URSI GASS 2020, Rome, Italy, 29 August - 5 September 2020

Scattering Modeling for Complex Radar Target based on Space Mapping Technique

Tianxu Yan, Dongying Li, and Wenxian Yu
Shanghai Key Laboratory of Intelligent Sensing and Recognition, Shanghai Jiao Tong University, Shanghai, China

Abstract

A methodology is designed for the construction of frequency domain scattering model for complex targets with small training parameter sets. The space mapping technique is applied to employ the prior information provided by the high-frequency asymptotic method to improve the modeling efficiency. A training scheme with iterative infilling training points is designed so that the generalization accuracy can be guaranteed. With the proposed method, only a small training size are needed to model the scattering response in frequency domain at different aspects. A numerical example with a complex radar target is used to validate the accuracy and efficiency of the proposed model.

1 Introduction

A modeling methodology with excellent accuracy and efficiency for complex target is important for various radar applications such as extraction of electromagnetic scattering signatures and scattering prediction. However, it is not an easy problem to balance the accuracy and computation complexity of the modeling process. The high-frequency asymptotic method such as shooting and bouncing rays(SBR) provides a very fast way to model the scattering process, but the accuracy is highly limited[1]. On the other hand, the full-wave electromagnetic computation or actual measurements achieves a high accuracy with a payment of tremendous time cost.

To this end, there are many research about the parameterized modeling of scattering response based on the geometrical theory of diffraction[2, 3, 4]. Most of the researches regard the scattering response as the superposition of the response from a series of isolated equivalent scattering centers. By introducing various dependencies on the aspect and the frequency, such kinds of methods try to improve the accuracy with a relatively low computational cost. For example, the *sinc* function and polynomial is employed to describe the aspect dependencies, and the power function is used to describe the frequency dependence with discrete exponents representing different kinds of canonical structures. With an appropriate scattering response data set, the parameters of these functions can be estimated so that the scattering model can be established. But the accuracy of such models is quite limited, because the realistic electromagnetic behavior is too complex to be depicted by the parametrical expressions.

The space mapping, as a surrogate-model based technique, is used to model the frequency-domain scattering response utilizing the efficiency of high-frequency asymptotic method and the accuracy of the full-wave method. [5, 6, 7, 8]. The results by high-frequency asymptotic method is regarded as the prior knowledge of the scattering response for the complex radar target, which can be obtained by a fast calculation. Then, a few training data generated by the full-wave results are employed to improve the accuracy based on the space mapping scheme. The proposed model will be established with a high accuracy but only using a small amount of training data.

The rest of the paper is organized as follow: Section 2 introduces the theory of the proposed scattering model, and the structure of the training scheme. Section 3 validates the proposed method with a numerical example of a complex target, and Section 4 concludes the paper.

2 Theory

For a given aspect angle, the frequency domain scattering response can be modeled by the space mapping technique. The space mapping is a surrogate-model based method combining an accurate fine model and a relatively fast coarse model. The fine model is a very accurate method but with a high cost, while the coarse model is cheap but the accuracy of it is limited. By constructing a mapping relationship between the fine model and coarse model, a surrogate model can be established based on the mapped coarse model. In general, only a few data of fine model is required to derive the mapping relationship. In this paper, the SBR is used as the coarse model, while the full-wave simulation is used as the fine model. Let X represents the parameter space of interest, e.g. a range of aspect angles and frequencies, for the proposed model, and a subset X_B including N_0 frequency points is used as the training set. $E^f(f)$ and $E^c(f)$ is the scattering response of fine model and coarse model, respectively. It should be noted that here the notation f means the fine model when it is placed at the superscript, otherwise, it means the frequency. The basic surrogate model based on space mapping technique can be formulated as:

$$\widetilde{E^s(f)} = a \cdot E^c(b \cdot f + c) \tag{1}$$

where the superscript s means the surrogate model, and (a,b,c) represents the linear mapping relationship over the frequency domain. The parameters of (a,b,c) can be calculated by optimizing the objective function as below:

$$(a,b,c) = arg \min_{a,b,c} \sum_{i=1}^{N_0} ||E^f(f_i) - a \cdot E^c(b \cdot f_i + c)|| \tag{2}$$

where f_i is the $i-th$ frequency samples in X_B. This process is usually regarded as parameter extraction in the space mapping theory. Then, a correction term is used to compensate the residue between the fine model and the basic surrogate model, e.g. the output space mapping. Thus, the overall input-output space mapping surrogate model can be formulated as:

$$E^s(f) = a \cdot E^c(b \cdot f + c) + \sum_{i=1}^{N_0} \lambda_i e^{(\frac{||f-f_i||}{\gamma})^2} \tag{3}$$

where $\boldsymbol{\lambda} = [\lambda_1 \; \lambda_2 \; .. \; \lambda_{N_0}]$ is the coefficient vector of the basis function and γ is a normalization factor. The coefficients can be calculated according to

$$\Phi \boldsymbol{\lambda} = F \tag{4}$$

where the $\Phi_{ij} = e^{(\frac{||f_i-f_j||}{\gamma})^2}$ and $F(i) = E^s(f_i) - \widetilde{E^s(f_i)}$. Thus, the $\boldsymbol{\lambda}$ can be obtained by $\boldsymbol{\lambda} = \Phi^{-1}F$ directly.

