Generation of Rayleigh Distribution Clutter in CR

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Abstract. Research on clutter modeling and generation is very important in echo analysis, especially for CR (cognitive radar) working in complex environment. In this paper, we propose a novel generation method for Rayleigh distribution clutter in CR. This method adopts white Gaussian noise sequence and Bessel filter, and Rayleigh distribution clutter can be generated through nonlinear transformation. Simulation results demonstrate the validity of the method, and the estimated value and theoretical value are consistent with each other in both clutter amplitude and spectrum. Finally, the whole paper is summarized.

Introduction

Radar is an electromagnetic system for the detection and location of reflecting objects. For both civilian and military needs, radar is widely used for surveillance, tracking, and imaging applications. The idea of CR is proposed by Simon Haykin. Cognitive radar builds on three basic gredients: Intelligent signal processing; Feedback from the receiver to the transmitter; Preservation of the information content of radar returns [1]. As the new transmitted waveform will be influenced by radar echo in the close loop, the accurate clutter modeling appears to be particularly important in CR.

Much work has been done in the related field. In [2], it is observed that when looking up or down wind there is a strong correlation between mean Doppler shift and local spectrum intensity. When combined with random fluctuations of spectrum width, these characteristics give the spectra a temporal and spatial variability. In [3], unlike traditional signal-dependent stochastic models, a new "stochastic transfer function" approach is presented that results from a fundamental physics scattering model. In [4], the authors propose a new method of modeling and simulation of temporal-spatial-correlated (TPC) clutter, based on the weighted norm in discrete complex linear space and a simple matrix transformation. In [5], the authors show a sample of results from a statistical and spectral analysis of a set of sea spikes selected from the radar returns, focusing on their Doppler properties, the spike duration and the temporal interval between spikes. In [6], a research in the area of bistatic radar clutter modeling is presented. After the bistatic clutter scenario is defined two land-clutter models, based on a common general geometry are described. In [7], the paper presents the statistical analysis of three types of land clutter terrains: Saudi Arabian urban, South African urban and Saudi Arabian date farms, all measured at low grazing angle. In [8], the authors propose an improved empirical model for radar sea clutter reflectivity. In [9], the authors propose a model for generating low-frequency synthetic aperture radar (SAR) clutter that relates model parameters to physical characteristics of the scene.

In this paper, we propose a novel generation method for Rayleigh distribution clutter. This method adopts white Gaussian noise sequence and Bessel filter, and Rayleigh distribution clutter can be generated through nonlinear transformation.

Principle Summary

The simulation of clutter data should meet a certain probability distribution in amplitude and the requirements in correlation properties. That means the first-order and second-order characteristics of
the data have to be produced to meet the requirements of the clutter. Monte Carlo methods are a broad class of computational algorithms, which rely on repeated random sampling to obtain numerical results. These methods are often used in physical and mathematical problems, especially when it is difficult or impossible to use other approaches, they appear to be particularly useful. At present, the method of spherically invariant random process, the method of zero memory nonlinearity transformation method and the method of stochastic differential equation are extremely common. But they have their own shortcomings and application scope limits.

This paper researches on Rayleigh distribution clutter in CR, so we will make a brief introduction to CR. Different from traditional radar, CR is constructed using intelligent signal processing, information feedback loop, and soft information processing. CR is the next generation radar system, and it has the capability to observe and learn from the environment information, through which the CR can transmit waveform suited to the working conditions. The radar returns and environment factors can help to reconstruct the waveform library. It operates closed loop and the transmitted waveform will be adaptive. Radar intelligent analyzer is an important part in waveform library, the basis of which is clutter modeling and analysis. The function of the intelligent analyzer is to provide information on the environment to the receiver, which is very important to the decisions made by the receiver on possible targets of interest. So it is very necessary to model and analyze clutter accurately.

Based on zero memory nonlinearity transformation principle, assume \( w(k) \) is white Gaussian random process. \( H(z) \) is linear filter. After getting through the filter \( H(z) \), such as Bessel filter, correlated (non-ferrous) Gaussian process can be obtained. Then we can get the required clutter sequence \( z(k) \) after the nonlinear transformation.

**Generation of Rayleigh Distribution Clutter**

The process of simulating correlated Gaussian clutter is to design the digital filter that has the requested power spectrum correlation characteristics. Suppose white Gaussian noise is generalized stationary stochastic process, and its sample of one moment is \( W(k) \), the response after getting through the filter \( H(z) \) is

\[
Y(k) = h(k) * W(k)
\]

where \( h(k) \) is the unit sequence response of \( H(z) \), \( Y(k) \) is the simulation for the correlated Gaussian clutter sequence, and \( * \) means convolution. Assume \( P_Y(w) \) and \( P_W(w) \) are power spectrum density function of correlated Gaussian noise and white noise, and \( H(w) \) is the frequency response function of \( H(z) \). According to the properties of Fourier transformation, we can obtain

\[
P_Y(w) = |H(w)|^2 P_W(w)
\]

We adopt frequency domain method to generate correlated Gaussian sequence \( Y \). Independent non-correlated Gaussian sequence \( V \) can be easily produced. To get the correlation coefficient sequence \( r(n) \), we can solve it according to the requested clutter power spectrum.

Make IFFT transformation to the known clutter power spectrum, and we can obtain correlated clutter sequence. Then through the relationship between two correlated sequence nonlinear transformation, we can finally get the correlation coefficient \( r(n) \) of the correlation Gaussian sequence. Then the correlated Gaussian sequence \( Y \) can be easily determined.

