RANGE SIDELOBE SUPPRESSION TECHNIQUE FOR RANDOMLY INTERMITTENT SPECTRA RADAR SIGNAL

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ABSTRACT

The randomly intermittent spectra (RIS) signal is a technique that increasingly employed to combat spectrum congestion in radars and other radio services to evade the external interferences. However, the spectra discontinuity of the signal gets rise to high range sidelobes when matching the reflected echo, which is much more difficult for targets detection. So it is indispensable to investigate the technique for sidelobes suppression of the range profile when RIS signal is utilized. In this paper we introduce a new processing technique based on time domain filtering to lower the range sidelobes, a robust and effective algorithm is adopted to solve the coefficients of the filter, and the restriction on the desired response of the filter is derived. The simulation results show that the peak range sidelobe can be reduced to -27dB from -9.5dB while the FBS is 200KHz.

1. INTRODUCTION

There are many interference sources in high-frequency (HF) and ultrahigh-frequency (UHF) bands, making it difficult to find broad clear frequency bands for radar to transmit signal. To minimize the interferences, signal with randomly intermittent spectra (RIS), has been proposed [1]-[3]. The main idea of RIS is that the frequency band for transmitting signal must be made intermittent to avoid interferences based on the result of exterior frequency monitor. The frequency band within which the carrier frequencies are randomly selected is defined as frequency band span (FBS). With their flexible energy distribution, the external interferences can be evaded. However, the spectrum discontinuity results in the rising of the range sidelobes when matching the reflected echo, which is difficult for targets detection. Moreover, the spectrum discontinuity also causes the spectral weighting method noneffective. So it is indispensable to study the range sidelobes suppression technique for RIS signal.

In literature [4]-[6], some algorithms for the processing of RIS signal, aimed at range sidelobes suppression, are described. However these algorithms are still far out of practical use. S. D. Green putted forward a method based on the spectrum reconstruction to lower the range sidelobes of RIS signal [4]. But it is very difficult to reconstruct the spectrum when sidelobes are extra high. Another method based on linear prediction in frequency domain by autoregressive (AR) model was proposed in [5]. In addition, the method based on adaptive targets echo reconstruction was introduced in [6]. This method has the similar problems that exist in Green's method.

In this paper, we investigate a new time domain filtering technique to suppress the range sidelobes of RIS signal. The simulation results show that the peak sidelobe can be suppressed to about –27dB while the FBS is about 200KHz. Section 2 introduces the radar system and waveform structure of the RIS signal used in our work, and the time domain filter technique for range sidelobes suppression is developed in section 3. The simulation results are presented in section 4. Finally, conclusions are drawn in section 5.

2. THE RIS SIGNAL RADAR SYSTEM AND WAVEFORM STRUCTURE

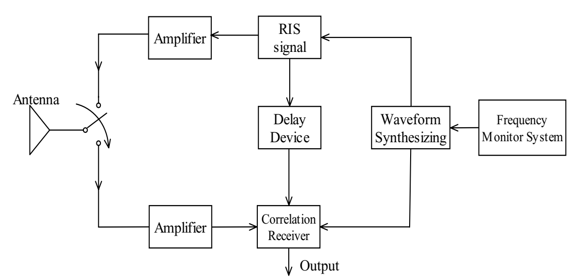

Fig.1. Block diagram of the RIS signal radar system

A simplified block diagram of the RIS radar system is shown in Fig.1. The frequency monitor system surveils the electromagnetic environment and gives the interferences-free zones that suitable for radar transmitting signal in the 3-30MHz frequency range. The synthesized waveform, after being modulated to the base carrier frequency, is amplified by a wideband amplifier and transmitted. The RIS signal is delayed by delay device and mixed with the received signal. After coherent receiving, we can obtain information of the targets.

