Computational Laser Forming
Origami of Convex Surfaces

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Introduction: Laser Origami

Polymer softening laser origami (Mueller et al. 13')

Release of pre-stressed films (Pique et al. 12')

Pre-stressed polymer strips

1.0 cm

1.5 cm

Laser forming airplane (Lazarus et al. 17')
Laser Forming vs. 3D Printing

- Cost: Low - High
- Accuracy: Low - High
- Material: Variety (mainly polymer)
- Time: Slow

- Cost: (same as fiber laser cutting)
- Accuracy: High
- Material: Variety (mainly metal)
- Time: Fast
Laser Forming vs. 3D Printing

3D printing: slicers

Laser Forming: ?
Most folding in laser origami has been limited to simple designs with very few folds and manual placement of folds. Our work is the first that procedurally generate laser-formable patterns and folding instructions that guide a low-cost laser cutter to cut and fold a sheet into a complex 3D shape.
Background: How Laser Forming Works

Temperature Gradient Mechanism

Heat → Expansion

Cooling → Contraction

Cooling time >> Heating time

Figure Credit: Lazarus et al. 17
Laser Passes vs. Folding Angles (for 75 um stainless steel)

TGM is more mature but BM is highly limited

* pre-strain needed
Computational Modeling and Constraints of Laser Forming

- **Work Plane Constraint**: The laser cutter with a single laser head can only emit laser vertically downwards and focus on the $z = 0$ plane.
Visibility Constraint: the existing folded structure must not block the visibility between a crease line (the dashed line) and the laser.
- **Rigidity Constraint**: the 2D pattern must be rigidly folded into the desired 3D shape without stretching or self-collision throughout the folding process.
The Computational Laser Forming Problem

Fabricating *3D Shapes* by Computational

2D Pattern Design + 2D Motion (Laser Passes) Planning

Subject to

- Work Plane Constraint
- Visibility Constraint
- Rigidity Constraint
- Thermal Constraint
End-to-end Fabrication Pipeline

(a) Input 3D mesh
(b) Unfolded Pattern
(c) 3D Folding Planning
(d) 2D Laser Motion
(e) Set Laser Power
(f) Result

(Fake Parallelization)
Origami Unfolding

Cut edges

Add tuck faces (in green)

3D Mesh

Polyhedral Net

Rigid Origami

Creases can be folded independently

Folding motion subject to closure constraints (violates work plane constraint)

tuck faces to be folded 180° (violates visibility constraints)
Outside-In Folding Algorithm

Example: Cube
Outside-In Folding Algorithm

Example: Cube
Outside-In Folding Algorithm

Example: Cube
Formability: Not all Convex Surfaces are TGM Laser Formable

Not TGM Laser Formable

TGM Laser Formable

$z = 0$
Formability: No All Unfoldings are TGM Laser Formable

Not TGM Laser Formable

TGM Laser Formable
Fake Parallelization

- Schedule sequential 2D motion of single laser head using parallelized 3D folding motion
- Maximize efficiency by allowing some creases to fold while other creases dissipating heat
Results: Curved Surface

Target Shape

Formable Net

Overlapping Cut

Fail (w/o overlapping cut)

Success (w/ overlapping cut)
Results: Sinuous Antenna with Various Tessellations

40 Faces

70 Faces

100 Faces

150 Faces

190 Faces

227 Faces
Video: Laser Forming Sinuous Antenna (70 Faces)

4x

20W fiber laser marker
75um x 10cm x 10cm stainless steel
This paper presents a computational method that can produce TGM laser formable structures of convex surfaces.

Our method increases the complexity of laser forming far more than the manually designed structures that typically contain only a few folds.

For the first time, an end-to-end laser-forming pipeline is presented, and, as g-code and slicers in 3D printing, this framework can pave the ground work and eventually transform laser forming and laser origami to a practical methods for low-cost customizable fabrication.

Laser forming has many potential applications (metal antennas, 3D circuits etc.) that well complement the applications of existing 3D printing technology.
Limitations and Future Work: Dual-Laser Setup

Dual Laser Forming For Closed Shapes
(Simulated)
Thank you!

More details can be found on the project page

http://masc.cs.gmu.edu/wiki/LaserOrigami