Obviously, the accuracy of the training process cannot be guaranteed when the amount of training sample is not enough. An algorithm is used to develop a model with guaranteed accuracy by infilling new training points iteratively which is depicted as Fig.1. With more training points, the accuracy of the model can be improved. A set of points which is different with the training set are chosen as the validation set. And the accuracy over the validation set are used to measure the generalization error of the proposed frequency-domain surrogate model. When the generation error is below a specified threshold, the iteration will be terminated. The iteration will also be terminated if the generation error can't be decreased further by adding new training points. Besides, a infilling strategy is designed to choose the location of added training points as depicted in Fig. 2. For each iteration, the infilling point is located near the validation point with the largest mismatch. After the establishment of the space-mapping surrogate model, the frequency-domain scattering response within the region of interest X can be generated easily.

3 Validation

The geometry of an unmanned aerial vehicle (UAV) is depicted in Fig.3. It is used as the radar target in the numerical example for validation. The size of the metallic target

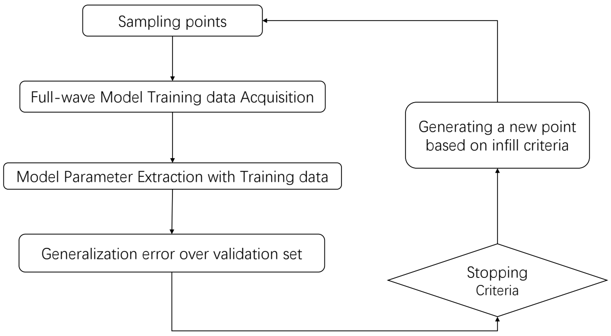

Figure 1. The training strategy for the proposed surrogate model based on space mapping in frequency domain

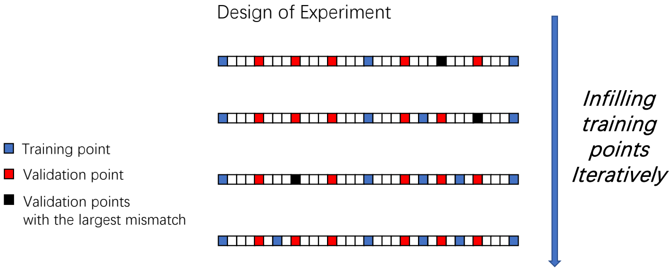

Figure 2. The sketch map of the iterative infilling criteria

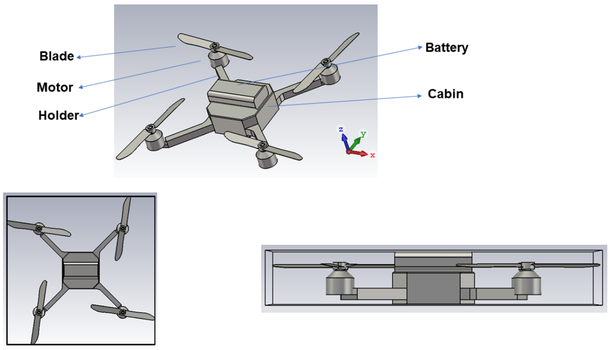

Figure 3. The solid model of complex radar target, the top is the perspective view, the bottom two figures are the top view and side view,respectively

is 42cm × 43cm × 17cm. The multilevel fast multipole algorithm(MLFMA) is employed as the full-wave simulation method. The monostatic scattering response at a distance of 1m is set as the model output. The modeling frequency range is set to be from 9GHz to 10GHz with a resolution of 20MHz.

