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

Michael Yip [1], Robert Wood [2]
[1]University of California San Diego, [2]Harvard University
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Introduction

- ➢ Biomimetic robot muscles are actuators that closely mimic the properties of biological muscles in nature.
- ➢ These technologies have covered a varied range of configurations, including:
  - **- shape-memory alloys (SMAs)**
  - **- dielectric elastomers (DEAs)**
  - **- super-coiled polymers (SCPs)**
  - **- piezoelectric actuators (PZTs)**
- ➢ They offer unique properties valuable in realizing compliant, compact, and safe robot designs and operation [1]:
  - **- controlled compliances**
  - **- large bandwidth ranges**
  - **- high power-to-weight ratios**
  - **- compact muscle-like form factors**
- ➢ Widespread use in robot systems and machines has been limited due to significant challenges for robot designers to overcome:

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

We are then motivated to investigate a unifying modeling, control, and design strategy for robot muscles that could lower the barrier to muscle-powered robotics research.

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].

Objectives and Methods

Objectives:

- Develop open-source platform that democratizes the fabrication, characterization/calibration, and control of robot muscles
- Investigate a unifying modeling and control strategy for robotic muscles.
- Improve performance / ease of construction of DEA-based, SCP, SMA, TSA, and pneumatic artificial muscles.
- Characterize and catalogue artificial muscles across a range of types and underlying physical principles.
- Apply these muscle-like actuators to unique devices that exploit their features and behaviors.

Methods:

- Implement multiple methods for data-driven selection and design of muscle-actuated biomimetic robots.
- Adapt techniques for multi-scale muscle-like actuators with more refined process steps.
- Develop easy-to-use and reproducible fabrication and testing modules for SCP, TSA, and McKibben actuators.
- Characterize piezoelectric and DEA artificial muscles and apply them to platforms requiring high energy density and bandwidth.

