Numerical optimization of periodic inflatable materials

Master-level internship (research), could be extended to a PhD

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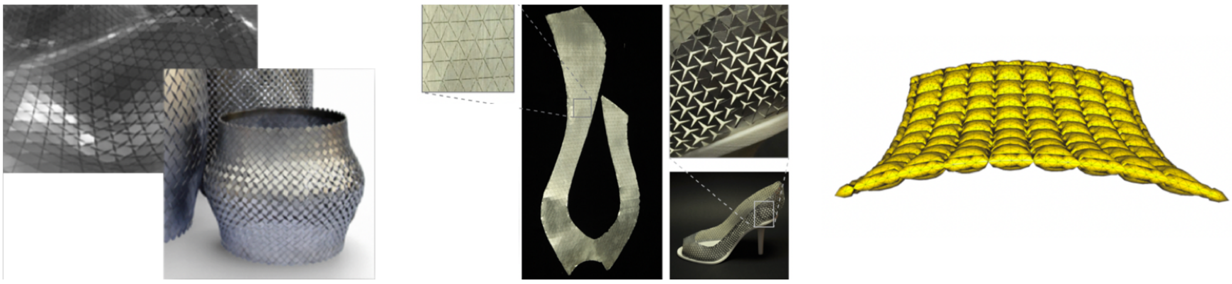

Figure 1: Left: Artwork by Haresh Lalvani. Middle: Computationaly designed doubly curved surface made of an initially planar cut metallic sheet [1]. Right: Simulation of a periodic inflatable material.

Context

According to a fundamental result from differential geometry (Gauss's Theorema Egregium), surfaces undergoing non-uniform metric changes become 3D. This property has been exploited by artists and researchers to design doubly curved 3D surfaces out of paper or metal (see Figure 1). Here, the basic idea is to tile quasi-periodic patterns on an initially planar surface whose contraction or expansion can be locally controlled by design so as to program a given 3D surface when the structure is stretched.

In the context of the ANR project MatAIRialS, we are exploring the use of inflatable"meta-materials" made of two planar membranes sealed according to a given pattern, regularly repeated to form a (quasi) periodic padding. Depending on the shape of the sealing pattern, the average contraction ratio of the padding can be locally programmed. One of our goals is to design parametric families of patterns that allow a wide range of contraction ratios. Tiling these patterns and adequately choosing their parameters will then allow us to locally modulate the metric change of the surface and in turn to control its inflated shape.

Objectives

The primary objective of this internship is to develop an algorithm to numerically optimize the shape of a sealing pattern so as to obtain a prescrived behavior (e.g. minimize/maximize the average contraction ratio of a periodic inflatable pad). This can be casted as a non-linear minimization problem subject to non-linear constraints (the static equilibrium of the system under pressure forces). We will then build the mapping between sealing pattern parameters and change of metric so that the family can be used for inverse design of a target 3D shape.

To compute the shape of the inflatables, we will use an in-house C++ simulator tailored to the simulation of such structures that has been extended to handle boundary conditions associated to periodic tilings. This simulator relies on a finite element method and a convexified membrane model that can robustly handle the large deformations and buckling of the membrane [2] .

This internship will give you the opportunity to learn about discrete differential geometry, non linear mechanics and numerical methods for simulation and inverse design.

If successful, this master's thesis is expected to be extended to a PhD thesis as part of the ANR project MatAIRialS.

Work environment and requirements

This internship will take place at Inria Grenoble – Rhône-Alpes and will be supervised by Mélina Skouras (melina.skouras@inria.fr, `http://imagine.inrialpes.fr/people/mskouras/index.htm`).

The candidate should have strong programming and mathematical skills, and ideally knowledge in computer graphics (geometry, physics-based simulation) and numerical optimization.

References

[1] Mina Konaković, Keenan Crane, Bailin Deng, Sofien Bouaziz, Daniel Piker, and Mark Pauly. Beyond developable: Computational design and fabrication with auxetic materials. *ACM Trans. Graph.*, 35(4), jul 2016.

[2] Mélina Skouras, Bernhard Thomaszewski, Peter Kaufmann, Akash Garg, Bernd Bickel, Eitan Grinspun, and Markus Gross. Designing inflatable structures. *ACM Trans. on Graphics*, 33(4), 2014.