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**RPPR Final Report**  
as of 03-May-2022

Agency Code:

Proposal Number: 70364SDICR

**Agreement Number: W911NF-17-1-0097**

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**Final Report** for Period Beginning 01-Feb-2017 and Ending 31-Jan-2018

**Title:** Stretchable Transducers for Haptic Communication in Augmented and Virtual Reality

**Begin Performance Period:** 01-Feb-2017

**End Performance Period:** 31-Jan-2018

**Report Term:** 0-Other

Submitted By: Robert Shepherd

Email: rfs247@cornell.edu

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**Distribution Statement:** 1-Approved for public release; distribution is unlimited.

**STEM Degrees:** 0

**STEM Participants:**

**Major Goals:** This project aims to use the business model canvas and customer discovery to explore the viability of stretchable transducers for haptic interfaces in augmented and virtual reality.

**Accomplishments:** We interviewed >100 potential customers and developed our hypothesis that consumers want to experience haptic sensation for greater immersion in AR/VR. The outcome was that VR is quite early and haptics is not needed at the consumer level in the short term. There are opportunities in Enterprise solutions such as automotive design. Ideally, our stretchable transducers would be electrically powered directly and not via a pump. Based on these outcomes, our research has pivoted towards electrical solutions such as DC motor driven tendons, or more energy efficient fluid systems that do not require large pumps.

**Training Opportunities:** Nothing to Report

**Results Dissemination:** Nothing to Report

**Honors and Awards:** Nothing to Report

**Protocol Activity Status:**

**Technology Transfer:** Nothing to Report

**RPPR Final Report**  
as of 03-May-2022

**Partners**

,

I certify that the information in the report is complete and accurate:

Signature: Robert Shepherd

Signature Date: 5/2/22 12:02PM

Project Summary - W911NF-17-1-0097  
(Reporting Period: 01 February 2017 - 31 January 2018)

Stretchable Transducers for Haptic Communication in Augmented and Virtual Reality \_

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Sibley School of Mechanical & Aerospace Engineering  
Cornell University, Ithaca, NY 14850

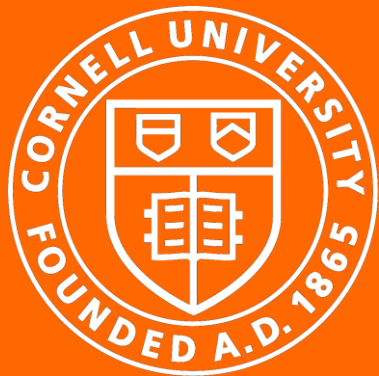
**Objective**

This project aims to use the business model canvas and customer discovery to explore the viability of stretchable transducers for haptic interfaces in augmented and virtual reality.

**Outcome**

We interviewed >100 potential customers and developed our hypothesis that consumers want to experience haptic sensation for greater immersion in AR/VR. The outcome was that VR is quite early and haptics is not needed at the consumer level in the short term. There are opportunities in Enterprise solutions such as automotive design. Ideally, our stretchable transducers would be electrically powered directly and not via a pump. Based on these outcomes, our research has pivoted towards electrical solutions such as DC motor driven tendons, or more energy efficient fluid systems that do not require large pumps.

A Powerpoint slideshow summarizing our efforts and pivots can be seen here:  
<https://drive.google.com/open?id=1oCCkn0xfSUK19cB3eAMeMXPjFCoEiC9T>



