Microwave Radar Signal Denoising Based on Wavelet Denoising with Adapted Threshold Function

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Abstract

Considering the advantage that microwave radar is not easily affected by weather and can work around the clock, it is widely used in military and civilian fields. However, because microwave radar will be affected by multipath interference and internal noise during operation, the noise in the radar signal will cause the Signal-to-Noise-Ratio (SNR) to decrease so that useful information is drowned in the noise. In order to denoise the microwave radar noise, this paper selected a more mature wavelet denoising method. However, the classic hard threshold function and soft threshold function have their own shortcomings, which is not conducive to accurate signal reconstruction. Therefore, an adapted threshold function based on Discrete Wavelet Transform (DWT) was proposed. To verify its effectiveness, three sets of simulations were performed for the microwave radar signal by MATLAB, the results verified the effectiveness.

Keywords

Wavelet Denoising, Microwave Radar Signal, DWT.

1. Introduction

The microwave radar is suitable for complex environment (day and night, fog, rain and snow), because that the microwave has longer wavelength than other electromagnetic waves, such as infrared rays, so microwave has better penetration. Therefore, the microwave radar is extensively applied to detect the targets in military applications and civil aviation. However, due to the complexity of the working environment, the radar signal contains various noise jamming that would affect the extraction of effective information from the radar signal. In order to eliminate noise contained in the beat signal, the wavelet denoising was considered in the paper.

There's a lot of related work related to using wavelet transform for denoising. SR Messer [1] proved that wavelet denoising can be used to remove white noise in heart sounds. Giaouris, D. et al. [2] used the wavelet transform to distinguish noise in the actual current signal and modulate motor speed. Yi Hu et.al [3] proposed the use of low-variance spectral estimators based on wavelet thresholding the multiple spectra for speech enhancement to suppress "musical noise". Debin et al. [4] identified weak characteristic signals in the gearbox vibration signals by using a local adaptive algorithm based on wavelet. Madhur Srivastava et al. [5] proposed a new threshold formula to denoise 1-D experimental signals, which can increase the SNR by more than 32dB without distorting the signal. CUI Hua et al. [6] posed a new threshold function, simulation experimental results indicated that the new method gave better SNR gains than hard and soft thresholding methods.

In this paper, in order to reduce the impact of noise on effective information, wavelet denoising method with the adapted threshold function was considered. The simulation results by MATLAB can verify the effectiveness of this algorithm.

2. Wavelet Denoising

2.1 Noise Sources Analysis

The noise here can be classified into two types according to their source, the external noise and the internal noise [7]. The external noise is incited by external interference factors, such as multipath interference, and noise signals enter the components of radar through the receiving antenna. The internal noise mainly includes weather interference and industrial interference. The entire noise signal is random, and the amplitude and phase are always changing in a random manner, although its waveform is continuous in the time domain. In the actual analysis, it often regarded as Gaussian noise. It is well known that the power spectral density of Gaussian white noise is uniformly distributed, and its amplitude is subject to a Gaussian distribution. If the SNR is low, the following situation may occur: the amplitude of the noise signal is much higher than the maximum value be pre-set, but at this point, the system treats it as a target, which produces a false target. Therefore, it is necessary to perform denoising processing on the radar signal, and after filtering and denoising, a purer beat signal can be obtained. The Wavelet Transform (WT) is suitable for analyzing abrupt signal and non-stationary signal. In addition, WT has the characteristics of multi-resolution analysis and bandpass filter, and can be implemented by fast algorithm, so it is often used for filtering and denoising. Thus, the paper studied the denoising of microwave radar signal based on DWT.

2.2 Discrete Wavelet Transform

The basic idea of wavelet transform is to use wavelet basis functions to represent or approximate the signal. When processing noisy signal using WT, it is necessary to discretize the wavelet and use the DWT. The DWT is a batch method, which can analyse a finite-length time-domain signal at different frequency bands and different resolutions by successive decomposition into coarse approximation and detail information [8].

