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Ratio improved adaptive systems moving target autoregressive type

The paper describes a comparative analysis of effectiveness of implementation methods of moving targets selection adaptive systems based on autoregressive approach. Autoregressive model of correlated interference enables to control passive jamming effectively without using algorithms based on inversion of correlation matrices. The paper discusses several methods of weight coefficients generation for moving targets selection adaptive systems where autoregression coefficients are used as weight coefficients. One of the main parameters determining effectiveness of the compared systems is an improvement factor used in this research.

Keywords: moving targets selection, radar stations, transversal filter.

Analysis of improvement factors of moving targets selection adaptive systems

Adaptive systems of moving targets selection (MTS) used in surveillance radars (SR) are usually implemented in the form of non-recursive filters (Fig. 1), which are also referred to as transversal or FIR-filters (finite-impulse-response filters) [1–4].

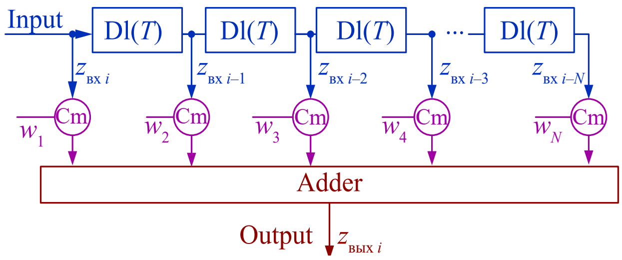

Fig. 1. Classical form of non-recursive FIR-filter for MTS

Number N is the order of transversal digital filter. As can be seen in Figure 1, the algorithm of MTS adaptive filter functioning includes weighted summation of previous samples of the input signal and is represented by the following formula:

$$z_{\text{вых}\ i} = w_1 z_{\text{вх}\ i} + w_2 z_{\text{вх}\ i-1} + \ldots + w_N z_{\text{вх}\ i-N},$$

where $z_{\text{вых}\ i}$ – integrated sample of signal at the filter output;

w_i – integrated weight coefficients which can be represented as vector $\mathbf{W} = (w_1, w_2, \ldots w_N)^{\mathrm{T}}$;

$z_{\text{вх}\ i}$ – integrated sample of signal at the filter input which can be represented as vector $\mathbf{Z}_{\text{вх}} = (z_{\text{вх}\ i}, z_{\text{вх}\ (i-1)}, \ldots z_{\text{вх}\ (i-N)})^{\mathrm{T}}$.

The main filter components are delay units Dl (delay line) of echo signals received per one repetition period T of the radar and complex multiplication units Cm which digitally multiply the input sample capture of echo signals, received from the delay lines, by corresponding weight coefficients. The complex multiplication results are sent to the adder where after adding a sample of output filtered interference signal is shaped.

Operation effectiveness of such MTS filters mainly depends on adaptive adjustment of the weight coefficients. Filtering quality is proportional to complexity of the generation algorithm of weight coefficients, which shall be adjusted in real time with due regard to correlation properties of passive jamming in a specific jamming environment.

A parameter, characterizing the MTS filter effectiveness is the improvement factor, which, according to *IEEE* [5], is defined as follows: improvement factor I of MTS system is the signal-to-noise ratio at the MTS filter output relative to signal-to-noise ratio at the MTS filter input, averaged uniformly for all expected radial velocities of the target. In other words the improvement factor of MTS system shows what fold is the signal-to-noise ratio at the MTS filter output larger than the same at the input. Target velocity is considered equally probable witin the entire radial velocity range. Improvement factor I can be presented as follows [6]:

$$I = \mathbf{W}^T \cdot \mathbf{W} / (\mathbf{W}^T \cdot \mathbf{R}_C \cdot \mathbf{W}^*), \quad (1)$$

where $\mathbf{R}_C$ – interference correlation matrix;

* – complex conjugation.

There are different methods of adaptive filter weight coefficient vector generation, which enable to determine effectiveness of the method and time required for vector generation [7], but until now there was no comparative evaluation of improvement factors of MTS adaptive systems

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in which autoregression coefficients are used as weight coefficients. The main attention is paid to such evaluation.

Improvement factors for different methods of weight coefficients (autoregression coefficients) generation were calculated with the use of *MATLAB* by statistic modelling for common parameters of the correlated interference model, depending on its first inter-period coefficient with Gauss distribution spectrum without Doppler shift, i.e.:

$$R(T)=\exp(-(2\cdot 0.165\cdot\pi\cdot\Delta\cdot T)/2),$$

where $R(T)$ – inter-period correlation factor;

T – radar repetition period;

Δ – two-side width of interference spectrum at the level of –20 dB (which is the cause of 0.165 multiplier introduction in the formula).

Fig. 2 shows a curve of inter-period correlation factor versus relative two-side width of interference spectrum Δ/F (F – radar repetition frequency) at the level of –20 dB. Dependence of this parameter on the correlation factor is important for analysis of MTS systems effectiveness.

