CAREER: Tensegrity Autonomous Deployable Millirobots for Minimally Invasive Interventions

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Milli-scale robots have emerged as next generation of intelligent technology for minimally invasive interventions, which call for autonomous millirobots to work as tiny "surgeons" or drug delivery "vehicles" to achieve in-vivo practices, see Fig. 1. It is beneficial to have a systematic approach to creation of autonomous millirobots with (1) simple and reliable mechanisms for morphing, and (2) an effective locomotion system. However, these two objectives are difficult to achieve due to the lack of well-established tools for milli-scale structural design, fabrication, locomotion planning and actuation development.

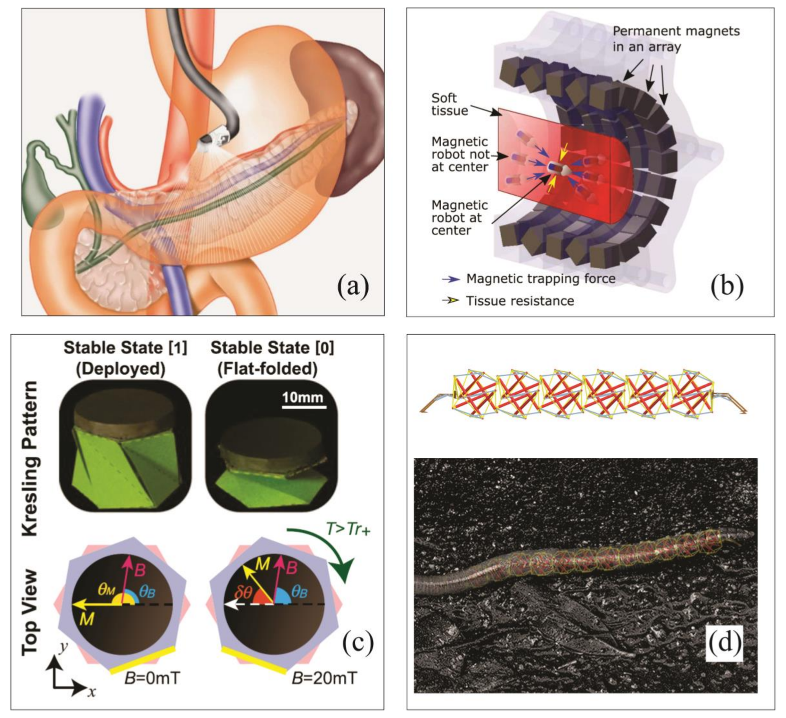

Fig 1: Motivation of this research: (a) traditional in-vivo diagnostic technique; (b) half-sectioned magnet array; (c) Kresling pattern origami microrobot with a magnetic plate at deployed and folded states; (d) tensegrity autonomous deployable millirobots proposed in this research.

Issues in traditional designs of millirobots:

- **Low reliability:** millirobots with soft bodies mainly rely on complex and fragile mechanisms for morphing, which is an issue if high operational reliability is required.
- **Poor morphing performance:** millirobots designed as remotely actuated rigid metal particles or structures cannot morphing in a flexible manner. They will inevitably suffer a high risk of retention in small spaces during navigation.

Intellectual Merit

This research will investigate the **tensegrity-structure-based** approach to **autonomous deployable millirobots (ADMs)** creation. The tensegrity structure is free-standing with lightweight and high stiffness, and can effectively morph by only using simple and reliable pin-joints.

This research is **new** in that it will create ADMs with **simple and reliable mechanisms** for supreme morphing efficiency, and an effective **bio-mimic locomotion** system by the tensegrity approach. These properties will grant the tensegrity ADMs the capability of **sustaining environmental loads** and **preventing damages when burrowing through high-pressure environments**, and will lower the risk of retention in small working spaces.

Effective ADMs Design: Tensegrity Approach

A new framework of effective ADMs design by the tensegrity approach is established. The framework will simultaneously integrate topology design, form finding and **fabrication at milli-scale level**, so as to create tensegrity ADMs with desired mechanical properties. Specifically, the topology design is restricted to **class-1** tensegrity, since bar-to-bar connection at will significantly downgrade the simplicity and reliability of the joints. The form finding, which determines nodal positions and member forces, will generate **uniform member lengths** to facilitate a smooth milli-scale fabrication process and to reduce sensitivity to external loads. Bar members are fabricated **individually** and cable members are fabricated as **a unified network** by **3D printing** to facilitate an easy structure assembling, see Fig. 2.

