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The Development of Iteration Method for Optimization of Pair "Signal-filter"

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ABSTRACT: This paper is devoted to the improvement of the working methods of the "signal-filter" pair using an iterative procedure to maximize the signal-to-noise ratio, namely, to highlight the useful signals to provide information about the environment during the adaptive radar sensing in the conditions of obstacles. An algorithm for determining the optimal filter for suppressing undesired side lobes is proposed, which allows improving the process of detection and identification the target objects.
Qualitative characteristics and the stages of space-time signal processing in the radar were justified under correlation conditions (CCF) between the received and expected signals. The using of probing radar signals, shortened in their duration were proposed in order to reduce the power of reflections from the underlying surface and increase the contrast of the radar image.
A simulation test of the developed methodology was carried out in order to confirm the reliability of the proposed algebraic expressions using a mathematical model implemented in the Matlab programming environment, and a conclusion is drawn about the practical quality of the technical solutions developed on the basis of the iteration method.

1 INTRODUCTION

The existing model of marine radars has a high peak power of the radiation, which worsens the quality of the main lobe and leads to harmful emission into the environment and worsens the property of the electromagnetic compatibility. To improve the effectiveness of the radar must be developed radar with a reduced pulse radiation power, which is actual topic nowadays.

The basis of almost all methods for detecting and identifying target objects is the use of complex probing signals with optimized correlation properties. Knowledge is needed to improve the contrast of radar images. Tasks can be solved by determining the phase-frequency properties of the surface of the target object. The fixed conditions are necessary for the analysis of phase and amplitude distortions of the probe signal at different frequencies [1]. Therefore, the use of adaptive filtration in combination with the radar processing method makes it possible to establish, with sufficient accuracy, the phase-frequency characteristics of probe radar signals, directly for each sensing period. Get radar information about the target object based on the adaptive filter in each sensing period. The procedure is to adapt the filter at the time of receiving an echo-signal. Further analysis of the error (rejection of echo and probe signals) is a transient characteristic of the adaptive filter after its adaptation. For each target object in one sensing period, a separate algorithm for adaptive filtration must be formed.

From the point of view of increasing resolution and accuracy (i.e., radar informativity), it is necessary to extend the frequency band of the probe signal, which, for example, is achieved by decreasing the duration of the sounding pulses or using special complex signals [2].

Further we consider it with more details. The Ambiguity Function (AF) corresponds to the time-frequency response function that is observed on the output of the filter. One of the most important characteristics of the AF is the level of side lobes, which in most cases are trying to reduce. Phase-manipulated (PM) signals are sequence of radio pulses, phases of which vary according to a given law. The complex envelope of such PM signals is a sequence of positive and negative pulses [3, 4]. Almost always is the same shape of pulses and in most cases it is rectangular. A rectangular pulse with unit amplitude and duration written as:

$$p_0(t) = 1 \text{ , at } 0 \le t \le \tau_0. \quad (1)$$

Let the amplitude of the n-th pulse in the video PM signal is equal to +1 or -1, which corresponds to the initial phases of 0 or π in radio PM signal. With this definition the PM signal is written as follows:

$$S(t) = \sum_{n-1}^{N} S_n p_0[t - (n-1)\tau_0]. \quad (2)$$

One of the important characteristics of the cross ambiguity function (CAF) is the level of side lobes, which in most cases are trying to reduce. Choice of form of CAF, that is actually a form of probing signal depends primarily on the purpose of radar station, interference environment, the form and nature of the objectives, parameters of movement, etc.

In general, the expression for the CAF phase-manipulated radio pulse can be written:

$$\chi_{sw}(\tau_0, f) = \sum_{n-1}^{N} W_n^* S_{n-k} e^{-j2\pi nfT_0}, \quad (3)$$

where
$S_{n-k} = e^{j\varphi_{n-k}}$ – the complex amplitude of signal;
$W_n^* = e^{-\varphi_n}$ – the complex amplitude of filter;

The analysis of CAF phase-manipulated signals with different phase modulation law leads to the conclusion that the level of side lobes of CAF of many peaks or many crest structure without the use of special measures has significant value, commensurable, sometimes, with a maximum value of CAF. Applying of weight processing with the use of quasi optimal weighting coefficients allows to reduce the side lobes level between peaks, but inevitably is the expansion of peaks, this, in its turn, affects the performance of accuracy and ambiguity of target coordinates estimation and their reliability.

