Simulation of Radar Signal Processing based on Matlab

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Key words: Signal processing; quadrature sampling, pulsed compression; echo accumulation.

Abstract: The simulation of radar signal processing is an important part of the simulation of the radar system. This paper introduces a method of the simulation of radar signal processing based on Matlab, including the simulation of radar echo and clutter, and researches the simulation method of important technologies in the radar signal processing, including quadrature sampling, pulse compression, echo accumulation and CFAR detector. The work in this paper can overcome the disadvantages such as difficulty and lengthiness and show the convenience and simplicity of the simulation of radar signal processing based on MATLAB.

1 INTRODUCTION

The modern radar system is getting so complicated that it can not be processed with simple analytical methods. Thus people usually make use of computer to simulate the functions and performances of the system, which is featured by great convenience, flexibility and low cost. However, Matlab has provided a powerful simulation platform which facilitates the operation for the simulation of the majority radar system. The typical radar is made up by antenna, transmitter, receiver, signal processor, servo system and terminal unit(Lufei Ding,1984). In the paper, the authors mainly probe into the radar signal processing part, and illustrate the application of Matlab in the radar signal processing system with the case of a certain pulsed compression radar signal processing system.

2 GENERATION OF SIMULATED SIGNAL

2.1 Generation of Radar Signal

The modern radar has diversified systems. The form of signal can be selected according to the radar system. In the following part, the method of how to generate chirp signals in Matlab will be introduced briefly.

Matlab provides the modulate function which can generate chirp signals in a convenient manner. The calling format for the modulate function is shown as follows:

y = modulate (*x, fc,fs*, 'method',opt)

The parameter *x* represents the sequence of modulating signal, *fc* represents the carrier frequency, and *fs* represents the sampling frequency. The 'method' is used to decide which kind of modulation will be adopted. opt represents the modulation sensitivity, that is, the stepping coefficient of chirp signal.

A chirp signal, with the starting frequency of 10MHz, tuning bandwidth of 2MHz, sampling frequency of 100MHz and pulse bandwidth of 10μs, is generated by a modulate function. The output result is shown in Figure 1.

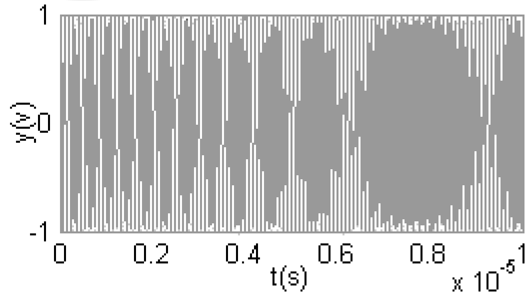

Figure 1. Chirp Signal with Carrier Wave of 10MHz and Bandwidth of 2M

2.2 Generation of Noise and Clutter

In the real radar echo signals, there are not only signals reflected from targets but also various

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noises and clutters such as thermal noises from the receiver, ground clutters, weather clutters and so on. Noises and clutters can be analyzed only with statistical properties because neither of them are deterministic signals. In the following part, the common method of generating noises and clutters will be presented.

1) Thermal noises subject to Gaussian distribution (random sequence): Matlab provides the random function which is used to generate the random number in standard Gaussian distribution. random (m,n) can generate the m×n random sequence matrix. Therefore, a random sequence subject to Gaussian distribution can be easily generated by a random function, as shown in Figure 2.

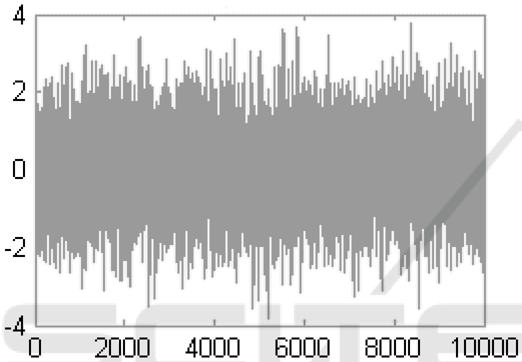

Figure 2. Random Sequence Subject to Gaussian Distribution

2) Generation of clutters in Rayleigh distribution: The Rayleigh distribution is the most frequently used and the earliest statistical model. When there are many scatterers within the discernible range of radar, the envelope amplitude for synthesizing echo is subject to the Rayleigh distribution according to the random characteristics of the amplitude and phase position of scatterers. If x represents the envelope amplitude of the clutter echo subject to Rayleigh distribution, then its probability density function can be expressed as

$$p(x)=\begin{cases}\frac{x}{\sigma^2}\exp(-\frac{x}{2\sigma^2}), x\geq 0\\ 0, x<0\end{cases} \tag{1}$$

In this formula, σ is the standard deviation of clutter.

