Radar Target Classification Using Multiple Perspectives

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Abstract

Three multi-perspective classifiers have been developed in order to investigate possible improvements in radar target classification when a number of target backscattered imageries collected from a multiplicity of views of the targets are available. That means collecting information from different orientations of the object. Classification results on a set of three vehicles raw data are presented for different classifiers, showing valuable accuracy improvements with different SNR levels.

Keywords: ATR, ISAR, polarimetry, feature extraction, multiple perspectives

Introduction

Radar target classification is a crucial task for both military and civil applications. Because of the currently accuracy and quality increase of available radar target signatures in terms of spatial resolution, classification performance has noticeably improved. Nonetheless, recognition ambiguities due to range profile variability still remain. This is mainly due to a number of factors that could cause range profiles changeability although the system parameters and the target orientation remain the same (*measurement noise*, *rotational* and *translational range migration*). Other sources that might return signatures that are difficult to be recognised accurately are *speckle* and *shadowing phenomena*. A possible solution to improve Automated Target Recognition (ATR) is employing a network of radars and exploiting the perspective differentiation of backscattered information collected by each node. The resulting decision is made on the basis of the processed multi-perspective signature. Furthermore, as described in [1], the possible use of both monostatic and bistatic modes of operation might provide a valuable counter to stealth technology.

In this paper, a brief description of the data used is followed by the multi-perspective implementation of three different one-dimensional classifiers. Their performances on a population of three classes of objects are then discussed. Improvement in accuracies is shown with respect to the different Signal-to-Noise Ratios (SNR) of signatures and the number of perspectives used. Since Zero-Doppler Clutter (ZDC) affects turntable ISAR data, one-dimensional and two-dimensional feature extraction are briefly described as the next stage of the project.

High–Resolution Imageries

HRR range profiles and ISAR images are well known methods to express backscattered information from radar targets [2]. In Figure 1, a sequence of high-resolution range profiles from four trihedral corner reflectors is shown as a function of rotating angle. Two moving corner reflectors rotate on a turntable over 360 degrees while two stationary corners are placed in front and behind the turntable with respect to the radar system. The non-moving trihedrals show a constant response as can be observed at near and far ranges.

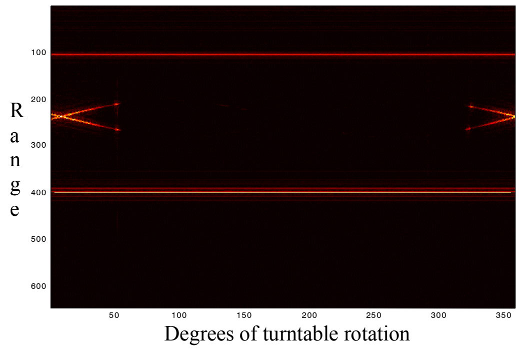

Figure 1: high-resolution range profiles from two rotating and two stationary corner reflectors.

Examining the history of range profiles for the rotating corner reflectors, the magnitude of reflected radiation varies as a function of the orientation angle of the object. When the line-of-sight is on the reflector bisector plane (i.e. looking along the axis of the trihedral), a flash of reflected radiation occurs. As expected from theory [3], as the reflector rotates, a small RCS decrease can be seen in the main lobe region, then it quickly drops until a second peak appears before the signal goes to zero. This is due to the specular reflection of one of the sides that make up the reflector. Then the target disappears until its orientation is such that it faces the radar beam again. This angular dependency of the backscattering of trihedrals or corner reflectors highlights how real target signatures may vary. Such reflectors are common on many manmade structures and multiple perspectives can help to characterize them. Furthermore, a multi-perspective environment could overcome shadowing effects due to the singularity of observation and, therefore, reconstruct more precisely those features from signatures that are useful in terms of classification.

To achieve high range resolution the Stepped-Frequency Compression technique has been applied [4]. The effect is to increase in overall bandwidth while instantaneous bandwidth requirement is reduced. In order to produce high-resolution signatures, a wideband reconstruction of the target reflectivity function is processed. As demonstrated by [2], by applying a two-dimensional FFT to a sequence of frequency domain reflectivity functions, the Doppler image of rotating targets can be formed with a cross-range resolution relying on the equivalent synthesized aperture. In order to avoid range bin migration of scatterering centres and subsequently blurring in the final image, it is necessary to process data collected from small arcs of circular aperture. After processing a number of partial images, they are rotated by the corresponding coverage angle and eventually superimposed. This method is known as Multi-Look Image Processing. In Figure 2, partial images of 4.25 degrees aperture, achieving ~20cm in cross range resolution, are rotated and superimposed covering 360 degrees of rotation of the target. As a result of 8 chirps of 500MHz stepped in frequency for half their bandwidth, the total band synthesized is 2.25GHz and the slant range resolution ~8cm after hamming windowing.