In our work, the waveform of the radar signal is simply a series of bursts of RIS pulses, the carrier frequency of each pulse is randomly selected within the given frequency range based on the result of the frequency monitor system. Then the waveform can be expressed as

$$s_i(t)=\sum_{m=0}^{M-1}\sum_{i=0}^{N-1}A_i rect(\frac{t-iT_b-mT_M-\frac{T_1}{2}}{T_1})e^{j2\pi\Delta B_i t+\varphi_0} \quad (1)$$

where T_1 is the width of the pulse, ΔB_i is the frequency of i-th pulse which is randomly selected within the FBS, φ_0 is initial phase, T_b is the pulse period, and T_M is the frequency sweep period. N is the number of pulses in one frequency sweep period, B is the FBS. To avoid the overlap of spectra among pulses, the restriction on each ΔB is given below.

$$\Delta B_i-\Delta B_j>\frac{1}{T_1},\ (i,j=0,1,2\cdots N-1,\ \ i\neq j) \quad (2)$$

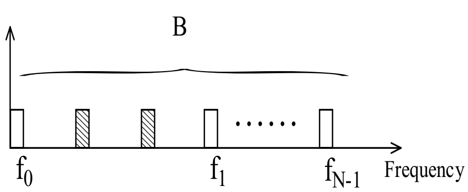

Fig.2 The frequency distribution of RIS signal waveform

The sketch map of the frequency distribution of the RIS radar signal waveform can be illustrated as Fig.2. The pulses with shadow denote there are interferences sources in corresponding frequency bands. Here our attention is focused on the sidelobes suppression of the radar range profile and the influence of the targets motion can be eliminated by motion compensation techniques, so the targets are supposed to be stationary.

We denote the target impulse response by $h(t)$. The received radar signals backscattered from the target can be represented as

$$s_r(t)=h(t)\otimes s_i(t) \quad (3)$$

where $\otimes$ denotes the convolution operation.

The output of the correlation, which is the cross-correlation function of the delayed base band transmitted signal $s_i(t-\tau)$ relative to the received signal $s_r(t)$, can be expressed as

$$R_{ri}(\tau)=\int_{-\infty}^{+\infty}s_r(t)s^*(\tau-t)dt=h(\tau)\otimes R(\tau) \quad (4)$$

where superscript $*$ denotes complex conjugate, and $R(\tau)$ is the auto correlation function of the transmitted signal $s_i(t)$, given by

$$R(\tau)=\int_{-\infty}^{+\infty}s_i(t)s_i^*(\tau-t)dt \quad (5)$$

Neglect the effect of the target impulse response, the range profile of radar targets mainly depends on the auto correlation function $R(\tau)$, then the sidelobes suppression of the target range profile is transferred to the sidelobes suppression of the auto correlation function of the RIS signal.

3. SIDELOBE SUPPRESSION TECHNIQUE

Because the spectrum of the signal $s_i(t)$ is discontinuous, the kernel of the auto correlation of the signal is not an ideal $\sin(\pi x)/(\pi x)$ function, or an ideal *sinc* function, but with many high irregular sidelobes around the main peak. Fig.3 illustrates an example of the auto correlation represented by (5). The system parameters of radar are given in section 4.

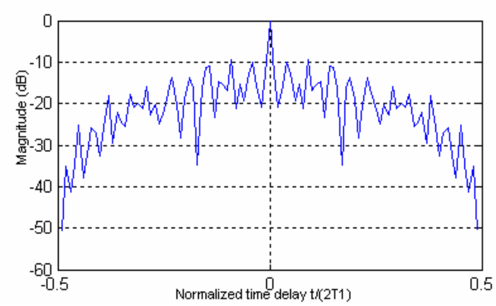

Fig.3. Auto correlation shape of the RIS signal

3.1. Sidelobe Suppression by Time Domain Filtering

Due to discontinuity of the spectra, the sidelobes of the RIS signal auto correlation cannot be reduced by simply spectral weighting using conventional window function, neither it can be processed by spectrum reconstruction algorithm since the sidelobes are too high to determine the mainlobe.

