Research of RCS sequence for Radar Target Feature Identification

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Abstract: Space object recognition technology is one of the key technologies of space monitoring system. Its main function is to detect and track space objects such as satellites, debris, missiles, space stations, spacecraft and meteorites in space, extract the characteristic information of targets, and then realize the recognition of various space targets. As one of the main sensors for the acquisition of space target information, radar has the characteristics of strong real-time performance, long operating distance, all-weather and all-day operation, and plays an important role in the identification of space target.

1. Introduction

RCS (Radar Cross Section) is Radar data that is not affected by the distance between the target and the Radar, its size depends on the shape, surface material and incident wave parameters of the target. The analysis of radar data is ultimately to identify the target. Radar target recognition is the acquisition of radar characteristics of various targets, the selection of target information to classify and determine the target. At present, it is one of the common methods to estimate the shape and size of space target by RCS sequence obtained by narrow-band radar. The space monitoring system has a large amount of tasks and high real-time requirements, so it is unnecessary to use high-resolution imaging technology to image and identify the target during the monitoring process. As narrow-band information, RCS has small data volume and relatively simple processing technology.

Since the emergence of radar, RCS has become one of the most important and basic parameters in radar data. In order to deeply study radar target characteristics, scholars of electromagnetic field theory also turn to radar target scattering theory.

RCS is defined as the ratio of the power scattered in the receiving direction by the target at a unit cube Angle to the power density of the plane wave incident at the target from a given direction by 4π times. According to the electromagnetic scattering theory, when the distance is far enough, the incident wave of the irradiated target is approximately plane wave, then σ and R is independent, and the expression of the far field is listed as follow:

$$\sigma = 4\pi \lim_{R\to\infty} R^2 \frac{|E_s|^2}{|E_i|^2} = 4\pi \lim_{R\to\infty} R^2 \frac{|H_s|^2}{|H_i|^2} \tag{1}$$

Where, E_i and H_i are the intensity of incident electric field and magnetic field respectively, while E_s and H_s are the intensity of scattering electric field and magnetic field respectively. The definition based on the radar measurement viewpoint is derived from the radar equation. The radar system consists of transmitter, transmitting antenna to target, target, target to receive antenna and receiver. Ignoring various losses, the expression of the target derived from the radar equation listed as follow:

$$\sigma = 4\pi = \frac{P_r}{A_r / r_r^2} \bullet \frac{1}{\frac{P_t G_t}{4\pi r_t^2}} = 4\pi \bullet \frac{\text{Receive the three-dimensional Angle scattering power from the antenna}}{\text{Irradiation power density at target}} \tag{2}$$

The formula derived from the radar equation from the radar measurement point of view is consistent with the definition derived from the electromagnetic scattering theory. Rotate the position of the target to be measured and the calibration object with known accurate value at the same distance.

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When the power coefficient of the measured radar is the same, the received power P_r and P_{r0} is measured respectively

$$\sigma = \frac{P_r}{P_{r0}} \sigma_0 \tag{3}$$

Up to now, a large number of academic works have appeared on RCS, and radar target recognition based on RCS data has become an independent branch in the field of radar. There are many methods for feature extraction of spatial target RCS, all of which adopt different techniques due to different purposes of feature extraction. At present, it is mainly divided into three categories. The first one is to estimate the structure and size of the spatial target. The focus is to study the RCS characteristics under the specific model, and then extract the characteristics of the spatial target RCS sequence by using the obtained statistical characteristics. Space target structure usually has the characteristics of simple, symmetry, for some simple forms of space target such as a sphere and cylinder, etc., can get the RCS with the analytical expression of the attitude Angle change and analyzes the shape, the structure characteristics of space target RCS sequence and the corresponding characteristic parameters, it can be used to estimate the shape and structure of the RCS data. The second one is to realize the classification and recognition of spatial targets. Based on the characteristics of RCS sequences of spatial targets, feature vectors that can be used for classification are extracted from time series, non-stationary sequences, one-dimensional vectors and other perspectives, which are mainly used for pattern recognition in the later stage to realize the detailed classification of targets. In this case, the idea of spatial transformation is generally adopted. Firstly, the characteristics of spatial target RCS are enhanced, and then the feature parameters are extracted and selected. The other one is to distinguish the motion attitude of the space target, mainly to analyze the characteristics of the dynamic change of the RCS of the space target with time. The typical attitude of space target includes three axis stable attitude, spin stable attitude and roll attitude. These changes in attitude will cause changes in RCS time series, which can be described by corresponding characteristic parameters.

2. The classification of the RCS

There are several ways to classify RCS. According to the field area, there are far field RCS and near field RCS. According to the frequency spectrum of incident wave, RCS with bit frequency and RCS with wide band. According to radar receiving and transmitting positions, there are single-station RCS, quasi-single-station RCS (receiving and transmitting without the same antenna, but close to each other) and dual-station RCS. In addition, RCS can also be classified by wavelength. If receiving and transmitting share the same antenna, it is called single-station scattering, also known as backscattering. If the receiving and transmitting antennas are not the same, but close to each other, it is called quasi-single-station scattering.

