

Transformer

**Shape-changing Space Systems
Built with Robotic Textiles**
(ro-textiles/ro-fabrics/ro-skins)

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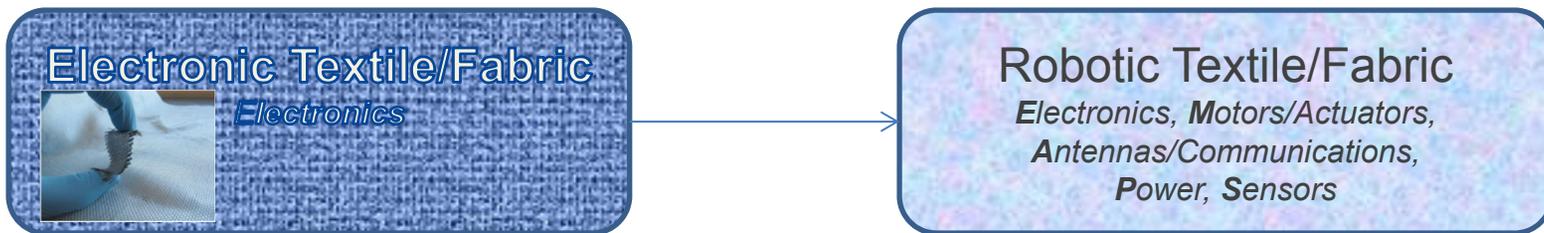
Transformer concept

This paper proposes *transformers*, a new kind of robotic space system, dramatically different from current systems in at least two ways:

1. The entire transformer is built from a thin flexible sheet, of “robotic textile”, *ro-textile*
2. The ro-textile sheet folds to small volume, and self-unfolds to adapt shape and function to mission needs.

Ro-textiles

- An extension of electronic textiles (e-textiles, e-fabrics)



- Gossamer-thin ($\sim 100 \mu\text{m}$) and light flexible layer
- Survivable to extreme environments
- Cellular ($\sim \text{cm square?}$, cells may be in patches)
- Each cell includes cells of all robotic sub-systems, from sensing to actuation, power, comms/antennas, control/computing
- Modular, distributed architecture

All sub-components demonstrated



All subsystems have been demonstrated on flexible substrate

- E: electronics (foldable in a radius less than 100 μm .),
- M: motor/mobility - actuators
- A: antennas/communications
- P: Power (e.g. solar)/batteries
- S: Sensors