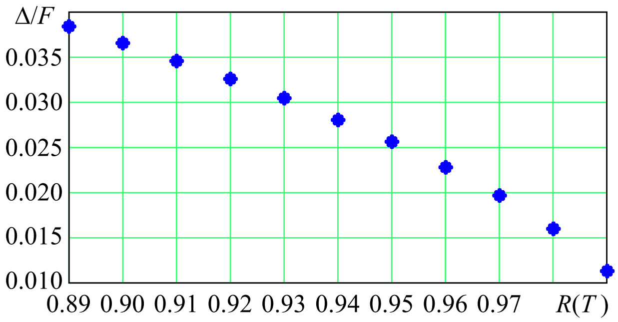

Fig. 2. Curve of relative spectrum width versus the first interperiod correlation factor for Gaussian interference spectrum

Improvement factors were calculated for three MTS systems on the basis of estimation methods of autoregression coefficients with the use of *MATLAB* functions [8]:

Berg method;

modified covariant method;

covariant method.

The Berg method uses *MATLAB arburg* function (input data, autoregression order), which returns the autoregression coefficients for input data and preset order of autoregression model. The obtained autoregression coefficients are normalised to the first coefficient. The order of autoregression specified as an integer number shall be less than the length of input data:

$$A1 = arburg\,(Z, N),$$

where Z – input signal vector;

$A1$ – vector of autoregression coefficients;

N – autoregression order, equal to 5 in the calculations.

In the modified covariant method, function *armcov* is used (input data, autoregression order), which returns autoregression coefficients for input data and preset order using the modified covariant method (function *modified*). The method is based on white noise passing through the autoregressive filter with sought autoregression coefficients. It minimises prediction errors in forward and backward directions in the root-mean-square context:

$$A2 = armcov\,(Z, N),$$

where Z – input signal vector;

$A3$ – vector of autoregression coefficients;

N – autoregression order, equal to 5 in the calculations.

In the covariant method, function *arcov* is used (input data, autoregression order), which returns autoregression coefficients for input data and preset order, using the covariant method (function *covariance*). The method is based on white noise passing through the autoregressive filter with sought autoregression coefficients. In contrast to the modified covariant method, this method only minimizes prediction errors in forward direction in the root-mean-square context:

$$A3 = arcov\,(Z, N),$$

where Z – input signal vector;

$A3$ – vector of autoregression coefficients;

N – autoregression order, equal to 5 in the calculations.

While the Berg method is widely known and its effectiveness has been analysed with regard to MTS adaptive systems in [6], the use of covariant method and its modifications in MTS adaptive

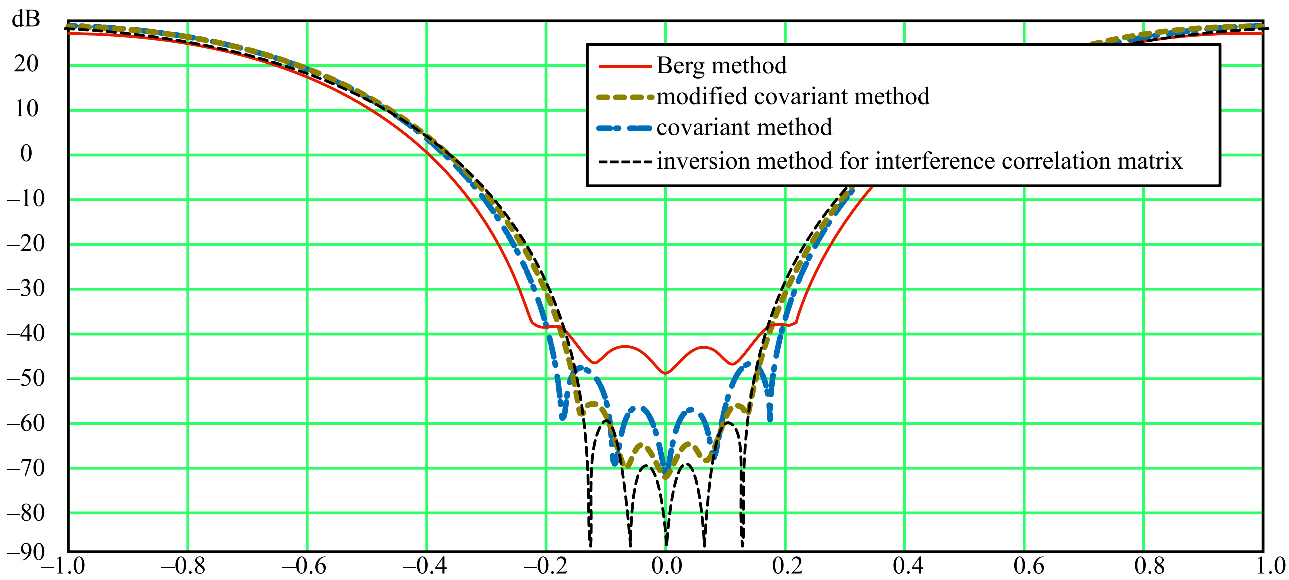

Fig. 3. Signal spectrum at the adaptive filter output

systems is only under study for the first time. Other methods of calculation of autoregression coefficients, such as Levinson or Yule – Walker method [7] are known; however, at the stage of preliminary analysis of their applicability in MTS adaptive systems these methods were not considered due to low resulting improvement factor.

