Radar NCTR Using Non-Radar Referents

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Abstract

Radar recognition of non-cooperative targets using simple non-radar data has been tested using a dataset of high-quality high-resolution profiles from five fighter aircraft. This paper summarises the techniques used and gives a qualitative account of the capabilities and limitations of the technique.

Keywords: Radar, Non-cooperative Target Recognition (NCTR), Backscatter Model

Introduction

This paper gives a qualitative account of findings on the use of simple non-radar referents (drawings, photographs and scale models) to achieve recognition of aircraft from high-resolution range profiles (HRRPs) measured by radar.

The most effective way of classifying aircraft using HRRPs is to make intensive radar measurements of all aircraft of interest, then use this database to train classifiers. Gathering all the required measurements is a tremendous undertaking, hence the search for alternatives.

The background to the current work has been described in [1]-[3]. This paper gives only an outline of recent findings.

Scattering Centre Models

Models of radar backscatter from aircraft may be represented as the sum of returns from a number of discrete scattering centres [3]; an example of such a model for a fighter aircraft is shown in Figure 1. These models give only the *location* of backscatter, not its *magnitude*.

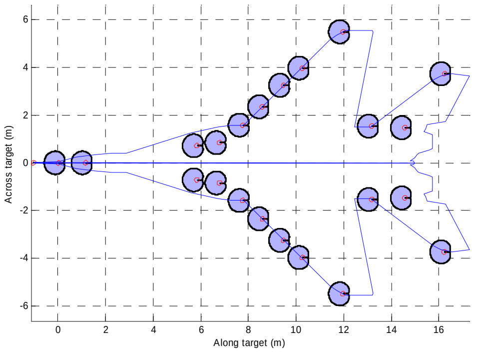

Figure 1 *A scattering centre model*

Classification Experiments

Statistical experiments have been undertaken both to quantify the performance of SCM-based classifiers and to compare these with conventional techniques. These experiments have been performed using data consisting of high-quality HRRPs of five different fighter aircraft. The nature of this data is militarily sensitive so that only a qualitative outline of the findings of the work will be given here.

In all cases, the core algorithm used is the nearest-neighbour algorithm [4]. This algorithm operates by considering profiles to be vectors in a high-dimensional space and by comparing them to reference vectors, which we refer to as templates. A *profile* is classified according to which *template* it lies closest to. To compare conventional and SCM-based classifiers, three types of classifier have been considered which differ in the way templates are derived.

Full Template These are derived from measured profiles, i.e. profiles obtained from a radar, and include both the magnitude and location of backscatter. Use of such templates is comparable to conventional classification using prior radar measurements.

Binary Template These are also derived from measured profiles but the backscatter magnitude is removed by applying a threshold to hard-limit the data; thus, only the location of backscatter is given. Use of these templates gives an indication of the best performance that may be expected from SCMs.

SCM-Derived Template These are obtained from SCMs, not radar measurements. SCMs give only the location of high backscatter, so the templates are binary vectors.

Binary and SCM-derived templates are binary vectors and are therefore compared with binary versions of the original profiles. Such transformed profiles are obtained by applying a sequence of point transformations to the profile, e.g.

$$p = |p|^2;\ p = p/\max(p);$$
$$p = 10\log_{10}(p);\ p = (p > \theta)$$

Similar transformations are applied to reference profiles to obtain templates. Full templates are compared with real-valued transformations of the original profiles.

Algorithms

As stated previously, the core algorithm used for classification is the nearest-neighbour algorithm. This is widely-recognised as a highly effective algorithm for conventional classification of aircraft profiles.

To classify profiles, there are two distinct phases - (i) align profiles with templates, and (ii) compare profiles with templates. The binary nature of SCM-based classification has greatest impact on the alignment phase. In conventional classification, alignment is most commonly achieved by minimising the cross-correlation between profile and templates. However, cross-correlation produces poor results when applied to binary templates/profiles because there are frequently several alignments which minimise cross-correlation so the alignment is ambiguous. Hence, in the experiments described above, alignment has been achieved by aligning the first prominent return, i.e. the first ‘one’ in a binary vector. For example, when a significant return is obtained from the aircraft nose, this leads to the nose of the aircraft being aligned with the first return predicted by the template. This method of alignment has proved to be highly satisfactory for the high-quality profiles used here; however, it does imply that binary-based classifiers are likely to be less tolerant of factors such as low signal-to-noise ratio and the presence of range sidelobes.

Once alignment has been achieved, profiles and templates are compared using the city-block metric:

$$d(p,q) = \sum_j |p_j - q_j|$$

When used with full templates, performance using this metric is similar to that obtained using the more conventional Euclidean metric. When applied to binary classifiers, the city-block metric becomes the Hadamard metric, which has the simple interpretation of giving the number of elements which are different in the binary vectors being compared.