Matlab provides a raylrnd function which is used to generate the random number in Rayleigh distribution. In the raylrnd (B,m), B is the parameter of Rayleigh distribution, and m is a one-dimensional vector that contains two elements which represent the line number and column number of the random number matrix which is subject to Rayleigh distribution respectively. Generally, the line number is set as 1, and the column number corresponds to the duration of clutter. When the parameter of Rayleigh distribution σ=2, the clutter generated with the raylrnd function is shown as Figure 3.

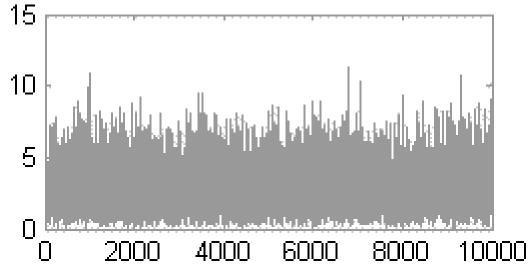

Figure 3. Clutter in Rayleigh Distribution

3 SIMULATION OF SIGNAL PROCESSING SYSTEM

The purpose of processing radar signals is to remove the unwanted signals (such as clutter) and the interference, and to extract and intensify the echo signals generated by the target. The radar signal processing provides many functions, and functions of different radars also vary(You He,1999). In this paper, a certain pulse compression radar's signal processing part is simulated. The signal processing part of a typical pulse compression radar mainly has the functions of A/D sampling, quadrature demodulation, pulse compression, video integration, constant false alarm processing and so on. Hence, the simulation model for the pulse compression radar's signal processing is as shown in Figure 4.

3.1 Quadrature Demodulation Module

Before the pulse compression for radar ' s intermediate-frequency signals, it is necessary to transform these signals into the I and Q quadrature signals with the zero intermediate frequency. The intermediate-frequency signals can be expressed as

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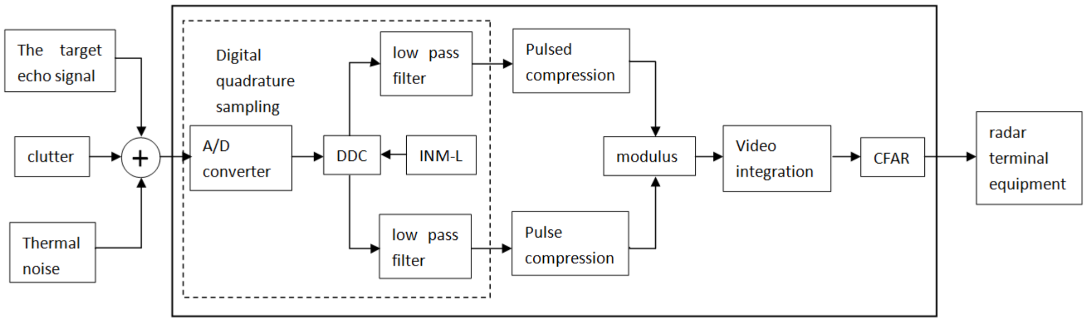

Figure 4. Simulation Model for Pulse Compression Radar's Signal Processing

$$f_{IF}(t) = A(t)\cos(2\pi f_0 t + \phi(t)) \qquad (2)$$

In the formula, f_0 is the carrier frequency.
To set

$$\begin{cases} I(T) = A(t)\cos\phi(t) \\ Q(T) = A(t)\sin\phi(t) \end{cases} \qquad (3)$$

Then

$$f_{IF}(t) = I(t)\cos 2\pi f_0 t - Q(t)\sin 2\pi f_0 t \qquad (4)$$

In the simulation, all the signals are expressed as discrete time series. Set the sampling period as T, and then the intermediate-frequency signal will be fIF (rT). Similarly, the local oscillating signals, after being sampled, will be expressed as

$$f_{local} = \exp(-j\omega_0 rT) \qquad (5)$$

The digitized intermediate-frequency signals and local oscillating signals will turn into baseband signals after they are multiplied and demodulated and then pass the low-pass filter. The baseband signal fBB (r) can be expressed as

$$f_{BB}(r) = \sum_{n=0}^{N-1}\{f_{IF}(r-n)\cos(r-n)\omega_0 T\}h(n) -$$

$$j\sum_{n=0}^{N-1}\{f_{IF}(r-n)\sin(r-n)\omega_0 T\}h(n) \qquad (6)$$

Wherein, h(n) is the pulse response of the low-pass filter which has an accumulated length of N.

