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Development of an efficient hybrid model for range sidelobe suppression in pulse compression radar

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ABSTRACT

An efficient hybrid model that substantially reduces the sidelobe of the compressed output of the binary phase coded waveforms is suggested by suitably combining a matched filter (MF) and a radial function (RF). The sidelobe suppression is achieved by modulating the MF output by the RF output. Simulation study is carried out to evaluate the performance of standard MF, multilayer artificial neural network (MLANN) and radial basis function neural network (RBFNN) based pulse compressors for binary phase coded pulse compression. The evaluation is based on comparative analysis of the peak to sidelobe ratio (PSR) of the compressed output under noisy as well as Doppler shift conditions. The experimental results demonstrate that the performance of proposed method is significantly superior compared to that of the other standard methods. Further, the hardware requirement of the proposed model is significantly less and unlike other neural networks it does not require training operation.

1. Introduction

Pulse compression technique is used in many modern radar signal processing systems to achieve the range accuracy and resolution of a narrow pulse while retaining the detection capability of a long pulse. Generally, the matched filter (MF) is used for pulse compression operation [8]. But the output response of the MF contains high range sidelobes which at times leads to false target detection. To minimize the range sidelobes, some novel techniques have been proposed in the literature by employing mismatch filters [1,2,9]. The multilayer artificial neural network (MLANN) with back propagation (BP) [7] and extended Kalman filtering (EKF) [3] algorithms have been employed for reduction of range sidelobes of binary phase coded waveforms. Neuro-fuzzy network based pulse compression (NFNPC) [4] has also been reported in the literature. Recently the radial basis function neural network (RBFNN) based method [6] has been shown to yield better sidelobes reduction compared to other competitive methods.

The basic concept of the development of the paper is the use of a radial function (RF) whose value depends only on the distance from a centre [5]. This RF helps in modulating the output of the MF. In the present case the output of the RF is used to weight the main and sidelobes of the MF output for minimizing the range sidelobes of the binary phase coded waveforms. This resultant MF-RF model provides significant improvement in pulse compression performance. The advantage of the proposed method is low complexity and no training requirement as direct kernel output of the RF is used for sidelobe suppression. So the hardware requirement and computation time are reduced. As a result, the proposed structure is suitable for online pulse compression operation.

The organization of the paper is as follows. Section 2 describes the proposed efficient hybrid MF-RF model for pulse compression. The simulation study of the complete scheme is carried out in Section 3 taking three different pulse trains, i.e. Barker code, optimal code and combined Barker code. The comparison of the various methods in terms of peak to sidelobe ratio (PSR) is also made in the section. Finally the conclusion of the investigation is outlined in Section 4.

2. Pulse compression using proposed hybrid MF-RF model

The basic diagram of the proposed hybrid MF-RF model for pulse compression is shown in Fig. 1. A Gaussian function is used as a kernel function of the RF. Its output is given by

$$\Psi(\bar{q}) = \exp^{(-\frac{\|\bar{q}-\bar{p}\|^2}{2\sigma^2})} \tag{1}$$

where $\bar{p}$ and $\bar{q}$ are the transmitted and received signals, respectively, σ^2 is the variance of Gaussian function and $\|\cdot\|$ represents the Euclidean distance between two variables. Since both the RF and the MF outputs show maximum value at perfect matching condition (which is achieved when received signal is a replica of the transmitted signal), the output of their product is maximum at this instant. But during other time instants final output becomes less than the MF output as the RF provides negligible output. The

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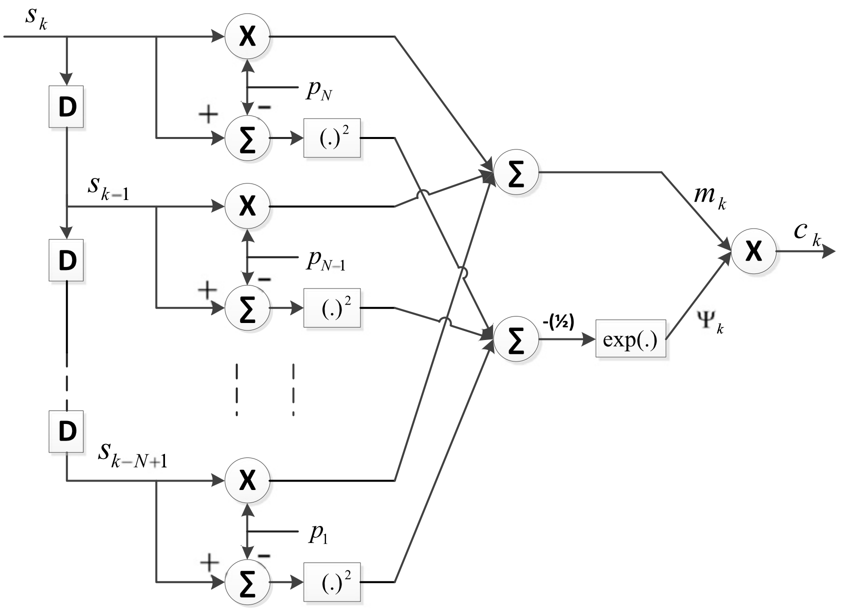