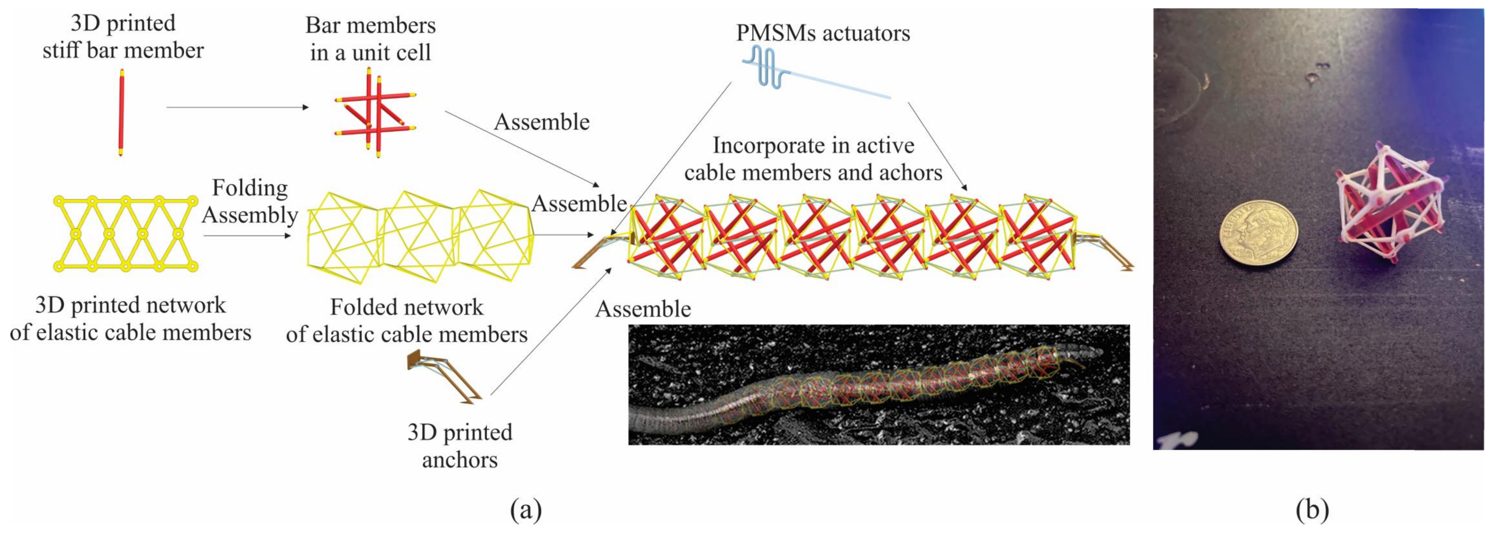

Fig. 2 (a) Illustration of a milli-scale fabrication plan for the tensegrity ADMs (b) A proof-of-concept single-unit tensegrity structure prototype.

Bio-mimic Locomotion System

This research aims to develop a locomotion system for tensegrity ADMs. The robot will **mimic the crawling motion of earthworms**, with its unidirectional body morphing being achieved by optimally placed **shape memory alloy (SMA) actuators**, See Fig. 3. To achieve this goal, a new method for optimal placement of SMA actuators in active cable members is developed and applied on an icosahedral unit cell of the robot body and is tested on a centimeter-scale prototype, see Fig. 4.

