Modeling and Simulation of Airborne Radar Clutter in a Littoral Complex Environment

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***Abstract*—Facing increasingly severe electromagnetic environment of complex coastal background, the capability of airborne radar for target detection and tracking is influenced seriously. So it is of great significance to study the modeling and simulation of the airborne radar clutter in coastal environment. Based on the coastal environment scattering theory, the compound clutter generation principle in coastal area is first explored and then the back scattering coefficient model of coastal clutter is established in this paper. Finally, the clutter power spectrum calculation of airborne PD radar around coastal environment is explored combining with the digital elevation model (DEM). Simulation results show that the model of compound clutter in coastal area and its power spectrum calculation are effective and practical.**

Keywords—clutter modeling; littoral environment; DEM

I. INTRODUCTION

At present, the coastal military status have become increasingly prominent, a growing number of marine radar will focus on exploring and searching the range from deep open sea to near the coast areas, especially for airborne radar, the scanning range of which is often across the land- littoral environment – ocean due to its flexibility. Compared with the purer land and sea, the coast is a more complex environment, radar which detects the momentous military target near the coast will suffer from both the ground and the sea clutters. Therefore, the received clutter of airborne radar around the coast is symbolized with compound property, and its scattering distribution, power spectrum and amplitude distribution is of great difference from the ground or sea clutter.

Aiming at the study of coastal clutter, the scholars and researchers is still in the initial stage. The relationship between the radar propagation model in the non-standard atmospheric environment and clutter back scattering coefficient is researched in that the coastal region complex environment is composed of different kinds of clutter in [2]. Reference [3] derived back scattering coefficient of coastal zone in different sea circumstance. A new clutter model around the coastal area based on the measured data is proposed in [4]. Furthermore, Li Qingxia et al [8] found a function that describes clutter amplitude distribution of composite situation, and simulated the compound clutter based on the Weibull distribution and lognormal distribution. Li Yuzheng et al [7] present a kind of clutter power spectrum calculation method of airborne PD radar under the compound environment by simplifying the coastline geometry based on the closed loop algorithm in airborne PD radar. However, all researches above have not taken the specific terrain models into consideration, the ideal simplified sea boundary conditions make it sketchy. In this paper, combining with the digital elevation model (DEM)of coastal special area, the spectrum calculation method of clutter power specific coastal region of PD radar is researched via the clutter scattering terrain unit division and the scattering model calculation. This method uses DEM terrain information and does not need to simplify the coastline, which makes the calculation more precise and the simulation more authentic. It is conducive to the clutter estimation and signal detection in those specific environments.

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II. MODELING OF THE COASTAL AREA CLUTTER

A. Analysis of clutter scattering mechanism in coastal area

Due to the presence of low-lying place or pond in the ground area, traditional ground clutter model has taken the effect of water area into account. In the contrary, the traditional sea clutter model is mainly effected on wind and sea condition, lacking of ground influence. Therefore, the analysis of scattering mechanism in coastal area is focus on variation of sea clutter.

However, in the offshore (or called coastal) region, there are four factors that mainly effect the sea surface scattering [2]:

1) Limited fetch
2) Wave refraction angle
3) Variation of tidal currents
4) Breaking in shallow water

These factors directly affect the calculation of clutter backscatter coefficient. In section C, a reasonable calculation model will be present, which is obtained by combining the characteristics of the coastal waters with thorough analysis of the backscattering coefficient model.

B. Coastal clutter cell division

In order to distinguish the sea clutter and ground clutter in the non-superimpose region, we divide the scattering unit when researching the clutter of a coastal region. Thus, it can be easily superposition calculated. According to the traditional Range-Doppler-division method[1], Range resolution unit is:

$$\Delta R = \frac{c}{2f_s} \tag{1}$$

Doppler resolution unit is;

$$\Delta f_d = \frac{f_r}{K} \tag{2}$$

Here, c is the speed of light, f_s is sampling frequency, and f_r is the pulse repetition frequency (PRF), K is pulse number.

The result is shown in Fig1:

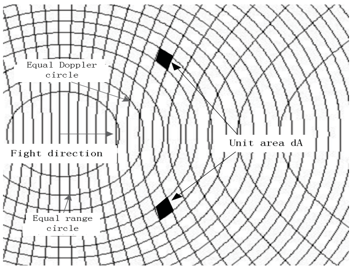


Figure1 traditional Range-Doppler-division

Division scattering unit is used to calculate the clutter power spectrum. The above division method does not consider the effect of real terrain, so that the calculation results is a little different from the real results. Therefore, the authors use improved classification of scattering unit based on DEM.