Specific Results

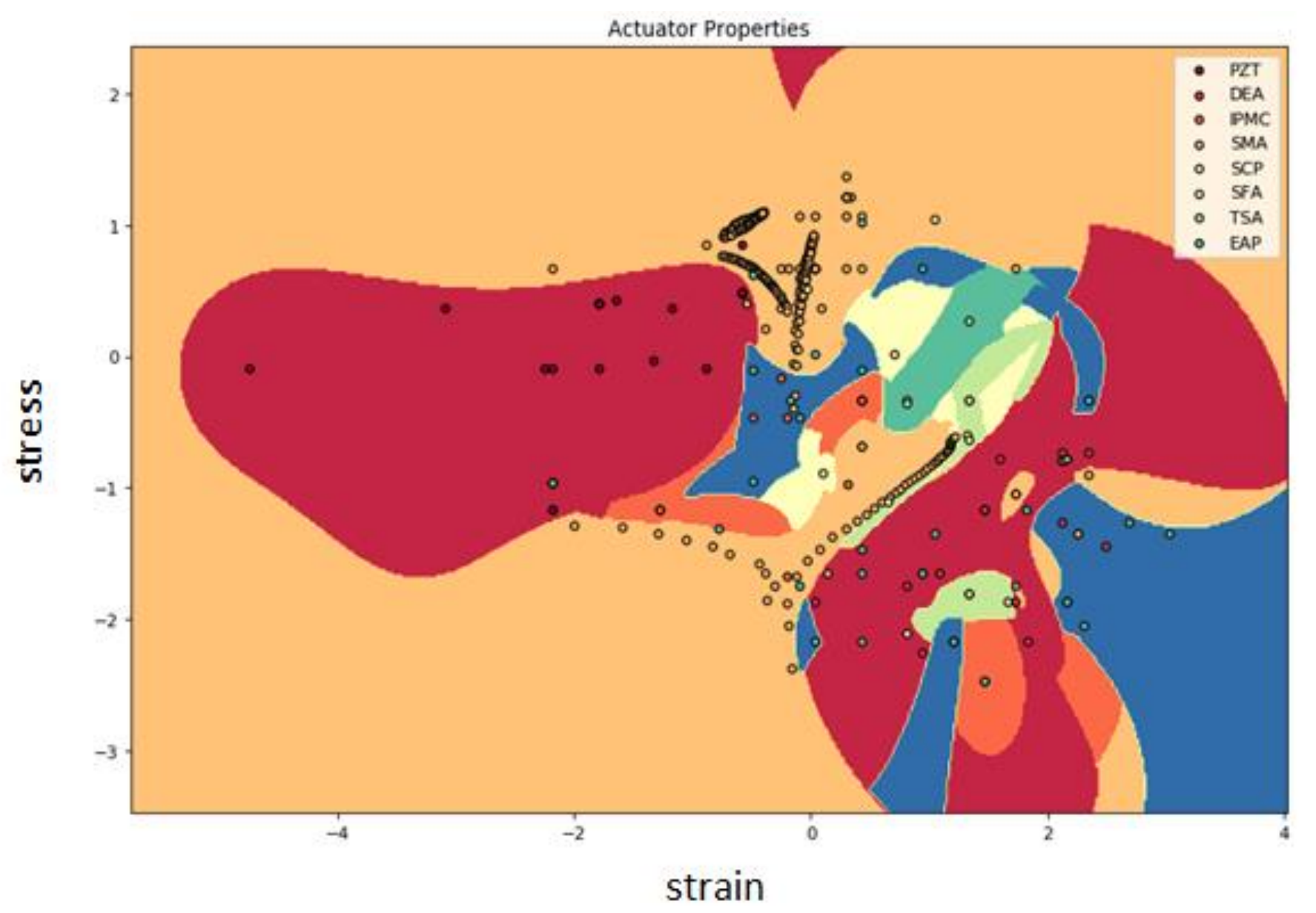

Figure 3: *Two performance spaces are displayed (stress, strain) with actuators compared. The method uses multiclass nonlinear SVM. Many performance spaces are logarithmic because of large differences in range.*

Several machine learning models evaluated for comparing actuators:

- multivariate SVM classifier with an RBF kernel and softmax to find separating boundaries of actuators
- 679 data points so far (over many hundreds of journal papers) across 8 types of actuators and 5 parameters
- Implementing data-imputation to solve for missing data

