Interaction Notes

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16 February 1994

Target Signatures and Pattern Recognition

Carl E. Baum
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Abstract

Pattern recognition is a well established set of techniques for categorizing objects by data features. In the context of radar target identification one can use parameters in electromagnetic scattering models and sets of same (signatures) for such features. This leads to a target-identification scheme in which a target in all its aspects to a radar is treated as a pattern class where a pattern is a set of data features.

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I. Introduction

A recent paper [2] considers the use of target signatures for target identification. Signatures are sets of parameters in electromagnetic-scattering models appropriate to various target features (geometrical shapes including constitutive parameters) of both local and global varieties. Some parameters (e.g., natural frequencies) are independent of the aspect (orientation) of the target with respect to the radar antennas. Other parameters are aspect dependent.

Noting that on a deeper level the scattering models are based on symmetries in the target features and the Maxwell equations, one can construct signature-based signal-processing algorithms which incorporate these symmetries is some sense. Combined with possible modification of the transmitted waveforms to enhance the signature information in the scattering data, the signal processing can improve the clutter and noise rejection so as to obtain more accurate signatures.

Having the signatures one next goes to the target library which contains the signatures organized by target type (particular model of aircraft, etc.). Comparing the signatures obtained with those in the library one can attempt to identify the target, assuming that the type being observed is in the library and that the signatures of the various targets are significantly different (disjoint) so as to allow a unique identification. Note that no measured signature is perfectly accurate due to noise and clutter.

This comparison of measured signatures to the target library can be viewed as a pattern-recognition problem. Electromagnetic scattering theory and pattern recognition are different disciplines each with its own respective terminology. So in this paper the appropriate electromagnetic terms and concepts are organized into a pattern-recognition format.

II. Target Identification Viewed as Pattern Recognition

Pattern recognition (or categorization) has some concepts and definitions which are rather abstract and can be applied to a variety of physical problems [3, 4]. This begins with a *feature* (or data feature) which is just a number. It could be some time sample in a transient waveform, or a number obtained after some manipulation of this waveform (e.g., a frequency). Note that this data comes in some way from an *object*, the thing to be recognized.

Defining a data feature as some number x_n, one can take a set of these as a vector (x_n) with an arbitrary number N of components. This vector is called by various names, including *pattern*, *pattern vector*, and *feature vector*. This pattern can be a member of a set of patterns known as a *pattern space*, an N dimensional hyperspace containing all possible patterns. A *pattern class* is a set of patterns in the pattern space having some common attributes. Such might apply to the patterns from an object viewed different ways, or to sufficiently similar objects. A basic idea is to assign a pattern to a particular class in some algorithmic way.

Pattern recognition is then the assignment of measured patterns to particular objects. A simple case is the *membership roster* when there is only one object for each of the patterns observed. However, noise in the pattern complicates this. There is also a *pattern cluster* in the event that pattern classes are sufficiently disjoint in the pattern space to effect recognition. A pattern class can also have a *common property*, perhaps certain features x_n common to the entire class, again noting the complication of noise.

Table 2.1 shows a way that the pattern recognition terms can be translated into electromagnetic terms associated with *signature-based target identification* [2]. The key idea here is the association of *pattern class* with *target aspect set*. This is associated with the fact that while we have some target type (e.g., an MD-11), its *manifestation* in a radar sense is in general *aspect dependent*. Nevertheless one would like to associate manifestations of this target type for all aspects with this one target type.

Our identification problem is then one of determining to which pattern class a particular pattern belongs. If the pattern classes cluster sufficiently well that they do not intersect, and the measured pattern belongs to one of these, then the target identification is accomplished. Of course noise means that the measured pattern will not exactly correspond to the patterns in the library (and so not be a member of a roster), but can be associated with a cluster based on some measure of proximity to the cluster.

Very conveniently, some of our electromagnetic signatures and associated parameters are aspect independent (e.g., natural frequencies). Considering these as a subset of the complete signature set of a target type, this subset is a common property. This follows from the association of pattern class with all aspects of a target type.