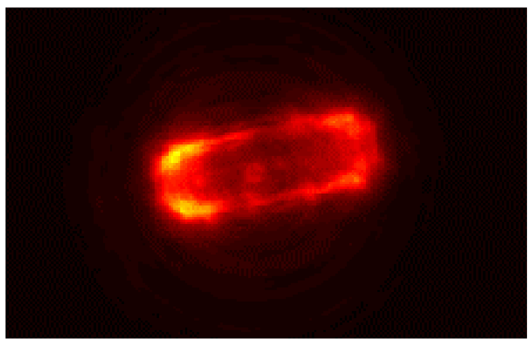

Figure 2: 360 degrees Multi-Look span image from a vehicle target (20cm x 8cm).

Unambiguous and complete images could generally be obtainable from turntable experiments where the target is rotated for 360 degrees. Conversely, in a typical radar target recognition problem, partial images processed from few degrees of rotation of objects are achievable. Multi-Look image reconstruction may be successfully implemented in a multi-perspective context: each node of the network of radars produces its ISAR image and, by knowing their angular displacement, they coherently contribute to the potentially enhanced final image formation for two-dimensional classification purposes. However, alignment and scaling problems could cause difficulties in the multi-perspective reflectivity reconstruction of a target in real world situations. Nevertheless, a network of radars is also capable collecting more accurate information about location and orientation of the object than a single-view scenario. Although best recognition performances are obtainable by two-dimensional image classifiers [5], the first stage of the problem concentrates on range profiles classification because of the simplicity of the system and algorithm implementation and faster signal processing.

Multiple Perspectives and Polarimetry

Since the set of data used is fully polarimetric, H and V polarisations are available as well as their co-polar and cross-polar signatures. By (non coherently) superimposing the four possible combinations, the span image of the target can be formed [6]:

$$span = |HH|^2 + \frac{|HV|^2 + |VH|^2}{2} + |VV|^2 \qquad (1)$$

The result is to emphasize scattering behaviours more than using a single polarisation. Furthermore, as the image is the composition of four signatures, less speckle is sensed. Many different approaches (*Pauli, Sphere/Diplane/Helix,* etc.) for the polarimetric target decomposition can be implemented in order to separate different scattering contributions and aid classification [7]. In a fully polarimetric multi-perspective environment, referring to figure 1, the odd bounce behaviour of a trihedral can be highlighted from a single perspective, but if a contribution from a 50 degrees displaced perspective from the peak is available, the odd bounce information can be integrated by the knowledge that the point is not present in the signature anymore. As a conclusion, the scatterer could be a trihedral or an occluded part of the target. In both cases it is evident how it may be valuable in terms of classification.

One-Dimensional Multi-Perspective Classification

In this paper we concentrate on the particular situation in which a single non-cooperative target has been previously detected and tracked by the system. Pre-processing raw data is necessary in order to increase the quality of the radar signatures: the target region is isolated and made more prominent thanks to the noise level subtraction from the rest of the range profile.

Principal discriminating factors for classification purposes are Range Resolution, Side-Lobe Level (SLL) and Noise Level. Higher resolution means better point scatterers separation but the question of compromise regarding how much resolution is needed for good cost-recognition is difficult to resolve. Generally, high SLLs means clearer range profiles but this also implies deterioration in resolution. Eventually, a low noise level means high quality range profiles for classification.

Real ISAR turntable data have been used to produce HRR range profiles and images. Three vehicles classified as *A*, *B* and *C* constitute the sub-population problem. Each class is described by a set of range profiles covering a 360 degrees rotation of the turntable. After noise normalisation, a 24.7 dB SNR is achieved. Single chirp returns are compressed giving 30 cm range resolution. The grazing angle of the radar is

8 degrees and 2" of turntable rotation is the angular interval between two consecutive range profiles. Therefore, ~10000 range profiles are extracted from each data file over the complete rotation of 360 degrees. The training set of representative vectors for each class is made by 18 range profiles, taken approximately every 20 degrees for rotation of the target. The testing set of each class consists of the remaining range profiles excluding the templates.