Substituting into the expression (3) $\Delta f = \frac{1}{4NT_0}$, then the expression for the CAF phase-manipulated radio pulse can be written:

$$\chi_{sw}(\tau_0, f) = \sum_{n-1}^{N} W_n^* S_{n-k} e^{j2\pi\frac{nl}{4N}}. \quad (4)$$

Using formula (5) were calculated optimal filter weighting coefficients:

$$W = R^{-1}S, \quad (5)$$

where R - the correlation matrix of similar to signal obstacle.

2 ITERATION METHOD

The iteration procedure of optimization of the signal and filter to find the maximum of signal/(noise + interference) ratio at their various dimensions lies in sequential solution of integral equations for the filter and the signal at the fixed norm of the signal and filter [5].

At the first step, for a given initial signal vector is being solved equation, determining the filter impulse response, then for the thus-obtained filter is being solved equation defining the signal, etc.

Thus, each value of the found filter or the signal passes normalization process. The methods of joined optimization of the signal and filter were considered earlier, taking into account additional restrictions on the permanent resolution of time, the amount of losses in the signal/noise ratio and methods of signal and filter optimization at a fixed amplitude signal modulation. The research of their efficiency is being considered in this paper

In the calculations we used the iteration procedure of maximizing the signal/noise ratio, taking into account the restrictions on losses in the signal/noise ratio and a constant resolution in time where the signal/noise ratio was considered as [6]:

$$\Sigma = \frac{\left| \int_{-\infty}^{\infty} W^*(t) \mathrm{S}(t) \, \mathrm{d}t \right|^2}{\nu \int_{-\infty}^{\infty} |W(t)|^2 dt + \sigma_0 \int_{-\infty}^{\infty} \sigma_\xi(\tau, 0) |\chi_{sw}(\tau, 0)|^2 d\tau}, \quad (6)$$

where $\chi_{sw}(\tau, \mathrm{f}) = \chi_\rho(\tau, f) \sum_{n=0}^{N-1} W_n^* S_{n+k} e^{i2\pi nfT_0}$ – ambiguity function, T_0 – elementary pulse duration in the signal, f – Doppler`s frequency, N – number of pulses in the signal, NT_0 – period of signal (in periodic mode of work), $S_{n+k} = \left[S_{n+k} \right] e^{i\varphi_{n+k}}$ – $\mathrm{S}_{n+k} = \left[\mathrm{S}_{n+k} \right] \mathrm{e}^{\mathrm{i}\varphi_{n+k}}$ the complex amplitude of signal, delayed on k positions, φ_{n+k} – phase of signal, w_n^* – complex amplitude of bearing signal (filter), σ_0 – the coefficient, which describes reflected properties of interference , $\sigma_\xi(\tau, 0)$ - the range-velocity distribution of interfering reflections, e parameters that determine the restrictions on losses of signal/noise ratio (ν) and a constant restriction on time resolution (ξ). Expression of constant time resolution is as follows [1, 3]:

$$\frac{\int_{-\infty}^{\infty}|\chi_{sw}(\tau,0)|^2\, d\tau}{|\chi_{sw}(0,0)|^2} = \frac{\int_{-\infty}^{\infty}\left|\int_{-\infty}^{\infty} W^*(t)\mathrm{S}(t+\tau)dt\right|^2 d\tau}{\left|\int_{-\infty}^{\infty} \mathrm{W}^*(t)\mathrm{S}(t)\,\mathrm{d}t\right|^2} = T_R. \quad (7)$$

The constant time resolution T_R has the best value, when all the side lobes of the cross-correlation functions are zero. The solution of task will be found for the values of parameters $\nu = N_{0,}\xi = 1$. In fact, we consider the problem of maximizing the signal/noise ratio (the noise with spectral density N_0) with restriction on constant time resolution. On the first iteration, we are looking for a filter that provides for the chosen parameters ν и $N_0 = 10^{-3}$ almost complete suppression of side lobes. This is connected to the fact that the problem of digital signals corresponds to suppress $N-1$ side lobes, which corresponds to the condition of the zero zone [7]. Zones with complete suppression of side lobes.

The expression of losses in signal/noise ratio is as follows:

$$\rho = \frac{|W^* S|^2}{W^*\,\mathrm{W}\cdot\mathrm{S}^*\, S}. \quad (8)$$

In the first step may be a large losses in the signal / noise ratio. Therefore, we shall use the procedure above to select the signals and filters, which allow to obtain minimal losses in the signal / noise ratio.

Program development using the iterative method

In the Matlab was developed a program that allows to realize the iteration process of joint optimization of filter and signal and receive graphics with CAF-sections $\Delta f = \frac{1}{4NT_0}$ given below (figures 1-7). In this case, as the initial approximation we considered a discrete signal sequence with N=10 with the following form s= [1; 1; 1; 1; -1; -1; 1; 1; 1; -1], In the result of the iteration process we received a couple of signal and filter, which ensures a constant value of time resolution $T_R = 1$ (it means complete suppression of the side lobes in L=0) and $\rho = 1$, which no losses in signal/noise ratio (figure 1б) and corresponds to the agreed treatment.