Let

\[
|H(w)| = \sqrt{FT(r(n))/r(0)}
\]

We can get the amplitude of \( H(w) \). Select an appropriate phase angle function, and make \( H(w) \) become physically realizable. Meanwhile make the non-correlated independent standard Gaussian sequence \( V \) transform into the frequency domain, then
\[
Y(w) = H(w)V(w)
\]

So the power spectrum density is

\[
S_y(w) = S_v(w) \cdot |H(w)|^2
\]

\[
S_y(w) = 1 \text{ is known, so}
\]

\[
S_y(w) = |H(w)|^2 = FT(r(n))/r(0)
\]

Make the obtained frequency domain \(Y_w\) change into time domain, then sequence \(Y\) is a correlated Gaussian random sequence whose power spectrum is \(FT(r(n))/r(0)\).

The probability density distribution function of Rayleigh distribution is

\[
\rho(x) = \frac{x}{\sigma_v^2} \exp\left(-\frac{x^2}{2\sigma_v^2}\right) \quad x \geq 0
\]

where \(x\) is clutter amplitude, and \(\sigma_v\) is standard deviation of clutter. In order to well describe the relationship of parameter \(\sigma_v\) and environment, assume \(\lambda_0\) is radar working wavelength and let \(\sigma_v = \sigma/\lambda_0\) into formula (7), we can obtain

\[
\rho(x) = \frac{x\lambda_0^2}{\sigma^2} \exp\left[-\frac{x^2}{2\sigma^2}\right] \quad x > 0
\]

We can obtain Rayleigh distribution clutter after making amplitude transformation to Gaussian distribution clutter, so designing filter according to the noise power spectrum characteristics is the key to generate Rayleigh distribution clutter. We will use the method of Fourier series expansion to design filter, making noise sequence have the characteristics of Gaussian spectrum.

Frequency response of filter's transfer coefficient expression is

\[
H(e^{j\omega T}) = \sum_{n=0}^{N} g_n e^{-j2\pi fn}
\]

And the Gaussian spectrum density of clutter is known as

\[
S(f) = \exp\left(-\frac{f^2}{2\sigma_f^2}\right)
\]

Therefore the Gaussian response of designed filter is

\[
|H(f)| = \exp\left(-\frac{f^2}{4\sigma_f^2}\right)
\]

Make expansion for Fourier series

\[
|H(f)| = \frac{C_0}{2} + \sum_{n=1}^{N} C_n \cos(2\pi fnT)
\]

Take absolute value of formula (9), according to the even function characteristic knowledge of frequency spectrum, \(C_n\) in formula (12) is equal to \(g_n\) in formula (9), which is the weighting coefficient of this filter. As the frequency response is known, it is easy to determine the coefficient of Fourier series is

\[
C_n = 2\sigma_f \sqrt{\pi} e^{-4\sigma_f^2 \pi^2 n^2 T_0^2}
\]
The power spectrum of the sequence after getting through this filter has the characteristics of Gaussian spectrum. Then according to the above steps, we will make Rayleigh distribution clutter simulation in a certain condition and analyze the simulation results.

Simulations

In this section, we will compare the generated Rayleigh distribution clutter with the theoretical value through two groups of experiments. Power spectrum adopts Gaussian spectrum model.

Simulation parameters of the first group are as follows. The length of the random sequence is 8192 points, sampling frequency $f_s = 1000\text{Hz}$, standard deviation of random sequence $\sigma_v = 1.2$, the center frequency $f_0 = 0\text{Hz}$, wavelength $\lambda_0 = 0.08$. Simulation results are in figure 1 to figure 4.

Simulation parameters of the second group are as follows. The length of the random sequence is 32768 points, sampling frequency $f_s = 2000\text{Hz}$, standard deviation of random sequence $\sigma_v = 1.2$, the center frequency $f_0 = 0\text{Hz}$, wavelength $\lambda_0 = 0.08$. Simulation results are in figure 5 to figure 8.

Figure 1 is independent non-correlated Gaussian random sequence in the first group. Figure 2 is Rayleigh distribution clutter obtained in simulation. We can observe the changes of sequences before and after the simulation comparing figure 1 with figure 2.

Figure 3 shows the comparison between actual amplitude distribution of clutter and the theoretical amplitude distribution of clutter. We can see that both are basically consistent with each other. Figure 4 shows the comparison between the estimated power spectrum of clutter that has been generated and theoretical power spectrum distribution. It can be seen that both are consistent with each other. Spectrum broadening is small, and the error of high frequency part is smaller.
Figure 5 to figure 8 shows the simulation results of the second group. We can get a similar conclusion with the first experiment. Contrast figure 3 with figure 7 and figure 4 with figure 8, it can be concluded that with the increase of sampling frequency and length of the random sequence, the estimated value in the first group is closer to the theoretical value than the estimated value in the second group.

Conclusions

How to model and analyze clutter is very important in the research field of cognitive radar. In this paper, we propose a novel generation method for Rayleigh distribution clutter. This method adopts white Gaussian noise sequence and Bessel filter. Simulation results show that actual amplitude distribution of clutter and the theoretical amplitude distribution of clutter are basically consistent with each other. Actual Gaussian power distribution and theoretical Gaussian power distribution are consistent with each other. The estimated value is more closer to the theoretical value with the increase of sampling frequency and length of the random sequence.

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References


