Impact of the Half Space on High Resolution Range Profile

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Abstract. High resolution range profile (HRRP) which contains the characteristics of the scattering centers of the target, has an important application in the field of radar automatic target recognition. Based on the formation principle of HRRP, this paper analyzes the scattering mechanism of targets in half space and the influence of half space environment on HRRP. The half space HRRP of the same object in different viewing angles and relative dielectric constant is obtained by simulation, and it is compared with the HRRP in free space to further verify the correctness of the analysis. The analysis results have certain significance for processing half space HRRPs and half space target recognition.

1. Introduction

A HRRP is the vector sum of the complex echoes return from scatter centers of a target on the radar line-of-sight (LOS) [1-2]. HRRP reflects the position relationship of the scattering center of the target, and includes the structural characteristics of the target. Therefore, it has a wide range of applications in the field of radar perception and radar automatic target recognition. HRRP is very sensitive to the environment and is easily disturbed by clutter. The radar echoes usually contain some clutter, which makes the simulation HRRP different from the real HRRP. Especially when the target is in a half space environment (such as vehicles on the ground, ships on the sea), the echoes received by the radar are not only the echoes from the target itself, but also the clutter brought by the half space. The interaction between the target and the half space environment makes the echoes more complex and the HRRP more complex. Different half space environments have different characteristics, such as the relative dielectric constant of the half space, which will also affect the HRRP of the target. In fact, most of the targets are in the half space environment, so it is meaningful to study the influence of half space on HRRP.

In this paper, the HRRP of half space object is simulated by high frequency algorithm [3]. simulate the HRRPs of objects in “High frequency algorithm” is to introduce the half-space Green's function into the conventional physical optics method, using a graphical-electromagnetic computing method, the radar cross-section of conductive targets can be calculated in half-space. A graphical-electromagnetic computing method3 is to add appropriate lighting mode to the physical models, determine the three primary colors intensity components of each element, and then calculate the value. According to the formation mechanism of HRRP, the scattering of targets in half space is analyzed. By calculating the HRRP of typical targets, the influence of half space on HRRP is studied.

The rest of the article is organized as follows. In Sec 2, the formation principle of Radar HRRP and the influence of half space on HRRP are described in detail. In Sec 3, the half space and free space HRRPs of a typical model are analyzed. Section 4 gives the conclusion.
2. Theory

2.1. Formation mechanism of HRRP
When the target size is much larger than the incident wavelength, the overall electromagnetic reflection of the target can be considered as a combination of electromagnetic scattering from the local position of the target. These scattering sources are called scattering centers. In order to get the HRRPs, we usually use the step frequency method. Suppose the frequency of N pulses transmitted by the radar is as follow:

\[ f_t = f_0 + n\Delta f (n = 0, 1, \ldots, N - 1) \]  

The transmitting signal \( e_n(T) \) is:

\[ e_n(T) = Ae^{j2\pi(f_nT + \theta_n)} \]  

(2)

A is the amplitude of the nth pulse, and \( \theta_n \) is the initial phase of the nth pulse.

The distance between the scattering center and the radar is \( R \), and \( s(n) \) is obtained by demodulating the echoes:

\[ s(n) = \rho e^{-j4\pi(f_n + n\Delta f)R/c} = \rho e^{-j4\pi n\Delta f R/c} \]  

(3)

\( \rho \) is the scattering coefficient.

\( g(m) (m=0, 1, \ldots, N-1) \) is obtained by inverse Fourier transform of sequence \( s(n) \):

\[ g_m = \sum_{n=0}^{N-1} s(n)e^{-j2\pi nm/N} = \rho \sum_{n=0}^{N-1} e^{-j2\pi mn(2N\Delta f/R)/N} \]  

(4)

The sequence of \( |g(m)| \) is the HRRP of the target.

