



Transformers: Shape-Changing Space Systems Built With Robotic Textiles

These easy-to-fabricate textiles can be used in robotics and smart habitats/shelters.

NASA's Jet Propulsion Laboratory, Pasadena, California

Prior approaches to transformer-like robots had only very limited success. They suffer from lack of reliability, ability to integrate large surfaces, and very modest change in overall shape. Robots can now be built from two-dimensional (2D) layers of robotic fabric. This expands on ideas of electronic fabrics for electronic textiles, and incorporates sensors, actuators, power, and communications. The 2D solution is easier/cheaper to fabricate, packs more compactly, and ensures a wider range of shape change than 3D modules.

These transformers, a new kind of robotic space system, are dramatically different from current systems in at least two ways. First, the entire transformer is built from a single, thin sheet; a flexible layer of a robotic fabric (ro-fabric); or robotic textile (ro-textile). The ro-textile would be produced as a gossamer-thin ($\approx 100 \mu\text{m}$) and light flexible layer, survivable to extreme environments. Along its large surface, the ro-fabric would be partitioned into modular cells. Each cell would include, distributed within this skin-like thin layer, all the structures for spacecraft/robotic subsystems, including propulsion and power (solar), avionics and controls, sensing, actuation (e.g., shape-memory alloys), and communication (circuits and antennas).

Second, the ro-textile layer is foldable to small volume and self-unfolding to adapt shape and function to mission phases. Tightly folded at launch, it would self-unfold to take the shape/function needed by the mission target, and then again transform its shape as needed. For dramatic changes, one can speculate it could morph between a large solar sail for interplanetary interstellar travel, its component patches could separate in swarms of winged flyers in atmosphere, or it could take shape as a limbed robot capable of surface mobility and sample manipulation.

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. Proper partitioning of the ro-fabric sheet would allow shaping of practically any 3D shape, as insured by various mathematical proofs. Flexible layers would provide further freedom for modification of shape at sub-cell resolution.

The surface of ro-fabrics 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). Each cell would normally embed

the circuits of all subsystems (electronics/computing, propulsion, and power photo-elements/imaging cells, actuators, conductors for antennas, etc.).

A cell-based architecture fits well with modular, reconfigurable electronics, based on field programmable (FP) arrays, or in general on distributed computing/electronics. From computational perspective, each (cm-size) cell of the ro-textile could be a basic computational element — a single FPGA (field programmable gate array)/FPAA (FP gate/analog array) mixed cell, a cluster of cells, or a large-density array of FP cells (the low density may be suitable for non-silicon materials that may be preferable for reasons other than high integration). The ro-textile would be built with materials that survive to extreme environments without insulation or thermal control.

In summary, this concept may be a solution to faster, cheaper, and lighter space systems, reducing the launch cost and the redesign cost for new missions; thus, one can launch more of them and at shorter intervals, and send them to more places after launch.

This work was done by Adrian Stoica of Caltech for NASA's Jet Propulsion Laboratory. Further information is contained in a TSP (see page 1). NPO-48349

Fibrillar Adhesive for Climbing Robots

This material can be used to hang items on walls without the need for drilling holes, as surgical sutures, or to attach and maneuver components during assembly.

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A climbing robot needs to use its adhesive patches over and over again as it scales a slope. Replacing the adhesive at each step is generally impractical. If the adhesive or attachment mechanism cannot be used repeatedly, then the robot must carry an extra load of this adhesive to apply a fresh layer with each move.

Common failure modes include tearing, contamination by dirt, plastic deformation of fibers, and damage from loading/unloading. A gecko-like fibrillar adhesive has been developed that has been shown useful for climbing robots, and may later prove useful for grasping, anchoring, and medical applications.

The material consists of a hierarchical fibrillar structure that currently contains two levels, but may be extended to three or four levels in continuing work. The contacting level has tens of thousands of microscopic fibers made from a rubber-like material that bend over and create intimate contact with a surface to