Land Clutter Characteristics Analysis of Low Altitude Flight Radar Platform

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Abstract. During the operation of the low altitude radar platform, the test of electromagnetic environment from the surface is becoming more and more severe, which has directly affected the various performance of radar detection. The land clutter is not only an important component of the radar electromagnetic environment, but also an important feature of the radar electromagnetic environment, therefore, it is necessary to measure and analyze the characteristics of the land clutter. In this paper, a small unmanned aerial vehicle (UAV) is used as a carrier to carry a certain type of pseudorandom code continuous wave radar for land clutter measurement, the clutter characteristics of the measured terrain are analyzed according to the amplitude distribution, temporal correlation and spatial correlation of land clutter, so as to get the statistical feature of the land clutter under different measurement conditions.

Keywords: low altitude radar platform, land clutter, unmanned aerial vehicle, statistical characteristics, clutter measurement.

1. Introduction
In modern warfare, the acquisition and control of battlefield information has become one of the important factors to win the war. Therefore, the use of small-scale, low-altitude battlefield surveillance radar platform has become a common means of information acquisition. However, whether it is airborne radar, missile-borne radar detectors, or unmanned airborne radars, it must withstand the strong interference of land clutter during low-altitude detection, thereby resulting in measurement errors and even more fatal accidents [1]. Unlike other weaponry, land clutter is particularly obvious to radar equipment. The clutter signal enters the radar receiving device along with the target echo signal, which is difficult to be separated and suppressed. It has always been a hot spot and a difficult point in the field of radar signal processing. In the process of signal processing, it is directly affected by the characteristics of the clutter itself: the amplitude fluctuation characteristics of the clutter are related to the performance of detection rate of the radar's constant false alarm detection processor; the power spectrum characteristics of the clutter signal are related to the performance of moving target display of the radar Filter; the spatial amplitude characteristics of clutter are related to the signal-to-noise ratio test before radar clutter cancellation [2]. In order to avoid the huge error in the radar measurement process, the clutter characteristics of the measured terrain are analyzed for the amplitude distribution characteristics, time correlation and spatial correlation of the land clutter.

In a long period of time, many experts and scholars from different fields and different disciplines have conducted detailed research on the characteristics of land clutter and the application of land

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clutter characteristics. At the same time, research results on the characteristics of land clutter have appeared one after another. Morin [3] et al. compared and summarized the recognition algorithms of land slow targets under the effect of strong clutter, and explained that, in order to improve the detection capability and accuracy of radar systems, it had emerged that there were a large number of clutter characteristics to eliminate clutter algorithms or derived improved algorithms, reflecting the impact of land clutter on radar systems and the importance of understanding clutter characteristics from one side. Based on the statistical analysis of land clutter, Marta [4] proposed a new mathematical method of data processing. According to the electromagnetic environment under different detection conditions, the clutter characteristics in the echo signal are analyzed to effectively judge the land clutter. The echo signal has been applied to a weather radar system in southern Italy. Wang Yu [5] et al. focused on the frequency characteristics of land clutter, and established a one-way Doppler frequency calculation model of clutter caused by relative motion. All trends of effect on earth rotation for the land clutter Doppler frequency is obtained by simulation. Liang Yuying [6] et al., beginning from land clutter simulation, studied the simulation method of land clutter statistical characteristics based on the condition of reverberation room, and changed the zero-mean amplitude characteristic of input signal of reverberation room by adjusting the amplitude pulse ratio in the input signal sequence. Finally obtained that the reverberation room clutter electromagnetic environment is consistent with the statistical characteristic parameters of the measured data, and realized the effective simulation of the measured land clutter characteristics. Li [7] et al. studied the land clutter characteristics of meteorological radars, and used the dual-polarization identification method and the statistical characteristics of land clutter to judge the meteorological signals and land clutter in the radar system echoes, and worked on the effective land clutter recognition within each resolution unit.

The backscattering characteristics of land surface targets are generally based on the scattering of rough surfaces. According to electromagnetic scattering theory developing approximation algorithms, it includes analytical methods and numerical methods [8]. Because the complexity of the model is difficult to establish, the factors affecting the clutter are more and there are mutual effects. It is difficult for the general calculation method to quantitatively calculate the complex surface targets such as the land clutter. Therefore, the field data measurement becomes an important means of land clutter research. In the research of PRC-CW radar clutter simulation, Zhang Zhiyong, Zhang Tianxu, Cao Zhiguo and others from Huazhong University of Science and Technology proposed a simulation method for spatial vector superposition of symbol echo amplitude to obtain the actual echo signal [9-10]. Zhang Changlong and Lou Shengqiang from National University of Defense Technology used Monte Carlo method to analyze the correlation between the probability distribution characteristics, power spectrum characteristics and range gate echo of clutter echo signals [11]. In this paper, the field measured clutter data is taken as the research object, and the relationship between different land objects, echo vector superposition times, pitching angle and clutter amplitude distribution characteristics, time correlation and spatial correlation is studied.

