NSF: FND: COLLAB A Foundational Approach to Muscle Actuators that Lowers Barriers to Muscle-Powered Robotics Research

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Biomimetic robot muscles are actuators that closely mimic the properties of biological muscles in nature.

- Offer unique properties to safer, more compliant robot designs [1]
- large bandwidth ranges
- high power-to-weight ratios
- compact muscle-like form factors

Figure 1: (a). Dielectric elastomer actuator [2]. (b). Supercoiled polymer actuator [3]. (c). Soft fluidic actuator [4]. (d). A hexapod robot driven by piezoelectric actuators [5]. (e). A robot hand driven by SCP actuators [3].

Significant challenges for robot designers

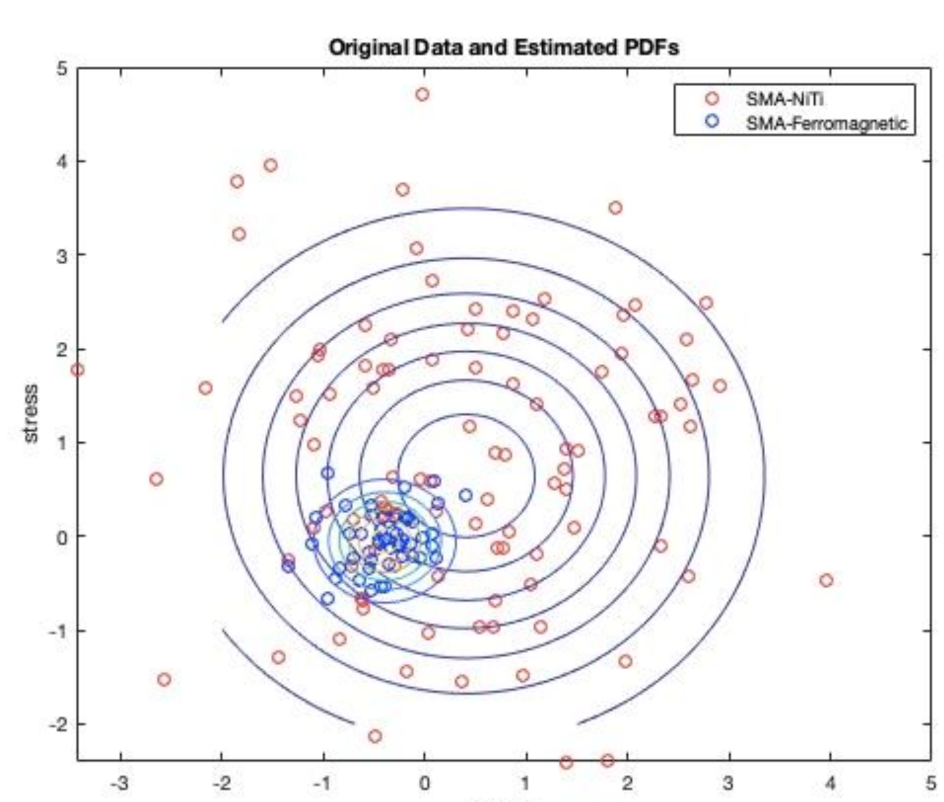
1. unclear how to select/compare actuators for use in an application
2. they exhibit significant nonlinear behaviors that require non-trivial modeling, control, and design
3. few resources available to manufacture repeatable and stable actuators and compare performance with state-of-art developments

Objectives:

- Investigate a unifying modeling and control strategy for robotic muscles.
- Characterize and catalogue artificial muscles across a range of types and underlying physical principles.
- Develop a design process and open-source platform that democratizes the fabrication, characterization/calibration, and control of robot muscles

