Study on the Signal Detection Algorithm of Weak Laser Radar Target Based-on Wavelet Transform

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Abstract—According to the different transmission characteristics under the wavelet transform(WT) domain and the different distribution characteristics of frequency domain of the signal and noise, a novel approach for detecting weak signal laser radar target based on wavelet transform has been proposed. In many cases, wavelet decomposition has been used to de-noise a digital signal submerged by mass noise. Differently in our approach, we applied the wavelet decomposition and the modulus maximum to detect the locations of laser radar echo signal. Simulation shows that the proposed algorithm is more efficient than only utilizing wavelet decomposition in a clutter environment.

Keywords- weak target ;laser radar; wavelet transform; wavelet decomposition; modulus maximum;de-noise

I. INTRODUCTION

In the past decade, Laser radar technology developed rapidly. Laser radar plays a more important role in military, and object detection technology is one of the most popular applications on Laser radar system. The technology of laser radar echo signal tends to be interference by multiple noise source, these noise sources will affect the laser radar detection accuracy and its effective detection range. It is the key of detection technology of extracting weak target information from the noise in a clutter environment.

Recently, WT has been proposed as a new and powerful signal processing tool. It has been applied successfully and made a lot of achievements in many fields as in [1].WT can give information in both time and frequency domains. As the main characteristic of WT, Multi-resolution makes it more suitable than traditional Fourier transform in analyzing weak targets signal. WT shows good robustness to effects of noise because WT of noise target responses is linear,therefore it does not present significant inaccuracies. Reference [2] introduced digital correlation detection method and single signal correlation and multi signal correlation are calculated with laser ranging radar. However, this method has a high request of the optical lens,and is unable to realize the complex algorithm. Reference [3] proposed by applying the wavelet decomposition based-on the target signal which is in the low frequency band, the high frequency information is noise, but with the diminished of SNR(signal-to-noise ratio), Only relying on Wavelet Decomposition method is very difficult to effectively detect the weak targets. We notice that laser radar signal transmission characteristics and echo signal frequency domain distribution characteristics are different form noise, So, in this paper, we use the wavelet decomposition and modulus maximum to detect the location of laser radar echo signals, and the simulation result shows that this method is effective to detect the laser target in a clutter environment.

II. DYADIC WAVELET TRANSFORM

The basic meaning of Wavelet Transform(WT) is the x signal through the scale and shift, decomposes to a series of sub-frequency having the different spatial resolution, the different frequency characteristic and the directional characteristic innertube signal, this innertube signal has a good time domain, a frequency band and other partial characteristics. Therefore the wavelet analysis to signal has an excellent detection performance under low SNR.

Given a real signal *x(t)* with the same interval of time m,the WT makes a time scale analysis by means of analyzing wavelet $\psi(t)$ .The WT depending on a scale parameter *a* and a shift parameter *b* as in [4]:

$$WT_x(a,b) = \frac{1}{\sqrt{a}}\int_{-\infty}^{\infty} x(t)\psi^*(\frac{t-b}{a})dt = < x(t), \psi_{a,b}(t) > \qquad (1)$$

Where (*) denotes complex conjugation.and the function $\psi(t)$ is said to be a wavelet if and only if its Fourier transform $\hat{\psi}(w)$ satisfies

$$\int_0^{+\infty} \frac{|\hat{\psi}(w)|^2}{w} dw = C_\psi < +\infty \qquad (2)$$

This condition implies that

$$\int_{-\infty}^{+\infty} \psi(u)du = 0 .$$

For computer Dyadic WT,parameters *a* should be discretized, as $a = 2^j$,Parameter *b* still took the successive value. So,we can written Dyadic WT as:

$$W_f(2^j, b) = 2^{-j/2}\int_{-\infty}^{\infty} x(t)\psi^*[2^{-j}(t-b)]dt \qquad (3)$$

The signal analysis of Dyadic wavelet can play the role of changing the focal distance, it is situated between the continual wavelet and the separate wavelet, which only discretizes the scale parameter, but still maintains the horizontal shift transforming continuously in time domain.Therefore the binary wavelet transformation still keeps the horizontal shift invariability of the continual wavelet transformation.

