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TOPOLOGY OPTIMIZATION USING AN ENHANCED IMPLEMENTATION OF THE SPECTRAL LEVEL SET METHODOLOGY

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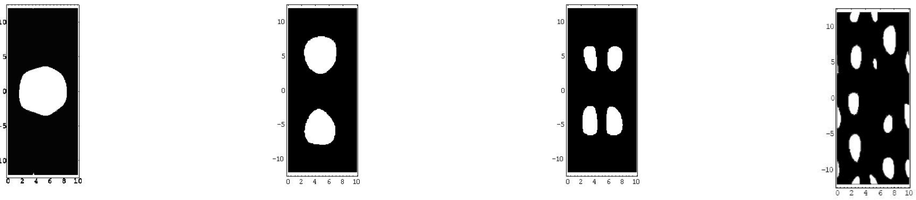
ABSTRACT

The spectral level set methodology is a tool to formulate topology optimization problems with the advantage of providing a reduction in the number of design variables under certain circumstances. Although the methodology has already produced excellent results in benchmark structural optimization, as well as in reinforced wing-box and morphing airfoil applications, it could greatly benefit from several improvements. The goal of this study is three-folded: first, it considers making the spectral level set methodology independent of parameter tuning; then, it considers the integration of volume constraints into the objective function evaluation; and finally, the emphasis is set on embedding the spectral level set methodology in a global optimization framework.

The problem in structural topology optimization is the determination of an optimal layout of material. The topological approach admits the structure is a set whose topology can be changed during the optimization process: breakages and merges of the set may occur and holes may appear or disappear.

Traditional approaches in topology optimization, such as the homogenization or the SIMP methods, [1], describe the structural set using a very large number of design variables, thus increasing the dimension of the design space and the difficulty in achieving a solution. The spectral level set methodology, based on the level set methods, avoids this drawback because it describes the set with a small number of design variables. In the framework of the level set methods, [2], the set boundary is an interface defined as the zero level set of a function. The nodal values of this function are the design variables of the optimization problem. During the search for the optimum, these variables evolve and so does the set.

The spectral level set methodology, [3], expands the function into a truncated Fourier series, and considers the Fourier coefficients as the new design variables. One advantage of the proposed methodology is to provide, asymptotically in the number of degrees of freedom and for a sufficiently regular boundary, a lower error bound than non-adaptive classical approaches. This implies that for a sufficiently smooth interface, the spectral level set methodology uses significantly less design variables (in some examples, 4% to 8%) than traditional techniques and the regular level set methods. This advantage suggests the possibility of accelerating the optimization process since the dimension of the design space has decreased. Other advantages of the spectral level set framework include the nucleation of new holes



(a) One hole. (b) Two holes. (c) Four holes. (d) Many holes

in the interior of the interface and the avoidance of checkerboard-like designs in comparison with the homogenization approach to topology optimization.

The spectral level set methodology has been validated with benchmark problems in structural topology optimization, [3]. However, the experience gathered so far has showed that to take full advantage of the reduction in the number of design variables we need to consider the following improvements: making the methodology independent of parameter tuning, including volume type of constraints in the evaluation of the objective function, and implementing the methodology in a global optimization setting.

To relieve the spectral level set methodology of parameter tuning and of the previous experience of the designer, our approach has been to incorporate relaxation parameters as design variables of the optimization problem. The volume type of constraints, which are very common in structural compliance minimization, are typically stated as follows: the structural volume should be less than or equal to a certain prescribed value. To carry out the embedding of the volume constraint in the objective function evaluation we have removed the Fourier coefficient corresponding to $k = 0$ from the set of design variables; after the optimization algorithm finds a new design point, a new value for the coefficient $k = 0$ is found, through bisection, such that the volume constraint is verified.

To evaluate the afore mentioned approaches we used COBYLA, a local optimization algorithm based on linear approximations by M.J.D. Powell. However, our tests were inconclusive since the algorithm was not able to get far from the closest local optimum. Therefore, we decided to postpone further testing of these two approaches until the methodology is implemented under a global optimization framework.

The implementation of the spectral level set methodology from a local to a global optimization algorithm has been accomplished and the first experiments are being carried out using a repulsive particle swarm algorithm. The optimization problem is simple: we wish to generate several holes over a ground domain with the largest possible radius given that the structural volume has to be greater than a given value. The initial solid volume fraction is one. The figure above shows the first results.

For topology optimization problems, the spectral level set methodology generally allows for a major reduction in the number of design variables. To take full advantage of this feature in the performance enhancement of optimization algorithms, we need to consider several improvements in the implementation of the methodology. This work focus on making the methodology independent of parameter tuning, on eliminating volume constraints from the problem statement by including them in the evaluation of the objective function, and finally, on implementing the methodology in a global optimization setting.

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