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APPLICATIONS OF ANGULAR CORRELATION FUNCTION MEASUREMENT IN TARGET DETECTION

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Abstract – A novel technique for detecting a target located near a rough surface is presented in this paper. This technique is based on a phenomenon known as the Angular Memory Effect, and involves measurement of the Angular Correlation Function (ACF) for scattered waves at antenna positions where the masking effect of surface clutter on the desirable target ACF return is minimized. Controlled millimeter-wave experiments were conducted and comparison with traditional techniques using radar cross-section measurement was made to demonstrate the effectiveness of this correlation technique.

1. Introduction

Over the past several decades since the invention of radar, various radar applications have required extensive research on the detection of targets embedded in clutter [1-4]. In reality, these applications may, for instance, address the situation in which the detection of a vehicle covered by a thick tree canopy or potentially active land/undersea mines for military or post-war removal purposes is required. While traditional approaches making use of radar cross-section (RCS) measurement usually result in inconclusive decision for the presence of target(s), modern radars with polarimetric, transient, and bistatic features provide alternatives with only conditional success [1-4].

In this paper, we propose a new technique for target detection based on the ACF measurement. We demonstrate the effectiveness of this correlation approach by performing wideband millimeter-wave (75–110 GHz) experiments on ACF measurement for the detection of a long conducting cylinder (diameter $\approx 1\lambda$) oriented perpendicularly to the plane of incidence. In our experimental setup, the cylinder was suspended at a distance of about 2λ above a two-dimensional conducting Gaussian random high-slope rough surface with known surface roughness profile. Our results indicate that given a wideband radar system by measuring the ACF corresponding to an appropriate set of incident and scattering angles, the masking effects of surface clutter on the desirable ACF return can be minimized, thus permitting successful target detection. Parallel comparison with traditional techniques using radar cross-section (intensity) measurement was made. It was found that given the same clutter environment and measurement bandwidth, while traditional techniques based on many spatial samples of measurement fail to provide a clear conclusion about the presence of the target, our proposed ACF-based technique provides high target-to-background visibility contrast with even one single spatial sample of measurement.

2. Angular Memory Effect

Recent studies showed that there is memory associated with the angular dependence of multiply scattered waves from random rough surfaces in response to a change in the direction of the incident wave [5-7]. This angular correlation phenomenon was known the Angular Memory Effect and can be characterized by the ACF defined as [8-9]

$$\Gamma(\theta_i, \theta_s; \theta_i', \theta_s') = \langle E_s(\theta_i, \theta_s) E_s^*(\theta_i', \theta_s') \rangle \tag{1}$$

$\Gamma(..)$ represents the angular correlation between the reference scattered wave observed at θ_s due to an incidence at θ_i and the variable scattered wave observed at θ_s' due to an incidence at θ_i', with angle brackets denoting an ensemble averaging operation. In general, the ACF of rough surface is negligibly small because of the phase cancellation due to multiple scattering, but becomes significant when the difference in the transverse wave numbers is the same for the incident and scattered waves [9]. This condition can be stated as

$$k(\sin\theta_i' - \sin\theta_i) = k(\sin\theta_s' - \sin\theta_s)\,. \qquad (2)$$

For a given pair of reference antenna positions (θ_i, θ_s), the magnitude of ACF is therefore almost zero everywhere except along the line (the *angular memory line*) defined by (2) on the $\sin\theta_i' - \sin\theta_s'$ plane. The lateral width of this line is quite narrow and is on the order of λ/L [8-9], where L is the illumination width. In our experiments, λ/L is smaller than 1°, indicating rapid decorrelation away from the angular memory line. In the case of a perfectly reflective flat surface, the condition for strong angular correlation is similar to (2), but without the sine dependence.

Since rough surface ACF is most significant when measurement is made along the angular memory line, in order to minimize the masking effect of surface clutter on the desirable target ACF return in the combined scene (surface together with the target), measurement should be made along a line (the *scan line*) which is *perpendicular*, or almost perpendicular to the angular memory line. In this study, this scan line was chosen to be a straight line intersecting perpendicularly with the angular memory line at the reference antenna positions ($\theta_i = 20°, \theta_s = -40°$). These two lines are shown in Fig. 2.

3. Experiments And Results

Millimeter-wave experiments were conducted to study the effectiveness of this correlation approach in target detection problems. A long conducting cylinder (diameter $\approx 1\lambda$) was suspended at a distance of about 2λ above a two-dimensional conducting Gaussian random rough surface with known roughness profile (rms height $= 1\lambda$ and correlation length $= 2\lambda$ with Gaussian correlation spectrum) [10-11]. Mechanical accuracy of the experimental setup was reinforced by use of computer-controlled rotational stages and electronic devices with angular position feedback. The ACF measurement was made along the scan line and the ensemble averaging operation in (1) was achieved using the available independent frequency samples over the frequency band of 80–105 GHz based on one single spatial sample. Because of the large dynamic range of the energy content in ACF measurements, target visibility (or target-to-background contrast) can be enhanced by taking the Fourier transform on the raw ACF data. Only the magnitude of the complex transformed-ACF is presented in this paper.

Fig. 3 shows the magnitudes of the transformed-ACF measurement with and without the presence of cylinder using TM incidence for the case of ($\theta_i = 20°, \theta_s = -40°$) based on one single spatial sample. As evident from the figure, the difference in the level of peaks of the two functions clearly reveals the presence of the target embedded in the strong clutter produced by scattering of the conducting random rough surface. Compared with traditional approach using bistatic cross-section (intensity) measurement as shown in Fig. 4, it is clear that the traditional intensity measurement doesn't produce a decision as clear as that produced by ACF technique about the presence of the target embedded in the same clutter environment, thus demonstrating the strength of this correlation approach in detecting targets embedded in clutter environment.