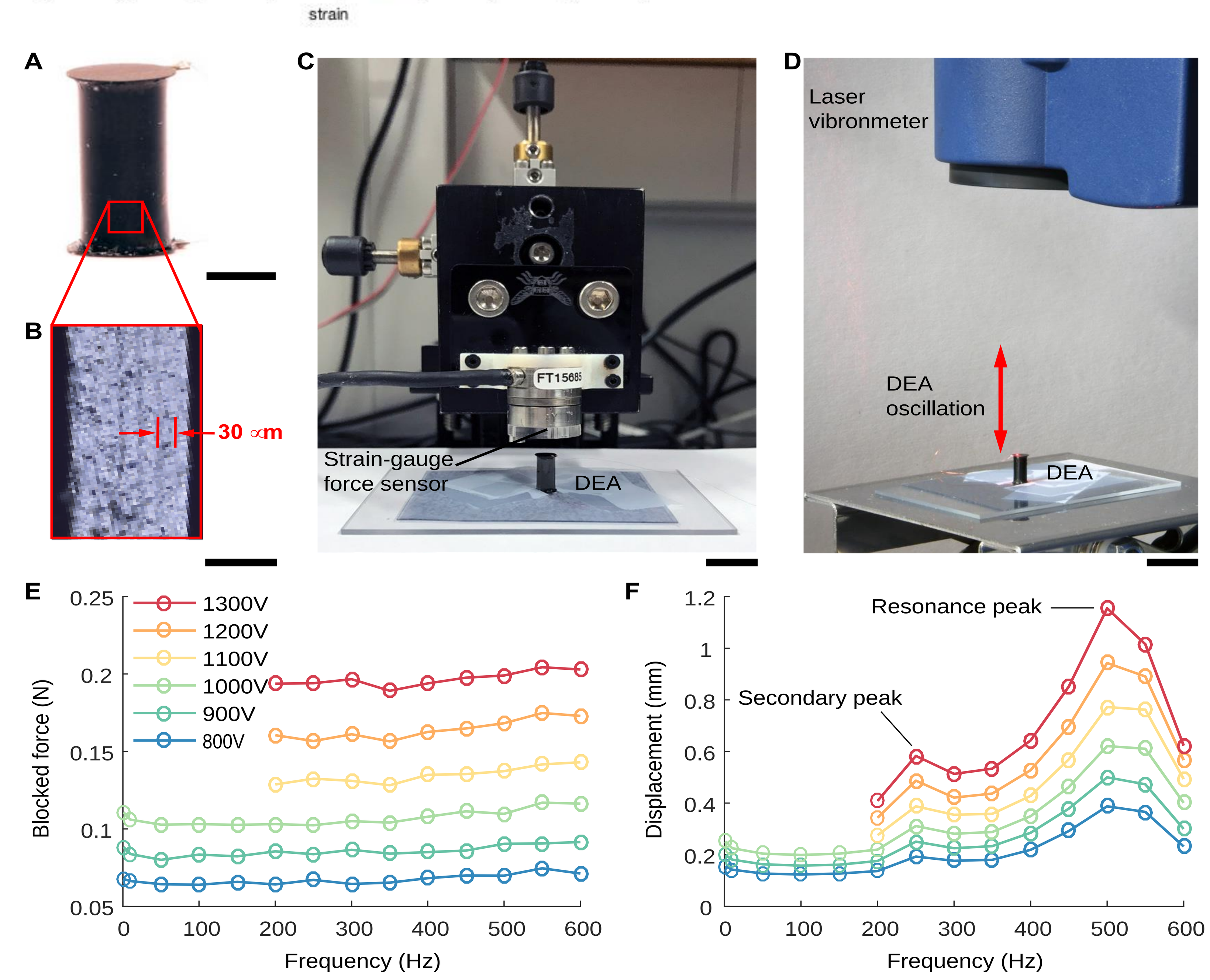
Specific Results

- Define two distinct spaces for these artificial muscle actuators:
  - **Configuration Space –** Each actuator is modeled as a GMM to account for the various configurations and forms an actuator type can take.
  - **Performance Space –** Relevant parameters of each actuator class (i.e. stress, strain, bandwidth, etc.) is then delineated using multiple SVM classifiers with an RBF kernels. (left-top figure)
- **Developed microscale DEA** and quantified performance (left figure)
  - free displacement peaks at 15% strain when it is driven at 500 Hz.
  - maximum blocked force, strain, and resonant frequency are 0.2 N, 15%, and 500 Hz.
  - The DEA energy and power density are 1.2 J/kg and 600 W/kg, comparable to natural muscles.
  - Measurements indicate the DEA can be used to power high bandwidth platforms, such as microscale flying robots.
- **Designed modular 155mg DEA-powered flapping wing robot** (Bottom figure)
  - Can generate a lift force that is 1.2 times its body weight
  - Assembles into various configurations to demonstrate various flight capabilities
  - Flies to a height of 23 cm within 0.75-second of takeoff



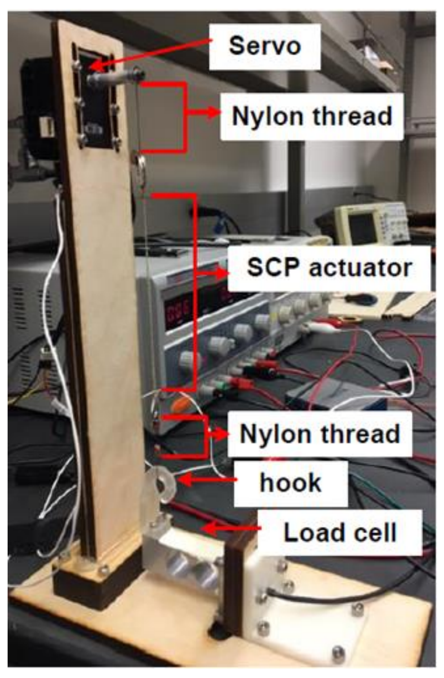
(left) Gaussian Mixture Model for two configurations of shape-memory alloy (SMA) actuators. The parameters used are stress (N) and strain (%). We can see that the pdf of the Ferromagnetic SMAs is contained within the pdf of the NiTi SMAs.

(Bottom) microscale DEA development and characterization showing comparable performance to natural muscle.



Broader Impacts

- Developed robot muscle fabrication and testing modules for accessible muscle-powered robot design/ benchmarking.
- These modules function as toolkits for various types of actuators, specifically SCP, TSA, and McKibben actuators.(right)
- Beginning HTML5 website for broadening data collection and visual parsing.



Publications:

- Y. Chen, H. Zhao, J. Mao, P. Chirarattananon, E.F. Helbling, N.P. Hyun, D.R. Clarke, and R.J. Wood, “Controlled flight of a microrobot powered by soft artificial muscles.” Nature 575, 324–329 (2019)
- J. Zhang et al., “Robotic Artificial Muscles: Current Progress and Future Perspectives”, T-RO 35 (), 761-781.
- T. Henderson, M. Yip. “Machine learning for generative design of artificial muscle-powered robots.” IROS2020. In preparation.

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