Mechanical Engineering Doctoral Defense

Studies on Origami-Inspired Metamaterials with Tunable Stiffness

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Abstract

Stiffness and flexibility are essential in many fields, including robotics, aerospace, bioengineering, etc. In recent years, origami-based mechanical metamaterials were designed for better mechanical properties including tunable stiffness and tunable collapsibility. However, in existing studies, the tunable stiffness is only with limited range and limited controllability. To overcome these challenges, two objectives were proposed and achieved in this dissertation: first, to design mechanical metamaterials with metamaterials with selective stiffness and collapsibility; second, to design mechanical metamaterials with in-situ tunable stiffness among positive, zero, and negative. In the first part, triangulated cylinder origami was employed to build deployable mechanical metamaterials through folding and unfolding along the crease lines. These deployable structures are flexible in the deploy direction so that it can be easily collapsed along the same way as it was deployed. An origami-inspired mechanical metamaterial was designed for on-demand deployability and selective collapsibility: autonomous deployability from the collapsed state and selective collapsibility along two different paths, with low stiffness for one path and substantially high stiffness for another path. The created mechanical metamaterial yields unprecedented load bearing capability in the deploy direction while possessing great deployability and collapsibility. The principle in this prospectus can be utilized to design and create versatile origami-inspired mechanical metamaterials that can find many applications. In the second part, curved origami patterns were designed to accomplish in situ stiffness manipulation covering positive, zero, and negative stiffness by activating predefined creases on one curved origami pattern. This elegant design enables in situ stiffness switching in lightweight and space-saving applications, as demonstrated through three robotic-related components. Under a uniform load, the curved origami can provide universal gripping, controlled force transmissibility, and multistage stiffness response. This work illustrates an unexplored and unprecedented capability of curved origami, which opens new applications in robotics for this particular family of origami patterns.

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