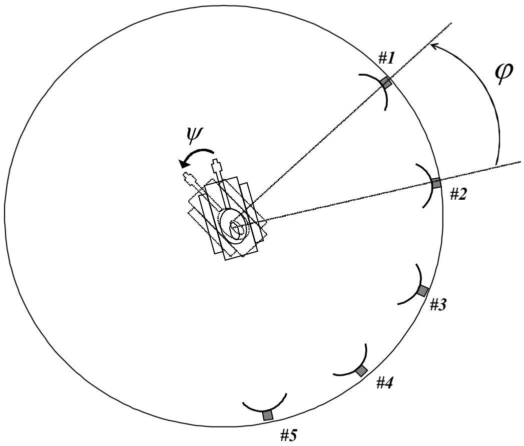

Figure 3: Multi-perspective environment deduced from ISAR geometry.

Three algorithms have been implemented in both single and multi-perspective environments. In this way any bias introduced by a single algorithm should be removed. The first is the statistical Naïve Bayesian Classifier. It reduces the decision-making problem to simple calculations of feature probabilities. It is based on the Bayes' theorem and calculates the posterior probability of classes conditioned on the given unknown feature vector [8]. Then, a rule-based method for classification has been implemented, the *K*-Nearest Neighbors (*K*-NN) algorithm. The rule consists of measuring and minimising the number of *K* distances from the object to the elements of the training set. The last approach involves Artificial Neural Networks (ANN), where the information contained in the training samples is used to set internal parameters of the network. In this work, Feed-forward ANNs (FANNs) supervised by a back-propagation strategy have been investigated and implemented.

Figure 3 represents a possible approximation of the multi-perspective scenario: each node of the network is assumed as having a fixed position as the target rotates by an angle ψ. The perspective angle φ is the angular displacement between the line-of-sights of two consecutive radars. From each of the radar positions either a series of range profiles can be generated as inputs to a one-dimensional classifier or they can be processed into an ISAR image that can be input to a two-dimensional classifier. In this way it is possible to perform classification using multiple perspectives.

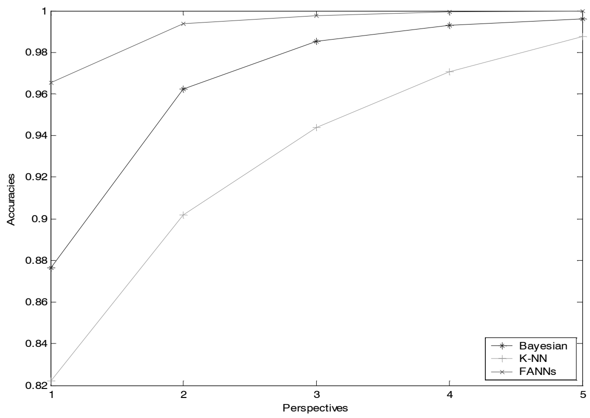

Figure 4: Multi-perspective environment deduced from ISAR geometry.

In Figure 4, the classification performances of the implemented classifiers are plotted versus the number of perspectives used by the network. Because of the nature of the data and the small available number of targets, the classifiers present a high level of performance when using only a single aspect angle. Improved performance is achieved increasing the number of radars in the network but the greatest improvement in performance can be appreciated with a small number of radars. Since the number of perspectives, and therefore the number of radars, is strictly related to complexity, costs and time burden of the network, in terms of classification purposes, it may be a reasonable trade-off to implement networks involving a small number of nodes.

However, this analysis is against a small number of target classes and these conclusions require further verification.

Multiple Perspectives and SNR

The extent to which SNR affects classification and whether multi-perspective scenarios are effective at different SNR levels are now examined. The FANNs classifier has been used for this particular task. The range profiles I and Q components are corrupted with additive white Gaussian noise. The original data, after noise removal, has a 24.7 dB SNR. Subsequently, the classifier is tested with range profiles with 19.7, 17.7 and 15 dB SNR.