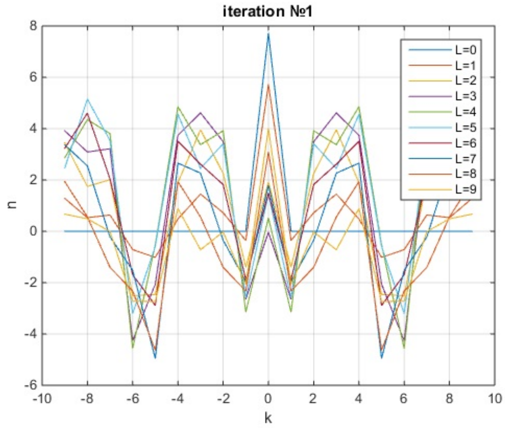

Figure 1. The shape of CAF and her sections at l=0…9 of periodic signal s = [1; 1; 1; 1; -1; -1; 1; 1; 1; -1]. The value of optimal filter: Wn = [2.1943; 0.4389; 0.0878; 0.7900; -0.6145; -1.6676; 0.4389; 0.0878; 0.7900; -0.6145] and optimal signal Snorm = [1.0002; 1.0000; 0.9999; 1.0000; -1.0000; -1.0001; 1.0000; 0.9999; 1.0000; -1.0000]. The value of losses in signal/noise ratio ρ = 0.5967.

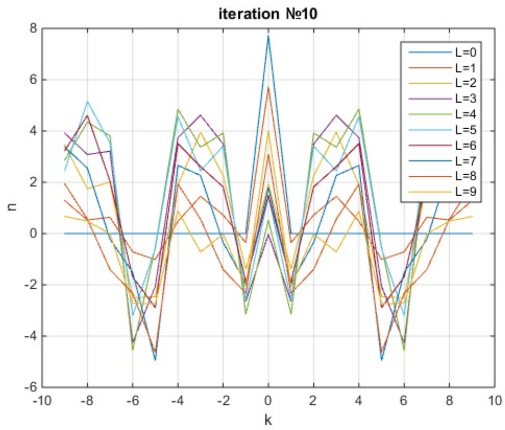

Figure 2. The shape of CAF and her sections at l=0…9 of periodic signal s = [1; 1; 1; 1; -1; -1; 1; 1; 1; -1]. The value of optimal filter: Wn = [2.1938; 0.4395; 0.0883; 0.7907; -0.6150; -1.6669; 0.4395; 0.0883; 0.7907; -0.6150] and optimal signal Snorm = [1.0018; 0.9996; 0.9991; 1.0000; -0.9998; -1.0012; 0.9996; 0.9991; 1.0000; -0.9998]. The value of losses in signal/noise ratio ρ = 0.5980.

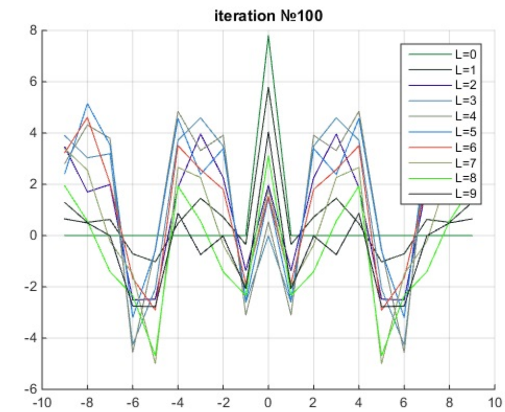

Figure 4. The shape of CAF and her sections at l=0…9 of periodic signal s = [1; 1; 1; 1; -1; -1; 1; 1; 1; -1]. The value of optimal filter: Wn = [2.1431; 0.4944; 0.1388; 0.8500; -0.6620; -1.5995; 0.4944; 0.1388; 0.8500; -0.6620] and optimal signal Snorm = [1.1593; 0.9598; 0.9182; 1.0013; -0.9799; -1.0963;

0.9598; 0.9182; 1.0013; -0.9799]. The value of losses in signal/noise ratio $\rho = 0.6101$.