Fig.1 indicates DWT decomposition process of the discrete-time radar signal (X). Among them, c_J is the detailed coefficients and d_J is the approximation coefficients. In return, approximate coefficients information is low frequency component, detailed coefficients information is high-frequency component. At the end of decomposition, no matter what decomposition levels it is, there has a wavelet decomposition tree, each layer has two branches, one is detail and another is approximation which has their own coefficients. Formula (1) is an example of 4-layer decomposition,

$$X = d_1 + d_2+d_3+d_4+c_4 \tag{1}$$

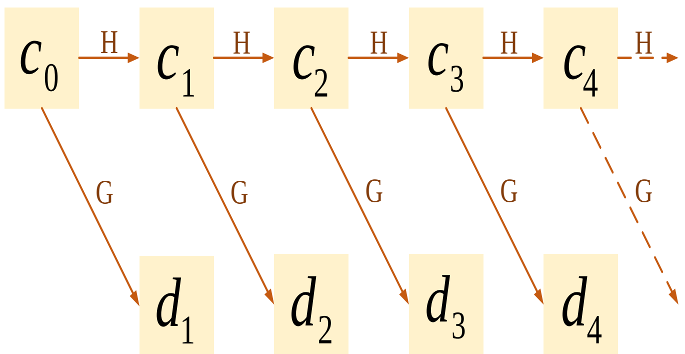

Fig. 1 The Decomposition Process of DWT

Discrete beat noisy signal of microwave radar is expressed by,

$$X_i = S_{bi}+n_i \tag{2}$$

Where, X_i is measured signal including with white noise, S_{bi} is useful beat signal to extract range information, n_i is white noise, i is sampling order. However the white Gaussian noise is not continue in the time domain, therefore the wavelet coefficients have strong randomness after DWT, that is, the coefficients corresponding to the noise still satisfy the Gaussian distribution.

The processes of DWT are, at first, choose a suitable mother wavelet. There have common mother wavelets which can support DWT and suit for actual signal denoising, as showed in Table 1,

Table 1 Common Mother Wavelet

Name	Haar	Daubechies	Coiflets	Symlets
Representation	haar	dbZ	coifZ	symZ

Wavelet basis functions are formed by scaling and translating transforms based on mother wavelets. Fig.2 presents examples of common wavelet basis function that are characterized by orthogonality.

