). As you know [2], the automated tracking system should be optimized by the criterion of the standard error minimum. The automated tracking system may be described by the recurrent relations:

\[ \mathbf{\bar{x}}(t_n) = \Phi(T_n)\mathbf{\bar{x}}(t_n) + K(t_n)[y(t_n) - H\mathbf{\bar{x}}(t_n)]; \]

\[ \mathbf{\bar{x}}(t_n + T_n) = \Phi(T_n)\mathbf{\bar{x}}(t_n); \]

where \( K(t_n) \) – the matrix of gain factors which is caused by expressions:

\[ K(t_n) = V_e(t_n)H\left[HV_e(t_n)H^T + v_f(t_n)\right]^{-1}, \]

\[ V(t_n) = V_e(t_n) - V_e(t_n)H^T \times \left[HV_e(t_n)H^T + v_f(t_n)\right]^{-1}HV_e(t_n), \]

in which \( V(t_n), V_e(t_n + T_n) \) – matrices of the central moments of errors estimation and extrapolation accordingly. Let the proposed flight models of targets and models of the tracking radars are reflected the real conditions of the air observation. Then the variance of the tracking error \( \sigma^2_e \) is equal to the element \( v_{311} \) of the matrix \( V_e(t_n) \).

With constant characteristics of external influences, calculations of the variance of the tracking error in the steady modes can be performed by multiple solutions of recurrent equations (11), (12).

The results of the solution for the range of the automated tracking system are shown in Fig. 1. As can be seen from the obtained graphs, the variance of the extrapolation error of the range depends significantly on the variance of the observation noise, weaker than the variance of the values of the acceleration of the target, and slightly depends from the constant maneuvering \( T_u \). Therefore, to ensure stable and stable tracking of the maneuvering target, it is necessary to ensure the maximum value of the signal-to-noise ratio and the sensitivity of the receiving path and the discriminator [7-12]. In the case when for the synthesis of the surveillance system the parameters of models (1), (7) are fixed and equal respectively to \( \sigma_\xi^*, T_u^*, v_f^* \), its accuracy may be below the potentially achievable: \( \sigma^2_e \geq v_{311} \).
It can be calculated in the general case only by statistical tests. For the steady mode there is an analytical solution, which is found by the spectral method [2, 3].

The expressions obtained with the help of this technique for variances of dynamic and fluctuation tracking errors are rather cumbersome and therefore are not given here.

In Fig. 2 graphs of the relative deterioration of the target tracking error of the radar with fixed parameters, which are relative to the optimal, are given:

\[ \Delta \sigma^2,\% = \left( \frac{\sigma^2_c - V_{el1}}{V_{el1}} \right) \cdot 100\% , \]  

(12)

In the Fig. 2 the solid lines are corresponding to the parameters recorded for the maximum, the dashed lines are corresponding to the parameters, recorded for the minimum, of the relative deterioration of the variance functions.

The choice of target tracking parameters in the middle of the range of the proposed parameters allows to achieve stable target tracking by radars in the conditions of interference.

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**Fig. 1.** Dependence of the variance:

- a – of the distance extrapolation error on the variance of the observation noise;
- b – of the error on the variance of the values of the acceleration of the target;
- c – of the distance extrapolation error on the time correlation constant of the target acceleration values.

**Fig. 2.** Relative deterioration:

- a – of the variance of the extrapolation error of the distance from the variance of the observation noise;
- b – of variance extrapolation error of range from the variance of values of targets acceleration;
- c – of variance of extrapolation error of distance from the time of the values of the targets acceleration.
Also, fixing the value of the variance of the noise of the target tracking \(v_f\), and the variance of the values of the maneuvering acceleration of the targets \(\sigma_m^2\) in the area of the average values: up to 7% – according to the parameter \(T_m\) allows to achieve stable target tracking. Thus, stable tracking of maneuvering targets is achieved either by selecting the parameters defined in the article in the middle of the dispersion area or by using adaptive target tracking radars [4, 6].

Conclusions

1. As follows from the analysis of the results, the choice of parameters of the target tracking radars based on the criterion of achieving a minimum error in the most difficult conditions, leads to losses of achievable accuracy in unfavorable tracking conditions (Fig. 2):
   - up to 2.5 times are according to the parameter of the dispersion of the tracking noise;
   - up to 60% are according by parameter the dispersion value of acceleration rate \(\sigma_m^2\).

