Sequential element rejection and admission method (SERA) for topology optimization using a constraint on perimeter

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This paper presents an implementation of the perimeter constraint for topology optimization of elastic structures using the Sequential Element Rejection and Admission Method (SERA). The perimeter constraint allows the designer to control the number of holes in the optimal design and to establish their characteristic length scale. This work shows an improved SERA methodology incorporating a strategy to efficiently control the optimization process satisfying a constraint on structural perimeter.

Topology optimization is a computational approach that optimizes material distribution within a fixed design domain and for a given set of loads and boundary conditions such that the resulting layout meets a prescribed set of the design requirements. It is an expanding research field of computational mechanics which has been growing very rapidly and has attracted the interest of numerous applied mathematicians and engineering designers, becoming extremely popular in the last years. Recently, additive manufacturing has opened the possibility to overcome limits currently imposed by conventional manufacturing techniques. In this sense, controlling the structural complexity for topology optimization problems has become an important investigation field since it affects the number and cost of the scaffold structures required by some of these manufacturing processes. It will be shown that the SERA method can be efficiently combined with the perimeter control method and it is capable of suppressing mesh dependency and control the number of holes and members of the final solution.

Since the landmark paper of Bendsoe and Kikuchi [1], where a so-called microstructure or homogenization based approach was used, numerical methods for topology optimization have been investigated extensively. At present the most popular topology optimization method is the SIMP method, which stands for “Solid Isotropic Material with Penalization”, proposed in the late eighties by Bendsoe [2]. A well known problem associated with topology optimization is that the optimal solution depends on the discretization level, as observed in many applications based on the finite element method. In order to ensure existence of solutions to the topology optimization problem, some sort of restriction on the resulting design must be introduced, combining the power law approach with, e.g., a perimeter constraint [3]. During last years Level Set Methods have emerged as an attractive and promising alternative to perform structural shape and topology optimization, inspired in the work on topological derivatives by Sokolowski and Zochowski and the paper by Sethian and Wiegman [4]. Apart from above mentioned approaches, a number of heuristic or intuition based approaches have effectively addressed a variety of size, shape and topology optimization problems. An important branch of these approaches for topology optimization is the evolutionary structural optimization approach (ESO) by Xie and Steven. The initial concept was that by systematically removing inefficient materials (elements with lowest strain energy density), the structure evolves towards an optimum. Its application in topology optimization of continuum media is quite extensive, see e.g., Xie and Steven [5]. Although initially solely based on intuition, this basic idea has developed from simple hard-kill strategies to more efficient soft-kill bi-directional schemes (BESO), which allow efficient materials to be added in addition to the inefficient ones being removed [6]. The newer BESO method has demonstrated its strength in solving a variety of topology optimization problems, but as it is presently defined, it uses a power law (SIMP) parametrization strategy and standard filtering techniques similar to those used in the density approach in order to stabilize results, so it could be categorized as a discrete update version of the standard SIMP scheme. Rozvany and Querin proposed some improvements of this method under the term SERA (Sequential Element Rejection and Admission) where a “virtual material” was introduced, without the use of any intermediate densities or power law interpolations [7]. Additionally, two separate criteria are

considered in the topology optimization process by SERA method, where the sensitivity numbers of real and virtual material present in the domain are sorted out separately. These ideas were developed for fully stressed design and extended to most of the classical problems in structural topology optimization and compliant mechanisms design [8,9].

The proposed perimeter control algorithm analyzes the effect on this constraint when an element is removed or added through the SERA optimization process, since it has different effects on the structural perimeter depending on its current connections with the neighboring elements. The classical algorithm based on a continuous approximation of the perimeter is substituted here by a discrete implementation of the algorithm, without the use of any intermediate densities or power law interpolations necessity. Preliminary results show the capability of SERA method in combination with perimeter control and are be demonstrated through different numerical examples. The following picture shows some preliminary results of the well known MBB beam problem when the SERA method is applied in combination with the perimeter control developed in this work.

Figure1 : MBB optimum topology with high and low perimeter constraints

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