Classification of scattering unit based on DEM means a method that contains a series of steps. First, each DEM grid data points as a scattering unit, and then according to the position relationship between the scattering unit and the airborne radar, calculate the Doppler frequency shift and range between each scattering unit and airborne radar, finally, based on ΔR and Δf_d ,search for every scattering unit which is in the same distance gate and Doppler channel, collect them together. A $\Delta R \times \Delta f_d$ region is a dividing unit. In this scattering unit division method, the resolution of DEM data is $d_s < \Delta R / 2$, it can be think of as more than one scattering unit in a dividing unit. The result of scattering unit division is a series of nonstandard concentric rings and nonstandard standard hyperbola. Classification results as shown in Fig 2, this improvement can make the power spectrum calculation more precise in clutter.

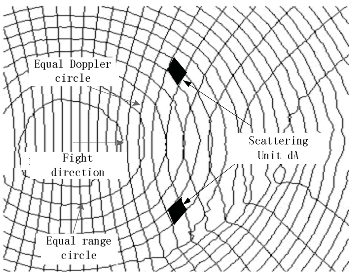


Figure2 Classification of scattering unit based on DEM

C. Coastal clutter backscatter coefficient model

Considering the actual situation in coastal scattering, composite clutter that received by airborne PD radar unit mainly has the following three cases. So we should establish three different backscattering coefficient models to discuss the ground clutter, sea clutter, sea and land interface clutter backscattering.

a. Ground cell clutter model

There is a scattering coefficient model depending on terrain, which called Morchin model. It firstly was proposed by C. M. William, and then revised by Peng Shirui, now it called modified Morchin model[5]:

$$\sigma^0_{land} = \frac{A\sigma^0_c \sin\Phi}{\lambda} + u\cot^2\beta_0 \exp\left[-\frac{\tan^2(B-\Phi)}{\tan^2\beta_0}\right] \tag{3}$$

Here, Φ is grazing angle of the terrain units, when $\Phi < \Phi_c$, $\sigma^0_c = \Phi/\Phi_c$; and when $\Phi > \Phi_c$, $\sigma^0_c = 1$; $\Phi_c = \arcsin(\lambda / 4\pi h_e)$; $h_e \approx 9.3\beta_0^{2.2}$, $u = \sqrt{f}/4.7$, f is the radar working frequency, its unit is GHz. A,B, β_0 , σ^0_c are constant parameters which determined by the different geomorphic types.

b. Sea cell clutter model

We select a common sea clutter coefficient model named Morchin model due to the large application of the model. The concrete expressions are as follows:

$$\begin{aligned}\sigma^0_{sea} = & \frac{4\times10^{-7}\times10^{0.6(ss+1)}\times\sigma^0_c\times\sin\varphi}{\lambda} \\ & +\cot^2\beta\times\exp\{-\frac{\tan^2(\pi/2-\varphi)}{\tan^2(\beta)}\}\end{aligned} \tag{4}$$

Here, Φ is grazing angle of the terrain units, ss is the level of sea condition, $\beta = [2.44(ss+1)^{1.08}]/57.29$, the unit is *rad*;

$$\sigma^0_c = \begin{cases} \left(\dfrac{\Phi}{\Phi_c}\right)^k, & \Phi < \Phi_c \\ 1, \quad \Phi > \Phi_c \end{cases} \tag{5}$$

$\Phi_c = \arcsin(\lambda / 4\pi h_e)$ *rad* ; $h_e \approx 0.025 + 0.046 ss^{1.72}$ *m* , means sea surface roughness; The range of coefficient k is between 1 to 4 ,the typical value is k=1.9.

c. Coast cell clutter model

When the radar irradiates the compound unit of sea and land region, the scattering centers in the unit are divided sea scattering centers and ground scattering centers. If the target is very large, and the wave length is very short, scattering unit RCS is the non-related sum of scattering center. The RCS of compound unit are as follows:

$$\sigma = \sum_{n=1}^{j} \sigma_n + \sum_{n=j+1}^{N} \sigma_n \tag{6}$$

Therefore, the backscattering coefficient of land and sea border unit is:

$$\sigma^0 = k_1 \sigma^0_{\text{land}} + k_2 \sigma^0_{\text{sea}} \tag{7}$$

σ^0_{land} and σ^0_{sea} are given respectively by the ground backscattering coefficient and the sea backscattering coefficient. k_1 stands for the proportion of the land clutter backscattering coefficient in the land-and-sea border unit, while k_2 represents that of the sea clutter. Their values are related to relative position of the unit and the radar.(also means grazing angle), $k_1 + k_2 = 1$ in addition.

