TARGET DISCRIMINATION USING MULTIPLE-FREQUENCY SCATTERING AMPLITUDE

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Abstract

A technique for radar target discrimination using multiple-frequency scattering amplitude is investigated in this study. Based on the concept of natural resonance frequencies, the technique proposed is aspect-angle independent. Simulation results also take into account the effect of noise which appears in practical measurement.

Introduction

The idea of aspect-independent natural frequencies established by singularity expansion method (SEM) proposed in early 1970's is a good starting point for target discrimination. The theoretical work of Marin[1] constructs the basic principle of SEM. According to SEM, the late-time scattering response from a variety of conducting scatterers could be represented as a series of damped sinusoids in time domain or as a series expansion of simple poles in frequency domain. In a word, natural resonance frequencies are the unique characteristics of targets and are useful in the application to discrimination.

Preparing a data base of known natural frequencies of the targets of interest is preferred in target discrimination, since usual methods for direct pole extraction are either time-consuming or seriously limited by noise. Convolving the scattering impulse response with the so called "E-pulse" which is unique for each specific target to achieve the expected extinction performance is a technique developed in time domain[2].

A frequency-domain discrimination scheme based on the concept of natural frequencies is proposed in this study. The method presented utilizes the fact that most targets of interest are high-Q structures thus having significant resonance phenomenon in radar cross section (RCS). By the experience that the phase measurement of scattered field usually is more noisy, this technique uses only the amplitude data with frequency scanning. This real-time procedure can be applied to broadband radar system operating in frequency domain. To overcome the effect of noise, an algorithm using FFT is investigated for practical situations.

Description

As is well known, the radar cross section (RCS) is proportional to the square of the scattering amplitude. At a given aspect-angle, the RCS of a perfectly conducting scatterer, $A(\omega)$, can be expressed as a function of real angular frequency ω

$$A(\omega)=\left|G(s)\big|_{s=j\omega}\right|^2 \tag{1}$$

where $G(s)$ is the scalar transfer function in Laplace s-domain which may represent either co-polarization or cross-polarization scattering coefficient. According to SEM, $G(s)$ can be expressed as a series expansion of simple poles $\{s_i=\sigma_i+j\omega_i\}$ plus an entire function. Note that $\{s_i\}$ is the unique set of the natural resonance frequencies for the scatterer and is independent of the aspect-angle. However, the residue of each pole depends on aspect, and the entire function depends on that also.

By straightforward manipulation, RCS can be split into two parts as follows

$$A(\omega)=\frac{2d_n(\omega-\omega_n)-2c_n\sigma_n}{(\omega-\omega_n)^2+\sigma_n^2}+K_n(\omega) \tag{2}$$

where $K_n(\omega)$ is the summation of contribution from all poles except $s_n=\sigma_n+j\omega_n$, the specified natural frequency. And c_n and d_n are appropriate real constants. When $\omega\approx\omega_n$, the first term in right-hand side of (2) is the most dominant term to make RCS change with ω , and $K_n(\omega)$ is a slowly-varying term approximately. This approximation is adequate for high-Q scatterers, such as spheroids.

Now we construct a "distinction polynomial" as

$$D(j\omega)=\prod(j\omega-s_i') \tag{3}$$

where $\{s_i'\}$ is a set of natural frequencies of some specific target in data base, but only those in the desired frequency range and with small damping factors are included. Apparently, in the vicinity of $\omega=\omega_n$, $|D(j\omega)|^2$ behaves approximately like a second-degree polynomial. If the natural frequency s_n' for the distinction polynomial is matched to that of the RCS response, i.e., $\sigma_n'=\sigma_n$ and $\omega_n'=\omega_n$, it turns out that $y(\omega)\equiv A(\omega)\cdot|D(j\omega)|^2$ will be a second-degree polynomial of ω in the vicinity of $\omega=\omega_n$. Thus a loss function $l(\omega)$, defined as the third derivative of $y(\omega)$, should approximately equal zero at $\omega\approx\omega_n$. If $\{s_i'\}$ is a subset of $\{s_i\}$, including all the natural frequencies which lie within the specified frequency range, then $l(\omega)\approx 0$ in the frequency range (ω_a, ω_b) where the RCS measurement is made.