organic robotics lab™

## Stretchable Transducers for Augmented/Virtual Reality



~0.2  
MJ/kg -  
system

~300 L  
min<sup>-1</sup>

~0.15 L/g

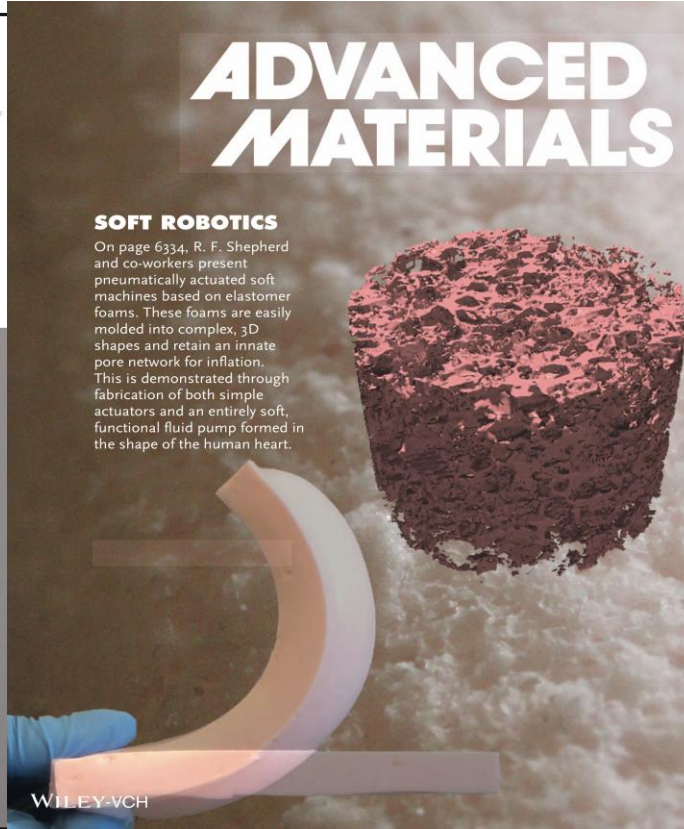
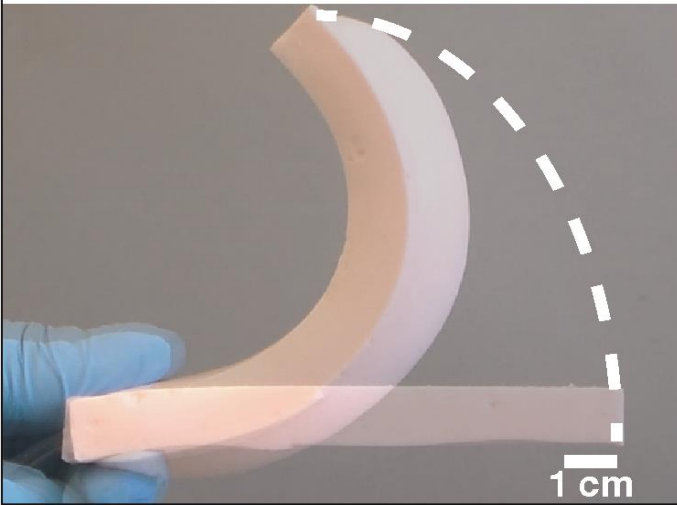
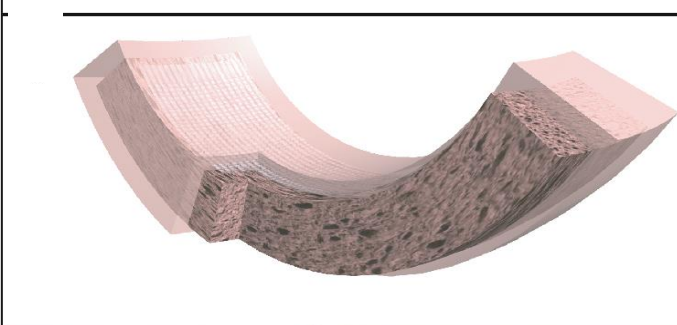
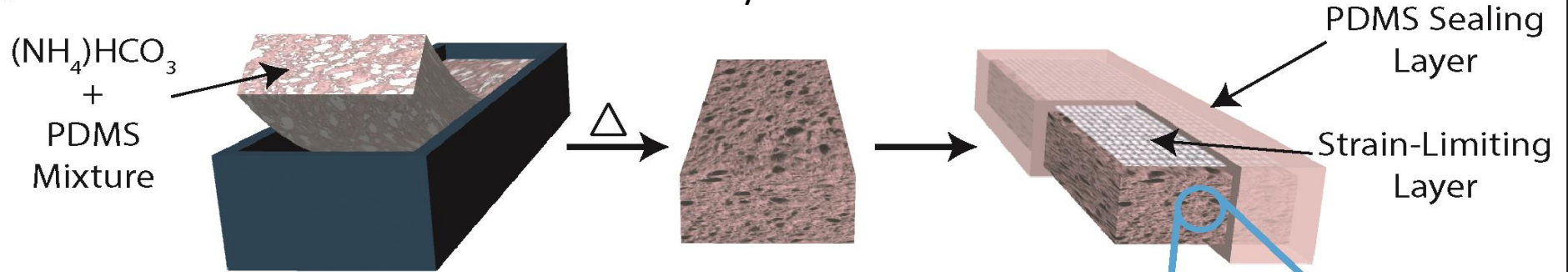
Mosadegh et. al Adv. Fun. Mat. (2014)



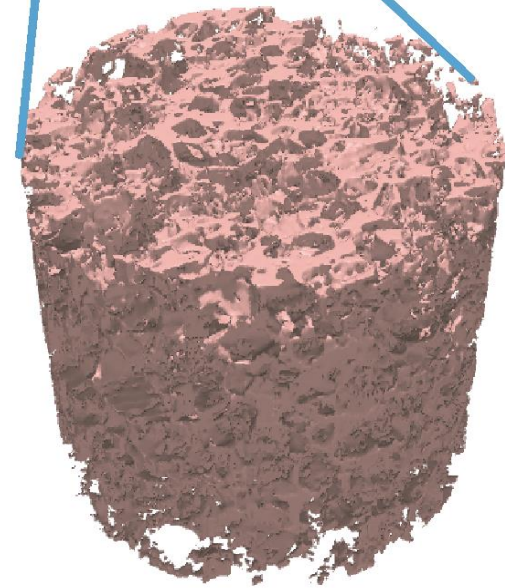
# Elastomeric foam actuators for injection molding of complex artificial muscle

