

Programmable 3-D surfaces using origami tessellations

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Abstract

Origami-inspired engineering has enabled new designs and functionality by allowing sheets to transform into reversible sets of shapes with varying compliance [Hawkes et al. \(2010\)](#); [Silverberg et al. \(2015\)](#). To achieve 3-D shapes from 2-D fold patterns, origami designs use folds to create out-of-plane deformation. For many of these reconfigurable designs, each individual fold must be actuated during the course of transformation, making control and actuation complex.

In this work, we explore how origami tessellations [Evans et al. \(2015\)](#) can be composed to create reconfigurable surfaces with fewer and controllable degrees of freedom. In particular, origami tessellations have the ability to globally expand or contract. When combined with fixed boundary conditions, these in-plane strains cause out-of-plane buckling. Our work builds on our previous work [Pikul et al. \(2017\)](#) where we were able to program the 3-D shape of inflated elastomer sheets by controlling the radial strain with embedded non-woven fabrics. We demonstrated the diversity of shapes that we can achieve with artificial camouflage that could transform into rocks, a *graptoveria amethorum* plant, or a topographical map. However, this work relied on pre-fabricated elastomeric materials actuated by an external pressure source, making on-site reconfiguration difficult. In this work, we use compositions of origami tessellations that can be individually actuated to produce local expansion, allowing us to control curvature and reconfigure the resulting 3-D shape on the fly.

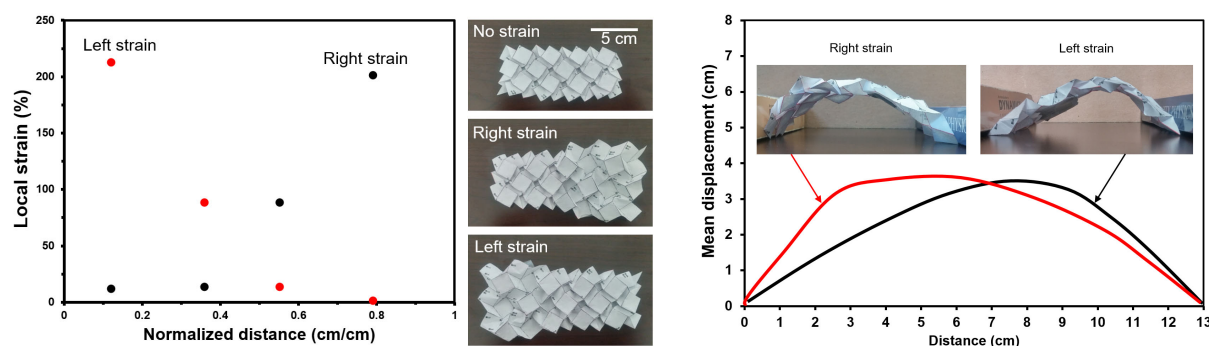


Figure 1: *Left:* Strain versus normalized distance for the square twist tessellation actuated on the left and right of center. The unactuated, left actuate, and right actuated origami patterns are shown on the right. *Right:* Displacement shape of the left and right actuated patterns when the ends are constrained to the original unactuated distance of 13 cm.

We leverage existing fold patterns such as the square twist for shape change. Since many of these tessellations are one degree-of-freedom, the resulting surfaces can be controlled with minimal actuation. Further, unlike pneumatically actuated surfaces that rely on the elasticity of the material to return to a flat configuration and can be slow, the dynamics of the origami pattern is dominated by the actuators themselves.

Figure 1 shows an example of this basic idea. In the fully folded state, the square twist tessellation is flat and exhibits no strain. As parts of the fold pattern are expanded, neighboring regions also expand due to the pattern's kinematics. The expansion decays and localizes the strain due to the material compliance. Fixing the two ends of the strip allows us to produce out-of-plane buckling with controllable curvature. In particular, although inducing strain in the right and left sides of the pattern both produce a strip of the same length, the differences in pattern geometry result in different stiffness characteristics and yield different displacement profiles.

In this paper, we expand upon this idea to create reconfigurable 2-D sheets. We will describe a radial version of this concept, enabling radial expansion in concentric rings of material. Building upon algorithms in [Pikul et al. \(2017\)](#), we approximate 3-D shapes with positive, zero, and negative Gaussian curvature (ref. Fig. 2).

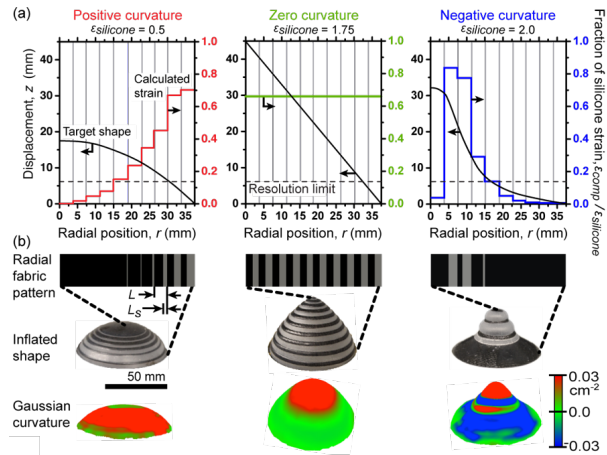


Figure 2: Design for positive, zero, and negative Gaussian curvature target shapes. a) The target shape and radial strain versus radial position required, discretized into 10 segments. b) The radial mesh patterns mapped from the composite radial strain. Black represents fixed rings and gray is stretchable material. L is the length between vertical gray lines in (a). The resulting shapes and Gaussian curvatures are shown below the mesh patterns.

References

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