

Merlin2: nonlinear structural analysis tool for origami

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keywords: origami mechanics, bar-and-hinge model, nonlinear analysis

Abstract

Sharing and publication of open-source and educational software has been a good tradition in the origami community. For instance, the “TreeMaker” by Robert Lang, the “Freeform Origami” by Tomohiro Tachi, and the “Rigid Origami Toolbox” by Joe Gattas. In this paper, we present the “Merlin2” software (Matlab code) for nonlinear structural analysis of origami assemblages, aiming at speeding origami design cycles and educating origami engineering.

The emerging of origami engineering poses a new challenge on our understanding of origami. For practical applications, engineers must know how the origami structural system interacts with environment and responds to human control. Origami folding is often idealized as rigid origami, concerning only geometry and kinematics. However, in practice, origami structures exhibit complicated behaviour, beyond simple folding, which cannot be explained by geometry alone, mainly owing to the flexibility of panels. Modelling of origami structures by means of shell finite-elements (FE) provides high-resolution analysis, but also requires a time-consuming cycle for both modelling and computing, costing unnecessary effort in cases such as a preliminary design stage. Thus, there is a need for a simple and effective analysis approach that fills the gap between the overly simplified rigid origami simulations and the superfluous full-scale FE analyses, while shedding light on the essence of origami mechanics.

Recently, we derived a new formulation built upon the bar-and-hinge model which brought nonlinear mechanics to origami structural analysis. Derived based on the principles of nonlinear elasticity, the formulation establishes internal force vectors and tangent stiffness matrices for large deformation nonlinear analysis. The bar-and-hinge model represents three major deformation modes in origami: *in-plane stretching*, *out-of-plane folding and bending*. With only a few degrees of freedom, the simplified model predicts surprisingly well the overall mechanical behaviour of origami structures. We implemented the basic formulation in “Merlin” (2017), a dedicated open-source software (Matlab code) for structural analysis of origami assemblages. The “Merlin” software simulates the deformation process of an origami structure subject to prescribed applied forces.

In this work, we proudly present the more powerful and sophisticated new version of “Merlin”: the “Merlin2.” Compared to the first published version of “Merlin,” the “Merlin2” offers the following new features:

1. **Displacement-driven loading.** The “Merlin2” admits input load as a displacement field. A certain amount of displacement on specific nodes can be applied by small steps, while each step

is solved by New-Raphson iteration. The step size is adjusted automatically to achieve a good convergence performance.

2. **Adaptive loading.** In “Merlin2”, there is a way to define adaptive loads that will change their loading direction in correspondence with the changing geometry of the origami structure during deformation.

3. **Implementation of the N5B8 model.** The N5B8 model is a recently proposed discretization scheme with refined resolution than the traditional scheme (i.e. N4B5) for quadrilateral panels that provides more accuracy. See Figure 1 for illustrations of both scheme.

4. **Discretization scheme for polygonal panels.** How to discretize polygonal panels in an origami structure is yet an unsolved question. In “Merlin2”, we propose two solutions to address this issues. One of them aligns with the features of the N4B5 model for quadrilateral panels, where no new nodes shall be added. The other solution is similar to the N5B8 model, where a new central node is added for each polygon. The location of the central node is determined by an optimization process, whose optimal solution is coincident with the already established N5B8 model for quadrilateral panels.

5. **Importing and exporting with OBJ format.** The wavefront OBJ file format is a standard format for sharing 3D geometry, supported by many design software programs including the origami design tool “Freeform Origami.” The “Merlin2” will support the OBJ format for importing and exporting geometric data. We hope this function can further help our users to make quick assessment of the performance of their origami designs!

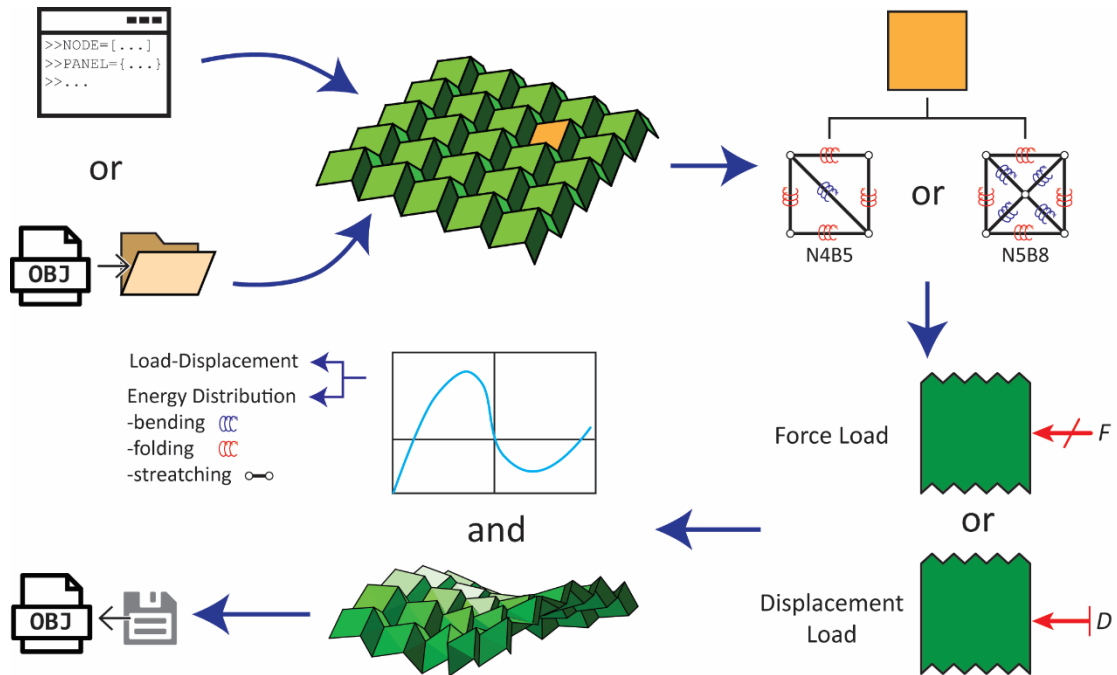


Figure 1: The workflow of “Merlin2.”