D. Clutter power spectrum calculations

After the backscattering coefficient is given, the clutter power spectrum can be calculated. The clutter power of tiny terrain scattering unit is:

$$dP_r = \frac{P_t \lambda^2 G^2(\theta,\varphi)\sigma^0(\theta,\varphi)}{(4\pi)^3 R^4(\theta,\varphi) L} dA \tag{8}$$

Here, L is Communication and system loss factor, θ、φ are azimuth angle and pitch angle scattering unit, $G(\theta,\varphi)$ is the antenna voltage gain scattering unit direction, $\sigma^0(\theta,\varphi)$ is the backscattering coefficient of scattering unit, and $R(\theta,\varphi)$, refer to the radial distance with radar scattering unit.

III. CLUTTER SIMULATION

A. Simulation process

With the development of radar system simulation technology and continuous improvement of the simulation requirements, it is better to analyze the actual scene clutter radar target detection performance by using the determining the designated position on the clutter ground scene information. Meanwhile, it can greatly improve radar working performance in specific scene. In this case, the study focus on the affect in the clutter of actual terrain characteristics. But traditional clutter model is lack of illustrating the influence of topography on the clutter, so it is proposed according to the given ground environment of digital information such as digital elevation information (DEM),to generate the clutter signal [9]

Using the improved the land-and-sea clutter processing, the clutter simulation is going well combining with the DEM information. Specific simulation process is shown in Fig 3.

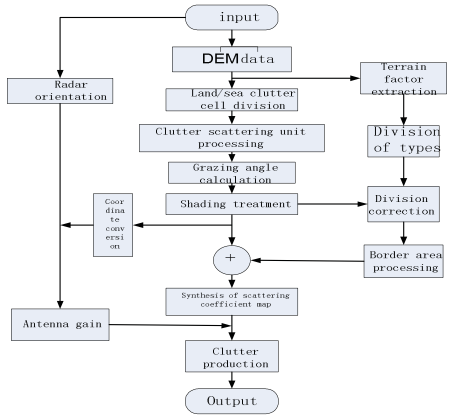


Figure 3 the simulation process

B. Simulation parameter

Simulation –related parameter is present as the following Table I:

TABLE I Simulation –related parameter

Airplane Height	Airplane velocity	Airplane pitching angle	Transmitting power	Working Frequency
5000m	500m/s	0 degree	9000w	10GHz
PRF	Sample frequency	Signal bandwidth	Sample pulse number	Antenna gain
20KHz	1.7MHz	0.8MHz	128	40dB
ele	azi	Array element spacing	System loss	Sea condition
90°	-30°	0.03m	1	4

DEM that describes the space distribution of regional geomorphology, is the actual terrain elevation information of a discrete representation model. It is easy to represent the real-time and automatic of ground scene, and it can be directly used to compute and deal with. The DEM data used in this paper is the interface between the land and the sea topography, its scope is: north latitude 24 ° to 25 °, east longitude 118 ° to 119 °. (The data set is provided by International Scientific & Technical Data Mirror Site, Computer Network Information Center, Chinese Academy of Sciences. (http://www.gscloud.cn))

The actual DEM data graph as shown in Fig 4:

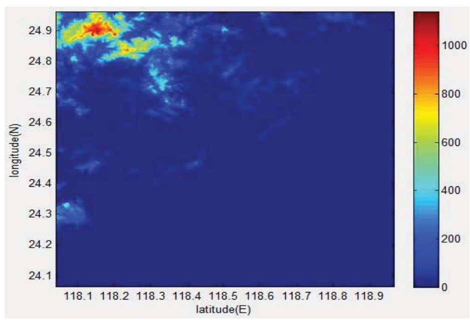


Figure 4 actual DEM data graph

C. Simulation result and ananysis

This paper use the airborne phased array antenna, the antenna directivity diagram is the following Fig 5:

