Feature Extraction using Attributed Scattering Center Models for Model-Based Automatic Target Recognition

Randy Moses and Lee Potter*
Department of Electrical Engineering
The Ohio State University
2015 Neil Avenue
Columbus, OH 43210
E-MAIL: {randy,potter}@ee.eng.ohio-state.edu
HOMEPAGE: http://er4www.eng.ohio-state.edu/ips/research/Projects/darpa/dapra.html

Abstract

This report summarizes our research plans and direction for the above-named DARPA IU program. The program begins in March 1997. We discuss the research objectives, the research questions to be considered, and our performance evaluation process.

1 Objectives

Our program is aimed at developing improved feature extraction for application in feature-based automatic target recognition (ATR) systems. Our focus is on synthetic aperture radar (SAR) ATR, although our methods also apply to non-SAR radar ATR, such as high range resolution radar ATR.

Our primary research objectives are:

1. **Develop and validate physically-based models for scattering that can be used for model-based ATR.** Our work is aimed at developing attributed scattering center models for radar scattering. These models are founded on electromagnetic scattering theory (uniform theory of diffraction and physical optics). We base our models on scattering theory to ensure that the derived models are physically meaningful.

   Our approach is to distill from these electromagnetic scattering theories models that balance between fidelity and simplicity. The electromagnetic theories contain much more detail of scattering behavior than is practical for ATR applications. Our goal is to obtain simplified approximations that contain few enough parameters to be reliably estimated from measured data. To do so, we build on our past successes as described, for example, in [Potter and Moses, 1997].

2. **Develop practical feature estimation algorithms.** The aim is to derive estimation algorithms that can be implemented in SAR ATR systems. Such algorithms should be computationally practical, should determine model order autonomously, and should be "hands off" algorithms, requiring little or no hand-tuning by the user.

   Our effort will be focused on developing algorithms that estimate model parameters from complex-valued SAR imagery in the image domain. This is in contrast to many existing parameter estimation methods that operate on SAR phase history data. Image domain processing is more practical, because existing ATR systems operate on SAR image "chips" that have been prescreened by front-end processing.

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In addition, we will consider model order detection and image segmentation algorithms needed for feature extraction. Finally, computational speed of the algorithms is of importance; we will aim to develop algorithms with good statistical properties while minimizing computation.

3. **Measure efficacy of these features for improvements to SAR ATR performance.** The goal is to quantify the ATR performance improvement afforded by our new models and estimation algorithms. We will quantify improvement first by determining the uncertainty of the estimated features. Feature uncertainty is needed in Bayesean evidence accrual used for scoring of candidate target hypotheses to the measured target data. We will consider algorithm-independent bounds, such as the Cramér-Rao bound, as well as algorithm-dependent performance. In addition, we will quantify ATR detection performance performance using the feature estimates in conjunction with feature-based match scoring.

The research program builds on past ATR work funded by a DARPA University Research Initiative. Our current technical approach is based on this past work, as summarized in [Potter and Moses, 1997, Ying, 1996, Chiang, 1996].

Our program is of value to battlefield awareness because we improve SAR ATR performance in the following ways:

1. **Richer feature set for ATR:** Our physically-relevant models characterize scattering using multiple attributes for each scattering center; this gives an increased level of target discriminability, which improves ATR performance. Richer features are especially important in extended operating conditions, when fewer target scattering centers are observable.

2. **Decreased feature uncertainty:** Because our models are physically based, we are able to exploit prior information in the feature extraction stage to improve resolution. We can thus achieve sub-pixel accuracy and superresolution of target scattering phenomena. The smaller the feature uncertainty, the more discriminable are targets, and ATR performance improves.

3. **Improved match scoring metrics:** We will develop match scoring rules that are tailored to the feature extraction algorithms we develop. By characterizing feature uncertainty and coding this uncertainty in a match score, we will further increase target discriminability.

The above performance improvements have application in feature-based ATR systems, such as MSTAR. We are closely following the MSTAR program, and are tailoring the research program to facilitate insertion of our developed technology into MSTAR.