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III. Laser Radar Signal Analysis

A. Signal and noise transmission characteristic in WT various scale

Regularity is used to characterize the level of smoothness. Generally, Lipschitz index denotes the level of function's regularity. Lipschitz index of radar signal commonly is greater than zero,even non-continuous singular signal, as long as it is bounded in a certain field, so *a=0*, and smaller scale modulus maximum number of points are approximation equal in a smaller scale. If *a>0*, the more scale, the more modulus maximum of the wavelet transform of function. However, Lipschitz index of the noise is usually less than zero.Such as Gaussian white noise exits widely in the form of random distribution, it has a negative exponential Lipschitz $a = -\frac{1}{2} - \varepsilon, \forall \varepsilon > 0$ .Moreover, when the scale of white Gaussian noise's average density is in reverse proportion to scale 2^j , the more scale, the less sparser average density as in [5].

The above analysis indicates that signal and noise have the opposite transmission characteristics in the wavelet transformation with various scale's modulus maximum value, this results in providing the important basis when the de-noising process of wavelet transformation is doing. Through the observation of the gradation rule of wavelet transformation modulus maximum value used in the different scale, the signal is separated from the noise.

B. Signal and noise distribution characteristic in Fourier domain

The laser radar is a narrow band system, and echo signal is a low-frequency signal, thus it is very difficult to withdraw the useful information in the high frequency information. Figure 1 is laser radar echo signal *x(n)*.And the pulse width 25ns, by 200MHz A/D sampling obtained. From Figure 1, The radar echo signal can be seen flushes trend. Figure 2 is amplitude-frequency characteristic of the noise. From Figure 2, laser radar echo signal is mainly in low-frequency band, while there is noise in high-frequency band.

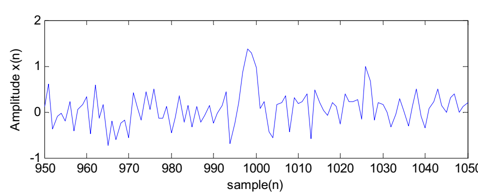

Figure 1. the target echo signal

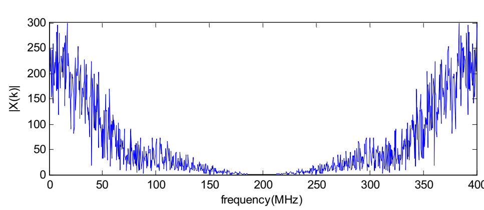

Figure 2. the amplitude-frequency characteristic of noise laser radar target detect based on WT

In the previous section, we analyzed transmission characteristic of the laser radar in wavelet scale and frequency distributed characteristic of echo signal. It is known that laser radar signal and noise have different transmission characteristic and the echo signal is mainly distributed in the low frequency band. It is interesting to note that we can use wavelet decomposition and modulus maximum value algorithm to achieve weak target detection result of laser radar.

C. Low-frequency information extract of wavelet domain

The echo signal is mainly distributed in the low frequency band that is to say that the high frequency information of Wavelet Decomposition is mainly noise. So the high frequency information is reset to zero. Only low-frequency information should be reconstructed.

The fast speed algorithm of the wavelet transformation, Mallat algorithm[6,7],is given by Mallat. The discrete wavelet decomposition is denoted in figure 3.

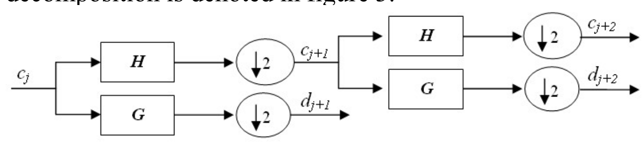

Figure 3. The discrete wavelet decomposition

Where *H* and *G* are respectively low-pass and high pass analysis filters respectively. *H* has the low-pass characteristic,and *G* has the high-pass characteristic.

Example 1: Figure 4 is laser radar echo signal and SNR is set to 8dB. The circle is representative of target the actual location. We select the well-known Daubechies wavelet of orders 5 and the scale is 3. *C3* is performed low-frequency signal corresponding to the lager scales,*s2* is signal of the low-frequency reconstructed wavelet. The result shows that wavelet decomposition is efficient to detect weak target location when the SNR is set to 8dB.