2. The parameters variance in the most friendly conditions of surveillance \(v_f^*\) and \(\sigma_m^*\) – minimum, \(T_m^*\) – maximum, lead to the fact that in unfriendly condition of surveillance, the error may be worse than the potentially achievable (Fig. 2) up to 80% – by the parameter \(v_f\); up to 120% - by parameter \(\sigma_m^2\); up to 25% - according to the parameter \(T_m\), which can increase the probability of failure of the maneuvering target by radars with fixed parameters in conditions of external interference.

3. Based on practical experience, it is shown, that the sensitivity of the targets range tracking module of the radar weakly depends on the targets acceleration parameter \(T_m\). Therefore, the regulation in the area of characteristics of the receiving system proposed in the article, which increasing the sensitivity and the signal-to-noise ratio of receiving module, allows to develop effective radars with fixed parameters for stable targets tracking in external interference.

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Аналіз чутливості систем супроводження цілей з фіксованими параметрами багатоканальної РЛС до характеристик зовнішніх впливів

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Анотація. У сучасних радіотехнічних системах військового призначення широко застосовуються багатоканальні радіолокаційні станції (РЛС) супровождення цілей з фазованою антенною решіткою (ФАР). Використання ФАР у комбінації з цифровою обчислювальною технікою дозволяє керувати діаграмою спрямованості РЛС і супровождувати декілька цілей в режимі роздіління часу. Супроводження повітряних цілей в багатоканальній РЛС зазнається підсистемами за дальностю, радіальною швидкістю та кутовими координатами, в більшості випадків без адаптації до характеристик зовнішніх впливів. Так, налаштування алгоритмів слідуючих систем на максимальні механічні характеристики повітряних цілей можуть призвести до суттєвого зниження точності супроводження відносно потенційно досяжного на ділянці відсутності маневрування, яка була досягнута тривалою. У разі налаштування алгоритмів слідуючих систем на низьку інтенсивність, або відсутність маневрування, можливо надто суттєве зростання помилки на ділянці здійснення маневру з максимальними можливостями літального апарату. Дана питання досить ефективно вирішується в адаптивних слідуючих системах. У даній публікації проведено аналіз можливих втрат в точності супровождання із представленням поліноміальних залежностей точності РЛС у відсутності маневрування, розроблено рекомендації по вибору і фіксації параметрів алгоритмів слідуючих систем на основі адаптації до характеристик зовнішніх впливів та максимальної механічної здатності слідуючої системи в режимі здійснення маневру з максимальними можливостями літального апарату.

Ключові слова: система супроводження цілей з фіксованими параметрами багатоканальної РЛС; характеристики зовнішніх впливів; адаптація.

Аналіз чувствительности систем сопровождения целей с фиксированными параметрами многоканальной РЛС к характеристикам внешних воздействий

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Аннотация. В современных радиотехнических системах военного назначения широко применяются многоканальные радиолокационные станции (РЛС) сопровождения целей с фазированной антенной решеткой (ФАР). Использование ФАР в сочетании с цифровой вычислительной техникой позволяет управлять диаграммой направленности РЛС и сопровождать несколько целей в режиме разделения времени. Сопровождение воздушных целей в многоканальной РЛС обеспечивается подсистемами по дальности, радiallyя скорости и угловым координатам, в большинстве случаев без адаптации к характеристикам внешних воздействий. Так, настройка алгоритмов следящих систем на максимальные механические возможности воздушных целей могут привести к существенному снижению точности сопровождения относительно потенциально достижимого на участке отсутствия маневрирования, которая бывает достаточно длительной. В случае настройки алгоритмов следящих систем на низкую интенсивность, или отсутствие маневрирования, возможно слишком сильное увеличение ошибки на участке осуществления маневра с максимальными возможностями летательного аппарата. Данный вопрос достаточно эффективно решается в адаптивных следящих системах. В данной публикации проведен анализ возможных потерь в точности слежения в системах с фиксированными параметрами, в случае настройки параметров алгоритмов следящих систем не совпадающих с характеристиками внешних воздействий относительно возможных. Исследовано влияние параметров стохастической модели движения цели с экспоненциальной корреляцией значения ускорения цели и модели наблюдений потенциальной точности радиотехнической следящей системы по дальности, а также в случае фиксации параметров, полученные зависимости относительного увеличения ошибки сопровождения. В результате проведенных исследований, появляется возможность оценки целесообразности адаптации к определенным характеристикам внешних воздействий, и рекомендации по выбору и фиксации параметров алгоритмов следящих систем для обеспечения их универсальности применения к сопровождению целей с постоянно растущими маневренными возможностями и малой заметностью.

Ключевые слова: система автоматического сопровождения; дисперсия погрешности экстраполяции; дальность; фиксированные параметры.