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STRUCTURES OF ADAPTIVE SIGNAL PROCESSING SYSTEMS FOR RADAR SENSORS OF EXTERNAL INFORMATION FOR CORRELATION-EXTREME AIRCRAFT NAVIGATION SYSTEMS

During the guidance of the aircraft on the final part of the flight, it is affected, along with other external factors, by interferences of various (artificial or natural) origins. These interferences have various effects on the receiving elements of the antenna array of the radar sensor of external information. Due to the variability and rapidity of the complex interference situation, adaptive interference protection systems are the most effective in combating these interferences. It is known that the use of adaptive processing systems allows for overcoming the practically inevitable a priori uncertainty of statistical characteristics of signals and interference of various origins. At present, due to the development of digital technology, new methods and devices for adaptive signal processing against the background of interference have appeared. Thus, the arsenal of methods of adaptation to Gaussian disturbances has been supplemented by methods involving the inversion (direct or recurrent) of the most plausible estimates of correlation matrices of disturbances or their regularized varieties. Wide possibilities of adaptation are opened up in modern radar stations with multi-element phased antenna arrays, which provide for digital information processing. Due to the very high speed of the aircraft during the operation of its correlation-extreme guidance system, as well as due to the dynamic and non-stationary interference environment, an important requirement for adaptive anti-jamming systems is their speed. The effectiveness of adaptive processing of signals against the background of interference can be significantly increased by using reliable a priori information. The paper considers a method of increasing the speed of adaptive protection systems against radar interference of various origins by taking into account a priori information about the central symmetry of the receiving channels of radar sensors of external information of correlation-extreme aircraft navigation systems. It is shown that taking into account such a priori information as the central symmetry of the receiving channels of radar sensors of external information leads to a corresponding change in the structure of devices for adaptive signal processing in the conditions of interference in these sensors and as a consequence, to an increase in their speed.

Keywords: *interference, antenna array, radar sensors, adaptive signal processing systems.*

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INTRODUCTION

While guiding an aircraft (AC) equipped with an external information radar sensor (EIRS), especially during terminal flight, the problems of the speed of protecting the EIRS from various interferences (active, passive, or mixtures thereof) come to the fore along with the problems of accuracy and speed of the aircraft guidance proper [1, 4—6]. High requirements for the speed of anti-jam systems are determined by both the instability and dynamism of the interference environment and a very short time allotted for correcting the environment and protecting against interference.

Using a priori information allows counting on an increase in the speed and efficiency of the anti-jam systems [2, 7].

It was shown in [2, 7] that if the antenna array (AA) receiving elements are symmetrical with respect to the array's geometric center, i.e., the difference in distances d between the pth and qth receiving elements and the difference in distances between the $(M+1-q)$th and $(M+1-p)$th elements are the same, i.e., when

$$d_p - d_q = d_{M+1-q} - d_{M+1-p},$$
$$p, q \in 1, M,$$

where M is the number of the array's receiving elements, and also, when the amplitude patterns of the elements symmetrical with respect to this center are identical, the spatial correlation matrix (SCM) of active interference is not only Hermitian but also has additional symmetry with respect to the secondary diagonal (the so-called persymmetry). Temporal SCMs of passive interference in pulse radars with a centrally symmetric sweep law can have the same properties [2, 7]. Mathematically, persymmetry means that

$$\Pi \Phi^T \Pi = \Pi \Phi^\circ \Pi \text{ , } \phi_{pq} = \phi_{M+1-q, M+1-p} \text{ ,}$$

where Π is the orthogonal symmetric permutation matrix ($\Pi\Pi = 1,\ \Pi = \Pi^{-1}$), containing ones on the side diagonal and zeros elsewhere, is the sign of a complex connection.