2 Research Questions

In order to achieve the above research objectives, the following specific research questions will be addressed:

1. **Determine a set of model primitives that balance between modeling fidelity and estimation accuracy.** As we mentioned, electromagnetic scattering models are often too detailed to be of practical use for ATR; we will distill from this theory models that contain a few parameters which can be accurately estimated, and which at the same time describe scattering behavior in sufficient detail to effectively discriminate between targets.

   We will characterize achievable estimation accuracy as a function of system parameters, such as bandwidth, center frequency, and signal-t-clutter ratio.

   During the February MSATR interaction meeting, discussions with researchers for the MSTAR Predict module suggest that our proposed model primitive set can be predicted by the MSTAR Predict module. This will facilitate transfer of our research to MSTAR program.

2. **Develop fast, automated computation for complex SAR image-domain processing.** We will develop image domain algorithms because nearly all SAR ATR processing streams operate on image chips. We will develop model order detection methods that are effective for SAR scattering features, to reduce sensitivity of performance on model order. We will develop "hands-off" algorithms that minimize or eliminate user tuning. We will develop algorithms that minimize computational cost while maintaining good statistical feature accuracy.

3. **Implement stand-alone match scoring to evaluate target discriminability and feature estimation tradeoffs.** We will develop a geometric hashing-based algorithm for match scoring. The purpose is twofold: i) to consider feature extraction and feature match scoring in a tight loop to exploit synergy for improved ATR, and ii) to quantitatively evaluate feature extraction performance at the system level as target detection probabilities. While geometric hashing is effective for scattering center locations, a research question is how to extend the procedure for other scattering attributes.

4. **Assess the potential for ATR improvement via superresolution of attributed scattering centers.** Some initial results in superresolution on SAR imagery by Lincoln Labs and ERIM suggest that enhanced resolution improves target discriminability and hence improves ATR performance. Superresolution is an active question of interest in the MSTAR program, to name one. Our attributed scattering center features naturally offer superresolution, both in sub-pixel accuracy of estimated scattering centers, and in ability to extract two (or more) scattering centers within the same resolution "bin". We will explore the gain in performance afforded by superresolution in our attributed scattering center models.

3 Performance Evaluation Process

Our research program includes a plan for quantitatively measuring performance. Below we summarize this plan for the major research goals.

- **Model validation:** The goal is to quantify fidelity of attributed scattering center models. We will use target scattering predictions and measurements from MSTAR of geometric primitive data. We will compare percent energy in our extracted model with original target energy, and also compare detection performance of scattering types for these models.

- **Estimation accuracy:** The goal is to quantify estimation accuracy for feature extraction. We will first use scattering prediction models (MSTAR, XPatch) and measurements of geometric primitives. We will corrupt these data with noise and apply our feature extraction methods. We determine mean and covariance of estimation errors and ROC curves for scattering center detection versus false alarm as SNR varies. We will compare these values with our theoretical predictions of feature uncertainty. We will then validate performance on MSTAR public release SAR imagery. Finally, we will obtain quantitative target classification performance (detection performance ROC curves; confusion matrices) from MSTAR public release imagery when used in conjunction with our match scoring metric.

  A goal of this program is to port our feature extraction algorithms to Khoros modules for use in other programs; thus, another measure of progress is completion of modules.

- **Superresolution:** The goal is to quantify ATR performance improvement afforded by superresolution. We will quantify subpixel accuracy of scattering center location estimates as above. We will also quantify classification performance at the output of our match scoring metric. Using a combination of scattering prediction models at higher resolution and high-resolution measurements as "ground truth", we can quantify attainable sub-pixel accuracy by applying feature extraction on reduced-resolution data.

4 References

References

[Potter and Moses, 1997] Lee C. Potter and Randolph L. Moses. Attributed scattering centers for SAR ATR. *IEEE Transactions on Image Processing*, 6(1):79–91, January 1997.

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