2. PRC-CW radar signal analysis

The PRC-CW radar signal transmission form and processing method are different from conventional pulse radar, which also leads to differences in the modeling and analysis of clutter signals. The signal form of the PRC-CW radar can be written as:

\[
S_d(t) = LPF[S_r(t) \cdot S_{ref}(t)] = \begin{cases} 
A_se^{j\omega_0 t} & |t - t_0| \leq \Delta \tau \\
\frac{A_s}{N} e^{j\omega_0 t} & |t - t_0| \geq \Delta \tau
\end{cases}
\]  

(1)

where, the radar resolution unit width is \( c \cdot \Delta \tau / 2 \). The measurement model of land clutter is shown in Figure 1.
where, the height of PRC-CW radar relative to the land is $h$, the pitching angle is $\phi$ and the vertical width of the antenna beam is $\theta$. The back edge of the beam distance from the land is $R_{\text{min}}$, the distance between the leading edge and the land is $R_{\text{max}} = R_{\text{min}} + \Delta R$, the distance difference between the leading and back edge of the beam is $\Delta R$. There are two situations at this point:

1) When $c \cdot \Delta t / 2 \geq \Delta R$, the receipt signal comes from a resolution unit, and all echo signals arrive at the receiver at the same time. At this time, similar to the conventional pulse signal, the resolution unit is determined by the antenna beam width, and the echo video signal can be expressed as:

$$Y_e(t) = a(t) \cdot K_s \cdot e^{i\omega t} \cdot e^{i\phi(t)}$$

(2) where, $a(t)$ is the complex modulation function, $K_s$ is the amplitude coefficient related to the radar equation, $\omega$ is the target motion center angular frequency. $\phi(t)$ is target phase, and:

$$K_s = \sqrt{\frac{2}{(4\pi)^2 R_n^4}} \sigma_0^n S_u \cdot G(\theta)$$

(3) where, $\sigma_0^n$ is the radar backscattering coefficient of the resolution unit, $S_u$ is the resolution unit area, $G(\theta)$ is the antenna pattern function, $R_n$ is the distance between the radar and the resolution unit, and $\lambda$ is the wavelength.

2) When $c \cdot \Delta t / 2 < \Delta R$, the receipt signal comes from a plurality of resolution units, and the echo signals are superposition composed of echoes of different resolution units after different delays, and the resolution unit is determined by the width of the code element. Equation (2) cannot describe the echo signal in this case, and the video signal of the echo in one repetition period is

$$S_e = \sum_{i=1}^{n} K_i u[i - 2(m + i)\Delta t] e^{i\omega(i - 2(m + i)\Delta t)} e^{i\phi(i)}$$

(4) where, $n = \Delta R / (c \cdot \Delta t / 2)$ represents the number of times of echo superposition, $[\ ]$ represents integer, $m = R_{\text{max}} / (c \cdot \Delta t / 2)$ represents the number of delay code units of the leading edge of the beam, $K_i$ represents the amplitude coefficient of the echo signal of the $i$th resolution unit, $\omega_i$ represents the Doppler shift of the $i$th resolution unit, and $\phi(i)$ represents the initial phase of the $i$th resolution unit, which obeys uniform distribution of $(0, 2\pi)$. The superposition process is shown in Figure 2.
Echo superposition is the main reason for the difference between the clutter characteristics of the PRC-CW radar and the conventional radar clutter characteristics, but the effect of the pseudo-code correlation after echo superposition is not mentioned. In fact, if the pseudo-code correlation is still ideal, the superimposed signals can be completely distinguished by the difference of the distance through correlation processing. In this case, the clutter characteristics of the PRC-CW radar are no different from the clutter characteristics of the conventional pulse radar. The different sub-beams are completely independent of time and completely correlated with the clutter time correlation under two ideal conditions. However, the actual situation is between these two ideal situations. Since both cases are idealized, the reference to the actual situation is still limited. The signal represented by the Equation (4) correlation process, and the obtained video signal can be expressed as:

$$ S_d(\hat{\tau}) = \begin{cases} \sum_{i=1}^{n} \frac{A}{N} e^{j\omega_{0}(m+i\Delta\tau)+\beta(i)} & , \hat{\tau} \in [0, 2m\Delta\tau] \cup [2(m+n)\Delta\tau, 2N\Delta\tau] \\ A_{1}e^{j\omega_{0}(m+i\Delta\tau)+\beta(i)} + \sum_{i=1}^{n} \frac{A}{N} e^{j\omega_{0}(m+i\Delta\tau)+\beta(i)} & , \hat{\tau} \in [2m\Delta\tau, 2(m+n)\Delta\tau] \end{cases} $$  

(5)

It is easy to expression, and let

$$ A_1 = \sum_{i=1}^{n} \frac{A}{N} e^{j\omega_{0}(m+i\Delta\tau)+\beta(i)} 
$$  

(6)

$$ A_2 = A_1 e^{j\omega_{0}\hat{\tau}+\beta(i)} 
$$  

(7)

$$ A_3 = \sum_{i=1}^{n} \frac{A}{N} e^{j\omega_{0}(m+i\Delta\tau)+\beta(i)} 
$$  

(8)

Equation (5) shows that the change of the signal with time delay $\hat{\tau}$ after the correlation processing is a piecewise function:

1. When the range gate is outside the range of the beam illumination area, the correlation signal is composed of the ‘leakage’ signal $A_1$ vector superposition of the echo regions outside the gate.

