Procedia Computer Science
Volume 80, 2016, Pages 1051–1060
ICCS 2016. The International Conference on Computational Science

Expedited Dimension Scaling of Microwave and Antenna Structures Using Inverse Surrogates

Slawomir Koziel[1*], Adrian Bekasiewicz[1†] and Leifur Leifsson[2‡]
[1]*Reykjavik University, Iceland*
[2]*Iowa State University, Ames, Iowa, USA*
koziel@ru.is, bekasiewicz@ru.is, leifur@iastate.edu

Abstract
Re-designing circuits for various sets of performance specifications is an important problem in microwave and antenna engineering. Unfortunately, this is a difficult task that is normally realized as a separate design process, which is often as expensive (in computational terms) as obtaining the original design. In this work, we consider the application of inverse surrogate modeling for fast geometry scaling of microwave and antenna structures. Computational efficiency of the discussed procedure is ensured by representing the structure at the low-fidelity model level. The explicit relation between design specifications (here, operating frequency) of the structure and its geometry dimensions is determined based on a set of predetermined reference designs. Subsequently, the model is corrected to elevate the re-designed geometry to the high-fidelity electromagnetic (EM) model level. Our approach is demonstrated through a compact rat-race coupler and a patch antenna with enhanced bandwidth.

Keywords: Surrogate modeling, inverse modeling, geometry scaling, computer-aided design (CAD), simulation-driven design, microwave structures, antennas.

1 Introduction

Computer simulation models are the key tools utilized in modern microwave and antenna engineering (Qing and Chen, 2009). High-fidelity computational models yield accurate responses of the structure at hand, accounting for environmental effects (Bekasiewicz and Koziel, 2015a; Koziel and Bekasiewicz, 2014) and various second-order effects (Koziel and Yang, 2011) that may affect the performance. On the other hand, high-fidelity electromagnetic (EM) simulations are numerically expensive, which is a fundamental problem for automated design of microwave and antenna structures exploiting numerical optimization procedures. The reason is that conventional algorithms require hundreds or even thousands of objective function evaluations to converge to the optimal design.

[*] Engineering Optimization & Modeling Center, School of Science and Engineering
[†] Engineering Optimization & Modeling Center, School of Science and Engineering
[‡] Department of Aerospace Engineering, 2271 Howe Hall, Ames, IA 50011, USA

Selection and peer-review under responsibility of the Scientific Programme Committee of ICCS 2016

doi:10.1016/j.procs.2016.05.407

Therefore, automated determination of the optimal solutions may be computationally prohibitive for expensive models (Kuwahara, 2005; Chamaani, Abrishamian and Mirtaheri, 2010). This is the case for most conventional methods including both gradient-based algorithms with numerical derivatives (Nocedal and Wright, 2006), and derivative-free procedures (Conn, Scheinberg and Vincente, 2009) especially population-based global search algorithms. Consequently, in many areas, design techniques based on parameter sweeps guided by engineering insight (typically, one parameter at a time) are industrial standard. Although such an approach is very laborious, it may lead to satisfactory results, especially if the search is guided by engineering experience and problem-specific knowledge. Nevertheless, hands-on design approaches cannot provide truly optimum designs (Koziel and Bekasiewicz, 2015a).

Automated design of microwave and antenna components can be accelerated by means of adjoint sensitivities (Ghassemi, Bakr and Sangary, 2013; Nomura *et al*. 2013; Koziel and Bekasiewicz, 2015a) which allows for evaluation of the system response and its derivatives at a cost of single simulation (Koziel and Bekasiewicz, 2014; Koziel and Bekasiewicz, 2015a). Unfortunately, adjoint sensitivities are supported by only a few commercial EM solvers (CST, 2013; ANSYS, 2012). Another approach to achieving a design speedup is by using surrogate-based optimization (SBO) (Queipo *et al*. 2005; Bandler *et al*. 2004a; Koziel, Bekasiewicz and Kurgan, 2014), where direct optimization of the high-fidelity simulation model is replaced by an iterative procedure of correcting and re-optimizing a cheaper representation of the system of interest (a so-called surrogate model). The most efficient SBO techniques are those exploiting physics-based models (Bekasiewicz and Koziel, 2015a; Koziel, Bekasiewicz and Kurgan, 2014; Leifsson and Koziel, 2011; Leifsson *et al*., 2008), where the surrogate is constructed by appropriate enhancement/correction of an underlying low-fidelity model of the structure at hand, e.g., coarse-discretization EM model or equivalent network representation. The state-of-the art SBO methods include, among others, space mapping (SM) (Bandler et al. 2004a; Bandler et al. 2004b; Koziel, Bekasiewicz and Kurgan, 2014), various response correction approaches (Koziel, Leifsson and Ogurtsov, 2013; Koziel, Ogurtsov and Szczepanski, 2012), feature-based optimization techniques (Koziel and Bandler 2015), as well as—in microwave and antenna engineering—adaptively adjusted design specifications (Bekasiewicz and Koziel, 2015b).

An important problem in microwave and antenna engineering is to re-design a given structure for various sets of performance requirements. Typically, the structures are designed for a given operating frequency and their re-design for other frequencies is realized as a separate task the cost of which is just as high as getting the original design. Due to the high-cost of simulation-driven optimization, reusing the results obtained for a given set of requirements to accelerate the design for new specifications seems to be an attractive idea that may significantly speed up the design process. Frequency of the structure operation can be adjusted by means of scaling its dimensions (Koziel and Bekasiewicz, 2015b; Koziel, Bekasiewicz, and Leifsson, 2015). Unfortunately, the relationships between the operating frequency and the dimensions are nonlinear which makes the scaling process a nontrivial task.

In this paper, we utilize inverse surrogate modeling for rapid geometry scaling of microwave and antenna structures. The considered algorithm exploits low-fidelity model to optimize the design for several operating frequencies. Subsequently, an inverse surrogate model which establishes an explicit relationship between the operating frequency of the structure and its geometrical parameters is extracted. The model is then corrected to enable reliable scaling of the high-fidelity EM model. Our approach has been demonstrated using two examples: a compact folded microwave coupler, and a patch antenna with enhanced operational bandwidth.

2 Microwave Device Scaling Using Inverse Surrogates

In this section, formulate the dimension scaling problem and outline of the considered scaling procedure. Its main component is an inverse surrogate model describing the relations between the structure parameters and its operating frequency. We describe the surrogate model construction and