Creating Folds: Origami Inspired Morphing

Manu Mulakkal

Valeska Ting, Richard Trask, George Whittell, Ian Manners and Annela Seddon
Self actuation - examples

S. Felton et al. *A method for building self-folding machines*; DOI:10.1126/science.1252610

Dickey et al. *Self-folding of polymer sheets using local light absorption*; DOI: 10.1039/c1sm06564e

(A) Composite hinge design with pre-stretched polystyrene (PSPS) for localised resistive heating (B) folded robot

(C) Shrinky-dinks (pre-stretched polystyrene) patterned with black in for localised IR absorption
Self actuation - examples

Ge et al. Active origami by 4D printing; DOI: 10.1088/0964-1726/23/9/094007

(a) Schematics of polymer active composite (PAC) hinge
(b) thermo-mechanical programming steps

Mao et al. Sequential Self-Folding Structures by 3D Printed Digital Shape Memory Polymers; DOI: 10.1038/srep13616

(c) Sequential hinge design of box (d-g) folding

Creating folds: Origami inspired morphing
Self actuation - examples

**A** - Ionoprinting with metal cathode on polyelectrolyte (sodium polyacrylate; pNaAc) hydrogel

**B** – Spiral: poly(N-isopropylacrylamide (PNIPAm)) hydrogel with patterned crosslinking

**C**- 3D printed box: rigid phase + active(hydrophilic polymer)

Palleau et al, *Reversible patterning and actuation of hydrogels by electrically assisted ionoprinting*; DOI: 10.1038/ncomms3257

Wu et al. *Three-dimensional shape transformations of hydrogel sheets induced by small-scale modulation of internal stresses*; DOI: 10.1038/ncomms2549

Skylar Tibbits, *4D Printing: Multi-Material Shape Change*; DOI: 10.1002/ad.1710

Creating folds: Origami inspired morphing
Morphing with paper

Creating folds: Origami inspired morphing
Morphing with paper

- **Principle of actuation**
  - Shrinking of hydrogel due to water loss result in strain mismatch
  - Diffusion + capillary + S.T

- **Factors affecting fold/ curve angle**
  - the amount of gel forming polymer, its spread, stiffness of paper (i.e grammage) and open area that needs to be folded

Creating folds: Origami inspired morphing

- 1x - 155°
- 4x - 113°
- 7x - 72°

- 5mm - Radius 6.1mm
- 10mm - Radius 4.9mm
- 15mm - Radius 4.0mm
Drying at elevated temperatures

Water in the hydrogel structure can be classified into bound, semi-bound and free water (bulk).

Creating folds: Origami inspired morphing

180 °C + 5 min

Construction
1-paper cut (bottom)
2-gel
3-paper cut (top)

Front view
Side view

Scale bar: 25 mm
Scale bar: 10 mm

University of Bristol

Creating folds: Origami inspired morphing
Coupled system

Creating folds: Origami inspired morphing

180 °C for 5 min

Flat → Pop-up

Coupled system
Coupled system

Mass of specimen - 0.31g

Supported mass – 222g

Creating folds: Origami inspired morphing
Conclusions and Future works

**Potential**
- Cost effective
- Simple
- Smart
- Low footprint

**Challenges**
- Extrusion
- Variability

**Future**
- ALM
- 4D printing

Supported by

Creating folds: Origami inspired morphing