As we know that the spectral weighting in the frequency domain is equivalent to a convolution in time domain, a time domain filtering technique can be developed to suppression the irregular sidelobes. Then our objective is to find a special time domain filtering function, such that by convolving the time domain data with the filtering function, a new response with much low sidelobes can be obtained. We denote such a filtering function as $X(\tau)$, the processed auto correlation of the RIS signal is expressed as

$$R_X(\tau) = R(\tau) \otimes X(\tau) \quad (6)$$

where $R_X(\tau)$ is the processed auto correlation with much lower sidelobes than the original one.

3.2. The Coefficients Solution of the Filter

Assume r is the digitized $R(\tau)$ within the time interval $\tau \in [-T_1, T_1]$ expressed as $r = [r_0, r_1, r_2 \cdots r_{L-1}]$, L is the length of r. To suppress the sidelobes by (6), r should be written in a matrix form, expressed as (7)

$$R = \begin{pmatrix} r_0 & 0 & 0 & & \cdots & 0 \\ r_1 & r_0 & 0 & & \cdots & 0 \\ \vdots & & & & \vdots & \vdots \\ r_{L-1} & r_{L-2} & & & \cdots & r_0 \\ 0 & r_{L-1} & r_{L-2} & & \cdots & r_1 \\ 0 & & r_{L-1} & r_{L-2} & \cdots & r_2 \\ \vdots & & & & \vdots & \vdots \\ 0 & 0 & & & \cdots & r_{L-1} \end{pmatrix} \quad (7)$$

The filter coefficients can be obtained by the following linear equation.

$$RX = D \quad (8)$$

where

$$X = [x_0, x_1, x_2, \cdots x_{L-1}]^T \quad (9)$$

$$D = [d_1, d_2, \cdots d_{2L-1}]^T \quad (10)$$

where $[\cdot]^T$ denotes the transposition. X is filter coefficients vector to be solved with length L, and D is the desired response vector of the filter with length $2L-1$.

The set of linear equations in (8) represents an ill-posed system which makes a direct solution practically impossible. We have to find an effective and robust algorithm to solve (8). In [7][8], an effective, yet robust projection method for solving ill-posed consistent system is introduced. The major advantage of this method is that it always converges for any given parameters.

The projection method is described as follow. We denote *i*-th row of the matrix (7) as

$$R_i = [r_{i0}, r_{i1} \cdots r_{i(L-1)}] \quad (11)$$

Let the initial guess solution of X be $X^{(0)} = [x_0^{(0)}, x_1^{(0)}, \cdots x_L^{(0)}]$, then determine the $X^{(i)}$ from the recurrence relation

$$X^{(i+1)} = F(D, X^{(i)}) \quad (12)$$

where F is the mapping function, defined as

$$F(D,X) = f_1(f_2(\cdots(f_m(x))\cdots)) \quad (13)$$

in the expression, f_i is defined as

$$f_i(X) = X - \frac{< X, R_i > - d_i}{< R_i, R_i >} R_i \quad (14)$$

where $< X, R_i >$ denotes the inner product of vector X and R_i.

If we start with an initial guess $X^{(0)}$, an expectably accurate solution can be obtained by repeating the cyclic procedure.

3.3. The Restriction on the Desired Response Vector

Although the projection method is always convergence, it requires the system is consistent. If the system can not meet this condition, although the algorithm is convergent, the obtained solution is not proper. Then guaranteeing (8) to be a consistent system, is an important premise of the algorithm, which is not mentioned in original literature [7].

In our work, since the coefficients matrix structure (as (7) expressed) of linear equations is fixed, then we have to construct a proper desired response of the filter to guarantee the consistence of the system. Observe the augmented matrix of (7), we find that the desired response output vector D must have at least L consecutive nonzero elements, the system is consistent.

$$D = [0, 0 \cdots d_n, d_{n+1} \cdots d_{n+L-1}, 0, \cdots 0]^T \quad (15)$$

where $d_n, d_{n+1} \cdots d_{n+L-1}$ are all not equal to zero, it is easily to prove that $rank\{R \vdots D\} = rank\{R\}$, then the system of (8) is a consistent system.