\*Mac Murray et al. Adv. Mat. 2015

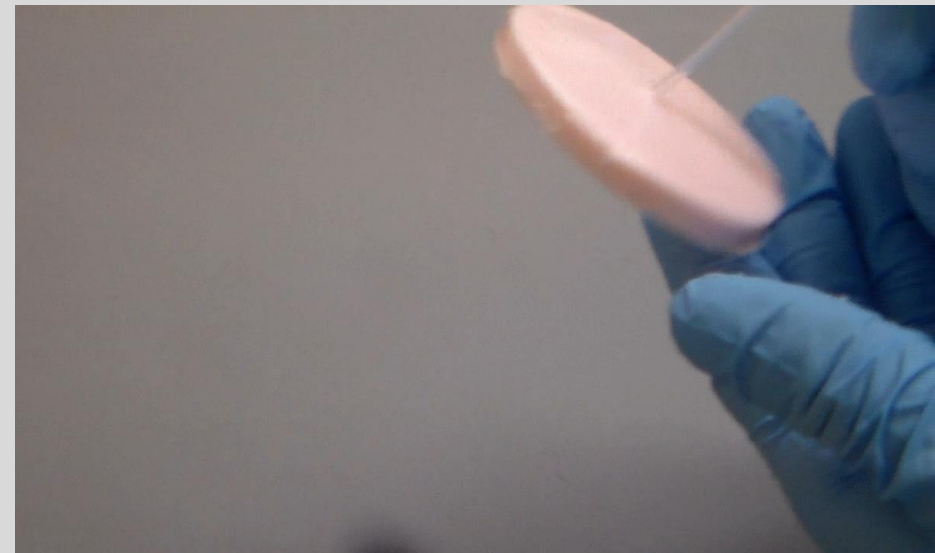
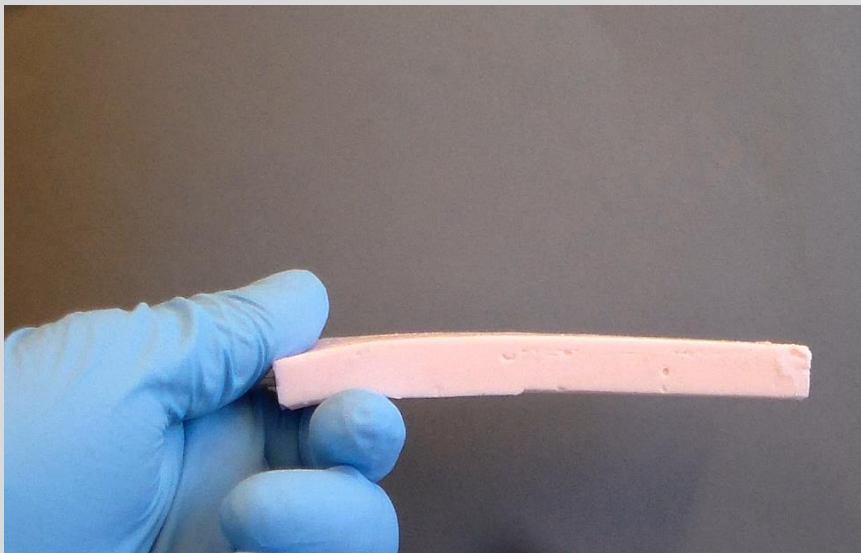
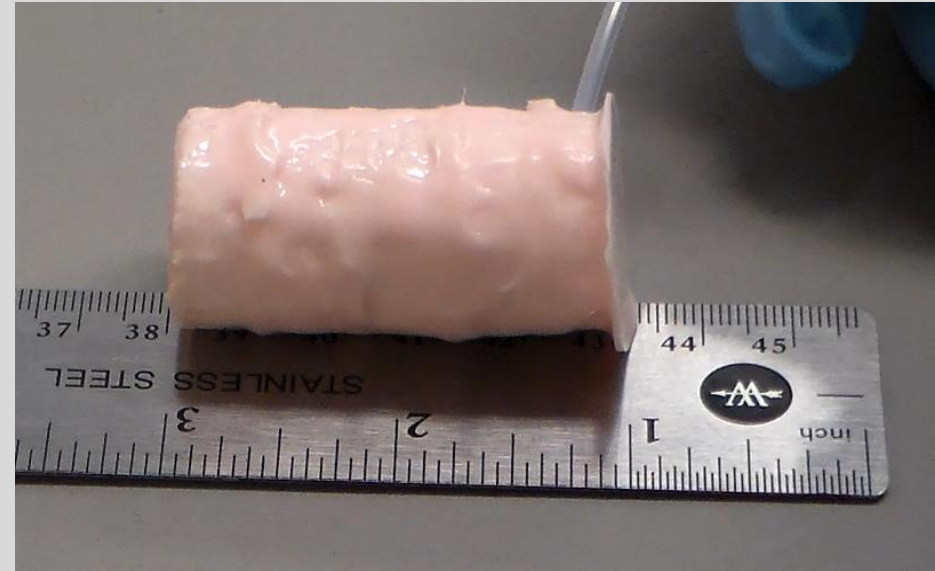
a



