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Optimization in Electromagnetics with the Space-Mapping Technique

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The Space-Mapping (SM) [1] technique was introduced as an efficient design optimization tool for microwave circuits. The underlying idea however is quite general and applicable to a broader class of minimization problems.

Optimization procedures in practice are based on high accuracy models that typically have an excessive computational cost. Within SM terminology, these models are called *fine models* and we will denote them as $\mathbf{f}(\mathbf{x})$, $\mathbf{x} \in X$ being the design parameters. A finite element solution of Maxwell's equations is an example of a model of this type. SM needs a second and computationally cheaper model. This is called the *coarse model* and acts as a surrogate for the fine one. We will denote it as $\mathbf{c}(\mathbf{z})$, $\mathbf{z} \in Z$ being the design parameters. An equivalent electromagnetic circuit can for instance be used as a coarse model.

The SM method relies on the coarse model to speed up the fine model optimization. The key element in this technique is the *SM function* $\mathbf{p} : X \to Z$, also known as *parameter extraction*. Its purpose is to obtain a relation between the design parameters of the fine and coarse models. With this relation both models become as similar as possible by aligning their two responses: $\mathbf{f}(\mathbf{x}) \approx \mathbf{c}(\mathbf{p}(\mathbf{x}))$. The SM algorithms come in two usually equivalent brands. On one hand, the *original SM* minimizes the coarse model cost function and translates afterwards the result to the fine one via the SM function. On the other hand, the *dual SM* optimizes the mapped coarse model $\mathbf{c}(\mathbf{p}(\mathbf{x}))$. None of these two algorithms is consistent in the sense that the fine model optimal solution is always achieved. In order to do that, some other classical minimization methods must be combined with SM [2]. The SM technique can be then either used as a solver or as a preconditioner, depending on the desired accuracy.

In the first part of the talk, SM theory will be analyzed from the well understood Defect Correction (DC) [3] framework. DC uses the same multiscale principles that SM in order to solve an operator equation. This alternative perspective of SM explains its reported success in optimization tasks [1,4]. Moreover, DC suggests the multilevel SM generalization in a manner analogous to the multigrid philosophy. If a hierarchy of models with respect to computational cost and precision is available, the multilevel SM approach can be applied like full multigrid.

In the second part of the talk we will show results of SM applied to electromagnetic shape optimization. The first design problem is a C-shaped magnetic circuit in which a given flux density is desired in a certain region in space. In the second problem we optimize the force response in a linear actuator. For this actuator a hierarchy of models is available, allowing then the use of the multilevel SM approach. For both problems the fine model is a vector potential formulation discretized by finite elements. The results give evidence of the promising nature of the SM technique for optimization in electromagnetics.

References

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