

Design, development and multiphysics analysis of an origami-inspired active-material-enabled self-folding reflector antenna

D. J. Hartl, S. Jape, E. A. Peraza Hernandez, B. Borges, D. Sessions, J. Ruff, G. Huff, D. C. Lagoudas

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Abstract

Reconfigurable engineering structures inspired by origami, the ancient art of transforming flat sheets into three-dimensional shapes, have garnered increased attention. Novel applications based on origami-driven reconfigurability have been proposed in diverse fields of deployable space structures, morphing airplane wings, robotics, biomedical devices, tunable antennas, stretchable electronics, and metamaterials. More recently, active (or smart) materials, a class of inter-metallic alloys or polymers with the capability to convert non-mechanical forms of energy (thermal, chemical, electromagnetic, etc.) into mechanical work, have been investigated to drive desired shape change in origami structures via localized deformation near fold lines. One possible origami-based application of interest is the adaptive antenna for space and military communication, which could provide desirable engineering characteristics such as portability, reconfigurability, compact storage/deployment capabilities and reduction in weight and manufacturing complexity (Toshiyuki et al., 2003). In this paper, the origami design of a reconfigurable parabolic reflector antenna that can achieve self-folding with the aid of shape memory alloy/polymer material, along with combined structural and electromagnetic (EM) analysis, design optimization, and development of a prototype, is presented.

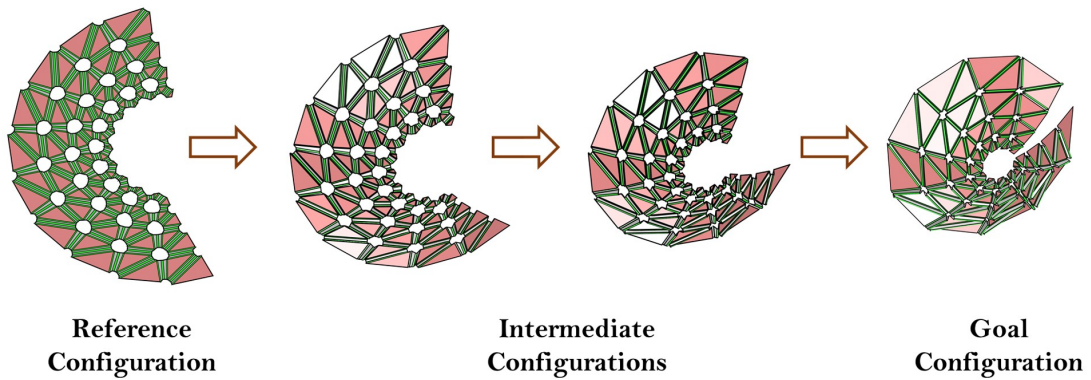


Figure 1: Active material actuation-driven folding of a planar sheet towards the goal configuration of a parabolic reflector antenna using the tucked-folding method.

Novel computational origami design tools and methodologies previously developed by the authors provide the capability to determine the geometry of a planar sheet in reference configuration, pattern of smooth folds, and the history of folding motion to achieve any arbitrary surface

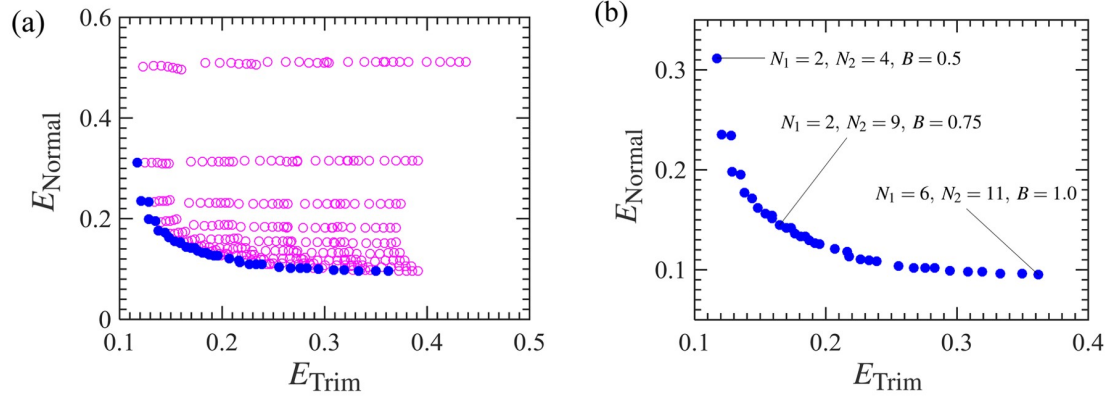


Figure 2: Results from a full-factorial DOE to determine a Pareto frontier of designs in the E_{Normal} - E_{Trim} space. E_{Normal} is the error due to deviation from an ideal parabolic shape and E_{Trim} is the error introduced due to reduction in surface area of the trimmed mesh (Peraza Hernandez et al., 2017b).

of non-zero Gaussian curvature (Peraza Hernandez et al., 2017a). A relatively simple example is that of a parabolic antenna represented as a polygonal goal mesh with an approximate faceted structure. The parabolic antenna is chosen as an example problem due to its application as a high-gain antenna in radio telescopes and other telecommunication systems (e.g. high speed data communication for satellites). Structural simulation of active-material-driven folding of the planar sheet to faceted parabolic shape is conducted for a range of antenna design parameters (diameter, focal length, thickness) and tessellation patterns using the finite element method. The resulting folded antenna configuration is systematically analyzed as part of an assembly consisting of a front-feed horn antenna with excitation source and feed-network. EM characteristics of the resulting physically feasible configurations, viz. radiation pattern, gain, efficiency, are determined using computational EM approaches. Insight into the EM performance of the antenna along with various environmental requirements can then be utilized to suitably tailor the structural response and guide the origami design of the flat sheet reference configuration. Through multiple iterations and multiphysics analyses, an optimized design of the active material based self-folding parabolic antenna is determined for fabrication using additive manufacturing facilities and its EM parameters are measured in an anechoic chamber.

References

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