Frequency characteristics of MTS filters calculated in *MATLAB* for the said three methods of weight coefficients generation are shown in Fig. 3 ($N = 5$, $R(T) = 0.99$).

To compare effectiveness of MTS adaptive systems of autoregressive type it is necessary to consider as well the optimal generation method of weight coefficients of MTS adaptive system. The optimal adaptive processing algorithm is described in [5], it requires the generation of a correlation matrix of interference and its inversion. Generation of weight coefficients of MTS filter requires a very high performance of signal processor and cannot be implemented using the up-to-date element base in real time even for a small dimension correlation matrix. Nevertheless the frequency response and improvement factor of the optimal MTS adaptive system have been calculated. Fig. 3 also shows a frequency response of optimal MTS adaptive system ($N = 5$, $R(T) = 0.99$).

The improvement factors were calculated in *MATLAB* system. Herewith, based on the variable first interperiod correlation factor $R(T)$, a rectangular correlation matrix was generated, which was inverted for generation of optimal weight coefficients, and from which a triangular matrix was generated for correlation superimposing on the initial noise sample with Gauss distribution. The correlated observation sample was used for finding by statistic testing the averaged autoregression coefficients for all considered methods. The number of tests was equal to 5000. For the purpose of verification of generation of the correlated sample of input interference signals the computation was performed analytically and by modelling of the 4-fold MTS system improvement factor with binomial weight coefficients. The results of modelling and analytical computation matched perfectly (Fig. 4.).

Fig. 5 shows the improvement factors for the adaptive MTS system under consideration. The improvement factor of the optimal MTS system stands out by its high effectiveness. A little bit worse are the improvement factors of the modified covariant method, while the Berg method just slightly outperforms the covariant method by effectiveness for broadband interference.

During calculation of coefficients the duration of this operation was also estimated for comparative evaluation of time spent by different

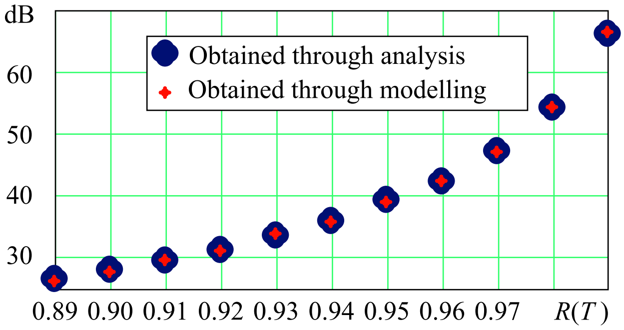

Fig. 4. Improvement factors for 4-fold MTS system with binomial coefficients

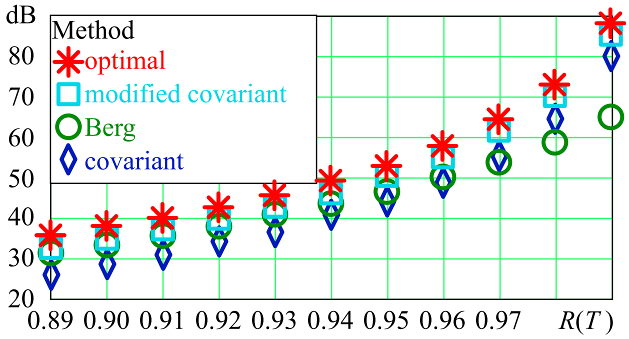

Fig. 5. Dependence of improvement factor versus interperiod correlation factor

quasi-optimal algorithms with account for coefficients averaging based on 32 samples per one test. The following results were obtained with the use of personal computer with processor *Intel* (*R*) *Core*^{TM} *i*3 *CPU M*330 with frequency of 2.13 GHz:

modified covariant method – 0.0087 s;
covariant method – 0.0084 s;
Berg method – 0.024 s.

Conclusion

The performed calculations for different options of estimation of adaptive MTS system weight factors show that the MTS system with optimal weight factors on the basis of interference correlation matrix and its inversion evaluation gives the highest improvement factor. The quasi-optimal adaptive algorithm based on modified covariant method is a little bit inferior. In case of Berg method the improvement factor is up to 10 dB less as compared with optimal processing for weakly correlated interference and over 20 dB less for highly correlated one. On the contrary, the covariant method is more efficient for highly correlated interference than for weakly correlated one. In terms of time expenditures, the modified covariant algorithm is slightly inferior to the covariant algorithm but due to its higher effectiveness this algorithm can be recommended for practical application in highly effective adaptive MTS systems of surveillance radars when processing a small number of pulses in a burst.

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