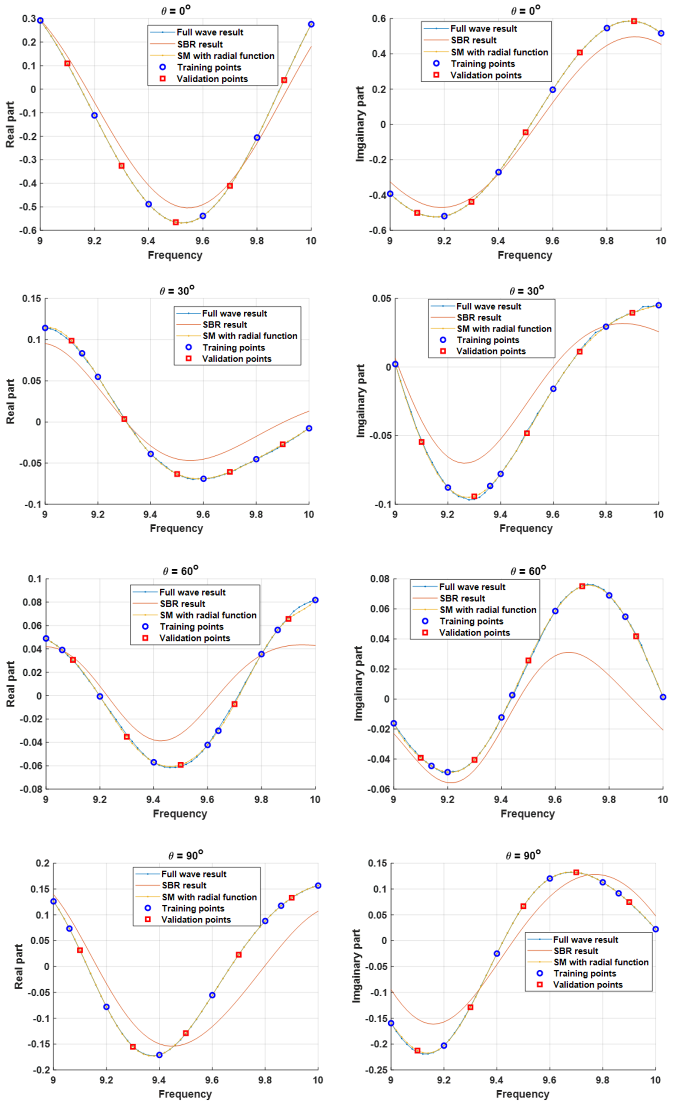

Figure 4. The real part and imaginary part of the proposed surrogate model based on space mapping in frequency domain at $\theta = 0^o$, $\theta = 30^o$, $\theta = 60^o$, and $\theta = 90^o$, respectively

By using the space mapping technique, we can model the scattering response at any specified aspect angle. Using the $\theta = 0^o, \theta = 30^o, \theta = 60^o, \theta = 90^o$ as examples, the results are presented in Fig.4, respectively. It can be observed that the proposed model achieve a very high accuracy by employing only about 7 or 8 training points.

4 Conclusions

By employing the space mapping technique, the prior information provided by the high-frequency asymptotic method is utilized properly to establish the proposed model in frequency domain with only a very limited set of training points by the full-wave method. With an iterative training scheme , the generalization accuracy can be guaranteed further. The accuracy and efficiency of the proposed method are validated by a numerical example of which the monostatic scattering response at serval aspects are modeled.

References

[1] H. Ling, R.-C. Chou, and S.-W. Lee, “Shooting and bouncing rays: Calculating the rcs of an arbitrarily shaped cavity,” *IEEE Transactions on Antennas and propagation*, vol. 37, no. 2, pp. 194–205, 1989.

[2] L. C. Potter, D.-M. Chiang, R. Carriere, and M. J. Gerry, “A gtd-based parametric model for radar scattering,” *IEEE Transactions on Antennas and Propagation*, vol. 43, no. 10, pp. 1058–1067, 1995.

[3] J. A. Jackson, B. D. Rigling, and R. L. Moses, “Canonical scattering feature models for 3d and bistatic sar,” *IEEE Transactions on Aerospace and Electronic Systems*, vol. 46, no. 2, pp. 525–541, 2010.

[4] H. Liu, B. Jiu, F. Li, and Y. Wang, “Attributed scattering center extraction algorithm based on sparse representation with dictionary refinement,” *IEEE Transactions on Antennas and Propagation*, vol. 65, no. 5, pp. 2604–2614, 2017.

[5] S. Koziel, Q. S. Cheng, and J. W. Bandler, “Space mapping,” *IEEE Microwave Magazine*, vol. 9, no. 6, pp. 105–122, 2008.

[6] S. Koziel and L. Leifsson, *Simulation-driven design by knowledge-based response correction techniques*. Springer, 2016.

[7] S. Koziel and J. W. Bandler, “Microwave device modeling using space-mapping and radial basis functions,” in *2007 IEEE/MTT-S International Microwave Symposium*. IEEE, 2007, pp. 799–802.

[8] J. E. Rayas-Sánchez, F. Lara-Rojo, and E. Martínez-Guerrero, “A linear inverse space-mapping (lism) algorithm to design linear and nonlinear rf and microwave circuits,” *IEEE transactions on microwave theory and techniques*, vol. 53, no. 3, pp. 960–968, 2005.