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DISCRETE TOPOLOGY OPTIMIZATION OF PLANAR CABLE-TRUSS STRUCTURES BASED ON GENETIC ALGORITHMS

V. C. Finotto*, M. Valášek**

Abstract: *This paper demonstrates the application of Genetic Algorithms to design optimal lightweight Cable-Truss structures, which are structures composed by bars and prestressed cables and offer a high potential in robotics. The optimal lightweight structure shape is determined through a discrete topology optimization process which starts from a ground grid of nodes and interconnect them using cables or bars in order to obtain optimal results. The optimal solution is considered to have the lower mass and highest stiffness, such relation is expressed in the parameter stiffness-to-mass ratio. The objective function of the optimization problem evaluates the bending stiffness and the mass of the feasible solutions searching for the maximum stiffness-to-mass ratio. Symmetric structural response is desired once that in movable machines the majority of the structures are moving parts in which forces can assume different directions during working cycle, as a result the algorithm must find solutions with are symmetric in the axis perpendicular to the loading direction. Simulations are also presented showing comparisons between Cable-Truss and Truss structures under the same boundary conditions, population and iterations. Structural static response is computed using nonlinear finite element iterative procedure. Examples with optimized modular layout of a 2D robotic arm are shown, which presents improvement of Cable-Truss structures in comparison with Truss structures in all cases that have been simulated.*

Keywords: ***Cable-Truss structures, Genetic Algorithms, Discrete Topology Optimization, lightweight design.***

1. Introduction

Lightweight structures research is based not only in material science but also in structural mechanics, processing and design. Is important noting that the scientific aim is to develop knowledge for the specific phenomena occurring in these areas and in the interface between them, in order to achieve increased performance for a wide range of structural applications. In this work, lightweight structures are defined as those which shape is determined through an optimization process to efficiently carry the loads from a critical loading case regardless of the type of material employed.

In the research of lightweight structures, trusses have attracted tremendous interest due to their extensive application in the contracture of infrastructures and space structures. Research works have focused on material characteristics, truss joint design, processing and construction of structural components. However, in recent years, influence of cables in such structures has also been investigated. Structural systems which are composed by bars and pre-stressed cables are known as cable-truss structures, and its optimal lightweight design aims to obtain optimal mass reduction with minimal losses in stiffness.

In this sense, the objective of this work is to propose a methodology for topology optimization of cable-trusses. Differently than common approaches for discrete topology optimization, the proposed method uses a Genetic Algorithm to decide not only the optimal interconnection between nodes, but also if these interconnections are going to be performed by bars or cables. In addition, cable elements exhibit geometrically nonlinear behavior which demands nonlinear analysis as strains are small but displacements are large as a reason of high flexibility. As a result, nonlinear Finite Element method is used for computing static structural response.

* Ing. Vitor Cores Finotto: Faculty of Mechanical Engineering, Department of Mechanics, Biomechanics and Mechatronics, ČVUT in Prague, Technická 4, 166 29, Prague, Czech Republic, e-mail: VitorCores.Finotto@fs.cvut.cz

** Prof. Ing. Michael Valášek, DrSc. : Faculty of Mechanical Engineering, Department of Mechanics, Biomechanics and Mechatronics, ČVUT in Prague, Technická 4, 166 29, Prague, Czech Republic, e-mail: Michael.Valasek@fs.cvut.cz

2. Cable-truss Structures

Planar cable-truss structures having simple configurations and fewer members can be solved analytically; however for complex cable-truss systems numerical procedures are needed. The numerical model is based on the characteristics of structural members, which can be simulated as bar element (compression-tension) or cable element (tension-only).

3. Discrete Topology Optimization

The proposed discrete topology optimization method searches for the best interconnectivity between nodes, and also for the elements in each interconnection. For that, ground structure approach is used, in which all possible interconnections are performed based on an initial grid of nodes. By increasing the amount of nodes in the ground structure, the number of feasible solutions sharply increases since more structural elements are used for forming the cable-truss system. Moreover, the nodes from ground structure can be deactivated when they are not used; however, these nodes cannot be moved during the optimization process. To achieve more complex structures, modular design can be used decrease design parameters when modeling cable-trusses.

4. Genetic Algorithms

Genetic Algorithms (GAs) are adaptive methods which can be used for searching and optimization problems, performing a stochastic search and optimization. Compared to traditional optimization methods, such as calculus-based and enumerative strategies, GAs are robust, global, and may be applied generally without recourse to domain-specific heuristics. In spite of its benefits, troubles in convergence may happen during optimization of cable-truss structures since: a) the number of possible elements to interconnect to nodes increases the number of feasible solutions, b) cables cannot resist compression leading thus to a sharp increase in the number of kinematically instable structures during the stochastic search, and c) static structural response of the structure requires the use of iterative solution, which is computationally costly since inversion of the stiffness matrix must be performed several times.

5. Study Case

The design of optimal planar cable-trusses comprises the choice of several design parameters, such as, the ratio between cable and bar cross section areas, pre-stress, slenderness ratio of the structure, materials, among others. Discrete topology optimization was performed for a robotic arm which is approximated by a horizontal cantilever beam, an additional constraint was used for maintaining a minimum set of nodes which represents the structure. After obtaining the optimal topology, the structure is analyzed using different number of modules increasing the slenderness ratio.

6. Final Considerations

In this article, a methodology for topology optimization of cable-trusses was presented. By combining Genetic Algorithm and Nonlinear Finite Element Method optimized cable-trusses were found. Such structures where obtained for an initial module, which was then patterned in order to form more complex structures. Comparisons between optimized symmetric truss and cable-truss structures were performed for different number of modules. Results indicated that, in all cases, the stiffness-to-mass ratio of cable-trusses was higher than those obtained for trusses. Moreover, optimized symmetric cable-trusses have shown an average improvement of 8.9% when compared to optimized symmetric truss structures.

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