The persymmetric matrix (2) is completely determined by the elements $(M^2 + 2M)/4$, which at $M >> 1$ is almost half as much as in the case of a general positive Hermitian matrix [6, 7]. Actually, it is this reduction in the dimension of the vector of the estimated parameters that allows for a further increase in the speed and efficiency of the anti-jam systems, since in order to obtain the value of the weight vector, which makes a "dip" in the radiation pattern of the EIRS receiving AA on the direction of influence of a particular interference (this is the adaptive signal processing against the clutter environment), this correlation matrix (CM) should be rotated in real time.

PRESENTATION OF THE MAIN MATERIAL

The central symmetry of the receiving AR of the EIRS, which gives rise to the specificity of the CM structure (i.e., persymmetry), also leads to a respective change in the structure of adaptive signal processing devices in the clutter environment in the EIRS.

As is known, an adaptive processing system should generate statistics of the following form [6]:

$$\hat{\xi} = V_{eX}^{*} \hat{\Psi} X \text{ ,} \tag{1}$$

where $\wedge$ is the evaluation symbol, * is the Hermitian message symbol.

If spatiotemporal signal processing in the EIRS is carried out jointly, then the V_{eX} role is played by the ML-dimensional complex amplitude vector of the input sample of the mixture of the desired signal, interference, and noise (L being the number of temporal receive channels), the $\hat{\Psi}$ role is played by the $(ML \times ML)$ matrix, inverse to the estimated interference CM $\hat{\Phi}$, and the X role, by the ML-dimensional vector of the desired signal.

Expression (1) also works in the case of only spatial or only temporal processing of signals against the clutter environment [1]; it is only the content of components (1) that changes. For example, during spatial processing, the M-dimensional vector $Y = Y_M + \gamma X$ plays the role of V_{eX}, where Y_M is the M-dimensional vector of input samples; the role of $\hat{\Psi}$ is played by the $(M \times M)$ matrix, inverse of the estimated spatial CM at the input of the spatial signal processing device against the clutter environment; the role of X is played by the M-dimensional spatial vector of the expected desired signal of the form $X = x(t)X(\alpha)$, where

$$X(\alpha) = \left\{ x_i^{(nm)} \right\}_{\mu=1}^{M}$$

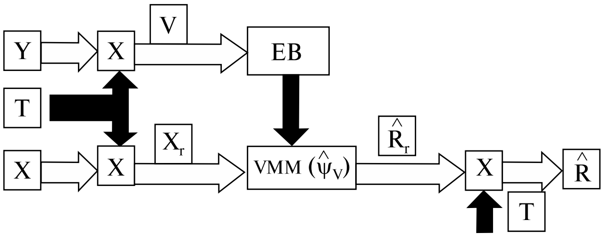

Figure 1. Generating the weight vector $\hat{R}$

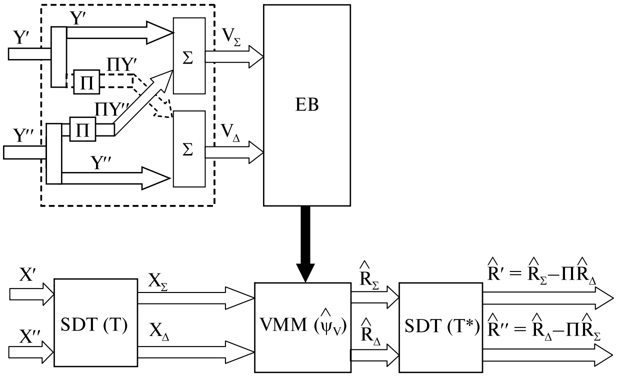

Figure 2. Internal structure of the Figure 1 blocks

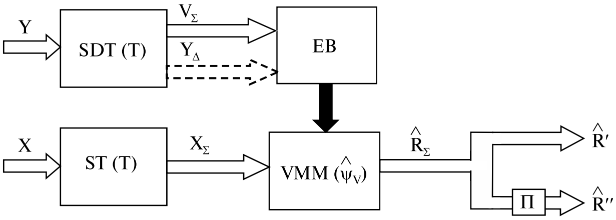

Figure 3. A simplified version of Figure 2, which takes into account the condition $X(\alpha) = \Pi X(\alpha)^\circ$

is the vector of the amplitude-phase distribution (APD) of the desired signal in space, and $x(t)$ is a random amplitude factor.

