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Optimal design of electromagnetic devices: Development of an efficient optimization tool based on smart mutation operations implemented in a genetic algorithm

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Abstract

Topology optimization methods are aimed to produce optimal design. These tools implement optimization algorithms that modify the distribution of some materials within a predefined design space without a priori ideas regarding the topology or the geometry of the best solution. In this paper, we study a specific tool that combines a genetic algorithm, a material distribution formalism based on Voronoi cells and a commercial FEM evaluation tool. In particular, this paper shows, through a simple but representative case study, that it is possible to improve the performance of the topology optimization tool during the local search phase, i.e. the geometrical and dimensional optimization phase for which the topology optimization methods are originally not well-suited.

Keywords: Optimization; Design; Topology; Genetic algorithm; Voronoi cells

1. Introduction

Today, optimization methods are becoming increasingly important in the design process of devices, whether electromagnetic or other [23,4,24]. These methods can help the designers in different ways in the design process. Actually, three approaches can be distinguished. Parametric optimization first, plays on the dimensional parameters of a solution whose geometry, and therefore topology, are defined a priori and once and for all the optimization process by the designer [5,19,1]. Geometric or shape optimization expands the space of possible solutions by changing the dimensions but also the geometry of a solution whose topology is defined by the designer [15,10]. Topology optimization finally, opens further the space of possible solutions by searching the best way to distribute given materials in a design space according to one or more objective functions [2,3,18,11]. The final solution is therefore free of any initial geometry or topology proposed by the designer.

Mostly topology optimization tools involve three coupled modules: an optimization algorithm, a material distribution formalism and an evaluation tool.

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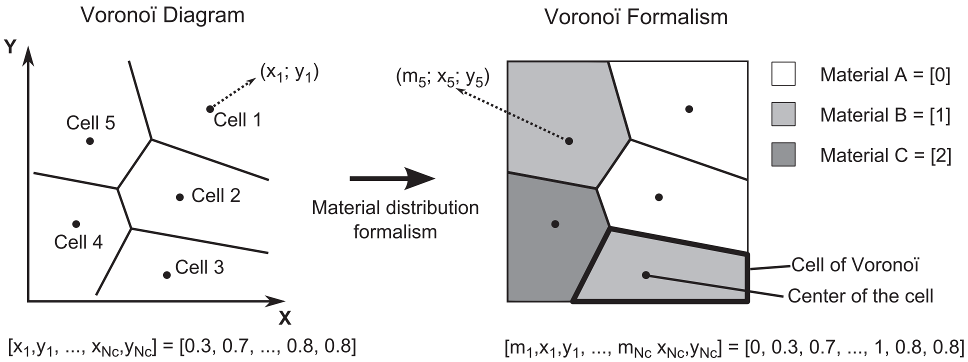

Fig. 1. Voronoi diagram and its equivalent material distribution formalism within a closed design space.

The optimization algorithm deals with the design parameters with the aim to maximize or minimize an objective function. These design parameters are used by the material distribution formalism. This module is necessary to link the set of design parameters and the graphical representation of the solution. Then, the graphical description is transferred to the evaluation tool. This last module plays two roles. The first consists in producing a numerical model of the solution described through the material distribution formalism and the design parameters, and in solving it. The second consists in computing the objective functions and the constraints.

Optimization algorithms are numerous. However, as the design problems treated by the topology optimization methods generally involve simultaneously a large number of design variables and nonlinear and nonconvex objective functions and constraints, the choice of the optimization algorithm as well as its implementation are decisive. The literature in the field of topology optimization shows that the optimization algorithms used are as well deterministic algorithms [2,16,17,13] as metaheuristic algorithms [21,7]. In the former case, the information of the gradient of the objective function is used to indicate the direction in which to change the design variables. Although offering a faster convergence, these methods handle difficult the nonconvex nature of the problems addressed [13]. In the second case, the stochastic nature of the algorithms avoids the trap of local minimum but at the cost of much slower convergence.

This paper focuses on metaheuristic algorithms and especially on genetic algorithms. Despite their ability to find the optimal topology, topology optimization tools using metaheuristic algorithms have some difficulties to converge both in terms of geometry and in terms of dimension. In order to obtain a final design, the user must therefore use additional tools, like geometric or parametric optimization tools, to optimize the solution with the topology found by the topology optimization tool [4]. To overcome this problem of convergence, some papers propose new operators for the optimization algorithm [6,12,14] or the material distribution formalism [22].

The aim of this paper is to present a study of new adapted mutations methods for the genetic algorithm coupled with the material distribution formalism, namely Voronoi diagram, in order to improve the performance of the topology optimization tool in the local search phase necessary to refine the geometry and the dimension of the final solution.

This paper is divided into four sections. Section 2 describes the reference topology optimization tool. Section 3 presents a study of new adapted mutation operators with a Voronoi formalism in order to improve local search step. The study case used as benchmark is described in Section 4. Finally, the results are exposed and analyzed in Section 5 while Section 6 is devoted to the conclusion.

2. Reference tool

This section describes the three modules composing the topology optimization tool used as reference. The tool is composed by a Voronoi diagram for the material distribution formalism, by a genetic algorithm for the optimization algorithm, and finally, by the software Matlab© coupled with the software Comsol© for the evaluation tool.

2.1. Material distribution formalism

The discretization of the design space is performed by a Voronoi diagram [20]. A Voronoi diagram (Fig. 1) is composed by a set of cells defined by a reference point, i.e. a Voronoi center. Let **C** the ensemble of Voronoi center