Finally a risk R is defined as

$$R=\int_{\omega_a}^{\omega_b} l^2(\omega)\,d\omega \tag{4}$$

Then R can be used as a quantity for target distinction. When identifying the correct target, R should be close to zero, otherwise it will be considerably different from zero. Therefore a discrimination scheme is achieved using only the RCS (or amplitude) response in the frequency domain.

Note that distinction polynomials for different targets may vary greatly and normalization is required. This is achieved by dividing $|D(j\omega)|^2$ by its values summed over the desired frequency range.

In the presence of noise, direct finite difference for approximating differentiation in the "direct approach" may cause ill-conditioned results, and hence an improved "FFT approach" is proposed. Transforming from ω to $\tilde{\omega}$ domain, differentiation with respect to ω is equivalent to multiplication by $\tilde{\omega}$. In addition, a proper window function like Hamming window is used in $\tilde{\omega}$ domain to eliminate the undesirable high frequency noise.

Simulation Results

For a prolate spheroid with long axis b(=15 cm) and short axis a and of axial ratio $a/b=0.1$, a code of moment method[3] is used to generate the simulated RCS which corresponds to the back-scattering data at 30° measured from the long axis. The frequency range considered is from 2.5 to 4.2GHz, with sample spacing 0.025GHz. The calculated RCS shown in Fig.1, which is simulated by adding a white-Gaussian noise to the complex transfer function, is used to verify the validity of the discrimination algorithm.

Spheroids of different sizes with axial ratio fixed to 0.1 are used in simulating various distinction polynomials for comparison. The subset $\{s_i'\}$ for constructing the distinction polynomial includes the first-layer poles with imaginary parts lying within (1.5GHz, 5.2GHz). The long axes of "comparison" spheroids are $b'=(\frac{1}{r+1})b$. When r equals 0, the "comparison" spheroid is the same as the "real" one, and we should have the correct distinction. The discrimination capability can be clearly demonstrated in Fig.2, where R values for wrong spheroids usually are at least about 8dB higher than the smallest which corresponds nearly to the correct spheroid. For further demonstration, spheroids of axial ratio 0.2 and thin wires of diameter-to-length ratio 0.01 are chosen as "comparison" targets. Still the long axes of "comparison" targets are $b'=(\frac{1}{r+1})b$. When r is 0, the long axis of "comparison" target is the same as the "real" one but with different structure. The discrimination results for spheroids and thin wires are shown in Fig.3 and Fig.4 respectively. Still the results are at least about 8dB higher than the correct one. Comparing these figures, clearly only the correct target gives the smallest risk value, and good discrimination has been shown accordingly.

Conclusions

A technique using only amplitude data to discriminate radar targets has been proposed. Based on the natural frequencies in SEM, the aspect-independent technique has been set forth and simulated numerically. An algorithm using FFT is incorporated and shown to work well in noisy situation. With the aid of data base of natural frequencies for targets of interest, this technique is nearly a real-time process thus providing fast response in practical application. Though the present method is limited to the discrimination of targets of high-Q structures, however it corresponds to the practical situations usually met.

References

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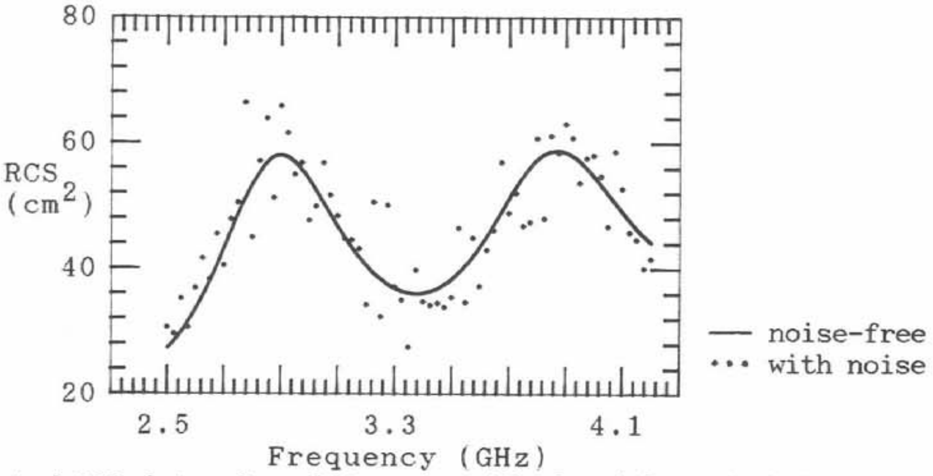

Fig.1. Simulated RCS data of prolate spheroid of axial ratio 0.1.