According to the practical application, the sampling using Nyquist sampling rate only will not obtain good mixing signals and filtering results. Generally, good real part and imaginary part of signal can be obtained when the sampling frequency fs is four times of the center frequency(Yingle Fan,2001). When the sampling frequency fs=4f$_0$, and $\omega_0 T = \pi / 2$, the baseband signal can be simplified as

$$f_{BB}(r) = \sum_{n=0}^{N-1}\left\{f_{IF}(r-n)\cos(r-n)\frac{\pi}{2}\right\}h(n) -$$

$$j\sum_{n=0}^{N-1}\left\{f_{IF}(r-n)\sin(r-n)\frac{\pi}{2}\right\}h(n) \qquad (7)$$

The steps for simulation of quadrature demodulation using Matlab are shown as follows.

1) To generate the ideal chirp signal y;

2) To generate the I-channel local oscillating signal and the Q-channel local oscillating signal. Set f_0 as the center frequency of the local oscillating signal, f_s as the sampling frequency, n as the length of the chirp signal's time series, then the I-channel local oscillating signal will be $\cos(n\frac{f_0}{f_s}2\pi)$. Likewise, the Q-channel local oscillating signal will be $\sin(n\frac{f_0}{f_s}2\pi)$. When f_s =4f_0, the I-channel and Q-channel local oscillating signals will be $\cos(\frac{n}{2}\pi)$ and $\sin(\frac{n}{2}\pi)$ respectively.

3) Multiplying the chirp signal y by the double local oscillating signal to obtain the I-channel signal and the Q-channel signal.

4) The I-channel signal and the Q-channel signal pass through the low-pass filter and filter off the high-frequency component in order to get the final result of demodulation(Haimang Hu,2004). Matlab provides a convenient filter function filter(*b,a,x*), in which x represents the input signal, and *b* and *a* represent the coefficient vectors of the filter transfer function's numerator and denominator.

Figure 5 shows the simulation of chirp signal with Matlab. Figure 6 and 7 show the demodulated I-channel signal and Q-channel signal respectively.

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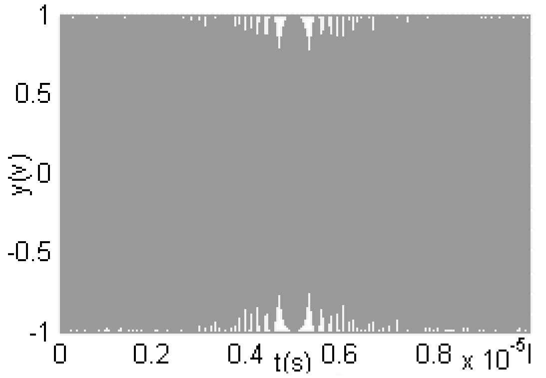

Figure 5. Chirp Signal With the Carrier of 10MHz and Bandwidth of 2MHz

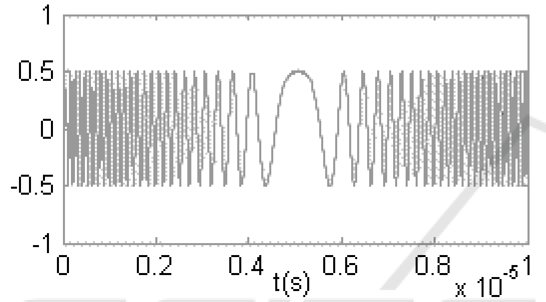

Figure 6. I-channel Signal after Demodulating the Chirp Signal

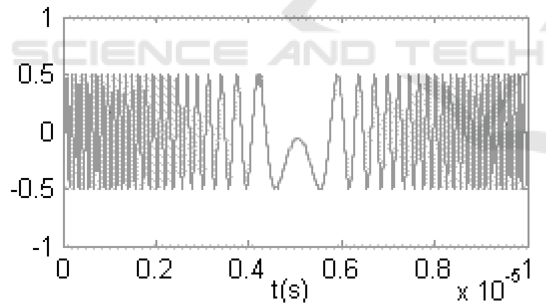

Figure 7. Q-channel Signal after Demodulating the Chirp Signal

3.2 Pulse Compression Module

Before the pulse compression, it is necessary to find a matched filter for signals transmitted by radar(Yu Zhou,2004). In real projects, pulse compression is usually done in the frequency domain because it can improve the computation speed by making use of the FFT algorithm. The result of pulse compression can be obtained after multiplying the radar echo by the matched filter's frequency domain response and then getting them transformed with IFFT. Hence, convolution processing has been replaced, thus greatly reducing the amount of operation. Therefore, it is necessary to firstly obtain the matched filter or pulse compression coefficient for the pulse compression when simulating the pulse compression. It is easy to work out the chirp signal's pulse compression coefficient, which can be achieved by conjugating and overturning the ideal chirp signal.