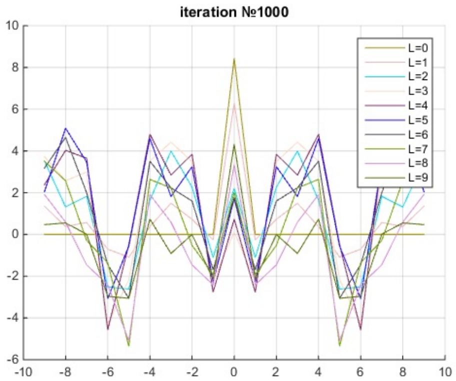

Figure 5. The shape of CAF and her sections at l=0…9 of periodic signal s = [1; 1; 1; 1; -1; -1; 1; 1; 1; -1]. The value of optimal filter: Wn = [2.1431; 0.4944; 0.1388; 0.8500; -0.6620; -1.5995; 0.4944; 0.1388; 0.8500; -0.6620] and optimal signal Snorm = [1.1593; 0.9598; 0.9182; 1.0013; -0.9799; -1.0963; 0.9598; 0.9182; 1.0013; -0.9799]. The value of losses in signal/noise ratio $\rho = 0.7126$.

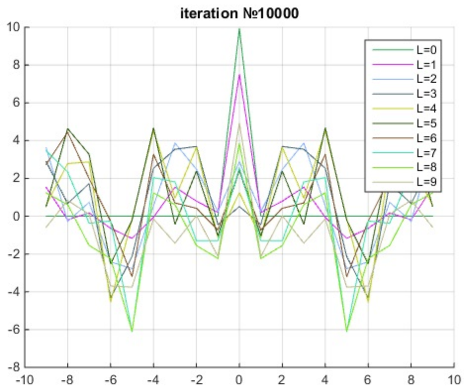

Figure 6. The shape of CAF and her sections at l=0…9 of periodic signal s = [1; 1; 1; 1; -1; -1; 1; 1; 1; -1]. The value of optimal filter: Wn = [1.8697; 0.6954; 0.4119; 0.9789; -0.8035; -1.4108; 0.6954; 0.4119; 0.9789; -0.8035] and optimal signal Snorm = [1.6835; 0.7814; 0.5702; 0.9927; -0.8681; -1.3477; 0.7814; 0.5702; 0.9927; -0.8681]. The value of losses in signal/noise ratio $\rho = 0.9888$.

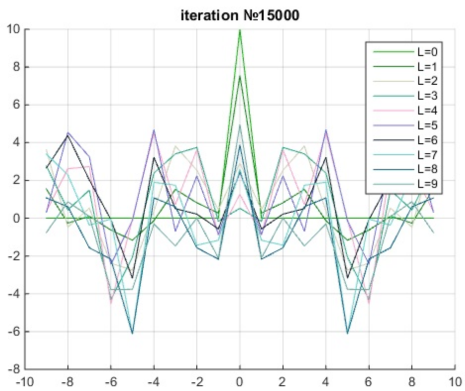

Figure 7. The shape of CAF and her sections at l=0…9 of periodic signal s = [1; 1; 1; 1; -1; -1; 1; 1; 1; -1]. The value of optimal filter: Wn = [1.8166; 0.7225; 0.4595; 0.9854; -0.8233; -1.3914; 0.7225; 0.4595; 0.9854; -0.8233] and optimal signal Snorm = [1.7456; 0.7548; 0.5198; 0.9898; -0.8482; -1.3690; 0.7548; 0.5198; 0.9898; -0.8482]. The value of losses in signal/noise ratio $\rho = 0.9984$.

Furthermore, calculations were performed with N = 3, 8, 9, 12 for the periodic case where similar results were obtained and also for aperiodic case. Using obtained signals for different N (N1, N2,…Np) new signals may be constructed with the method based on element-wise multiplication of signals with mutually prime periods [7]. In particular we can get resultant signal due to the product of two signals: N= N1N2 (for example N1=3, N2=4; N1=5, N2=4; N1=7, N2=9; and others). Also can be used products of three, four signals and so on.

Considered in this article method of signal-filter pair synthesis can also be used for range-velocity distributions of the interfering reflections, which contain a few cross-sections CAF with different Doppler shifts.

3 CONCLUSIONS

The sidelobe suppression helps to reduce the level of harmful radiation to the surrounding space. Also an important part is to reduce the level of background noise in the antenna, as it is created due to the differences of the amplitudes and frequencies of side lobes from the main lobe.

In this paper we considered the the task of maximization of signal/noise ratio with additional restrictions in it and restrictions on constant time resolution. The results of calculations confirmed the effectiveness of the considered iteration procedure allowing at the appropriate choice of the initial signal to get known globally optimal solutions. Therefore, we will consider the tasks with the help of this procedure to suppress of interfering reflections with random range-velocity distribution of preventing reflections, the best solutions of which are unknown.

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