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Multi-stable Mechanical Metamaterials for Soft Robots with Contour Recognition

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ABSTRACT

In rescue and exploration missions, recognizing operations, such as contour detection of people and target objects, play a crucial role. To work in extreme environments, robots with contour recognition functions are devised to take the place of human operations. For example, rescue robots can recognize trapped people and radioactive wastes at the site of nuclear accidents. However, the exposed robotic components, such as electronic touch, light, and ultrasonic sensors, are particularly vulnerable to extreme radiative/high-temperature/corrosive/high-pressure environments and thus cannot durably and reliably recognize contour information. In contrast, programming soft robots with adaptive mechanical metamaterials can self-conform around an object of interest as a physical route for recognizing the object's contour.

Mechanical metamaterials are rationally designed composites with properties that go beyond those of the base materials. Adaptive mechanical metamaterials can adapt their geometry to their surroundings without the need for the supervision of electronic sensors. Their response can be viewed as a self-shaping feature that is stimuli-responsive to mechanical, thermal, or electromagnetic inputs. In this research, we attain touching sense and contour recognition by metamaterial adaptive deformations. As a kind of adaptive mechanical metamaterials, multi-stable metamaterials have two or more different stable stages that can be switched reversibly among each other under mechanical loading caused by contact. Distinct stable configurations represent the difference in the contours of contacted objects. Applying electrically conductive material, local contacts in building blocks turn on circuits and mutate partial voltage. In connected periodic building blocks, distinct stable configurations represent and memorize the difference in the contours of contacted objects. Through analyzing the relationship between deformation-induced voltage changes and object contours via artificial intelligence algorithms (e.g. a Multilayer Convolutional Neural Network), metamaterials can be engineered to perform contour recognition. The programming soft robots equipped with adaptive metamaterials reduce dependence on electrical sensors and thus have higher viability for aerospace, rescue, energy, and medical applications in extreme environments.