The steps for simulation of chirp signal's pulse compression using Matlab are shown as follows.

1) To generate the ideal chirp signal y;

2) To make quadrature demodulation for signals in order to obtain the demodulated signals ;

3) To generate the ideal chirp compression coefficient. To achieve this, you shall firstly find out the matched filter for the signal *fbb* which has been processed with quadrature demodulation, and then work out the pulse compression coefficient by making use of the discrete Fourier transform.

4) To generate the ideal echo signal and to process the signal with quadrature demodulation. The idea echo signal is the echo signal received by radar within a pulse repetition period, and the target is assumed to be a stationary-point target.

5) To make pulse compression. Firstly, make the discrete Fourier transform for the echo signal in order to obtain signal_fft, and then multiply the signal_fft and the matched filter's frequency domain response, and then make inverse discrete Fourier transform for it, thus obtaining the result of pulse compression(Zewei Wang,2005). Assuming the signals transmitted by radar are the chirp signals, the relevant parameters are shown as follows: bandwidth 10μs, center frequency 10MHz and tuning bandwidth 2MHz. The frequency of sampling radar's echo signals is 40MHz. The intermediate frequency is processed with quadrature down-conversion. In Figure 8 and 9, the oscillograms have shown the simulation of radar pulse compression using Matlab.

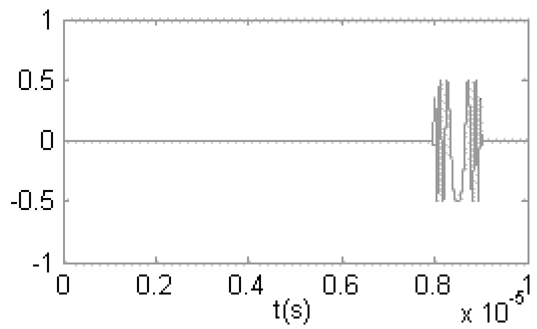

Figure 8. Result Obtained after the Quadrature Demodulation for Echo Signal

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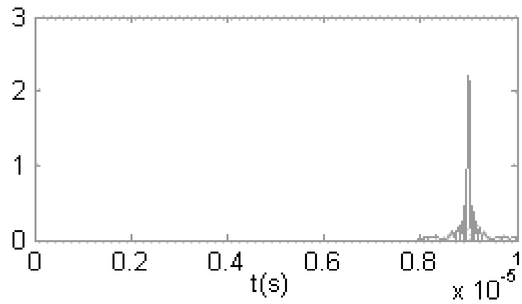

Figure 9. Result Obtained after the Pulse Compression for Echo Signal

3.3 Echo Accumulation Module

The modern radars make detection based on multi-pulse observation(). The integration of multiple pulses can effectively improve the

$$h(n) = \frac{\sin^4(na\Delta\theta)}{na\Delta\theta} \quad (9)$$

Δθ represents the angle that the antenna has swept across within a pulse repetition period. Such integration can be realized by the FIR integrator, with its structure shown in Figure 10.

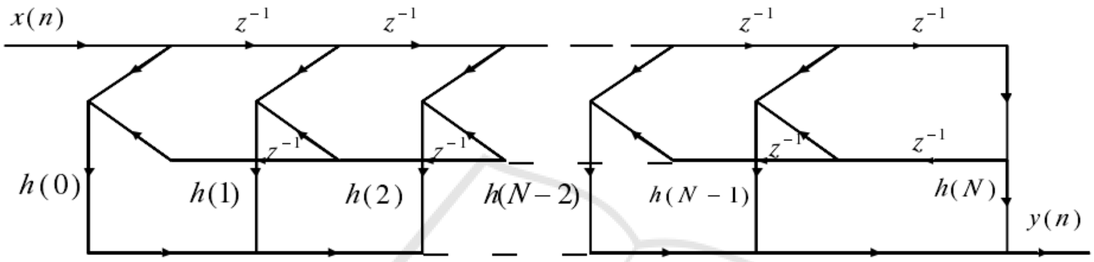

Figure 10. Structural Diagram for FIR Accumulator

3.4 Constant False Alarm Rate (CFAR) Processing Module

There are many methods to make constant false alarm processing. In broad classification, there are mean level CFAR, order statistics CFAR, clutter map CFAR and so on. There are many ways to realize the mean level CFAR, including cell averaging, GO, SO and so on, all of which operate under the same fundamental theory. The procedures for simulation of CFAR using Matlab are shown as follows.