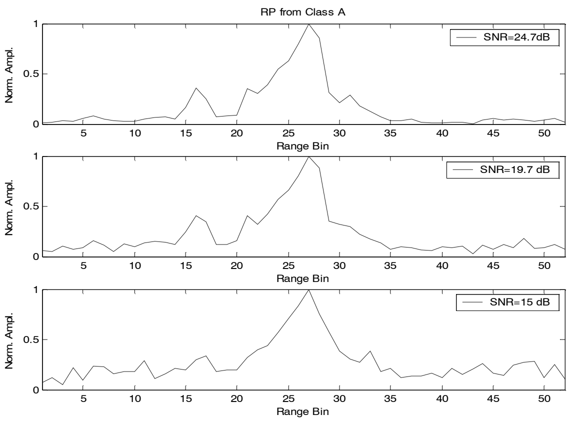

Figure 5: different SNR levels of the same range profile.

In Figure 5, three different SNR levels of the same range profile from class *A* are represented. From the particular orientation, the length of the object is 6.2 metres (it falls into about 20 range bins). As the SNR decreases, some of the useful features become less distinct, making the range profile more difficult to be classified.

In Figure 6 performance is plotted versus the number of perspectives used and SNR levels, showing how the enhancement in classification varies with different noise levels. The graph illustrates an increase in classification performance with numbers of perspectives in each case, particularly valuable for lowest SNR levels.

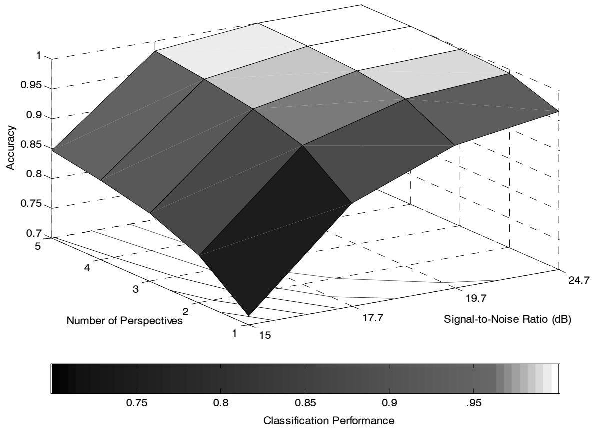

Figure 6: FANNs classifier accuracies for different SNR levels and netted radars.

However, below an SNR of 15 dB the performance quickly degrades indicating that classifiers will be upset by relatively small amounts of noise.

1D and 2D Feature Extraction

ISAR turntable data are usually affected by stationary clutter. ZDC decorrelates with different velocities as the target rotates on the turntable, depending upon the variableness of the clutter. For example, mounds of gravel show high time correlation between range profiles while grass is characterized by fast decorrelation over relative small turntable rotation angles as well as multiple-bounce returns from the clutter to the rotating target and vice versa. Trees and ground discontinuity are other possible sources of ZDC. Since classification is often made on lower level scatterers, ZDC may influence the recognition process. For this reason ZDC estimation and subtraction has been performed in frequency domain [9].

Feature extraction is a method for further reducing unwanted contributions from scatterers not belonging to the target of interest. 1D and 2D feature extraction algorithms have been chosen from time signatures because of their immediate significance and correspondence to the geometry of the target. From range profiles, the peaks location, value and width together with geometrical moments are extracted and first results on these features show a reduction of classification accuracy depending on the number of features selected.

From ISAR images, log-spiral transform from the outline of target [10] has been performed and 2D classification using multiple perspectives is planned. Shape based recognition implies a discharge of information related to the scatterers distributed inside the contour formed by the three-dimensional surface of the target and the ISAR projection plane. On the other hand, such classification might be less sensitive to a number of variable features belonging to the same class of targets that often cause misclassification.

Conclusion and Future Work

Using different perspectives has showed improvements in classification performances. In addition, the increase in recognition accuracy is not linear with the number of perspectives used. Greater positive variations can be seen for small numbers of nodes employed in the network. Furthermore, the results obtained at lower SNR levels show valuable improvements in target recognition for more practical classification purposes. Whilst encouraging, these conclusions should be treated with some caution as they are somewhat limited by the restricted available data and by their nature.

Feature based classification is planned from both 1D and 2D signatures as well as classification using multiple perspectives characterized by different angular displacements. Furthermore, by back-projecting features extracted from different perspectives it may be also possible to reconstruct composite signatures from partial information.

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