Optimization of Complex Microwave Systems with CORS RBF Network Backed by FDTD Analysis Data

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Abstract— With computer-aided design (CAD) and optimization of microwave (MW) systems being the subjects of considerable interest due to their potential of direct practical use, computational tools available for efficient optimal design still remain relatively limited. They are effectively restricted to certain classes of MW systems for which suitable physical or empirical models exist (and thus make space-mapping (SM) technologies [1] applicable) and to those structures whose electromagnetic (EM) analysis takes reasonably low CPU time. Optimization techniques based on the EM-simulated responses seem to be attractive for a very large group of MW systems whose complex physics is accessible for 3-D full-wave numerical analysis. However, direct optimal CAD of such devices may require a large number of design variables (and thus substantial amount of EM analyses) to be involved and hence be impractical.

This explains the motivation for the current trend of further cultivation of the SM-based optimization techniques, but also indicates that new avenues enhancing efficiency of methodologies backed by full-wave EM simulation are definitely worth further exploring. In our previous study [2], we have explicitly addressed, for the first time, the problem of reduction of the number of necessary simulations in FDTD-backed optimization: the introduced artificial neural network (ANN) algorithm featuring special mechanisms (e.g., the decomposed radial basis function (RBF) network, its dynamic training with adding a local minimum from each iteration to the database, etc.) has been shown to be capable of finding good local optimal solutions in specified domains with the use of relatively small data sets.

In this contribution, we outline two crucial revisions of the RBF network optimization algorithm [2] that result in dramatic improvement of its performance. Dealing with frequency responses of S-parameters of MW structures, we introduce a new objective function (OF) that measures the bandwidth of the respective characteristic over specified "optimality zones". Second, we principally advance the technique of dynamic training: when selecting additional sample points, we use, for the first time in electromagnetic optimization, constrained optimization response surfaces (CORS) technique [3] — a global optimization response surface type algorithm designed to minimize the number of function evaluations in the process of finding the global minimum. As earlier in [2], analysis data for this optimization algorithm are generated by the 3-D conformal FDTD simulator QuickWave-3D [4].

We compare the resulting technique with its predecessor [2] by monitoring the effects of the new OF and the CORS sampling. The CORS-RBF technique operating with the new OF appears to be responsible for getting optimal solutions of better "quality" (when the solution satisfying all the applied constraints does not exist in the specified domain) and a spectacular reduction of the number of EM analyses in comparison with the technique [2]. Performance of the CORS-RBF algorithm is illustrated by optimizing $|S_{11}|$ frequency responses of an inductively coupled waveguide band-pass filter, a microwave oven with a cylindrical load, and a dielectric resonator antenna. Their optimal designs are found from 5-parameter optimizations requiring only 167, 177, and 99 analyses, respectively, whereas the RBF technique [2] with both old (norm-based) and new (bandwidth-based) OFs and the CORS-RBF algorithm with the old OF are merely unable to find those optima with as many as 1000 analyses. These examples show that the reported algorithm substantially outperforms its predecessor [2].

It is important to note that the CORS-RBF technique and the new OF are independent of the source of data. That is, even though in the presented version the algorithm works with data of FDTD analyses, it will be fully operational working with data generated by other numerical techniques (MoM, FEM, etc.). Overall, the results of this paper clearly show a feasibility of further development of full-wave modeling-backed techniques and a great potential of the CORS-RBF algorithm as a practical CAD tool applicable to a wide array of complex MW systems.

REFERENCES

1. Koziel, S., J. W. Bandler, and K. Madsen, "A space mapping framework for engineering optimization: Theory and implementation," *IEEE Trans. Microwave Theory Tech.*, Vol. 54, No. 10, 3721–3730, 2007.

2. Murphy, E. K. and V. V. Yakovlev, "RBF network optimization of complex microwave systems represented by small FDTD modeling data sets," *IEEE Trans. Microwave Theory Tech.*, Vol. 54, No. 7, 3069–3083, 2006.
3. Regis, R. G. and C. A. Shoemaker, "Constrained global optimization of expensive black box functions using radial basis functions," *J. Global Optim.*, Vol. 31, No. 1, 153–171, 2005.
4. QuickWave-3D, QWED Sp. z o.o., Warsaw, Poland, 1998–2009. http//:www.qwed.com.pl/.