Note that the data features can be real (e.g., times), complex (e.g., natural frequencies s_α), vector (e.g., spatial orientations), and dyadic (e.g., 2 x 2 scattering-dyadic coefficients). In pattern-recognition parlance a feature is taken as a real number x_n. It is, however, natural to take electromagnetic parameters in several forms: scalars, vectors and dyadics (real and complex). This is not an essential difficulty since one can break up vectors and dyadics into scalar components which, if complex, can be represented by two real numbers. Nevertheless, it may be convenient to generalize the concept of feature to include these other mathematical entities due to their physical significance and the associated conceptual simplification. A pattern or signature set is then a set of various kinds of elements which can be organized in various ways (e.g., supervectors and supermatrices [1]).

Pattern Recognition	Electromagnetics
object	target (or scatterer) type for one aspect
feature (data feature): a number (real)	parameter: real, complex, vector, dyadic
pattern (pattern vector, feature vector): features as elements	signature set: all signatures for a given target (one aspect) – Signature is itself a parameter set.
pattern class	target aspect set (class): set of signatures including variation over incidence (4π) and polarization (2π) for a particular target type
pattern space (pattern hyperspace)	domain of all signature sets in target library
membership roster	library of targets with non-intersecting aspect sets
pattern cluster: a pattern class with members close together in pattern space	domain of variation of aspect-dependent signature(s) for one target type
common property (in a pattern class)	aspect-independent signatures

Table 2.1. Correlation of Electromagnetic and Pattern-Recognition Terminology (Rosetta stone, tablet 1).

III. Signature-Based Target-Identification Radar as a Pattern Classifier

Now to put the concepts in a broader perspective, consider the pattern recognition concepts as part of a pattern classification system. As exhibited in Table 3.1 the three parts of such a system [3] plus the object to be recognized can be correlated with parts of a signature-based target-identifying radar system plus the target to be identified. This latter form is a reorganized *target-identification concatenation* from [2].

The concept of *feature extractor* from pattern recognition is a key one. Here we understand that features are not necessarily the raw data itself (e.g., time-domain samples of some physical quantity), but can be something more subtle in the data obtained through various mathematical manipulations. Noting that a feature vector is a pattern, then signatures are the patterns of interest here. We need to manipulate the data to obtain signatures, and a feature extractor which does this is a *signature-based signal processor*. As discussed in [2] the development of such signal processing utilizing the symmetries inherent in various types of signatures is of great importance in target identification. Some has been done but much more is needed.

The *classifier* is the *target identifier* which selects a target type from the library by matching the measured signature(s) (pattern vector) to those stored. This process can be aided by additional information. Such information such as aspect and velocity may be available from other measurements, for example, from a tracking radar. This can reduce the region of pattern space to be searched.

Pattern-Classification System	Target-identifying Radar System
object	target: Viewed as set of target features (physical) for some particular aspect.
transducer: Senses and records data from the object.	radar system: Includes transmitter, interrogating waveforms, scattered waveforms, receiver, and recorder.
feature extractor: Processes the data by measuring certain features or properties that distinguish one object from another.	signature-based signal processor: Signatures (parameter sets from models) are the things of interest in the data.
classifier: Takes features and decides which object is observed.	target identifier (discriminator, categorizer, classifier): Selects one target type (and perhaps the target aspect also) from the target library.

Table 3.1. Radar as a Pattern Classifier (Rosetta stone, tablet 2)

IV. Concluding Remarks

While the type of target-identification/pattern-recognition technique discussed here has some interesting advantages, it is not the only one of interest. In some applications target images can be constructed through sufficient high-frequency/fast-transient data for multiple aspects (e.g., SAR/ISAR). In such cases it is the images which are to be associated with target types. Perhaps yet other concepts in target identification will emerge.

With the signature-based target-identification scheme cast into a pattern-recognition format, one can now apply the various pattern classification techniques [3, 4] to the target identification problem. Much is yet to be done.

References

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