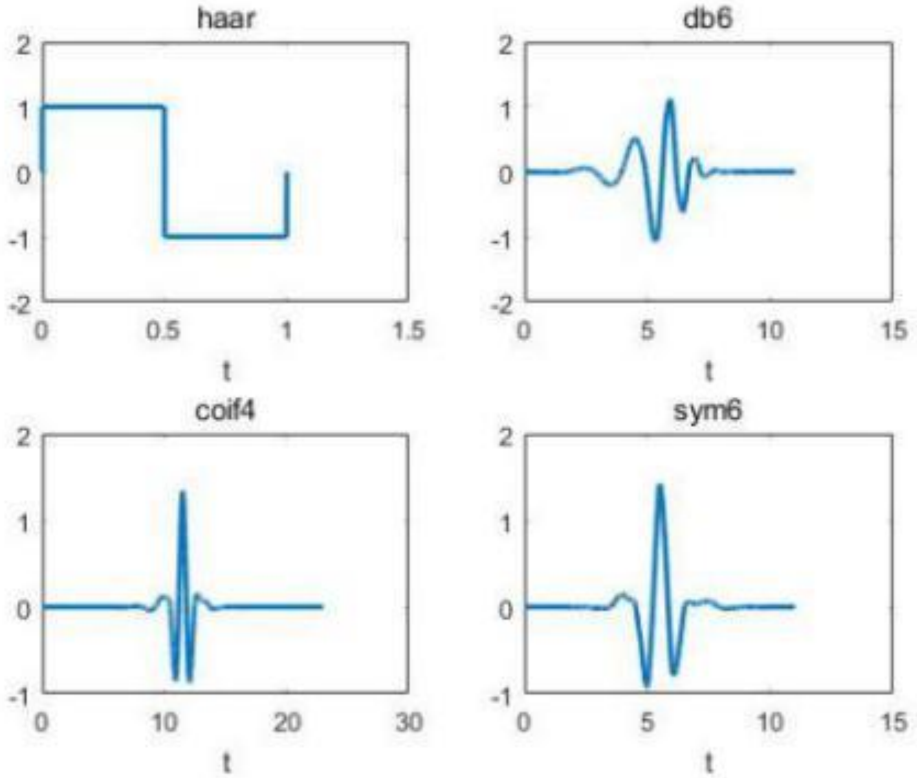

Fig. 2 Examples of Wavelet Basis Function

Next step is to determine the number of decomposition layers J. In general, the larger J is, the easier it is to distinguish between signal and noise, and the better the denoising effect, but the larger the reconstruction error. The microwave radar signal is usually decomposed into 3-5 levels [9, 10]. In the jth level, the formula (3) is used to calculated wavelet coefficients of c_j and d_j by orthogonal DWT [11]

$$\begin{cases} c_{j,k} = \sum_{n=-\infty}^{+\infty} c_{j-1,n} h_{n-2k} \\ d_{j,k} = \sum_{n=-\infty}^{+\infty} c_{j-1,n} g_{n-2k} \end{cases} \tag{3}$$

Where, h and g are orthogonal filter banks to each other. The $c_{j,k}$ is the k_{th} detailed coefficient, $d_{j,k}$ is the k_{th} approximate coefficient. And $k=1, 2, \ldots K$.

2.3 Adapted Threshold Function

As the classical threshold function of the DWT, the soft and the hard threshold denoising methods are widely used in practice, they all have some shortcomings [12]. The hard threshold is discontinuous in the whole wavelet domain and there are interrupted points in the place of $\pm\lambda$, as shown in Fig 3. So the signal $f'(k)$ which has been reconstructed by $d'_{j,k}$ may appear some oscillation. In the soft thresholding function, there is a constant deviation between $d'_{j,k}$ and $d_{j,k}$ when $abs(d'_{j,k})>=\lambda$. This will causes a deviation between the reconstructed signal $f'(k)$ and the real signal [13].