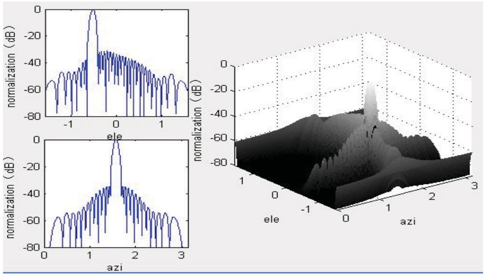


Figure 5 antenna directivity diagram

In this paper, using MATLAB, simulation has been made to calculate the clutter power spectrum of airborne PD radar in coastal environment. The RCS result is shown as the following Fig 6:

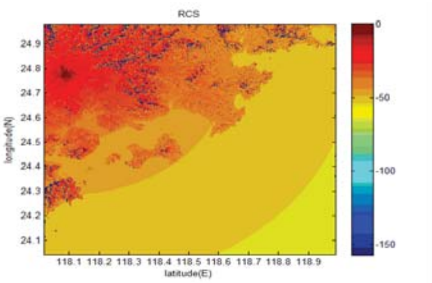
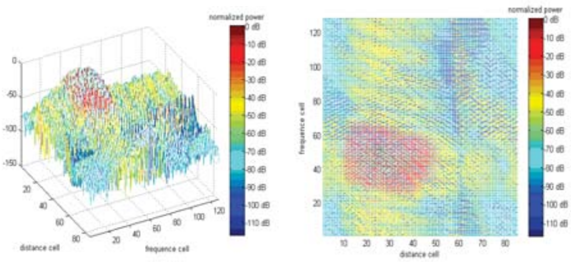


Figure 6 simulation RCS result

Because the plane may be in different positions, the RCS will have great changes. In Fig 6, RCS value has been a mask processing, in order to better reflect the real topography results.

Clutter data result is shown in Fig 7(a) and Fig 7(b):

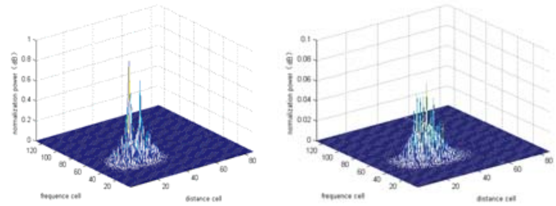


(a) (b)

Figure 7 clutter data result (a) 3-D result (b)2-D result

Given that the position of aircraft in the ground scene geographic Cartesian coordinates (2740000, 610000, 5000), the direct distance between the scattering unit of the antenna main lobe beam center and the fight is calculated approximately 2200m, distance unit corresponding to mod (2200m, R_u)/ ΔR≈25. While the Doppler frequency is about 7800Hz, and Doppler frequency unit corresponding to mod(7800Hz, f_r)/ $\Delta f_d \approx 50$. From the simulation results in fig 7(b) we can see, the main lobe clutter is in the 24 distance units (about 2118m), near the 50 Doppler frequency unit(about 7812.5Hz), and it is the similar with the analysis of results.

Fig 8 shows the coastal area clutter comparing with pure sea clutter in the deep sea. Simulation data represents that, due to the same plane and beam, clutter main area Range-Doppler unit concentration is similar, but the coastal area clutter amplitude is significantly higher than that in deep sea area, and clutter fluctuation wave is more acute. Result means that clutter in the coastal area is fully non-uniformity.



(a) (b)

Figure 8 compare with two simulation results(a)coastal clutter(b) sea clutter

IV. CONCLUSION

Ability of airborne PD radar target detection may be weakened due to the influence of clutter in detecting the military target around the coastal area, so it is of great significance to master the environment clutter power spectrum distribution to improve the ability of target detection. Starting from the principle of generating complex clutter, this paper presents a spectrum calculation algorithm of airborne PD radar in coastal environment based on airborne PD radar clutter power spectrum algorithm with DEM information. Simulation results show that clutter power spectrum of airborne PD radar in the coastal environment is greater and more non-uniformity than that in the deep sea area. Although this algorithm is accurate, the computation amount is large. It is difficult to meet the high real-time performance, and do not have the affect with flight movement, which needs to be further studied.

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