When the distribution is very wide, it is called double-station scattering, also known as non-backscattering, and the Angle between the emitted incident wave and the received scattered wave in the target coordinate system is called double-station Angle (double-base earth Angle).A parameter representing the size of target feature size normalized by wavelength is introduced, which is called ka value:

$$ka = 2\pi \frac{a}{\lambda} \tag{4}$$

Where, *k* is called the wave number, and *a* is the characteristic size of the target, usually taken from half of the maximum size of the target in the cross-section perpendicular to the radar line of sight. According to the different electromagnetic backscattering characteristics of the target, *ka* is divided into three regions, named Rayleigh region, resonance region and optical school district.

1. The characteristic of Rayleigh region is that the working wavelength is larger than the target characteristic size, generally taking the range of ka<0.5. In Rayleigh, the determinant of the target RCS is the volume of the object normalized by wavelength.

2. The value of k and an in resonance region is generally within the range of $0.5 \le ka \le 20$. In this region, the RCS oscillates with the frequency due to the interference between the scattered components, so the approximate calculation of RCS is very difficult. In order to solve the scattering field in resonance region strictly, it is necessary to have a strict solution or a good approximate solution of the vector wave equation. In the resonance region, the RCS changes rapidly with the attitude and frequency of the target and produces many peaks and valleys.

3. The optical region is the upper bound of the resonance region, and the value is generally $ka>20$. The RCS value depends on the shape of the target surface and the roughness of the surface. The discontinuous shape of the target leads to the increase of RCS. For smooth convex conductive targets, the RCS is often approximate to the contour sectional area of the radar line of sight. However, when the target contains edges, corners, cavities or media, the RCS increases significantly.

In Rayleigh region, the determining factor of RCS size is determined by the volume of the object with normalized wavelength, and the fluctuation changes slowly. In multi-attitude Angle, the value difference of RCS is no more than a few dB, so it is difficult to represent the structural information of the target. However, in the resonance region, the approximate calculation of RCS is very difficult and requires a strict solution of the vector wave equation. For most space target feature measurement radars, generally large space targets are located in the optical region. According to the localization principle of high frequency scattering field, the interaction between electromagnetic waves and targets has local characteristics, which is closely related to the shape and structure of targets.

3. Research status of target RCS characteristic

RCS theory is based on various electromagnetic scattering theories to study the mechanism of scattering field generated by the target, and various approximate calculation methods and computer technology are used to quantitatively estimate the radar cross section characteristics of the target under various circumstances. The theoretical calculation has the advantages of small investment, short period and flexible, which is not only applicable to the study of existing military targets, but also can be used to predict and optimize the scattering characteristics of future weapons.

Goal there are many types of produce electromagnetic scattering mechanism, in order of decreasing strength mainly includes: reflection Angle structure, reflection, concave cavity structure on the surface of mirror reflection, edge and tip diffraction, surface travelling wave backscatter, crawl wave diffraction, secondary or multiple scattering, as well as the discontinuous surface curvature or discontinuous surface scattering and so on.

Among them, the first three scattering mechanisms are all based on the law of reflection and refraction of geometrical optics, while edge and tip diffraction, surface traveling wave back scattering and creeping wave diffraction do not follow the law of geometrical optics, and their scattering mechanisms are more complex. In view of the scattering characteristics of the above radar targets, a variety of radar target RCS calculation methods have been proposed. The angular reflector with the strongest scattering is generally composed of two or three planes orthogonal to each other, which can produce a very strong radar cross section within a wide attitude Angle.

The RCS of a space target is related to many factors, such as shape and structure, target attitude, radar observation Angle, etc. For the actual space target, the movement speed is very fast, and the slight attitude change may cause the RCS to change by dozens of decibels, so the sequence transformation of the target RCS is very complex. Therefore, for RCS as a random variable, it is necessary to study its probability distribution and establish a statistical model. At present, there are three main models: 2 distribution model, Rice distribution model and log-normal distribution model. The motion characteristics of spatial objects are different from those of point scattering models, and its probability distribution cannot be simply described by these distribution functions. It is of great significance to establish the RCS fluctuation statistical model of spatial target for feature extraction.

The probability distribution of RCS for different spatial targets is different. By analyzing the probability distribution of a large number of measured RCS data, it is found that the probability distribution of RCS sequences for the same spatial target is basically the same. On this basis, this paper extracts the statistical characteristics of spatial target RCS sequences for target recognition

4. Conclusion

The idea of spatial transformation in modern signal processing technology broadens the idea for the development of spatial target RCS feature extraction technology. Feature extraction of the transform domain of RCS can better reflect the characteristics of the target, or expand the feature extraction method to reduce the difficulty of feature extraction. Measurement is an important means to study radar target characteristics. Through actual measurements of various targets, not only the basic scattering phenomena can be understood, the results of theoretical analysis can be tested, but also a large number can be obtained, thus establish the target characteristic database. The integrity and reliability of RCS data can promotes the understanding of radar target characteristics, and provides certain reference for radar system design and performance analysis.

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