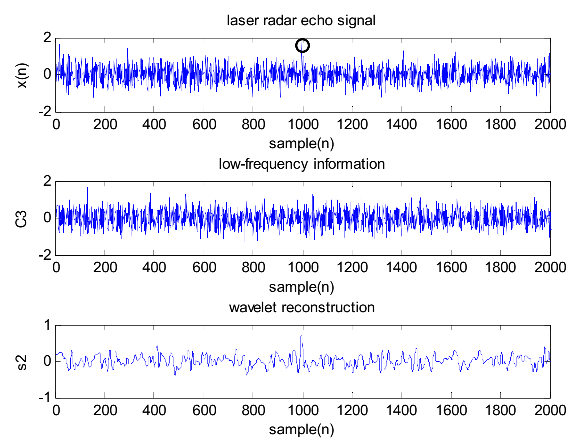

Figure 4. wavelet decomposition laser radar echo signal(SNR=8dB)

D. Modulus Maximum denoising

Considered that the wavelet decomposition is helpless under a low SNR, according to the fact that signal and noise have different transmission characteristic of modulus maximum in various scales,which can isolate low-frequency signal and noise. The implementation step includes:

1) Discrete the Dyadic Wavelet Transform from the signal of wavelet decomposition. Choose the appropriate scales to 4 or 5.

2) Calculate the corresponding Wavelet modulus maximum value points in each scale.

3) Remain the modulus maximum value points only corresponding to location of changing suddenly in relative high-frequency, and set other WT value to zero; In low-frequency range, remain the suddenly-changing points and its near modulus maximum points, set other points' value to zero.

4) After reconstructing the wavelet factor according to the remained modulus maximum points and their locations. reconstituted WT coefficients, transform the Dyadic wavelet and get the de-noised signal.

IV. SIMULATION ANALYSIS

In this section, we give two weak target detection experiments.

Example 2: Parameter setting and Example 1,only the SNR is set to 1dB.From figure 5,As a result of Wavelet Decomposition can only remove noise of high-frequency part. As SNR is low,the signal can be annihilated from the noise of low-frequency band. In other words, Wavelet Decomposition can't eliminate the noise of low-frequency band.

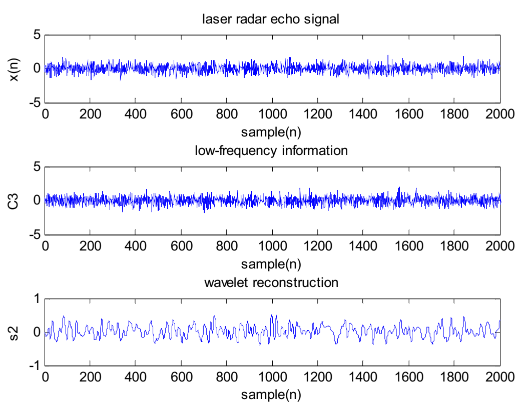

Figure 5. wavelet decomposition laser radar echo signal(SNR=1dB)

Example 3: Figure 6 shows the Wavelet Decomposition and modulus maximum combined simulation waveform. In accordance with Figure 5, give wavelet reconstruction signal, choose to process the data (length is 2000 points, series 3, iteration 10 times, Db(5) wavelet function). Figure 6 shows each series of waveforms. From third-wave figure, when the SNR is set to 1dB, the paper proposes the algorithm still can detect weak target location.

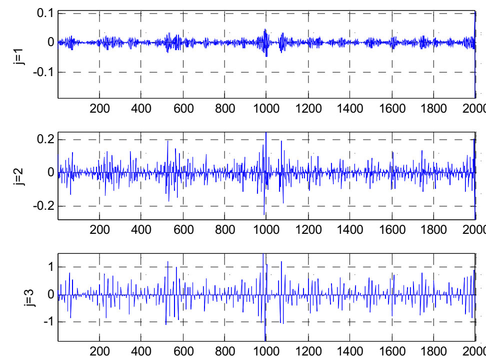

Figure 6. proposed algorithm(SNR=1dB)

V. CONCLUSION

By analysis transmission characteristic of laser radar signal and distribution characteristic of the echo signal in frequency domain, we know that modulus maximum of signal and noise has opposite transmission characteristic, and echo signal is mainly performance the low-frequency band of frequency domain. So, we propose a new method for the laser radar target detection. Our simulation result demonstrates its effectiveness successfully.

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