Classification Results

Two groups of classification experiments have been performed - those involving 3 targets and those involving 5 targets. The principal results of the experiments are as follows.

For 3 targets, all three classifier types (full-template, binary template SCM-derived template) perform similarly over a range of aspect angles from 0° to 40° from the nose. Performance using only a single profile to assign class is satisfactory in all cases.

For 5 targets, the 2 additional targets have profiles which are sufficiently similar as to be confused by all three classifier types. However, while the full-template classifier is able to distinguish these from the 3 original targets, both the binary-template and SCM-derived template classifiers confuse them with one of the 3 originals. From this, it is concluded that conventional, full-template classification is capable of greater discrimination than that using binary templates/profiles. Further experiments show that binary/SCM-based classifiers can satisfactorily classify aircraft within a *class* consisting of several individual *types*, e.g. labelling the aircraft types 1-5, the full classifier can distinguish amongst classes {1}, {2}, {3} and {4,5}, whereas binary/SCM classifiers can distinguish amongst classes {2}, {3} and {1,4,5}.

The above experiments perform classification using only a single profile; further experiments show that error rates can be decreased substantially by using a small number of profiles, e.g. 8. An effective way of using several profiles is to classify using a single profile, then take a majority vote over several results.

Conclusions

General

1/ Useful models of radar backscatter from aircraft may be constructed using non-radar data such as engineering drawings, photographs and commercially available scale models.

2/ The models of radar backscatter that can be inferred from non-radar data do not accurately identify individual scattering centres but they do enable major scattering regions on the aircraft to be identified.

Limits of Classification Performance

1/ Results using profiles from 3 fighter aircraft have shown that scattering centre models can achieve satisfactory classification rates.

2/ This performance can be achieved using one scattering centre model for each aircraft over a range of azimuth aspect angles exceeding 0-40°.

3/ Results using profiles from 5 fighter aircraft have shown that sufficient similarity exists amongst profiles from some types of aircraft that individual types of aircraft cannot be distinguished using scattering centre models.

4/ Results using profiles from 5 fighter aircraft show that, if similar aircraft are combined into classes, satisfactory classification rates can be achieved.

5/ Within-class classification accuracy can be improved significantly by using a small number of range profiles rather than just a single profile.

Comparison with Conventional Techniques

Conventional classification techniques using measured radar profiles are able to take advantage of backscatter amplitudes, not just positions, which enables a greater discrimination amongst aircraft types. A considerable degree of discrimination can nonetheless be obtained using binary profiles.

Required Algorithms

1/ Because SCMs give information only on the positions of scattering centres, not their amplitudes, amplitude information in the profiles to be classified must be discarded prior to comparison with SCM-derived templates. Hence, thresholds are applied to profiles to reduce them to binary-valued vectors.

2/ The binary nature of profiles and templates has most affect on the alignment process. Alignment using cross-correlation is commonly used in conventional classification. This does not work with SCM-derived templates. The alignment techniques used throughout the current study is to align the first significant return in the profile and template.

3/ Classification is performed by comparison of binary templates and profiles using a city-block metric with a nearest-neighbour classifier.

Non-Radar Data Requirements

1/ An engineering drawing giving a plan view of an aircraft is required to construct a planar scattering centre model.

2/ Positions of obvious structural scattering centres, e.g. junction of wing and fuselage, may be estimated from the plan.

3/ Photographs available from the Web may be used to identify some features, such as weapon mounts and sensor housings which may give rise to additional scattering centres.

4/ Scale models of the aircraft are most useful in identifying trapping regions which may be responsible for high backscatter. For example, several of the aircraft examined in the current study have channels between air-intake housings and the fuselage which may act as trapping regions.

Miscellaneous

Methods based on the use of scattering centre models are expected to be intolerant to poor quality signatures, e.g. high range sidelobes, low SNR. (It is also expected that conventional techniques using different reference and classification radars and those using EM predictions from CAD models would be similarly intolerant.) SCMs cannot accurately predict sidelobe structure and sidelobes may disrupt the alignment process required by SCM-based techniques.

References

[1] R. Miller, D. Shephard, M. Newman, “Aspects of NCTR for Near-Future Radar”, NATO RTO Proceedings, Symposium on Target Identification and Recognition, Oslo, Norway, October 2004.

[2] R. Miller, C. Sarno, D. Shephard, “Progress in Radar Recognition of Aircraft Without Using Radar-Derived Databases”, EMRS DTC Conf. Proc., May 2004.

[3] R. Miller, C. Wyllie, D. Shephard, “Advances in Radar NCTR Using Non-Radar Referents”, EMRS DTC Conf. Proc., June 2005.

[4] R. O. Duda, P. E. Hart, D. G. Stork, “Pattern Classification, Second Edition”, Wiley-Interscience, 2001.

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