d



# Simple foam actuators

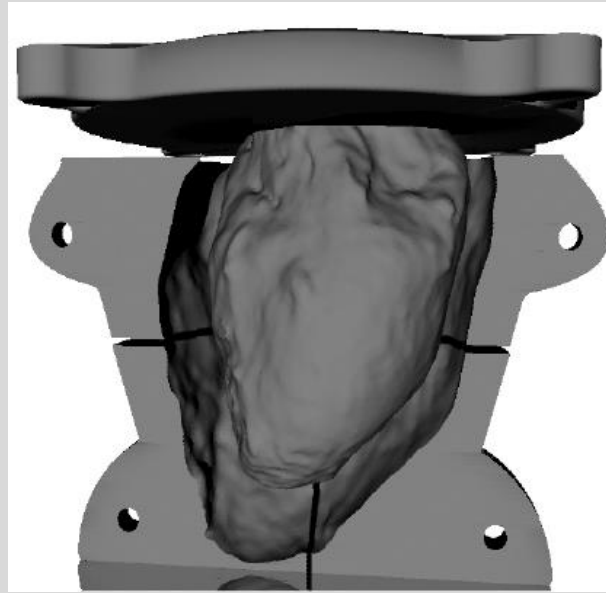




# Complex soft machine from foam actuators



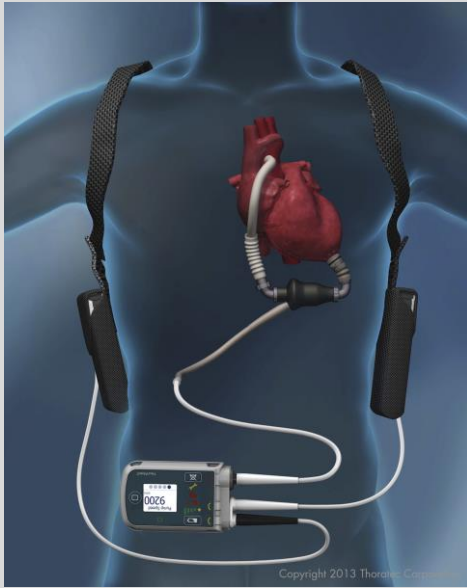
Pig heart



\*Mac Murray et al. unpublished  