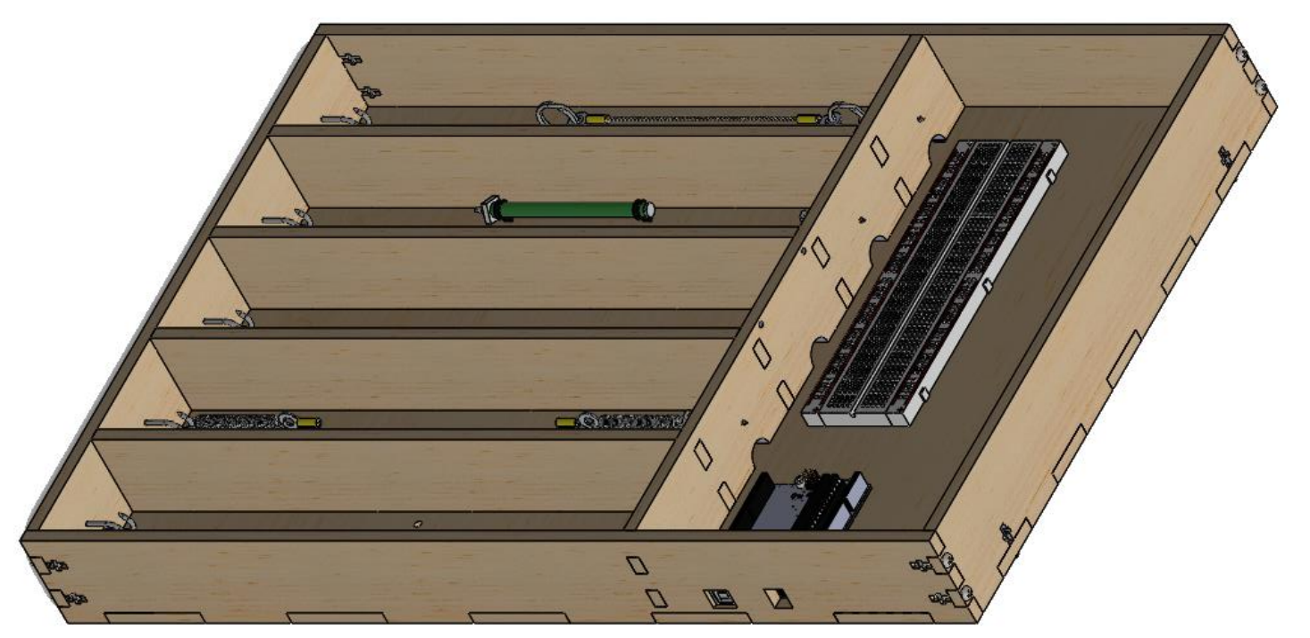

Figure 3: *Toolkit designed with SMA, SCP, Mckibbon, Twisted String, and DEA actuators on one test platform*

Hands-on toolkits:

- Toolkit designed for hands-on learning for multiple robot actuation types

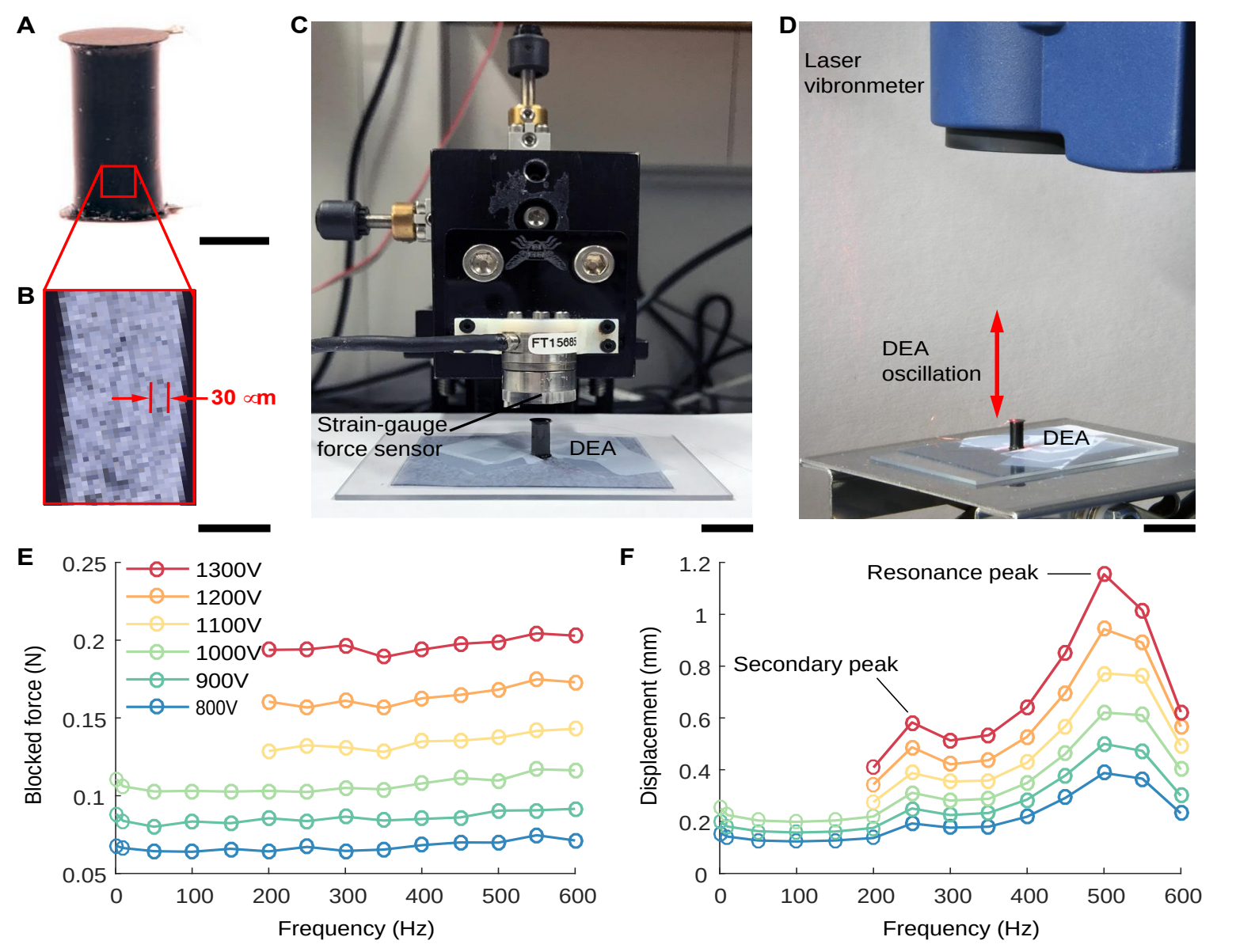

Figure 4: *DEA characterization.* ***A****, Front view of a DEA. Scale bar represents 3 mm.* ***B****, Confocal microscopy image of the DEA's cross section. The elastomer sheet is 220 μm thick and it has seven elastomer layers. The thickness of the top and the bottom layers are approximately 65% of the middle layers. Scale bar represents 100 μm.* ***C****, Experimental setup for measuring the DEA's blocked force. A Nano 17 Titanium force sensor is lowered until it touches the DEA's top cap.* ***D****, Experimental setup for measuring the DEA's free displacement. A laser vibrometer measures the DEA's oscillation velocity. Scale bars in C and D represent 1 cm.* ***E****,* ***F****, Measured DEA blocked force (E) and free displacement (F) as functions of operating frequency and voltage amplitude.*

- In addition, we have developed a microscale DEA and quantified its performance including:
- blocked force, free displacement, and energy and power density.
- The DEA's free displacement peaks at 15% strain when it is driven at 500 Hz.
- Experiments show the 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.

We have applied DEAs to the control of fluidic actuation systems by creating one of the first DEA-based fluidic valves (Fig. 5).

- ***Fluidic actuators are widespread in soft and bioinspired robots***
- ***Control of fluid flow to pressurize and control actuator motion has primarily relied on traditional rigid, bulky, power-hungry valves and regulators***