1) To generate the point-target echo which has superimposed the Rayleigh clutter and thermal noise. In this step, the Gaussian thermal noise and Rayleigh clutter are generated with the above-mentioned method, and then are superimposed with the point-target echo, during which the amplitudes of Rayleigh clutter and thermal noise shall be weighted.

2) To make constant false alarm processing for the point-target echo which has superimposed Rayleigh clutter and thermal noise. In this step, the number of reference cells shall be determined firstly. If the number of reference cells are 16, the mean value of the first point noise for constant false alarm processing will be decided by its subsequent 16 points of noises, while mean value of the noises from the second point to the 16th point will be jointly decided by the 16 points of noises before and after it. The mean value of noises on normal data points for constant false alarm processing is determined by its former 16 points of noises and its subsequent 16 noises, and the constant false alarm processing for the last 16 points of noises is the same as that for the first 16 points of noises. The signal output lastly is the ratio between the estimated mean values of each detection unit and the clutter.

In the following part, we will simulate the GO-CFAR using Matlab. The number of reference cell is 16, and the radar's pulse repetition period is 1ms. There are clutter echoes subject to Rayleigh distribution in the range from 7.5 km to 30 km away, and there is a point target 15km away. The results of simulation are shown in Figure 11 and Figure 12.

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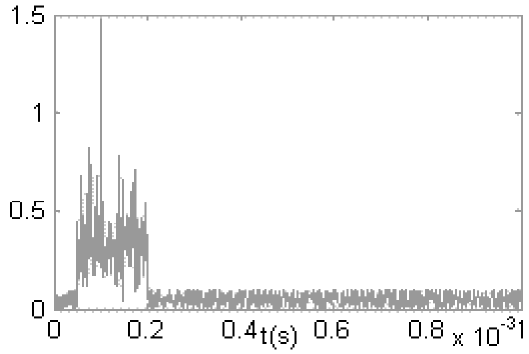

Figure 11. Target Echoes Which Have Superimposed Clutters in Rayleigh Distribution and Thermal Noise

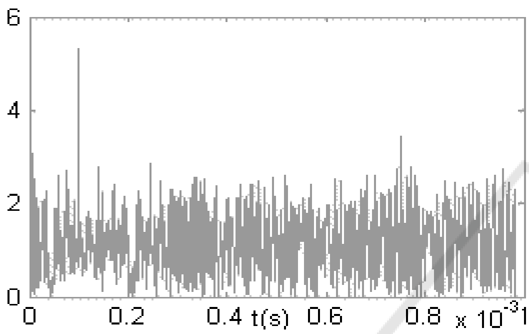

Figure 12. Outcome of GO-CFAR

4 CONCLUSIONS

In the simulation of radar signal processing system using Matlab, a system model can be formed rapidly, and your design concept can be reflected in each little detail. It is featured by a short modeling time and a high calculation accuracy. The model formed is simple and clear. The model and evaluation result can be revised, and the system behavior can be verified at any phase of the design. In this paper, the authors have take a certain pulse compression radar as an example to study the Matlab-based simulation of radar signal processing, which achieves good outcome.

REFERENCES

Lufei Ding and Ping Zhang, 1984.Radar System. Xi’an: Xidian University Press

You He, Jian Guan et al,1999.Radar Automatic Detection and Constant False Alarm Processing. Beijing: Tsinghua University Press.

Yingle Fan, 2001.Detailed Introduction of Application of MATLAB-based Simulation. Beijing: Posts and Telecom Press.

Yu Zhou, Linrang Zhang and Hui Tian, 2004. Radar System Simulation Based on Matlab/ Simulink [J]. Computer Simulation.

Haimang Hu and Wanhai Yang, 2004. Simulink-based Modeling and Simulation for Pulse Compression Radar . Radar and Countermeasures.

Zewei Wang and Hongjin Jia,2005. Research on Modeling and Simulation of Search Radar Radar and Countermeasures.

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