Provisional IP filed

# Towards Ventricle Assist Devices

Present State of the Art



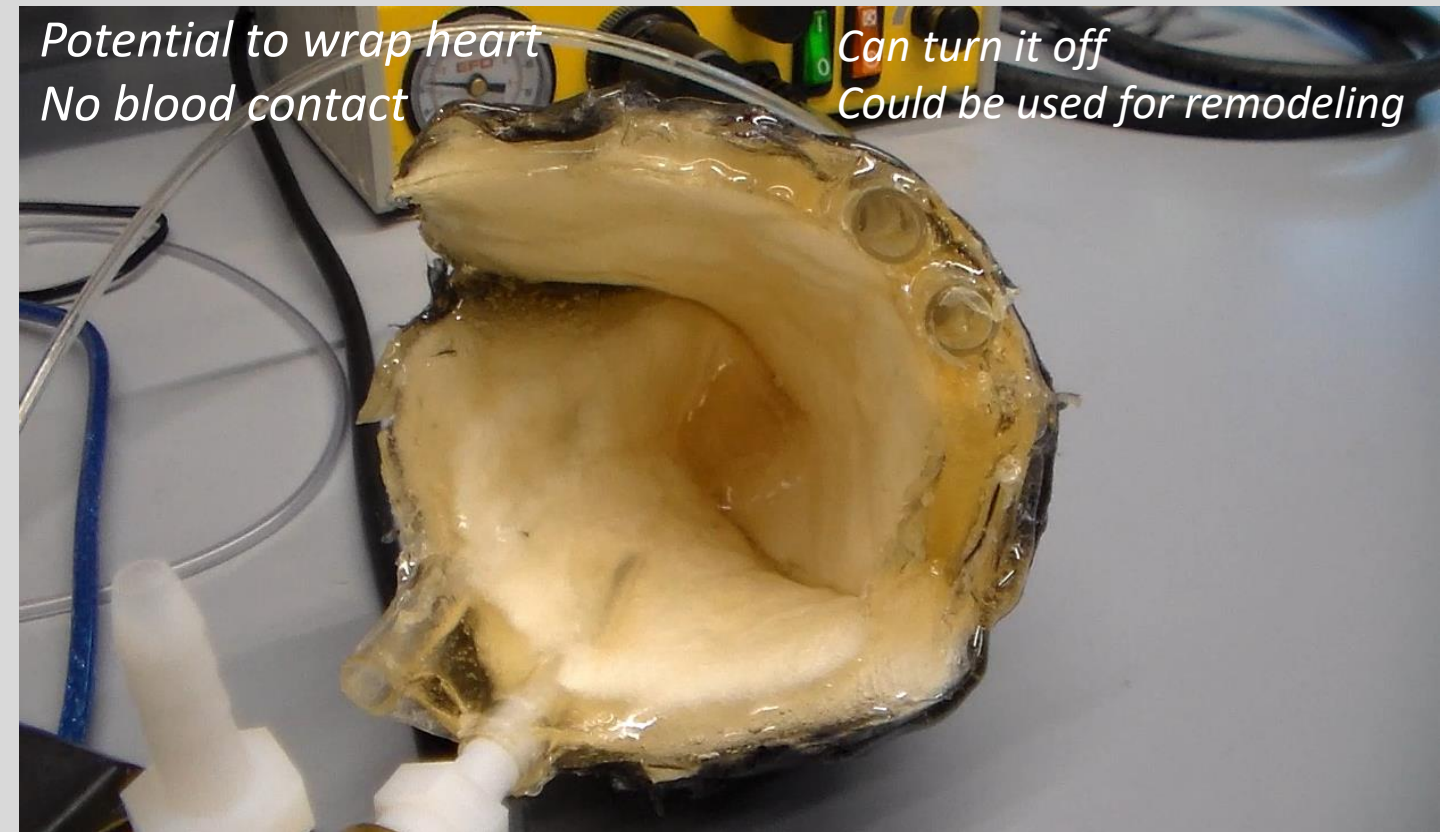
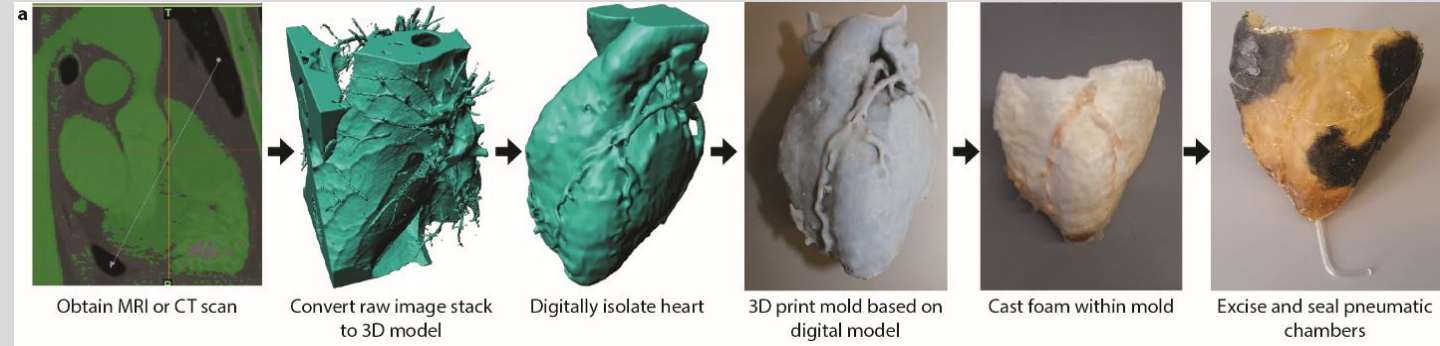
Heartmate II  
Thoratec, Inc.

