Parametric Models for Signature Prediction and Feature Extraction

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Abstract **—** This paper compares and contrasts numerical electromagnetic (EM) prediction methods and parametric scattering models for radar signature prediction and feature extraction.

Index Terms **—** Attributed scattering centers, radar cross section, radar feature extraction, scattering prediction.

I. INTRODUCTION

Both radar model validation and target recognition applications require accurate, and preferably fast, signature prediction methods, as illustrated in Fig. 1. Prediction methods are nonparametric (e.g., numerical electromagnetic prediction codes) and parametric (e.g., attributed scattering centers). Choice of method should be based on the trade space between model accuracy and computational efficiency. Computational efficiency includes not only the ability to quickly compute the prediction model (the forward problem) but also the complexity and feasibility to extract signatures from measured data (the inverse problem). Numerical electromagnetic (EM) prediction methods are geared toward the forward problem, while parametric models (PMs) have been developed with the inverse problem in mind. The complexity-accuracy trade space for each model type is qualitatively depicted in Fig. 2.

II. SIGNATURE PREDICTION

EM numerical prediction techniques include method of moments (MoM), differential techniques, integral equation solvers, shooting and bouncing rays (SBR) geometric/physical optics (GO/PO), and many other methods, discussed in [1-5]. Computation time varies with the electrical size of the target and is extended by the time it takes to draw/import and facetize/mesh a target model. A method to speed up the EM part of SBR is given in [6], and [7] provides a technique to extend single frequency computations over a band of frequencies. An attempt to speed the drawing portion is provided in [2], which converts a picture into a facet model. Alternatively, [2] lets users build simple targets by combining primitive shapes, which can be characterized by PMs.

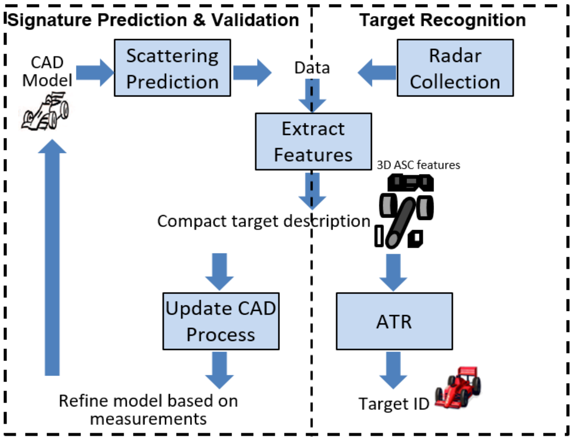

Fig. 1. Process flow diagram for signature prediction (forward problem) and signature extraction (inverse problem).

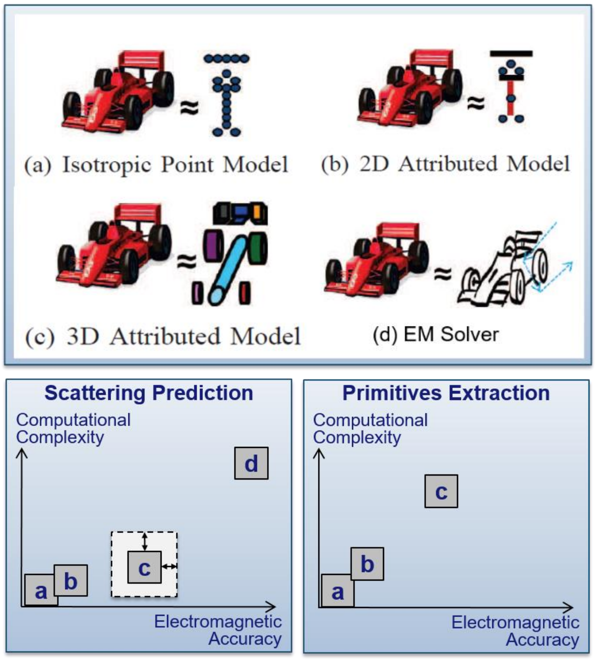

Fig. 2. Scattering models and notional complexity vs. accuracy trade space.

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PMs developed for signal processing tasks may also be used for signature prediction. The isotropic point model is characterized by scatterer position and radar cross section (RCS). The isotropic point model is a key assumption in radar imaging; however, realistic scatterer persistence is typically less than 20° [8]. The monostatic 2D attributed scattering center (ASC) model [9] is parameterized by frequency, polarization, aspect (along the length of the target), and length. Other monostatic models include the Huynen and Cameron decompositions that break monostatic polarization responses into primary forms [10-12]. Bistatic canonical shape models parameterized by type, size, and orientation capture 3D physical geometry and model frequency, polarization, and azimuth and elevation aspect dependence [13]. The canonical models are built from products of planar solutions for strip, dihedral, and circular scattering mechanisms [14], [15] to approximate the 3D solution. A full analytic 3D GO/PO solution for bistatic scattering from a dihedral is given in [16]. EM predictions, PMs, and measurements of a dihedral are compared in [17]; PMs took milliseconds to compute, while MoM took hours.

PMs are extremely fast because the equations are written analytically and do not need a numerical solver like EM methods. However, accuracy is limited by underlying GO/PO and planar assumptions; edge diffraction, traveling waves, etc. are not included. Also, the dihedral and trihedral models are defined only within the interior of the corner, though plate models could be combined to model the back sides. Furthermore, PMs do not capture interactions between scatterers. Thus, a major challenge for using PMs for prediction is how to break a complex target into scattering primitives. For example, constructing a vehicle's sides with plates neglects vehicle/ground interaction, which is better modeled with dihedrals.

III. SIGNATURE EXTRACTION

Numerical EM techniques are not suited to signature extraction since each iteration in an optimization would require update to the facet model and re-run of computationally expensive prediction code. However, as shown in Fig. 1, other feature extraction methods can be used along with model refinement and EM predictions for RCS signature validation.

Parametric methods were developed with signal estimation techniques and target recognition applications in mind. Parameters may be estimated from measured data, though estimation complexity increases with model complexity. Isotropic points may be estimated using the CLEAN algorithm [18], [19]. Two-dimensional ASCs may be estimated using Prony's method or matrix pencil method [9]. Canonical shape primitives are more difficult to extract since shape selection and parameter estimation are coupled; however, an initial iterative approach is given in [20]. Other approaches to parametric model extraction include Expectation-Maximization [21], sparse dictionary techniques [22-24], and ray-tracing methods [19], [25]. Limited data from practical radar flight paths complicates the classification and estimation problem, as illustrated in [26], since objects may look similar for a narrow-angle data slice.

IV. CONCLUSION

We have provided an overview of numerical EM prediction versus PMs. While PMs are limited to simple scattering mechanisms, they are fast and well-suited to signature extraction. Numerical EM codes enable high fidelity prediction of complex targets; however, it is not computationally feasible to use EM methods for signature extraction. Thus, one should choose a signature prediction method depending on the application.

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