Fig. 1. Proposed MF-RF pulse compression model.

output of RF is independent to the MF output, it only depends upon the received signal. As a result, the sidelobes present in MF-RF output are practically absent compared to that in the MF output. Hence the proposed method provides significant improvement in the PSR.

Let the binary phase coded waveform of length N is given by $\bar{p} = [p_1, p_2, \ldots, p_i, \ldots, p_N]$ where $p_i = \pm 1$. Referring to Fig. 1, let s_k represent the input of the MF-RF at kth instant. It is a time shifted sequence of the binary phase code and can be written as

$$s_l = \begin{cases} p_l & \text{for } l = 1, 2, \ldots, N \\ 0 & \text{for } l \leqslant 0 \text{ and } l > N \end{cases} \tag{2}$$

The MF output is defined as

$$m_k = \sum_{i=1}^{N} p_i s_{k+i-N}, \quad k = 1, 2, \ldots, (2N-1) \tag{3}$$

The main lobe of MF output exists at $k = N$. The output of RF at the kth instant is given by

$$\Psi_k = \exp^{(-\frac{\|\bar{q}_k - \bar{p}\|^2}{2\sigma^2})}, \quad k = 1, 2, \ldots, (2N-1) \tag{4}$$

where $\bar{q}_k = [s_{k-N+1}, s_{k-N+2}, \ldots, s_{k-1}, s_k]$. The transmitted binary phase coded signal $\bar{p}$ acts as the centre of Gaussian kernel. The RF output is used to weight the lobes of the MF output. At $k = N$, the RF output is one because the received pulse ($\bar{q}_k$) is same as the transmitted pulse ($\bar{p}$). The corresponding output of the model is then given by

$$\begin{aligned} c_k &= \Psi_k m_k \\ &= \exp^{(-\frac{\|\bar{q}_k - \bar{p}\|^2}{2\sigma^2})} \sum_{i=1}^{N} p_i s_{k+i-N} \end{aligned} \tag{5}$$

where $k = 1, 2, \ldots, (2N-1)$. At $k = N$, the output of the model c_k becomes maximum because of the product of maximum values of MF output m_k and the RF output Ψ_k. But for $k \neq N$, the sidelobes of MF-RF output are substantially small because of low value (< 1) of Ψ_k.

In this MF-RF model, the output of the MF is being multiplied by a value less than or equal to unity. When there is a perfect match, the value of the RF is unity. On the contrary, whenever the radar return is different from the transmitted code the value of the RF is smaller than one leading to further attenuation of the output of the MF.

Table 1
Comparison of PSR obtained from different methods under no noise condition.

Method	PSR (dB)		
	13-BC	21-OC	35-CBC
MF	22.27	20.43	13.97
MLANN	42.08	43.43	41.08
RBFNN	53.38	65.14	121.84
MF-RF	74.39	113.30	195.91

3. Performance evaluation

Three binary phase coded waveforms, i.e. 13-bit Barker code (13-BC), 21-bit optimal code (21-OC) and 35-bit combined Barker code (35-CBC) are used to test the effectiveness of the proposed method. The same parameter values are used for training of MLANN and RBFNN as given in [6,7]. The variance (σ^2) of kernel function of MF-RF is taken to be 1. Since the proposed method does not require training, the direct test results are obtained.

3.1. *Performance under noiseless condition*

The PSR is defined as the ratio of main lobe power to maximum sidelobe power. For all the three codes, the PSRs obtained by four different methods are listed in Table 1. It is evident from the results that the PSR obtained from proposed method is significantly higher than that obtained by other methods for all three received waveforms.

3.2. *Performance under noisy condition*

Table 2 shows the comparison of PSR performance of different methods at various SNR conditions. White additive Gaussian noise is used in the simulation study. Table 2 and Fig. 2 show the distinct superiority in terms of least sidelobes of the proposed MF-RF method over other three methods.