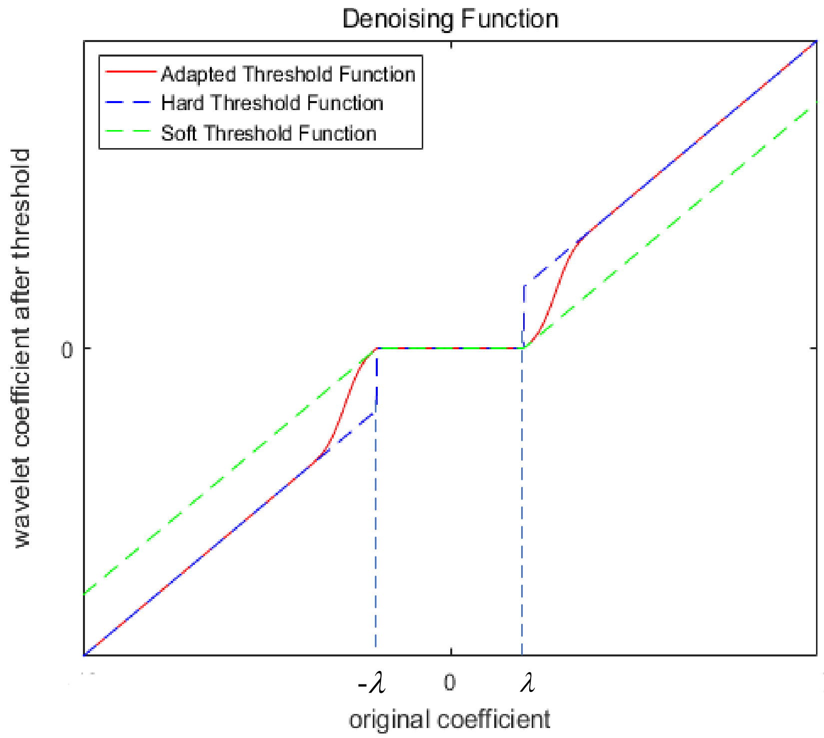

Fig. 3 Adapted Threshold Function and Compering with Classic Functions

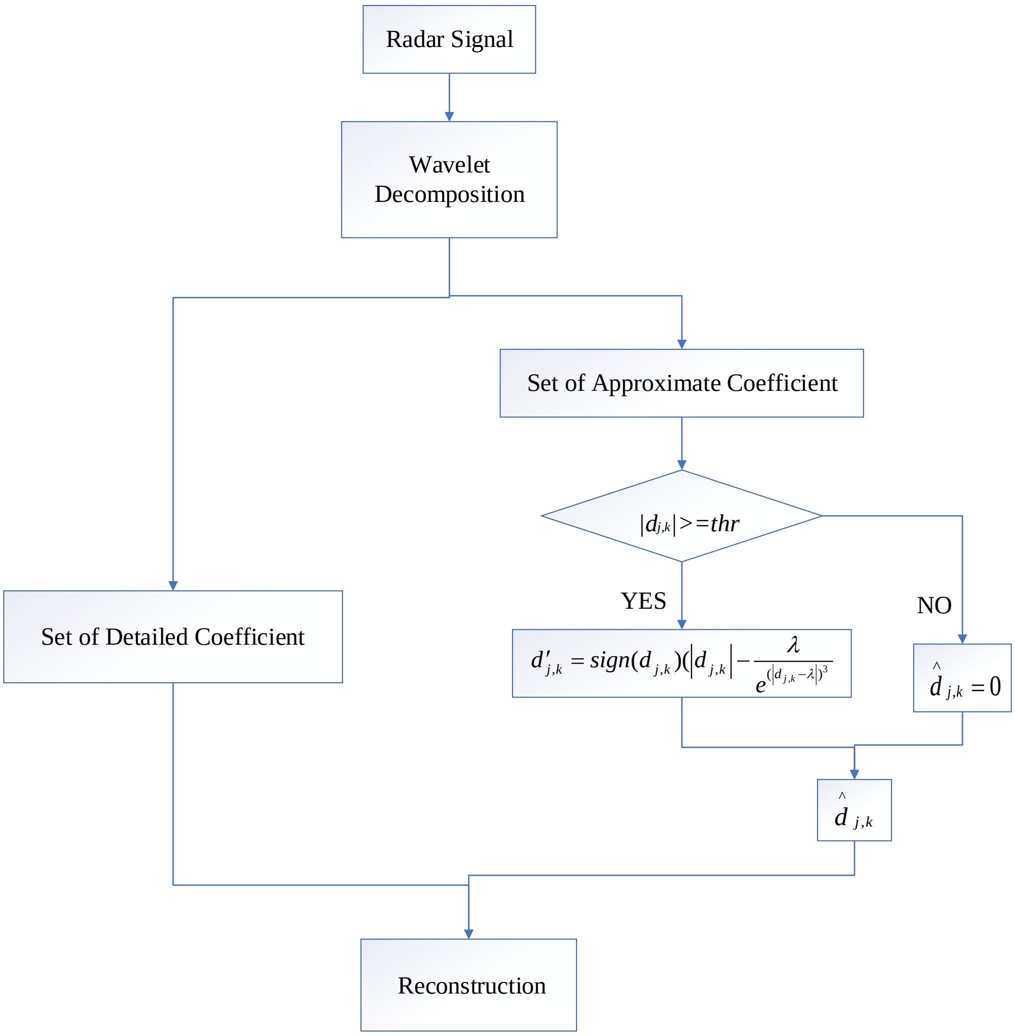

Fig. 4 The Flow Chart of Wavelet Denoising based on Adapted Threshold Function

Thus, an adapted threshold function is proposed in this paper. And this function as shown in Fig. 3.

$$d_{j,k}^{'} = \begin{cases} sign\left(d_{j,k}\right)\left(\left|d_{j,k}\right| - \dfrac{\lambda}{e^{\left(\left|d_{j,k}-\lambda\right|\right)^{3}}}\right), d_{j,k} \geq \lambda \\ 0, \left|d_{j,k}\right| < \lambda \end{cases} \tag{4}$$

From Fig. 3, it can be seen obviously that the adapted threshold function has improved compared with the hard threshold function and the soft threshold function in terms of hopping and fixed difference. The flow chart of wavelet denoising based on the adapted threshold function is shown in Fig. 4.