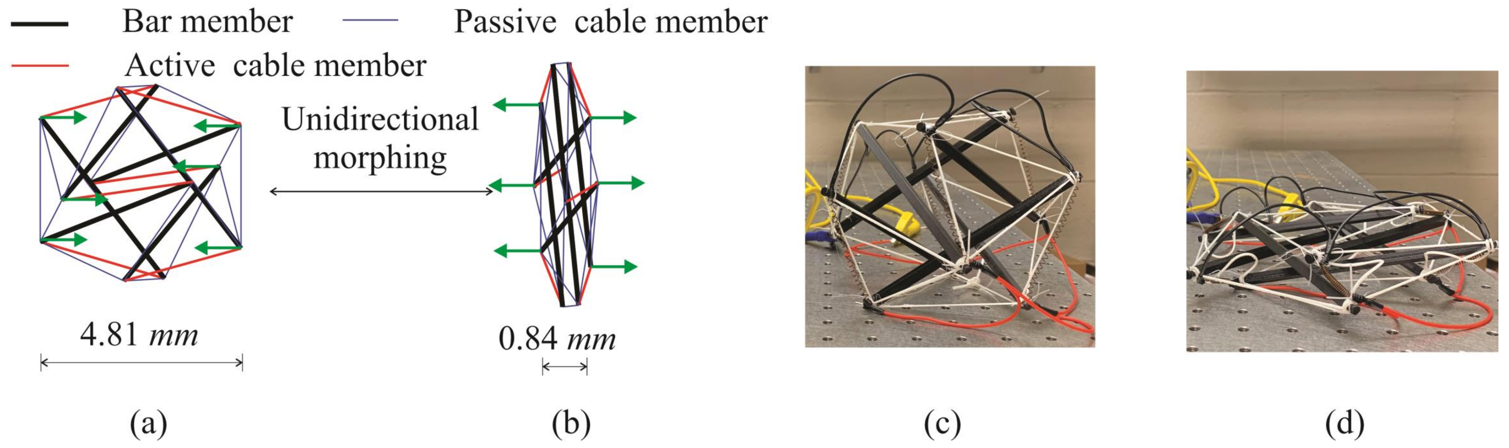

Fig 4: Optimal placement of active cable members for a reconfigurable tensegrity unit cell: (a) simulation of deployed unit cell; (b) simulation of folded unit cell; (c) deployed macro-scale prototype; (d) folded macro-scale prototype.

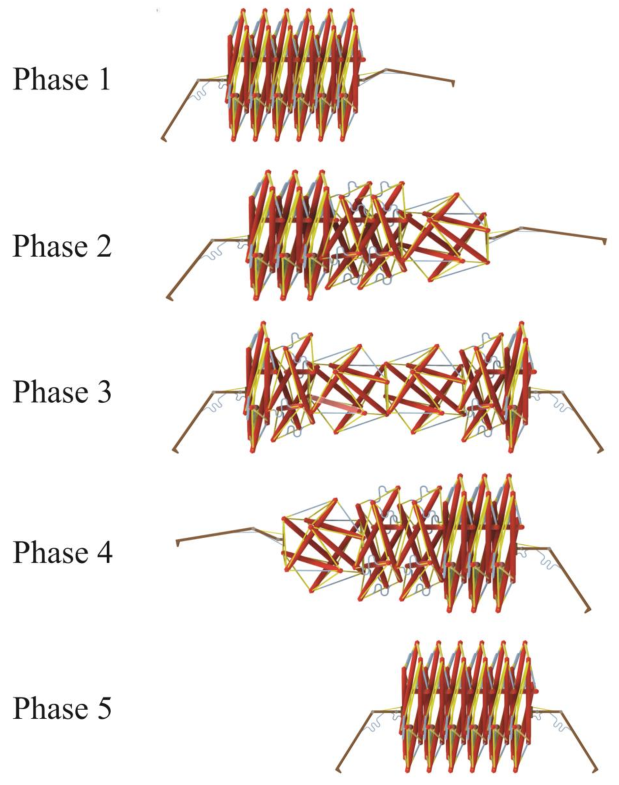

Fig 3: Locomotion planning of a tensegrity ADM.

Broader Impact (impact on society)

The research will build a solid foundation for future development of milli-scale soft robots, and will play an essential role in advancing next-generation technologies in bio-medical devices, military equipment and spacecrafts, as soft robotics are inherently interdisciplinary across broad engineering fields.

Broader Impact (education and outreach)

From the proposed research, the PI will establish cross disciplinary collaborations to form the foundation of an education program in robotics, with the focus on improving learning and retention of engineering students from historically underrepresented groups. Findings and methods of this research will be incorporated in graduate and undergraduate curricula, and K-12 outreach activities.

Broader Impact (quantify potential impact)

The scholarly contributions of this project, new methods and physical insights from synthesized experimental results, will be published in high quality journals and the proceedings of top conferences. An online and user-friendly platform for design, modeling and control of tensegrity ADMs will be created.

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