$E \rightarrow R$

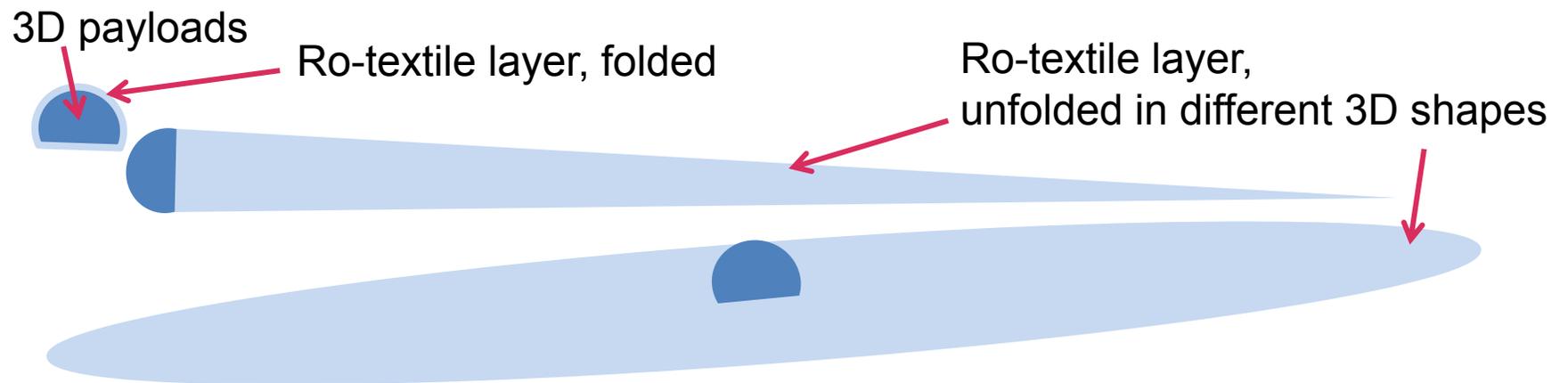
$R = E + M + A + P + S$

R layer or EMAPS layer

Spatial and functional integration is the next challenge

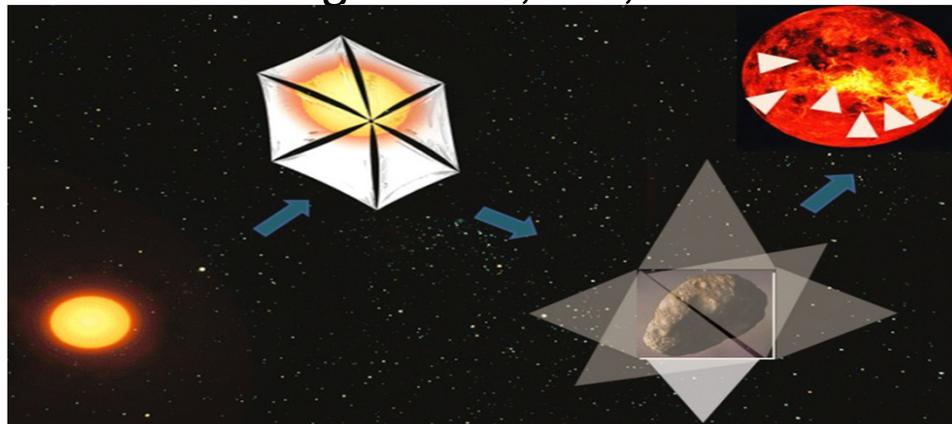
Non-integrated instruments

- Some 3D payloads may still be needed,
 - e.g. some special instruments that cannot be integrated as 2D structures;
 - these would be carried as payloads in kernels around which the 2D layer would fold.
 - Ro-textile layer would unfold to needed 3D shapes



Foldable, self-unfolding

- The ro-textile layer is
 - foldable to small volume (tightly folded at launch)
 - self-unfolding to adapt shape and function to mission phases.An Ares V would have had $\sim 1000\text{m}^3$ divided by depth of 100micron gives $10,000,000\text{m}^2 \sim 3\text{km}/3\text{km}$ sail/dish



large solar sail for interplanetary/ interstellar travel



component patches separate in swarms of winged flyers in atmosphere

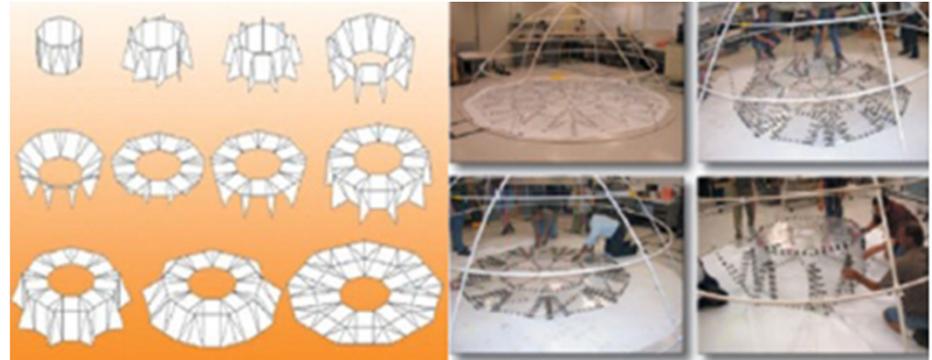


limbed robot capable of surface mobility and sample manipulation

3D from 2D



MC Escher – Bond of Union.
Reflects the idea of using a
band to shape 3D things.



Right: Origami for folding
lenses, at Livermore (LLNL)



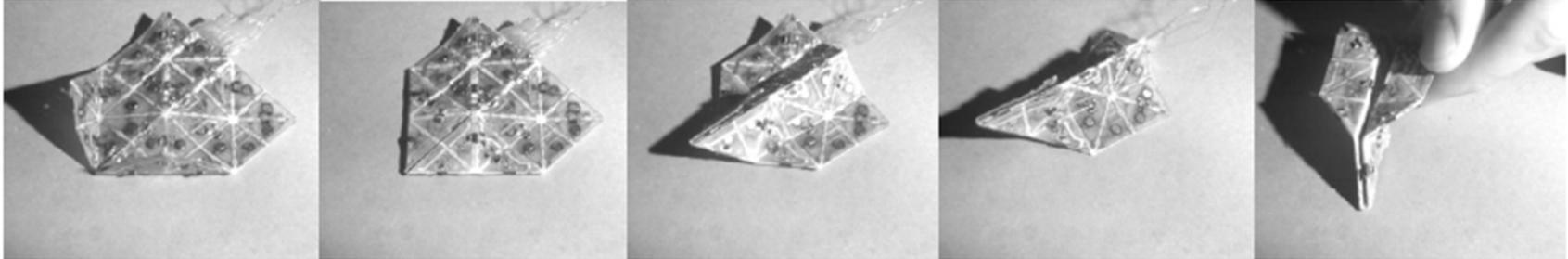
Printable electronics



SULSA is the world's first 'printed' aircraft

Project SULSA UAV printed on an EOS EOSINT P730
nylon laser sintering machine, which fabricates plastic or metal
objects, building up the item layer by layer. 7