3. Simulatin Results

The simulations were carried out in MATLAB. Assuming that a pure radar signal, which sample time 3ms, sample frequency 50kHz, modulated frequency 500Hz, as shown in Fig 5, and set SNR to 20dB. Fig. 6 and Fig. 7 are the examples of wavelet denoising by using a hard threshold function, a soft threshold function and the adapted threshold function respectively, in addition, the wavelet using in this example is ‘sym6’.

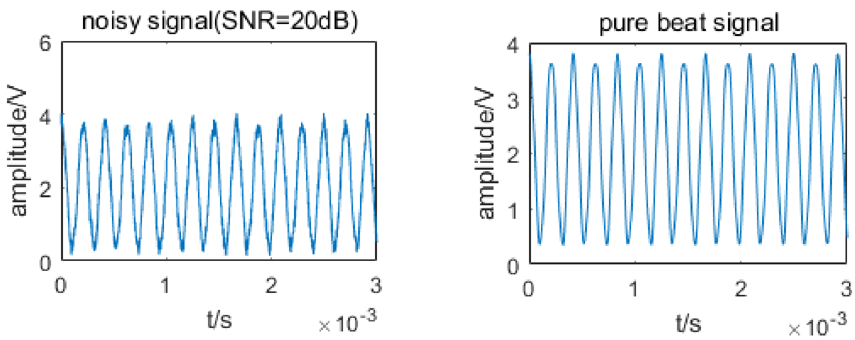

Fig. 5 Radar Signal and Noisy Radar Signal

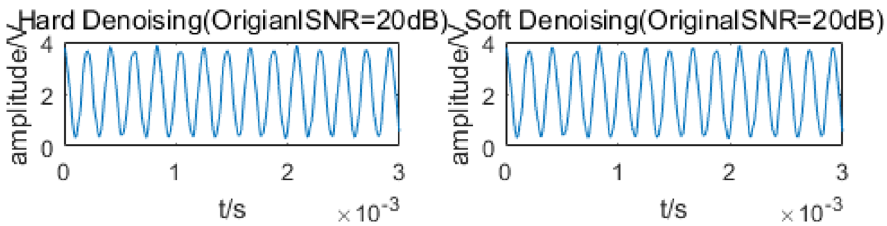

Fig. 6 Hard Threshold Denoising and Soft Threshold Denoising

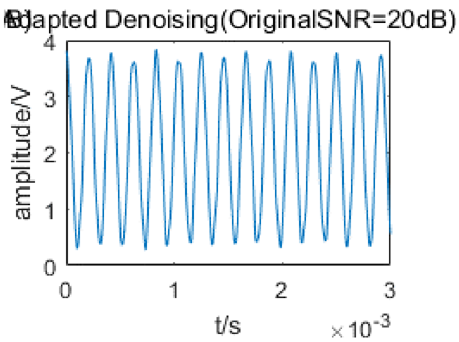

Fig. 7 Adapted Threshold Denoising

The SNR after wavelet denoising based on hard threshold function, soft threshold function and adapted threshold function respectively are extracted and compered with each other. The result is shown in Fig. 8, Fig. 9 and Fig. 10.