*Highly invasive*

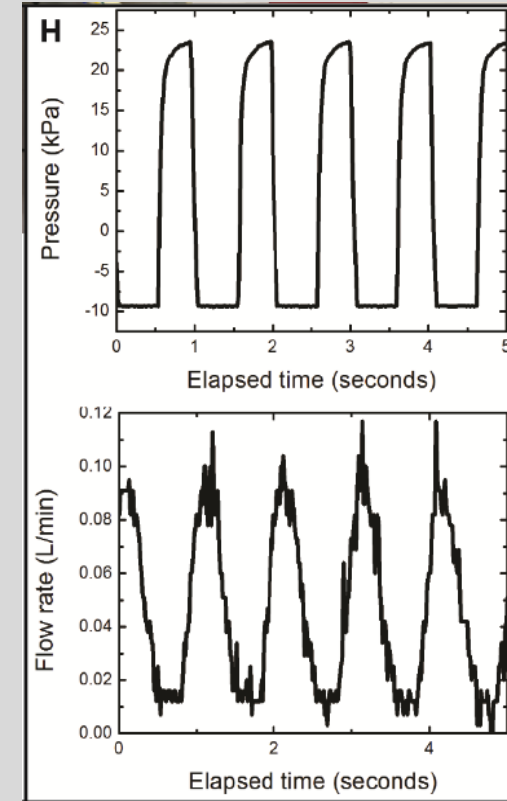
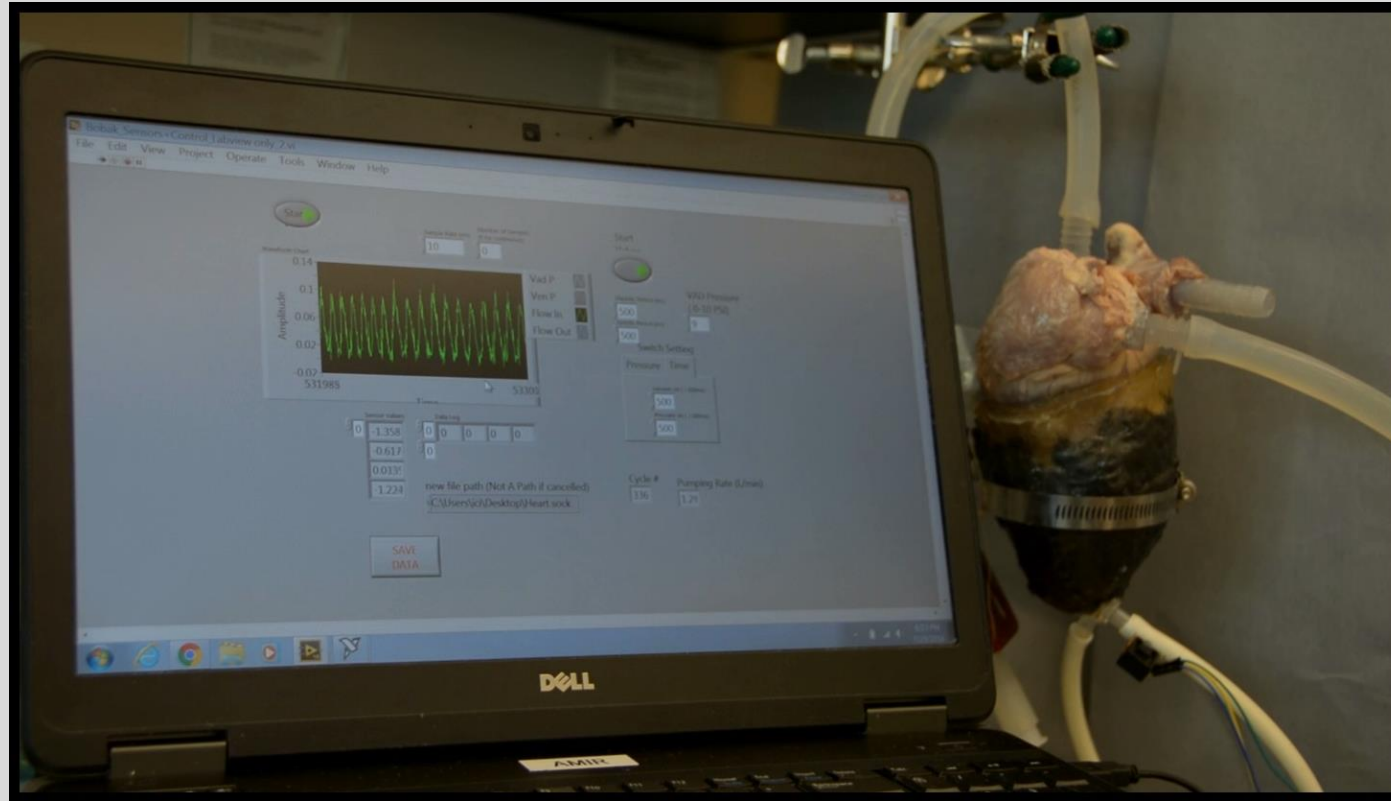
*Clotting issues*