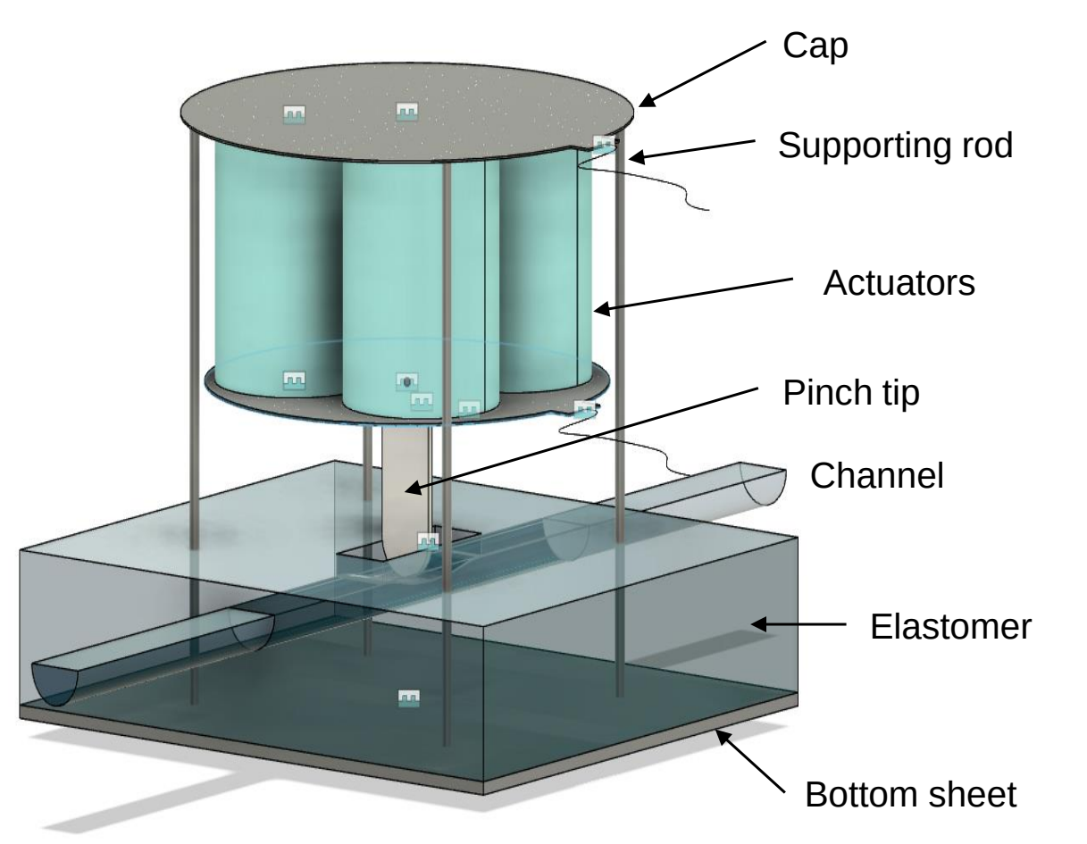

Figure 5: *Design of a DEA-based soft valve that consists of a fluidic channel embedded in an elastomer matrix, a rigid indenter, and a multi-DEA actuation mechanism that controls the flow within the channel when activated.*