In the case of temporal (interperiod) processing, V_{eX} is the L-dimensional Y_i complex amplitude vector, $\hat{\Psi}$ is the $(L \times L)$ matrix, inverse of the estimated CM of interperiod fluctuations of interference $\hat{\Phi}$ at the input of the temporal (interperiod) processing device, X is the L-dimensional temporal vector of the desired signal of the form $X = x(t)X_\times$, where

$$X_\times = \left\{x_l^{(\times)}\right\}_{l=1}^{L}$$

is the vector of the desired signal APD in time.

The paper proposes the following engineering solutions, described below, suitable for all addressed options of processing in the EIRS, if the corresponding interference CM $\hat{\Phi}$ at their inputs is persymmetric.

Let us introduce the following matrix [2] (let us say, it will be $(M \times M)$ in size):

$$T = \left\{t_{il}\right\}_{i,l=1}^{M} = \frac{1}{\sqrt{2}}\left[I_M - j\Pi_M\right] \qquad (2)$$

with the following properties:

$$T = T^T = \Pi_M T \Pi_M = -jT^\circ \Pi_M = -j\Pi_M T^*,\; TT^* = I_M,$$

where I_M is the identity matrix $(M \times M)$, Π_M is the permutation matrix $(M \times M)$.

It is known that any complex matrix can be represented by a set of its real and imaginary parts:

$$\Phi = \left\{\phi_{il}\right\}_{i,l=1}^{M} = \Phi + j\Phi''.$$

Using the matrix T, the Hermitian persymmetric matrix turns into a real symmetric matrix $(M \times M)$:

$$\Phi_\epsilon = T\Phi T^* = \Phi' + \Phi''^T \Pi_M.$$

Given the notation introduced above, let us rewrite the expression (1):

$$\hat{\xi} = Y^* \hat{\psi} X = Y^* T^* T \hat{\psi} T^* T X = V^* \hat{\psi}_V X_T = V^* \hat{R},$$

where

$$V = \{v_i\}_{i=1}^{K} = TY = V_\Sigma + jV_\Delta \qquad (3)$$

is the transformed input sample vector,

$$V_\Sigma = \{v_{\Sigma i}\}_{i=1}^{K} = \frac{1}{\sqrt{2}}(Y' + \Pi_M Y''),$$

$$V_\Delta = \{v_{\Delta i}\}_{i=1}^{K} = \frac{1}{\sqrt{2}}(Y'' - \Pi_M Y'), \qquad (4)$$

$$X_T = TX = (X_\Sigma + jX_\Delta) \;— \qquad (5)$$

is the transformed vector of complex amplitudes of the expected desired signal, whose components X_Σ and X_Δ are equal to:

$$X_\Sigma = \frac{1}{\sqrt{2}}(X' + \Pi X''),$$

$$X_\Delta = \frac{1}{\sqrt{2}}(X'' - \Pi X'), \qquad (6)$$

$\hat{\Psi}_V = T\hat{\Psi}T^* = \hat{\Phi}_V^{-1}$ is the real matrix, inverse of the transformed real estimated CM:

$$\hat{\Phi}_V = T\hat{\Phi}T^*,$$

$\hat{R}$ is the estimation of the weight vector consisting of the ratio:

$$\hat{R} = T^*\hat{\Phi}_V^{-1}X_T = T^*\hat{R}_T\,,\ \hat{R}_T = \hat{\Psi}_V X_T\,. \qquad (7)$$

Figure 1 shows the diagram of generating the weight vector $\hat{R}$ based on (7). Double arrows indicate the vectors, shaded arrows, the matrices. Here, the vector $\hat{R}$ is generated by multiplying the vector $\hat{R}_T$ by the matrix T^* at the output of a vector-matrix multiplier (VMM) with a matrix impulse response (MIR) proportional to the real matrix $\hat{\Psi}_V$ indicated in parentheses in the VMM block. The transformed reference vector of the desired signal X_T (5), (6) arrives at the inputs of this VMM. The parameters of this VMM are estimated in the estimation block (EB) thanks to the processing of the *k*-dimensional interference sample transformed based on (3), (4).

