Homogenization of an inflatable architectured material for free-form surface design

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Abstract

There has been growing interest in inflatable structures across fields such as civil engineering, soft robotics, and aerospace due to their lightweight nature and ease of deployment. In the present work, we propose an inflatable made of two identical quasi-inextensible layers welded flatwise with spatially varying regular patterns. The inflation of air chambers induces nonuniform auto-contraction in the plane (or metric change) which from the Gauss theorem makes the inflatable become a 3D shell. In order to reach a given target surface, we rely on quasi-conformal transformation of a non-structured coarse triangular mesh filled with specific welding patterns. The main challenge for designing such free-form inflatable shells comes from the programming of the metric change. By means of non-linear periodic homogenization, we are able to compute the isotropic metric change of a single triangular welding pattern after inflation. This allows us to build a mapping of achievable contraction ratio as a function of geometric parameters of the welding pattern. Then we solve the inverse fitting problem as follows. First, we built a 3D coarse mesh on the target surface which is flattened as a 2D mesh with a quasi-conformal transformation. Then, we compute the area shrinkage per triangle and find the welding pattern according to the mapping of achievable contraction ratios. This approach already allows us to fit a rather wide spectrum of doubly curved surfaces. Nevertheless, as our mesh is non-structured, we are able to introduce cone singularities in the flat mesh. This opens an even wider design space. Our methodology is validated against full-scale simulations and fabricated models, demonstrating the strong applicability of our inflatable architectured material.

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