*Turning it off is  
not good*

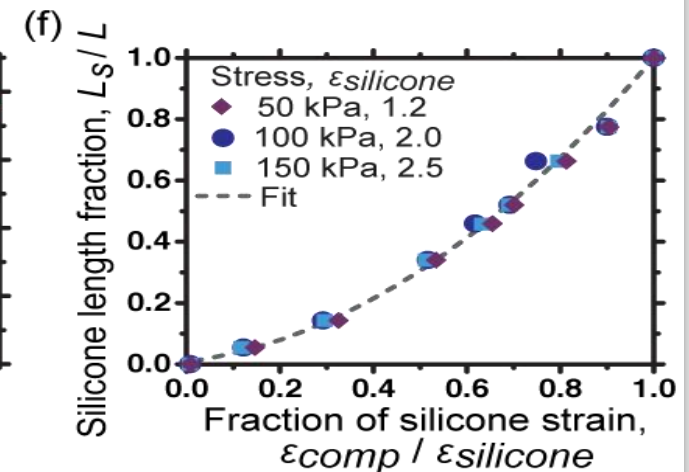
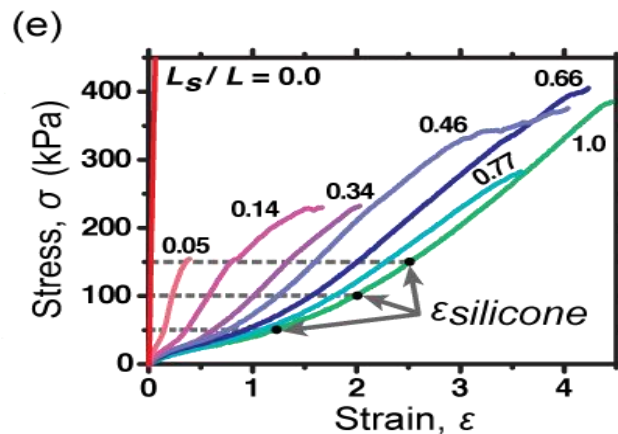
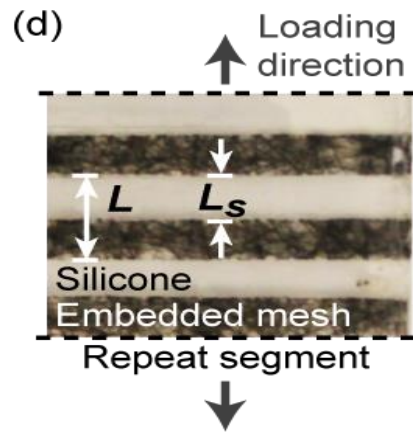
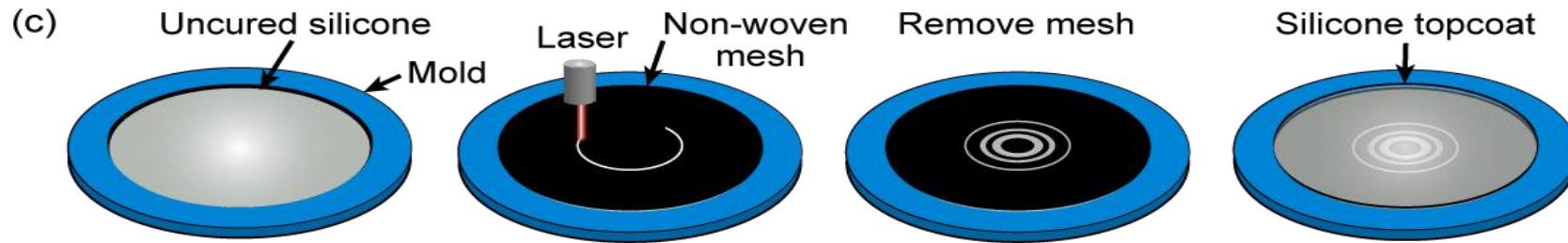
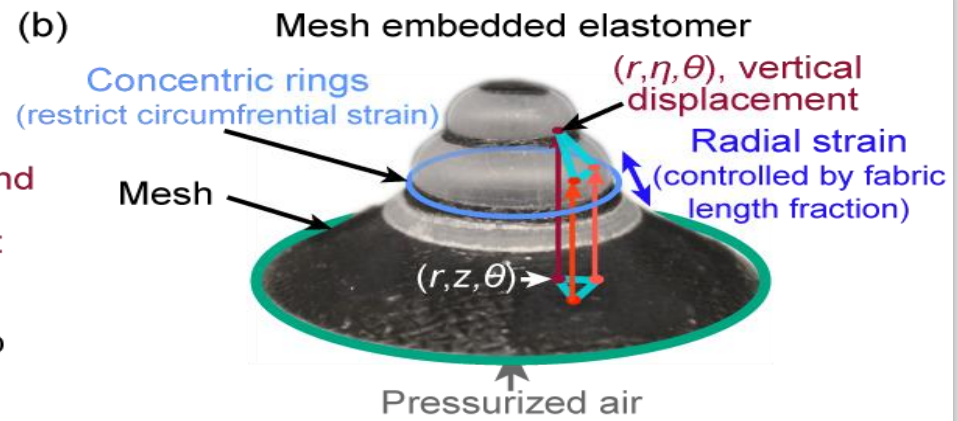
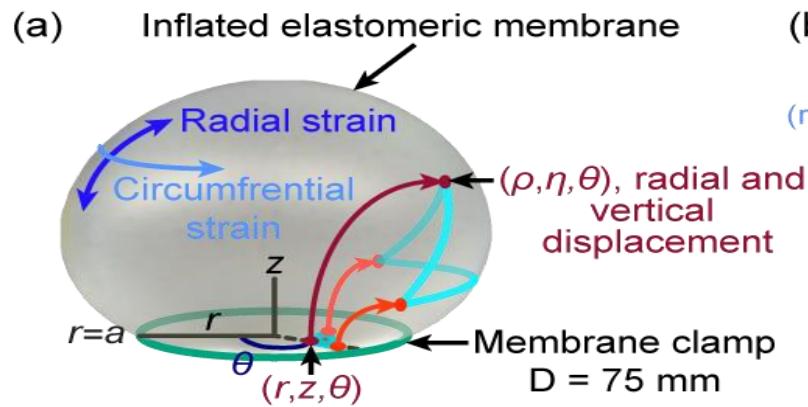
Potential for minimally invasive soft foam assist devices