2. When the range gate is within the range of the beam illumination area, the correlation signal is composed of a two-part vector superposition of the clutter signal $A_2$ in the range gate and the ‘leakage’ signal $A_3$ the clutter outside the range gate.

It can be found that regardless of the segment in which the correlator delay $\hat{\tau}$ is, the correlation signal is composed of a plurality of component vectors superposition, and the difference can be considered as the difference of the weight coefficients. When the PRC-CW radar is downward-looking condition, the pulse scan width is generally smaller than the beam longitudinal projection width, that is $c\cdot\Delta\tau/2 < \Delta R$. Therefore, the default in this paper is the superposition of this signal, and the receipt signal comes from multiple resolution units.
3. Amplitude characteristics analysis of field measured clutter

For the clutter data measured in the field, the three models of Rice distribution, Log-normal distribution and Weibull distribution are used for fitting. Rayleigh distribution is used as an idealized distribution model. The main simulation is the echo of uniform scattered, which there is a big difference with the field measured data, so this paper does not consider it.

1) Bare land clutter

The bare land clutter data is selected as the estimation object. The test results of the distribution model after the field measured data and parameter estimation are shown in Table 1. Where, \( \hat{p} \) and \( \hat{q} \) is the shape parameter and scale parameter of the Weibull distribution; \( \hat{a} \) is the point clutter intensity of the Rice distribution; \( \hat{X}_m \) and \( \hat{\sigma} \) are mid-value and standard deviation of the Log-normal distribution, respectively; \( K \) is the hypothesis test value.

It can be seen from the test results that the optimal model of bare land is Weibull distribution, and the test values of Log-normal and Rice models are relatively large. Figure 9 shows the clutter amplitude fitting comparison curve for the pitching angles of 30° and 50°. It can be seen intuitively that Weibull is closest to the field measured data histogram, which is consistent with the test results.

![Figure 3](image-url)  
Figure 3. Bare land clutter statistical distribution histogram in 30° and 50° pitching angle.

(2) Grassland clutter

The grassland clutter data is selected as the estimation object. It can be seen that the test result of grass clutter is similar to that of bare land. What the Weibull distribution corresponds to test value is the smallest, and the fitting effects of the other two models are quite different. Therefore, it is more reasonable to describe the grass echo by Weibull distribution. Fig. 10 is a comparison curve of the amplitude of the clutter when the pitching angle is 30° and 50°. It can be seen from the figure that Weibull is very close to the measured data histogram and is consistent with the test results.

![Figure 4](image-url)  
Figure 4. Grassland clutter statistical distribution histogram in 30° and 50° pitching angle.

(3) Grove clutter

The grove clutter data is selected as the estimation object. The optimal distribution of clutter in the grove is the Rice distribution. Therefore, the Rice distribution is considered to be a good description of grove clutter. Weibull's test value is between Rice and Log-normal. The Log-normal test has the largest value and is not suitable as a model for grove clutter. Fig. 11 is the amplitude fitting
comparison curve of the clutter when the pitching angle is 30° and 50°, which can be concluded consistent with the test results.

Figure 5. Grove clutter statistical distribution histogram in 30° and 50° pitching angle.

The optimal amplitude distribution of bare land, grassland and grove clutter is obtained through analysis. It can be found that the Weibull distribution is more accurate in describing these land objects. Even if it is not optimally distributed to the grove clutter, but the actual fitting effect is also ideal. Theoretically, the Weibull distribution is a two-parameter distribution model. The probability density function can change within a very large range, as the change of shape parameters and scale parameters. Log-normal distribution and Rayleigh distribution are all exceptional case of Weibull distribution. Therefore, Weibull is a very widely used distribution in the simulation of land clutter. The Rice distribution increases the normal distribution component on the basis of Rayleigh and fits the strong scattering points in the uniform terrain. Therefore, the Rice distribution is more accurate in the fitting of the grove clutter. Log-normal and Weibull distribution are approximate distribution of approximation, mainly describing sea clutter, low incident residual angle, and high-resolution radar clutter, which are limited in application.

4. Conclusion
Based on the analysis of the working principle and structure of a type of PRC-CW battlefield surveillance radar, the far field test platform is constructed, and the land clutter test of PRC-CW radar is carried out, and the land clutter field measured data of PRC-CW radar is obtained; data processing is used to summary and calculate the amplitude distribution characteristics, time correlation and spatial correlation of land clutter. Rayleigh, Rice, Log-normal, Weibull model and Gauss model are used respectively to carrying out hypothesis test on the amplitude characteristics and relevant characteristics, and the optimal fitting under different scenarios was obtained; the effects of PRC-CW system and the grazing angle on the above clutter characteristics and fitting model parameters were discussed in combination with theoretical analysis and measured data, to provide the original data of land clutter characteristics for the detection of low-altitude surveillance airborne radar system and missile-borne. Meanwhile, it has some practical application value and application prospects.

Reference


