1-D Feature Extraction Using a Dispersive Scattering Center Parametric Model

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I. INTRODUCTION

Automatic object recognition, the ability for a machine to classify an object it has detected, is an area of continual interest. The classification of objects requires extraction of discriminatory information, and this process is called feature extraction. The extractable features are inextricably tied to the type of sensor used, and this work addresses one-dimensional, High Resolution Radar (HRR).

Several approaches have been proposed for feature extraction in HRR. The most straightforward approach lies in using the magnitude of range bins in range profiles as features. This approach generally denotes template matching [1]; however, template matching is not an optimal approach because it includes many noisy range bins as features. A different approach is based on finding sinusoids in noise by a sum-of-damped exponentials (DE) model. These superresolution techniques include Prony [2-5], Matrix Pencil [6], and many others. The features of the DE-based scattering models, range and amplitude, have been used for feature extraction, but the DE model simplistically assumes that all scattering centers on the object have the frequency response of an ideal point scatterer. One high potential improvement to the damped exponential model lies in estimating the frequency response of each scattering center uniquely. This improvement is based on the Geometric Theory of Diffraction (GTD) [7] and the Uniform Theory of Diffraction (UTD) [8] and includes electromagnetic scattering theory as a basis for scattering center modeling. Research in adapting DE models to include GTD/UTD has been performed [9, 10], but has had limited implementation in object recognition problems. This work provides analysis and a proof-of-concept for implementing the GTD/UTD-based dispersive scattering center (DSC) model to perform object recognition. The DSC model presented here is based directly upon Potter's work at The Ohio State University [10].

II. THE DISPERSIVE SCATTERING CENTER MODEL

GTD as developed by Keller [7] predicts that at high frequencies, the backscattered field is related to the incident field and appears to originate from a discrete set of independent scattering centers. The backscattered field is given by

$$\bar{\mathbf{E}}^s(f, z) \approx \frac{\bar{\mathbf{E}}_0}{|z|} e^{j\frac{2\pi f}{c}z} \sum_{m=1}^M \phi_{m,f} e^{-j\frac{4\pi f}{c}\hat{\mathbf{z}} \cdot \bar{\mathbf{r}}_m} \quad (1)$$

where $|z|$ is the spreading factor, ϕ_m is the frequency dependent magnitude of the scatterer, and r_m is the distance to the m th scattering center from the zero phase reference.

Assuming a given polarization and a normalized field, the GTD/UTD-based dispersive scattering center (DSC) model is given by [10]

$$E(f) = \sum_{m=1}^M A_m \left(j \frac{f}{f_c} \right)^{\alpha_m} e^{-j \frac{4\pi f}{c} r_m} \quad (2)$$

Although one also estimates the complex magnitude, A_m , the parameters of interest for object recognition are the type parameter, α_m , and the range parameter, r_m . The range parameter gives the location of the scatterer, and the type parameter describes the frequency response of the scatterer. The type parameter is an integer multiple of $1/2$ as given by GTD/UTD. A listing of type parameters and their associated scattering geometries is provided in Table 1.

Table 1. Type Parameters and Their Associated Scattering Geometries [10]

Value of α	Example Scattering Geometries
1	flat plate specular; dihedral
1/2	singularly curved surface
0	pt. scatter; doubly curved surface; straight edge specular
-1/2	edge diffraction
-1	corner diffraction
less than -1	multi-bounce; unresolved or combined mechanisms

The advantage of the GTD/UTD-based DSC model is that certain types of scattering (i.e. dihedral, curved edge, straight edge, point scatterer, etc.) will display a continuous change in magnitude with change in frequency. Therefore, as was stated before, one can essentially model an object as a sum of independent scattering geometries. From Equation 2, the magnitude of scatterer m_0 is proportional to $(jf/f_c)^\alpha$ where f_c is the center frequency of the "chirped" radar pulse. Therefore, the frequency response of each scatterer determines the scattering geometry.

III. PROOF OF CONCEPT

An example fifth-order scatterer estimation for an aircraft at 5 degrees azimuth and 0 degrees elevation is provided in Table 2. For this feature extraction example, a fifth order DSC model has ten parameters of interest, a type and range parameter for each scattering center estimated. These ten parameters may be described by nine features. Only four, not five, distance features are needed to provide four shift-invariant features, the distance of each

of the four other scatterers from the first scatterer. These four distance features are used because, in general, the first scatterer is the most stable scattering center in the radar return. This stability is derived from the absence of intermediate and late-time returns consisting of multi-bounce and shadowed scatterers which are more aspect dependent and unpredictable. Notice, however, that with these four values, a linear combination of two of them can derive the distance between any two scatterers. Due to the simplicity of this linear combination, all distances between scatterers are readily accessed by a neural net if any should prove useful for class discrimination.

Table 2. DSC Model Estimation Results and Corresponding Features Extracted

α_n	r_n	geometry feature	distance feature
-0.5	-0.1308	-0.5	-
-1	-0.0460	-1	0.0848
-1	-0.0012	-1	0.1296
0.5	0.0447	0.5	0.1755
-0.5	0.1050	-0.5	0.2358

It is obvious that a model order of five will not capture all of the scattering centers in as complex an object as an aircraft, where dozens of localized scatterers of various geometries could certainly be predicted and perhaps modeled. However, if the largest five scatterers estimated do not completely model aircraft, they may still sufficiently represent the object class for this data set. This principle is very important in object recognition. Simply stated, the criteria is not that scattering is precisely modeled, but rather, that the features are

1. reasonably stable across all samples of one class and
2. discriminatory between samples of different classes.

To demonstrate the viability of feature extraction based on the DSC model's range and type parameters, a typical object classification experiment was performed. The experimental data contained 1204 direct range measurements of four model aircraft of similar size and shape at 0 degrees elevation and from 0 to 30 degrees azimuth. After implementing DSC model feature extraction on this data, a fully-connected, two-layer neural net obtained over 98% classification accuracy. Furthermore, DSC model feature extraction gave an approximate 85% reduction in the number of features required to characterize objects compared to the numerous range bin magnitudes used in template matching approaches. As expected, this feature efficiency greatly reduces computer memory and processing time over the template-based approach. In addition, template formation usually ignores the phase information contained in the phase history of the radar measurement. Conversely, DSC modeling takes full advantage of the phase information.

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