2.2. Influence of half space on HRRP
The scattering of the same target in half space and free space is different [4][5], which makes the HRRPs different. In free space, the echoes received by the radar are only the scattering from the target itself. But in half space, the wave will scatter twice or even three times between the target and the half space plane. So, the echoes received by radar in half space are more complex than that in free space. As shown in the Fig. 2, in free space, there is no influence of the half space, the echoes received by the radar only come from path 1 (radar-target-radar). But in half space, the echoes received by radar come from path 1 + path 2 (radar-target-half space plane-radar) + path 3 (radar-half space plane-target-half space plane radar) + path 4 (radar-half space plane-target-half space plane-radar) + others (except for the above four cases, the rest of the scattering cases.). The four paths in Fig. 2 are only part of the scattering, there will also be other scattering. At the same time, when the half space is different, the

![Fig.1 Example of a HRRP](image-url)
relative dielectric constant of half space will also change, so that the echoes received by radar are also different, which will affect the HRRP.

3. Experimental Results and Analysis
In order to analyze the influence of half space on HRRP, we use half space electronic computing software to calculate the HRRP of a perfect electrical conductor sphere. As shown in Fig. 3, the radius of the sphere is 0.5m, and the distance between the center of the sphere and the half space plane is 0.6m. The start frequency of the radar is 5GHz and the bandwidth is 1024MHz.

The sphere can be equivalent to a scattering center [6]. Fig. 4 shows the HRRP of a sphere in free space. In free space, the wave received by radar only comes from path 1 in Fig. 2. Therefore, the HRRP of the sphere in free space should have only one scattering center (that is, only one peak). The free space HRRP with a pitching angle of 30 degrees is shown in the Fig. 4. It can be seen from the Fig. 4 that HRRP has only one peak value, which means that the target has only one scattering center. The result is consistent with the theory.

Moreover, when the pitching angle is fixed, the free space HRRP of the sphere does not change with the change of azimuth angle.

When the sphere is in half space (we set the half space to PEC), its HRRP is shown in Fig. 5. Due to the influence of half space, the echoes path increases, and the echoes received by radar also increase. This makes the scattering centers of the HRRP increase, which appears as an increase in the number of peaks in HRRP. As shown in Fig. 5, the position of the first peak in half space HRRP is consistent with that in free space HRRP. This shows that both scattering centers are from path 1. in addition to
the first peak, other peaks also appeared, and the value of these peaks are not less than that of the first peak. It can be seen that half space has a great influence on scattering.

Fig. 5 Half space HRRP of the sphere at the pitching angle 30°

However, when the pitching angle is too large (close to 90 degrees), free space HRRP is very similar to half space HRRP. When the pitching angle is 90°, the free space HRRP and half space HRRP are shown in Fig. 6, there is only one scattering center in each HRRP, and the positions of the two scattering centers are the same.

Fig. 6 Half space and free space HRRP of the Sphere at the pitching angle 90°

Different materials of the half space will affect the scattering of the wave on the half space surface, which will lead to different amplitude of the echoes received by the radar. The value of peak of HRRP will also be different. When the pitching angle is fixed to 30 degrees, the half space HRRPs with relative dielectric constant of 4 and 81 are shown in Fig. 7.

Fig. 7 Half space HRRP with relative dielectric constant of 4 and 81

As shown in Fig. 7, since the first peak is generated by path 1, it is independent of the relative dielectric constant of the half space. Whether the relative dielectric constant is 4 or 81, the value of the first peak of the two HRRPs is the same. But the following peaks are all related to the half-space, so
the peaks will be different for different relative dielectric constant. It can be seen that the peak value of HRRP increases with the increase of relative dielectric constant.

4. Conclusion
In this article, we analyze the influence of half space on HRRP. Compared with free space, scattering in half space is more complex. The scattering centers of the same target in half space are more than those in free space, resulting in more peaks in half space HRRP than in free space. However, when the pitching angle is large, the half space HRRP is very similar to the free space HRRP. The relative dielectric constant of half space will also affect the HRRP, the peak value of HRRP will increase with the increase of relative dielectric constant.

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