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Geometry optimization of trusses by Force Density Method

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This work concerns geometry optimization of truss structures. More specifically, our goal is to minimize the volume of a truss by adjusting the position of nodes (member joints) within a given design domain while assuming that: i) topology of the truss remains unchanged in the optimization process, ii) member forces are in static equilibrium with the external load, and iii) member stresses achieve the limit value in tension or compression.

Employing the idea of force density, that is a ratio of member force to member length, allows for reformulating the objective function and constraints as linear and quadratic polynomials in five indeterminates: three vectors of nodal coordinates and two vectors of force densities. Detailed explanation of the latter is dropped here, we only mention that introducing two (instead of one) force density vectors helps circumventing certain computational issues associated with volume minimization of fully stressed trusses.

Thus formulated, finite-dimensional variational problem is nonlinear and non-convex in general. Such shortcoming is usually associated with geometry optimization methods, and absent in algorithms using linear programming for topology optimization, where the location of nodes is fixed. This, in turn, means that numerical strategies for geometry optimization carry large computational cost, especially for trusses that are heavily populated with members and nodes. Consequently, our approach is not a practical choice in the numerical study aimed at predicting the layout of Michell structures.

On the other hand, however, limiting the scope of computations to structures with a relatively small number of design variables compensates (to some extent) for long CPU time. This makes the numerical strategy proposed in this study suitable for rational solutions, which can be easily transformed into manufacturable projects with clearly arranged members.

Geometry optimization methods are also useful in tackling the optimal form-finding problem, that is a design challenge of finding such a structural form, which optimally adjusts to the profile of the applied load. This goal is naturally achieved by relaxing the constraints on spatial location of loaded nodes, e.g. by allowing them to be positioned anywhere in a prescribed region instead of fixing them at given points.

The conference paper contains short theoretical introduction to the problem and discusses several optimal solutions in 2- and 3-dimensional design spaces.