The structure of the EB and the algorithms for estimating the required parameters can be varied, depending on the VMM block structure.

Figure 2 shows the diagram presented in Figure 1, but the structure of the blocks transformed with the matrix T (2) spelled out. In these blocks, the input complex vectors, having the form of a set of their real and imaginary parts, are transformed into the output sum and difference vectors determined by (3)—(6). In this context, the blocks are called blocks of the sum-difference transformation (SDT). The real $(\hat{R}')$ and imaginary $(\hat{R}'')$ parts of the vector $\hat{R} = \hat{R}' + j\hat{R}'' = \hat{\Psi}_V X_T$ are then equal to:

$$\hat{R}' = \hat{R}_\Sigma - \Pi\hat{R}_\Delta\,,\ \hat{R}'' = \hat{R}_\Delta + \Pi\hat{R}_\Sigma\,,$$

$$\hat{R}_\Sigma = \hat{\Psi}_V X_\Sigma\,,\ \hat{R}_\Delta = \hat{\Psi}_V X_\Delta\,. \qquad (8)$$

Figure 3 shows a simplified version of the Figure 2 diagram, which takes into account the condition [2, 7] that is essential for a radar with central symmetry of receive channels $X(\alpha) = \Pi X(\alpha)^\circ$, therefore:

$$X_\Delta = -X_\Sigma\ , \qquad (9)$$

which allows representing the vector $\hat{R}$, taking into account (2), (5), (6), (8), as:

$$\hat{R} = \frac{1-j}{2}(\hat{R}_\Sigma + j\Pi\hat{R}_\Sigma)\,.$$

In this regard, under conditions (9), for the complete plotting of the complex vector $\hat{R}$, it is sufficient to generate only the vector:

$$\hat{R}_\Sigma = \hat{\Psi}_V X_\Sigma\,,$$

which is taken into account in the diagram shown in Figure 3. Processing here is simplified by extracting the operations associated with the generation of vectors X_Δ, $\hat{R}_\Delta$ and subsequent operations associated with them. If there is no need for the vector X_Δ, the SDT(T) block is replaced by the sum transformation block ST(T).

The values $\hat{R}'$ and $\hat{R}''$ in the Figure 3 diagram differ from the corresponding values in the Figure 2 diagram by a constant factor

$$\left[\frac{1-j}{2}\right]$$

that does not affect the output value of the signal-to-noise ratio.

CONCLUSIONS

The article shows that using the estimate of the persymmetric correlation matrix, which is inherent in centrally symmetric receiving systems, in particular in the EIRS, in combination with the sum-difference transformation of input influences, allows expecting a reduction in the number of calculations by almost four times.

The article proposes the structures of adaptive systems of spatial, temporal, and spatiotemporal signal processing against the background of interference of various origins for the EIRS with central symmetry of receive channels. The main elements of the proposed structures are the blocks of the sum-difference transformation, vector-matrix multipliers, and the evaluation blocks to adjust the parameters.

Various types of adaptive devices, differing in structure and algorithms for estimating a priori unknown interference CM, can be used as EB and VMM in the proposed diagrams. Among them, adaptive lattice filtering methods are of the greatest practical interest due to their important practical advantages [3] such as:

- suitability for a wide range of tasks,
- structure regularity,
- universality,
- high numerical strength,
- ease of accounting for and using of a priori information,
- ease of control of malfunctions and failures, etc.

