HAPTIC INTERFACES

Origami for the everyday

Origami engineering has long held the promise of complex and futuristic machines. A new foldable haptics system shows that this paradigm can be functional as well.

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Origami-inspired designs have been applied to a diverse range of problems, from microrobots to space deployment. But despite this futuristic potential, there have been few origami systems that are tough enough and functional enough for consumer use. In this issue of *Nature Machine Intelligence*, Mintchev et al.[1] demonstrate just such a machine: an origami-based haptic device called Foldaway that performs as well as many commercial alternatives, in a package that's a fraction of their size. Even more impressive, it can collapse into a flat state without sacrificing its performance. This engineering feat is accomplished by harnessing the potential of origami while improving its stiffness, speed and durability to create a machine that is both transformable and functional.

Origami engineering refers to a set of design and fabrication principles that are inspired by the eponymous art form[2] (Fig. 1). Its allure comes not just from these artistic roots, but also its theoretical complexity. For example, Demaine and Tachi have proved that a single sheet of paper can be folded into any flat-sided shape, and they have developed software that will generate the fold pattern for us[3]. Along with many other proofs and algorithms, these results indicate that origami could replicate any structure or machine if we could engineer these ideal geometries into physical artefacts.

At the same time, origami-based fabrication techniques have become popular for rapid prototyping or small-scale fabrication. Instead of manufacturing and assembling three-dimensional components, a thin laminate is machined when flat and then folded into its functional form. This process takes a fraction of the time and works when the system would be too small to assemble manually: in one example, roboticists used a 'pop-up'-based assembly technique to create centimetre-scale flying robots[4].

Most origami research sounds like science fiction. In addition to robotic insects, another application is in space exploration. Astronautical engineers have been studying origami for deploying space structures for decades, dating back to 1985 when Miura proposed a new origami pattern for solar arrays[5]. These structures can transform from a very small volume to a large and functional structure, enabling easy transport. Also, materials scientists have created a variety of self-folding microstructures, including one example reminiscent of *The Fantastic Voyage* in which they developed a microscale mechanism that could autonomously retrieve cells from within a live pig[6]. But none of this research has entered daily consumer use, in part because these origami devices are slender and fragile, and in part because low-profile, origami-compatible actuators are slow.

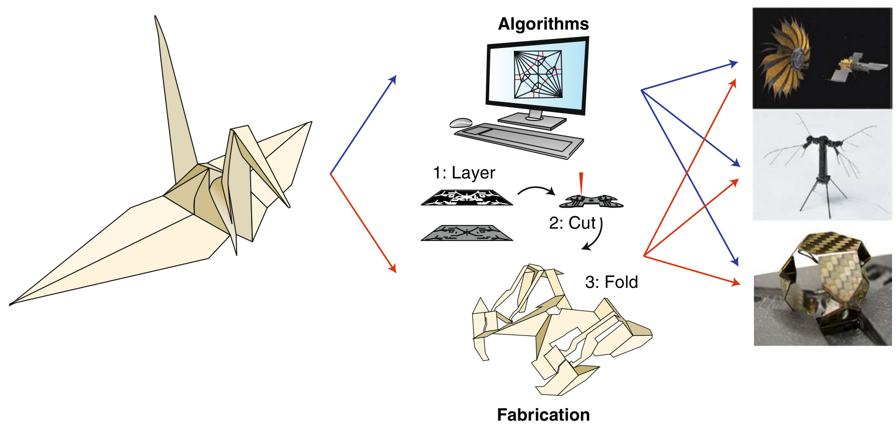

Fig. 1 | Origami has inspired many computational tools and fabrication techniques, collectively known as origami engineering. This paradigm has been applied to a wide range of challenges including satellite deployment (top right), microrobot design (middle right)[7], and now haptic interfaces (bottom right)[1]. Credit: Top right, NASA/JPL-Caltech; middle right, Noah T. Jafferis and E. Farrell Helbling, Harvard Microrobotics Laboratory; bottom right, reproduced from ref. [1], Springer Nature Ltd.

Now Mintchev et al. have applied these techniques to a new field: haptics. Haptic interfaces allow machines to communicate with humans through tactile sensations. One ubiquitous example is a vibrating phone. More advanced haptic devices can augment virtual reality or manual teleworking, such as a doctor operating a remote surgical robot and feeling resistance against her scalpel. Realistic haptics have high performance standards: they must be strong enough to resist human motion and fast enough to convince the user that they're instantaneous. To achieve this high performance, most haptic devices are large; for example, 3D Systems' Touch, a typical haptic interface representing a single pen, weighs 1.8 kg and is over 10,000 cm^3 in size.

Mintchev et al. have shown that this realistic performance can be achieved with a substantially smaller design by creating Foldaway, an origami-inspired haptic interface intended for education, gaming and robotic control. They used the origami paradigm to create a small but complex linkage assembly: one iteration consists of 19 facets and 21 folds in a volume less than 200 cm^3 and with a total weight of 0.13 kg. This mechanism moves in three directions to replicate the sensations of a finger pushing or sliding, but is stiff enough to resist the user's thumb press. And because it is stiff yet light, the mechanism can move quickly, at frequencies up to 20 Hz. But the most unique innovation in this machine is its collapsibility. Because of origami's inherent geometric behaviour, this three-dimensional, three-degrees-of-freedom mechanism can fold itself flat to a thickness less than five millimetres, and can therefore be safely and easily stored and transported. In short, Foldaway exploits the complexity and transformability of origami, while making it robust and fast enough for everyday use.

There are still large gaps in our knowledge of origami engineering. Despite our extensive understanding of origami geometry, there is no unified model that can account for all the non-ideal aspects of physical systems, such as flexible faces, thick walls and fabrication imperfections. We also lack the low-profile sensors and actuators to make origami machines competitive with traditional ones — even Foldaway runs on three traditional motors installed at its base. However, as our understanding of both the theory and practice of origami engineering grows, we will see it affect the design, manufacturing and transportation of a variety of systems, from disposable consumer goods to cutting-edge extraterrestrial structures. Foldaway has brought this goal closer by showing that origami engineering is not just theoretically complex, but practical as well. ❐

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Competing interests

The author declares no competing interests.