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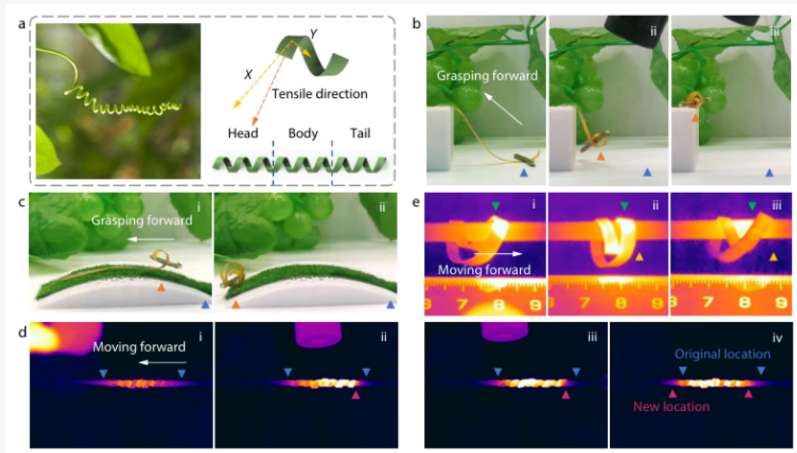
Bioinspired liquid crystal actuators unlock programmable climbing and shape-shifting motion



Light-driven vine-inspired LCE actuator enabling grasping and forward climbing.

FAYETTEVILLE, GA, UNITED STATES, December 19, 2025 / EINPresswire.com/ -- Soft robotic systems are evolving toward life-like motion, but precise shape-morphing and adaptive grasping remain difficult. This study presents a hierarchical design strategy that engineers liquid crystal elastomers (LCEs) into programmable structures capable of reversible helix-plane transformation, NIR-controlled climbing, and topology-dependent locking behaviors. By integrating photothermal-responsive silver nanowires and mechanically pre-aligned LCEs, the actuators achieve remote operation, terrain-adaptive grasping, and even koala-like pole climbing. The work demonstrates how controlling molecular orientation and topology enables motion patterns including curling, tightening, locomotion, and self-locking. These innovations point toward autonomous soft robots for unstructured environments, minimally invasive manipulation, and bioinspired motion control.

Soft robots draw inspiration from organisms such as octopus tentacles and plant tendrils, where motion arises from continuous deformation rather than rigid motors. Liquid crystal elastomers (LCEs) are promising due to their reversible phase transitions and programmable anisotropy, allowing deformation under light, heat, or magnetic stimuli. However, achieving precise, reversible helical actuation and climbing behavior has remained challenging because traditional fabrication methods struggle to encode complex molecular orientations and topological pathways. The need for remote, adaptable shape-morphing systems is growing across search-and-rescue, biomedical and micro-manipulation fields. Due to these challenges, it is necessary to explore hierarchical structure design and light-responsive actuation mechanisms for LCE-based soft robotics.

Researchers from Jiangsu University reported (DOI: 10.1007/s10118-025-3418-3) on October 11, 2025, in the journal Chinese Journal of Polymer Science, a light-responsive soft robotic platform based on LCEs featuring hierarchical and topological structural programming. The team designed mechanically pre-strained LCE helices integrated with silver nanowire photothermal layers to enable NIR-controlled reversible deformation, grasping, helical climbing, and Möbius ring actuation. The work demonstrates multi-mode bioinspired motion including vine-like curling and koala-style pole climbing under remote light control.

The researchers fabricated LCE films via a two-stage thiol-acrylate reaction and introduced helical pre-programming reaching 1000% strain, which significantly improved molecular alignment verified by Small-Angle X-ray Scattering (SAXS) patterns. A tri-layer structure (AgNW/LCE/PI) enhanced NIR absorption through localized surface plasmon resonance, enabling efficient photothermal-mechanical conversion. These materials showed reversible helical-to-planar switching, allowing gripping of objects across multi-terrain platforms such as caves, hill slopes and canyons. Under illumination, the actuator contracts with controllable bending angles and stable cyclic performance. Next, a vine-like actuator achieved light-driven climbing through sequential contraction of tail–body–head regions, driven by traveling temperature gradients during NIR scanning. Infrared imaging confirmed coordinated heat transfer during climbing on vertical poles.

The team further introduced Möbius topological programming, where 180° twist structures enabled reversible actuation, while 360° twists produced self-locking deformation, forming concentric rings or "8-shaped" states depending on illumination. Based on this mechanism, a koala-inspired climbing device was developed, capable of advancing ~5–7 mm per cycle and climbing inclined rods, even while loaded with 1.6 g.

The authors emphasize that the key breakthrough lies in integrating molecular orientation programming with light-triggered topological actuation. They note that hierarchical LCE structures allow actuation modes previously inaccessible to conventional soft robotics, enabling climbing without motors, contactless manipulation, and deformation under remote control. This design demonstrates how structural programming at molecular and geometric scales unlocks shape-shifting behaviors resembling biological tendrils and animals. The researchers believe the approach offers a general framework for designing future soft robotic systems capable of navigating complex three-dimensional environments.

This study presents a scalable strategy for next-generation soft robotics, where a single material system can climb, grasp, anchor, and reconfigure without electronics or rigid actuators. Potential applications include pipeline inspection, minimally invasive surgical tools, environmental exploration, and micromanipulation under NIR guidance. The programmable Möbius topology provides a new route for mechanical memory and locking structures, enabling energy-efficient locomotion and deployable devices. Future development may focus on integrating sensing modules, increasing response speed and extending operation to untethered autonomous platforms. The work highlights how bioinspired structural logic can transform LCEs into adaptive robotic systems.

References
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