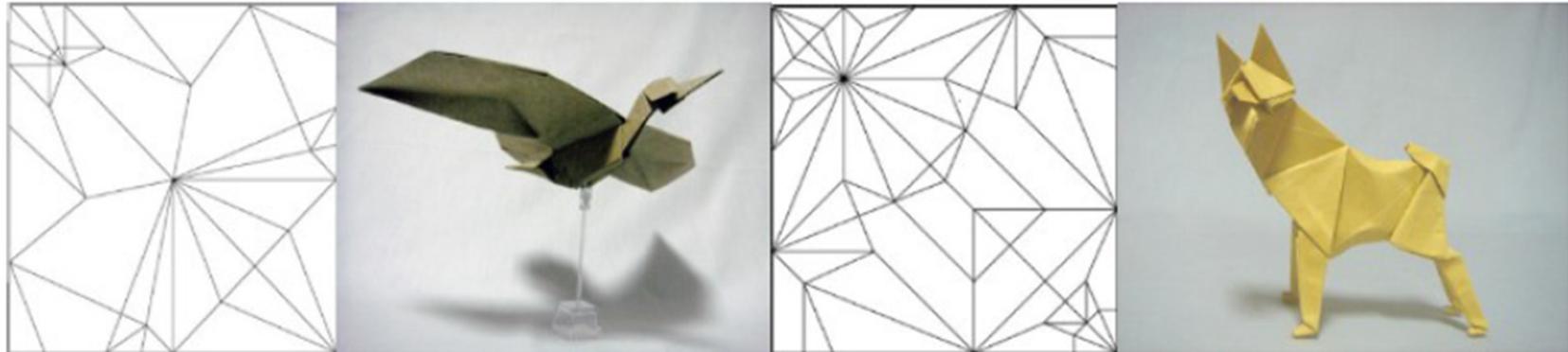
Simple self-folding surface (an origami 'robot')



Controlled 2D robotic origami that self-reconfigures, with shape-memory alloy actuators (Harvard-MIT).

- So far it only includes actuators (M-layer)
 - power brought to the surface by cables
 - controls also being computed/induced from outside

Folding



Diagrams, folding designs on 2D thin layer, and shaped 3D, dog and bird

- Proper partitioning (sufficient resolution and choice of lines) would allow shaping of practically any 3D shape, as insured by various mathematical proofs.
- Common lines for multiple shapes (multi-function design) ensure ability to transform from one shape to another.
- *Flexible layers would provide further freedom for modification of shape at sub-cell resolution.*

Ro-fabric patches

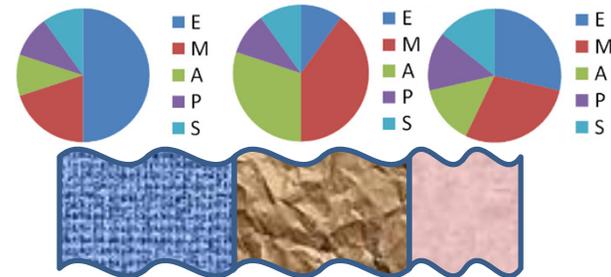
- The surface is composed of connected ('zipped') multi-cell patches that can separate to operate in formations
- these may be all the same or specialized (e.g one with more sensing circuitry)



homogeneous mixture of functions along a single sheet.



homogeneous mixture of functions separated in multiple sheets, which can become a formation/swarm



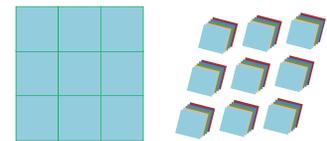
heterogeneous single-sheet s/c (a 2D mechanical collapse of current s/c solutions) illustrating specialized functionality in each module



multi part, heterogeneous

Ro-fabrics cells

- Cell embeds circuits of all s/c sub-systems (EMAPS)
- A cell-based architecture is used in
 - Distributed computing
 - Sensor array, etc
- Reconfigurable electronics
 - Field Programmable Arrays type architecture
 - Electronic/computing/function change/optimization
 - Sensor/antenna/ reconfiguration
- Should survive extreme environments without any protective layer



Transformer platforms

The ro-textile –based transformer concept has the potential to revolutionize how we think about exploration missions and the building of space platforms.

- Low cost *design* paradigm
 - with reusable design, standard production of many similar platforms,
 - the built-in multi-functionality, with EMAPS
- Low cost *manufacturing* paradigm by production in the 2D format, for example by printing methods.
- Low cost *deployment* method, in highly folded form, low volume, low mass.
- Cost-effective *operation*, deploying a single space craft adaptive to multiple missions/targets.

Cheaper, fast response time

- *Faster, cheaper and lighter space systems, reducing the launch and redesign cost for new missions:*
 - *can launch more of them and at shorter intervals,*
 - *can send them to many more places after launch.*

It would enable an intense and persistent exploration program with a fleet of low cost, shape/function changing robotic spacecraft, adaptive to mission/phase needs.