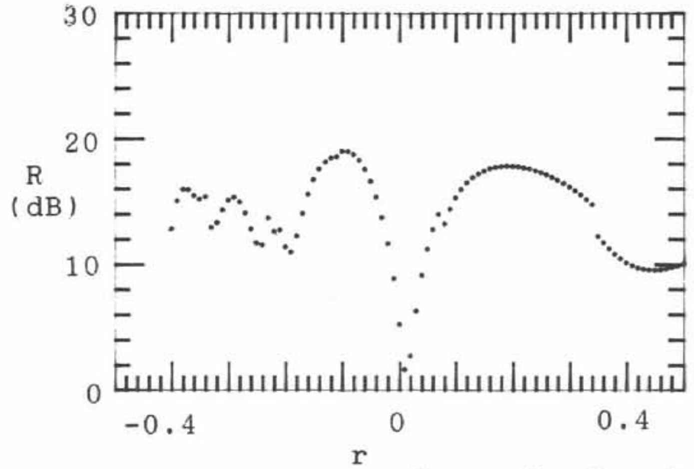

Fig.2. Risk value for discriminating "comparison" spheroids of different sizes with axial ratio 0.1 by "FFT approach" applied to noisy data.

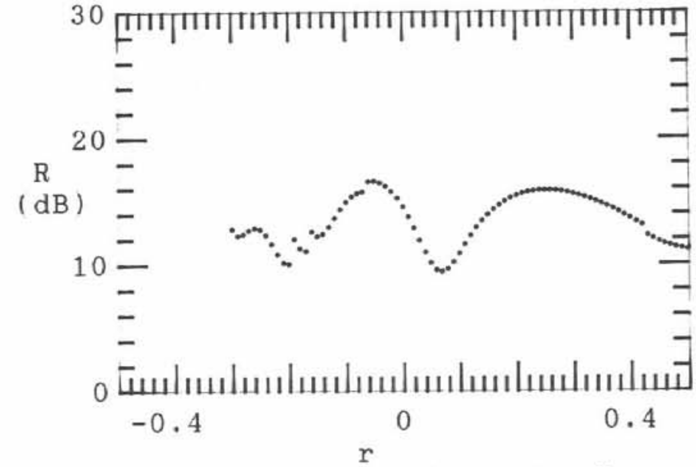

Fig.3. Risk value for discriminating "comparison" spheroids of different sizes with axial ratio 0.2 by "FFT approach" applied to noisy data.

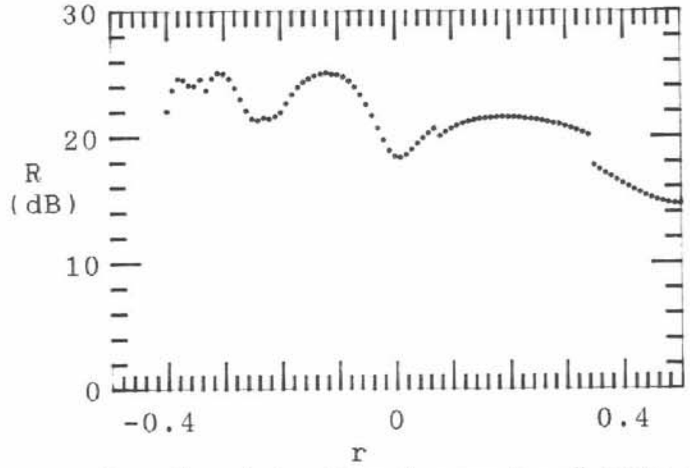

Fig.4. Risk value for discriminating "comparison" thin wires of different sizes by "FFT approach" applied to noisy data.