A new reconfiguration strategy for modular robots inspired by origami folding

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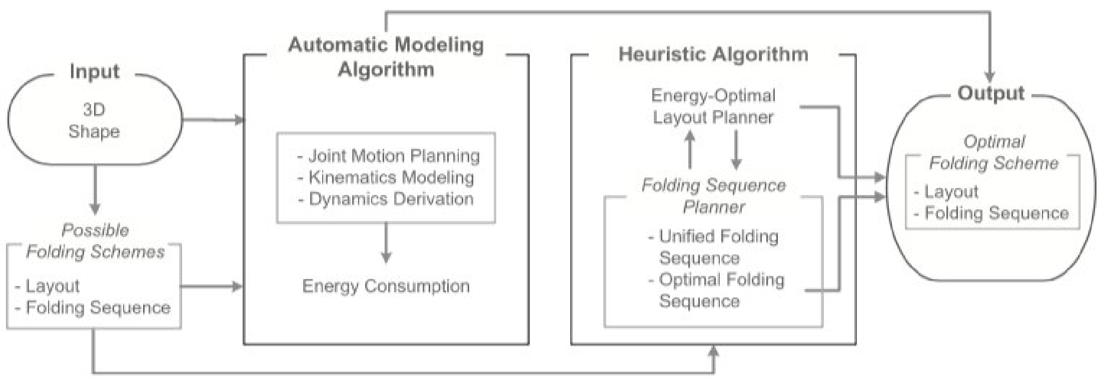

Overview of energy-optimal reconfiguration planning for modular robots using two approaches, an automatic modeling algorithm and a heuristic algorithm. Credit: Yao et al.

Researchers at the Reconfigurable Robotics Lab (RRL) of École Polytechnique Fédèrale de Lausanne (EPFL) have recently developed a new approach for the reconfiguration of modular robots that is inspired by the art of origami. This method, outlined in a paper published in Sage's *International Journal of Robotics Research*, eliminates connectivity changes during a system's transformation.

Modular reconfigurable robots are versatile systems that can transform their shape to perform different tasks in a variety of environments. This can be particularly useful in mission-based settings, such as space, recognition, sampling, or search and rescue operations. In these instances, conventional fixed-morphology robots might struggle to adapt to complex and uncertain environments, while modular robotic systems can autonomously reconfigure and adapt to new circumstances.

The reconfigurability of modular systems is achieved by changing the morphology of their overall structure, as well as by connecting and disconnecting their modules. Despite the notable advantages of using these systems, the large number of individual components and degrees of freedom (DoFs) involved make changing their configuration highly challenging.

To plan and optimize this process, past studies have proposed a variety of approaches, which can be divided into two main categories. The first category entails target configuration by dividing the system's modular architecture into different sets of modules, which can simplify the reconfiguration process. These approaches can facilitate the design of the final configuration for specific tasks, yet they fail to address the dynamic reconfiguration process.

Another approach to optimizing reconfiguration is minimizing the number of connectivity changes when the system is transforming into the desired shape. Although these reconfiguration planners are aimed at reducing the number of connectivity changes, they still require some form of disconnect and connect between modules in the process. These connectivity changes are time-consuming, can cause complications in the overall transformation and can result in misalignment, leading to the system's mechanical failure.

Addressing the limitations of existing approaches, the team of researchers at RRL introduced a new strategy for planning the reconfiguration of modular robotics systems, which draws from the process of folding origami. Origami is the traditional Japanese art of folding flat sheets of paper into a variety of 3-D objects or shapes.

"Our method consists of an energy-optimal reconfiguration planner that generates an initial 2-D assembly pattern and an actuation sequence of the modular units, both resulting in minimum energy consumption," the researchers wrote in their paper.

The algorithmic framework devised by the researchers includes two main components: an automatic modeling algorithm and a heuristic algorithm. The automatic modeling algorithm generates the kinematic model and dynamic derivation of robotic aggregates, calculating the torque consumption of pre-folding patterns for pre-defined folding sequences and using motion planning to consider the thickness of the structure. The heuristic algorithm, on the other hand, includes an optimal 2-D layout planner followed by two folding sequence planners: a unified actuation planner for different layouts and an optimal planner within a specific layout.

The new approached devised at RRL effectively tackles the NP-complete problem of energy-optimal reconfiguration planning in modular robots, generating energy-optimal reconfiguration schemes for the initial assembly and folding sequence of the system's modules. The researchers evaluated their strategy using simulations on Mori, a modular robotic platform, and attained very promising results.

"We demonstrate the effectiveness of our method by applying the algorithms to Mori, a modular origami robot, in simulation," the researchers wrote in their paper. "Our results show that the heuristic algorithm yields reconfiguration schemes with high quality, compared with the automatic modeling algorithm, simultaneously saving a considerable amount of computational time and effort."

More information: Meibao Yao et al. A reconfiguration strategy for modular robots using origami folding, *The International Journal of Robotics Research* (2018). DOI: 10.1177/0278364918815757