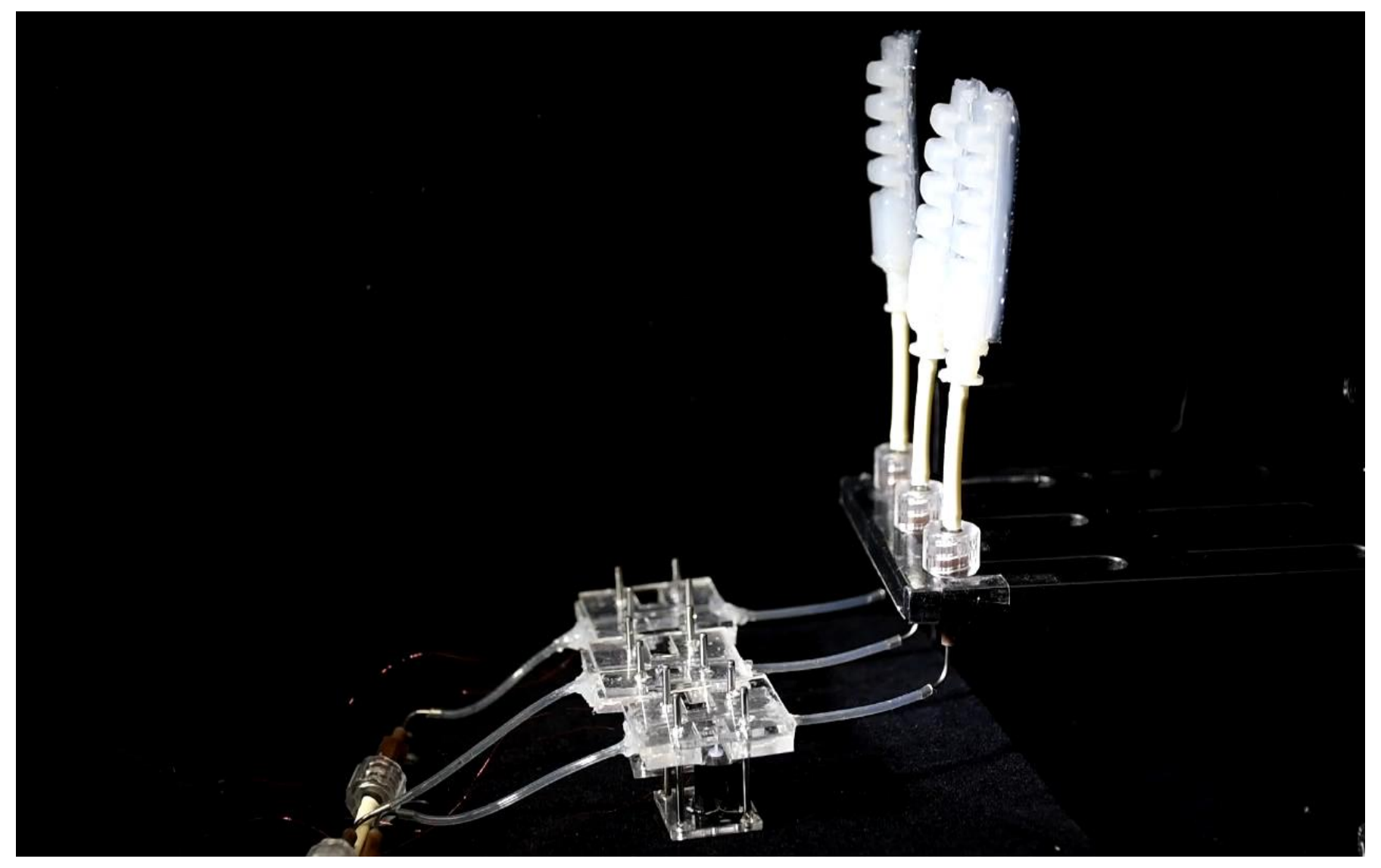

Figure 6: *Operation of three DEA valves, each controlling flow to separate fluidic actuators.*

- A DEA-based valve has been developed and used to control fluidic soft actuators, leveraging the maturity and high performance of fluidic soft actuators and the high energy density and bandwidth of DEAs.

Key Outcomes and Future Work

- Many technologies exist for artificial muscles, but typically exist as research prototypes.
- No universally accepted metrics for performance; therefore, no comprehensive reporting on common properties.

Key Outcomes:

- Multi-dimensional modeling strategy using performance and configuration spaces
- EM method for actuation selection
- Data imputation method for missing data

- Further DEA process development and characterization
- Creation of a new DEA-based fluidic valve and integration into demonstrations of controlling fluidic artificial muscles using electrically-activated DEAs.
- Demonstration of piezoelectric artificial muscles: integration of high performance piezoelectric artificial muscles into a compact surgical laser steering device.

Future Work:

- Data imputation evaluation, and use for driving design of new actuator
- Integrate DEA valve into wide array of fluidic actuator types, sizes
- Continue development of toolkit modules and website
- Develop a quantitative categorization of numerous classes of artificial muscles

Publications:

S. Xu, Y. Chen, N.-S. P. Hyun, K.P. Becker, and R.J. Wood, "A dynamic electrically-driven soft valve for control of soft hydraulic actuators," In preparation.

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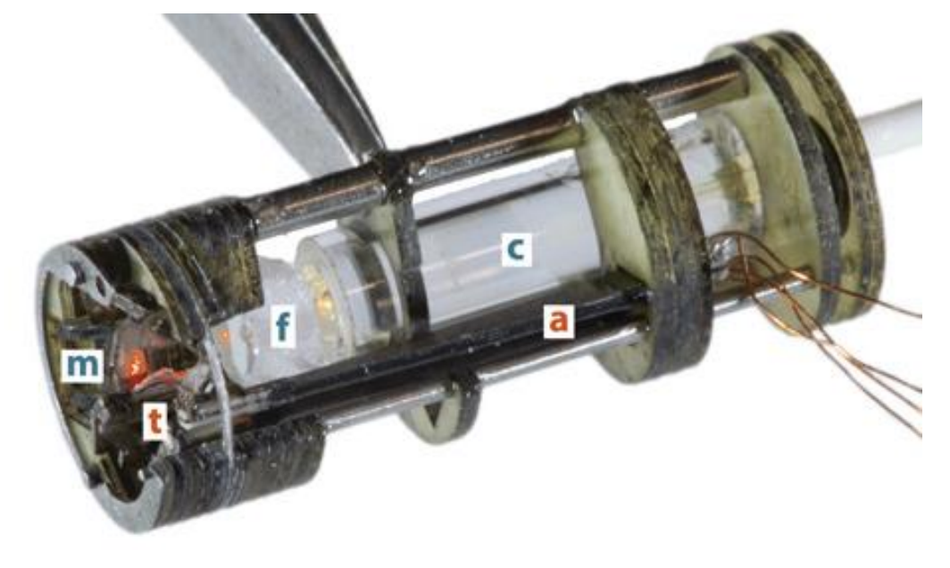

Figure 7: *Example outcome of high performance artificial muscles: the creation of a piezoelectric laser-steering compact (6mm diameter) surgical tool.*

References

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