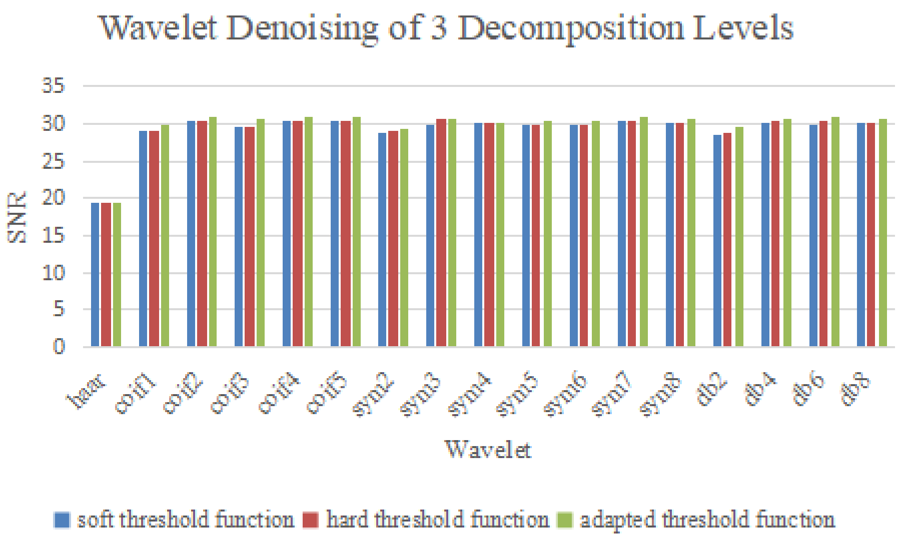

Fig. 8 Wavelet Denoising of 3 Decomposition Levels

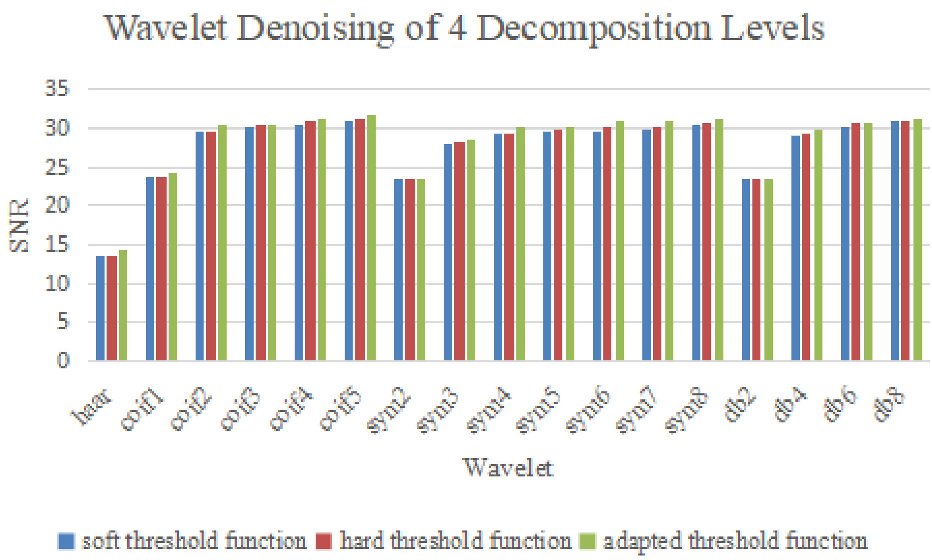

Fig. 9 Wavelet Denoising of 4 Decomposition Levels

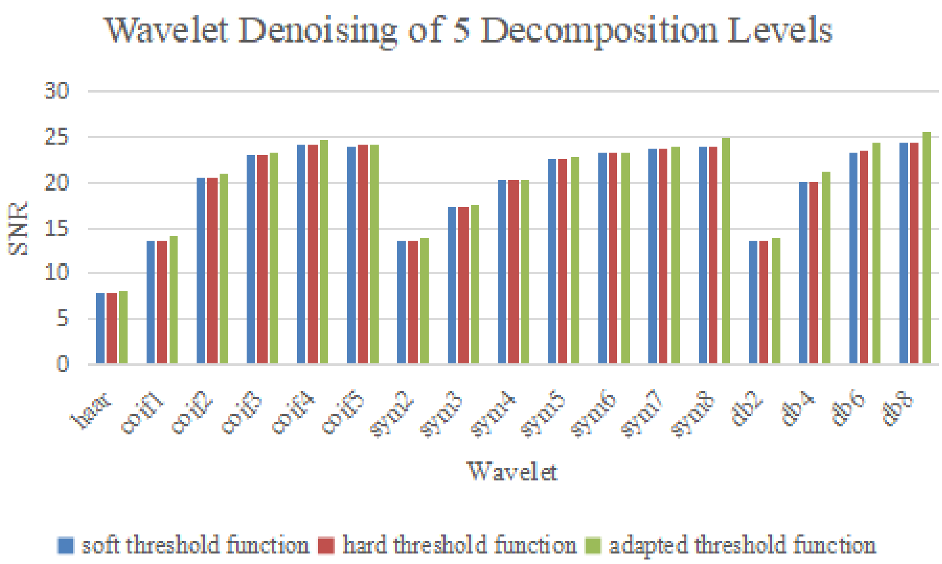

Fig. 10 Wavelet Denoising of 5 Decomposition Levels

From Fig. 8, Fig. 9 and Fig. 10, it can be seen clearly that the adapted threshold function compared with the hard threshold function denoising and soft threshold function denoising has been improved. Therefore, the proposed adapted threshold function denoising is feasible and can be selected for microwave radar signal.

4. Conclusion

In the process of wavelet denoising of the microwave radar signal, in order to make up for the shortcomings of the hard threshold function and the soft threshold function, an adapted threshold function is studied in the paper. First simulated the real microwave radar signal and add noise interference by MATLAB, and then used the adapted threshold function based on DWT to calculate the denoised SNR, and compared with the results of the hard threshold function and the soft threshold function to verify the validity of the adapted threshold function. In the future, this method can be considered in real microwave radar denoising.

References

[1] Messer, Sheila R., John Agzarian, and Derek Abbott. "Optimal wavelet denoising for phonocardiograms." Microelectronics journal 32.12 (2001): 931-941.

[2] Giaouris, D., and J. W. Finch. "Denoising using wavelets on electric drive applications." Electric Power Systems Research78.4 (2008): 559-565.

[3] Hu, Yi, and Philipos C. Loizou. "Speech enhancement based on wavelet thresholding the multitaper spectrum." IEEE transactions on Speech and Audio processing 12.1 (2004): 59-67.