4. SIMULATION RESULTS

To observe the effect of the technique discussed above on range sidelobes suppression of the RIS signal, we present some simulation results in this section. The system parameters are: FBS=200KHz, pulse width T_1 =0.25ms, pulse repetition period T_b =3ms, the number of pulses in one repetition period N =15, τ is limited in $\tau \in [-T_1, T_1]$. ΔB_i is randomly selected in FBS with the restriction of (2), and the value as follow (KHz):

$\Delta B_1 = 4.7075$ $\Delta B_2 = 9.6403$ $\Delta B_3 = 21.4468$
$\Delta B_4 = 34.5033$ $\Delta B_5 = 39.2268$ $\Delta B_6 = 82.9241$
$\Delta B_7 = 94.9548$ $\Delta B_8 = 103.5085$ $\Delta B_9 = 130.7285$
$\Delta B_{10} = 144.2568$ $\Delta B_{11} = 152.1714$ $\Delta B_{12} = 157.9585$
$\Delta B_{13} = 163.8566$ $\Delta B_{14} = 169.5010$ $\Delta B_{15} = 184.8541$

The length of r is L =100, then the length of the desired response output D is $2L-1$=199. The form of D is restricted by (15). In the simulation, the mainlobe is located in the central of D, and the shape is similar to a Hanning function with the width 15, set the peak of the mainlobe to be 1. The other points within [50,150] are set to random nonzero numbers with the magnitude -40dB lower than the peak of the mainlobe, set the rest points to be 0. It is clearly the D meets the requirement of (15). Fig.4 is the result of the range profile of RIS signal radar after filtering by the solved filter. It is clearly that the sidelobes of range profile are suppressed significantly. Before the filtering, the peak sidelobe level (PSL) is about -9.5dB as shown in Fig.3, and the PSL is suppressed to -27dB after the filtering as shown in Fig.4.

The simulation result of the system is not consistent is also given. The system parameters are holding unchanged, the desired response D is altered as follow: the mainlobe of D is same as that of the last simulation, but set a few point within [50,150] to be 0, set the other points of D to be 0. Substitute D and R into (8), solve (8) by projection methods. Filtering range profile by the obtained filter, the result is shown as Fig 5. The range profile is changed but, the out of the filter is not as desired.

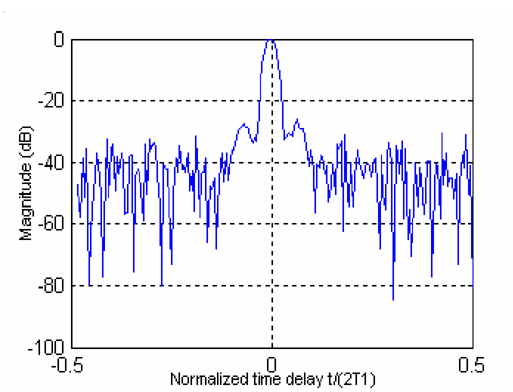

Fig.4 The profile after filtering

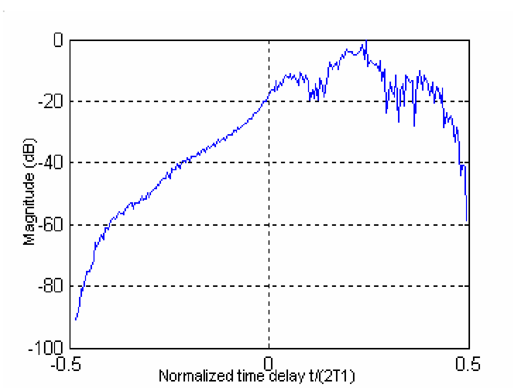

Fig.5 The profile after filtering when the restriction on D is broken

5. CONCLUSION

A novel time domain filtering technique for suppressing the range sidelobes of the RIS signal radars is introduced in this paper. The projection method for solving the coefficients of the filter is adopted, and the condition to guarantee the algorithm effective is derived. The simulation results show that the range peak sidelobe can be reduced to about -27dB after processing from -9.5dB before processing, while the FBS is expanded to 200KHz. Note that the coefficients of the filter can be solved beforehand, then it is adaptable to practical radar systems and applicable for other real-time signal and image processing.

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