REFERENCES

1. Elagin V. V., Bakut P. A. (1974). Spatial-temporal processing of signals from many targets and sources of interference radiation. *Radiotechnique and electronics*, № 2, 422—427.
2. Koshevoy V. M., Radionov V. V. (1994). Effectiveness of adaptive filters with central symmetry of receiving channels. *Radio engineering and electronics,* № 11, 17.
3. Lekhovytskyi D. I., Kirillov I. G., Mylovanov S. B. (1992). Universal adaptive grating filters. Part 1. Adaptation at a given estimate of the interference correlation matrix. *Radiophysics*, № 4.
4. Meyirbekov M. N., Ismailov M. B., Manko T. A., Kozis K. V. (2022). Study of the influence of rubbers on the strength properties of carbon fiber. *Space Science and Technology*, **28**, № 5 (138), 67—74.
5. Shirman Y. D., Manzhos V. N. (1981). *Theory and technique of processing radar information against the background of interference.* Moscow: Radio and Communication, 415 p.
6. Voevodin V. V., Kuznetsov Yu. A. (1984). *Matrices and calculations*. Moscow: Nauka, 320 p.
7. Zarytskyi V. I., Kokin V. N., Lekhovytskyi D. I., Salamatyn V. V. (1985). Recurrent algorithms of adaptive processing with central symmetry of spatial-temporal reception channels. *Izv. Univ., Radiophysics*, **28**, № 7, 863—871.

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СТРУКТУРИ АДАПТИВНИХ СИСТЕМ ОБРОБКИ СИГНАЛІВ ДЛЯ РАДІОЛОКАЦІЙНИХ ДАВАЧІВ ЗОВНІШНЬОЇ ІНФОРМАЦІЇ КОРЕЛЯЦІЙНО-ЕКСТРЕМАЛЬНИХ СИСТЕМ НАВІГАЦІЇ ЛІТАЛЬНИХ АПАРАТІВ

Під час супроводу літального апарата на кінцевій ділянці польоту на нього впливають поряд із зовнішніми факторами ще й завади різного (штучного або природного) походження. Ці завади мають різноманітний вплив на приймальні елементи антенної решітки радіолокаційного давача зовнішньої інформації. Через мінливість та швидкоплинність складної завадової обстановки найбільш ефективними у боротьбі з цими завадами є адаптивні системи завадозахисту. Відомо, що використання адаптивних систем дозволяє подолати практично неминучу апріорну невизначеність статистичних характеристик завад різного походження. На теперішній час у зв'язку з розвитком цифрової техніки з'явились нові методи і пристрої адаптивної обробки сигналів на фоні завад. Так, арсенал методів адаптації до гауссівських завад поповнили методи, що передбачають обертання (безпосереднє або рекурентне) максимально правдоподібних оцінок кореляційних матриць завад або їхніх регуляризованих різновидів. Широкі можливості такої адаптації відкриваються у сучасних радіолокаційних станціях з багатоелементними фазованими антенними решітками, у яких передбачається цифрова обробка інформації. Через дуже велику швидкість літального апарата під час роботи його кореляційно-екстремальної системи наведення в умовах динамічної та нестаціонарної завадової ситуації важливою вимогою до адаптивних систем захисту від завад є їхня швидкодія. Ефективність адаптивної обробки сигналів на фоні завад може істотно підвищуватися завдяки використанню достовірної апріорної інформації. У статті розглянуто спосіб підвищення швидкодії адаптивних систем захисту від радіолокаційних завад різного походження завдяки врахуванню апріорної інформації про центральну симетрію приймальних каналів радіолокаційних давачів зовнішньої інформації кореляційно-екстремальних систем навігації літальних апаратів. Показано, що врахування такої апріорної інформації, як центральна симетрія приймальних каналів радіолокаційних давачів зовнішньої інформації, призводить до відповідної зміни структури пристроїв адаптивної обробки сигналів в умовах завад у цих давачах і, як наслідок, до підвищення їхньої швидкодії.

Ключові слова: завади, антенна решітка, радіолокаційні давачі, адаптивні системи обробки сигналів.