4. Conclusion

A new approach for target detection based on the angular correlation (memory) effect is proposed. The experimental studies conducted with a conducting cylinder on a two-dimensional rough surface indicate the effectiveness of this correlation technique. The fact that successful detection can be based on one single spatial sample makes this technique a competitive candidate to practical implementation of a target detection system. Proposed research based on this technique may focus on its potential applications in the detection of land/undersea mines embedded in clutter.

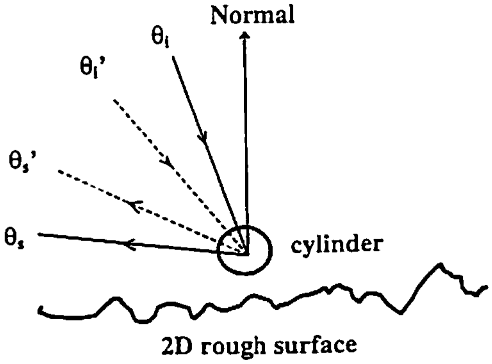


Fig. 1 Scattering geometry of the experimental setup. Rough surface: rms height = 1λ, correlation length = 2λ, Gaussian surface correlation spectrum. Cylinder diameter ≈ 3λ. TM incidence.

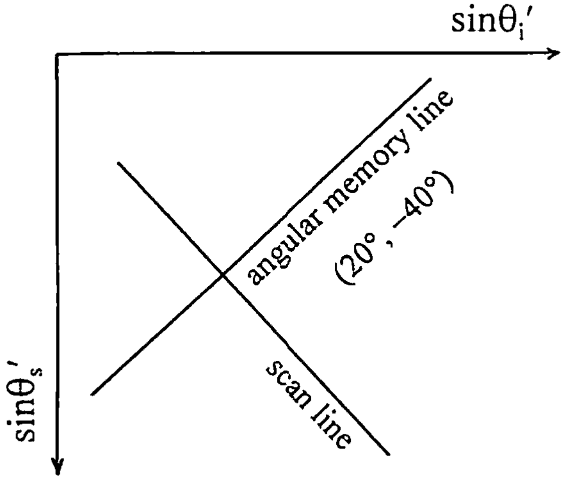
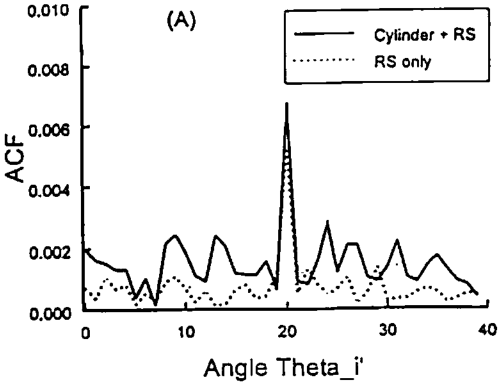


Fig. 2 The angular memory line and the scan line.



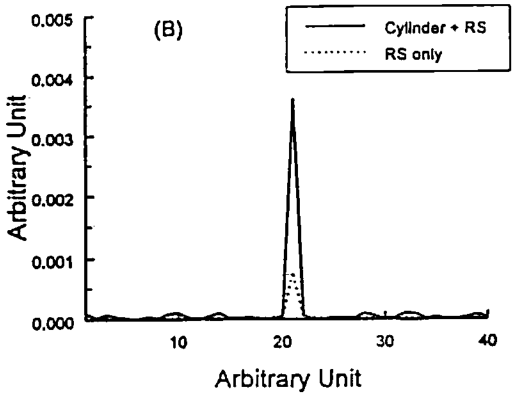


Fig. 3 (a) The magnitude of the ACFs along the scan line in linear scale. (b) The magnitude of the Fourier transformed-ACFs along the scan line in linear scale. Solid line: 2D rough surface together with cylinder. Dotted line: 2D rough surface alone. Rough surface: rms height = 1λ, correlation length = 2λ, Gaussian surface correlation spectrum. Cylinder diameter ≈ 3λ. TM incidence.

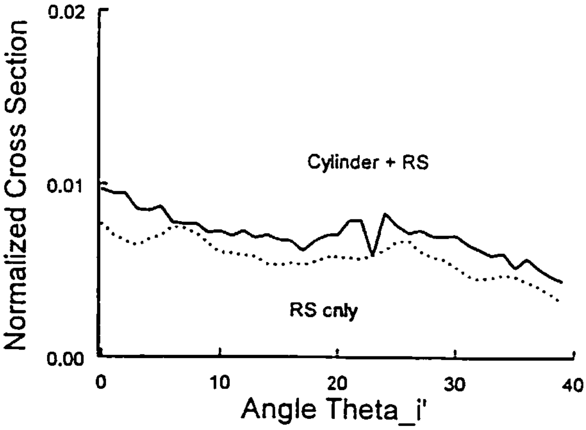


Fig. 4 Bistatic cross-section as a function of θ'_i in linear scale. Solid line: 2D rough surface together with cylinder. Dotted line: 2D rough surface alone. Rough surface: rms height = 1λ, correlation length = 2λ, Gaussian surface correlation spectrum. Cylinder diameter ≈ 3λ. TM incidence.