[4] Debin, CHEN Zhixin XU Jinwu YANG. "New method of extracting weak failure information in gearbox by complex wavelet denoising." Chinese Journal of Mechanical Engineering 21.4 (2008): 87-91.

[5] Srivastava, Madhur, C. Lindsay Anderson, and Jack H. Freed. "A new wavelet denoising method for selecting decomposition levels and noise thresholds." IEEE Access 4 (2016): 3862-3877.

[6] Cui, Hua, and Guoxiang Song. "A Kind of Modified Project Based on the Wavelet Treshold Denoising Method [J]." Modern Electronic Technique 1 (2005).

[7] Kai Zhao. Radar design and signal processing of automobile anti-collision system. Diss. [In Chinese]

[8] Paraschiv-Ionescu, Anisoara, et al. "Wavelet denoising for highly noisy source separation." 2002 IEEE International Symposium on Circuits and Systems. Proceedings (Cat. No. 02CH37353). Vol. 1. IEEE, 2002.

[9] Postolache, O., et al. "Multi-usage of microwave Doppler radar in pervasive healthcare systems for elderly." 2011 IEEE International Instrumentation and Measurement Technology Conference. IEEE, 2011.

[10] Stirman, Charles. Applications of Wavelets to Radar Data Processing. No. OA-11606. MARTIN MARIETTA ELECTRONICS AND MISSILES GROUP ORLANDO FL MISSILE SYSTEMS, 1991.

[11] Guo, Dai-fei, et al. "A study of wavelet thresholding denoising." WCC 2000-ICSP 2000. 2000 5th International Conference on Signal Processing Proceedings. 16th World Computer Congress 2000. Vol. 1. IEEE, 2000.

[12] Jing-yi, Lu, et al. "A new wavelet threshold function and denoising application." Mathematical Problems in Engineering 2016 (2016).

[13] Huimin, C. U. I., Zhao Ruimei, and H. O. U. Yanli. "Improved threshold denoising method based on wavelet transform." Physics procedia 33 (2012): 1354-1359.