# Device Demonstration on Pig Heart at Weill Cornell



Pneumatic Pressure of Foam Chamber and Flow Rate of Pumped Water



\*Pikul J et al., In Preparation

$$e_r = \left( \frac{\frac{dr^2}{dr} + \frac{dh^2}{dr}}{1 + \frac{dz^2}{dr}} \right)^{1/2} - 1 \quad e_c = \frac{r}{r} - 1 \quad e_r = \left( 1 + \frac{dh^2}{dr} \right)^{1/2} - 1$$

# Texture Displays for Non-Spherical Fluidic Actuation



# Outline:

1. Motivation
2. OmniPulse
3. Variable-stiffness controller
4. Next steps

# Outline:

1. Motivation

2. OmniPulse

3. Variable-stiffness controller

4. Next steps

# A Brief History of Game Controllers



**Atari 2600**

1977



**NES**

1985



**Nintendo 64**

1996



**XBox**

2001



**PlayStation Move**

2010



**HTC Vive**

2016



**Sega Genesis**



1989

**PlayStation DualShock**



1998

**PlayStation**



1995

**Wii**



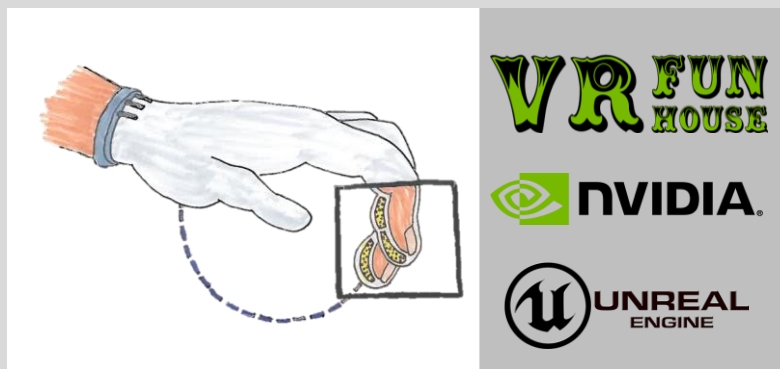
2006

**Oculus Touch**

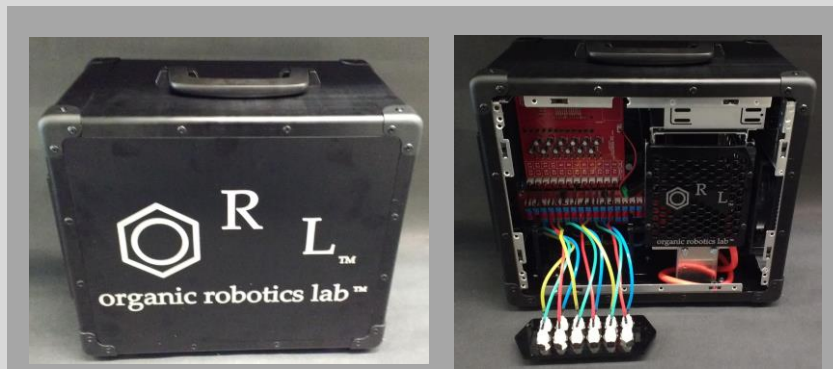


2016

# Technology Platform



**Software**



**Fluidic Controller**



**Human Interfaces**



**OmniPulse**      **Soft Controller**

# Outline:

1. Motivation

2. OmniPulse

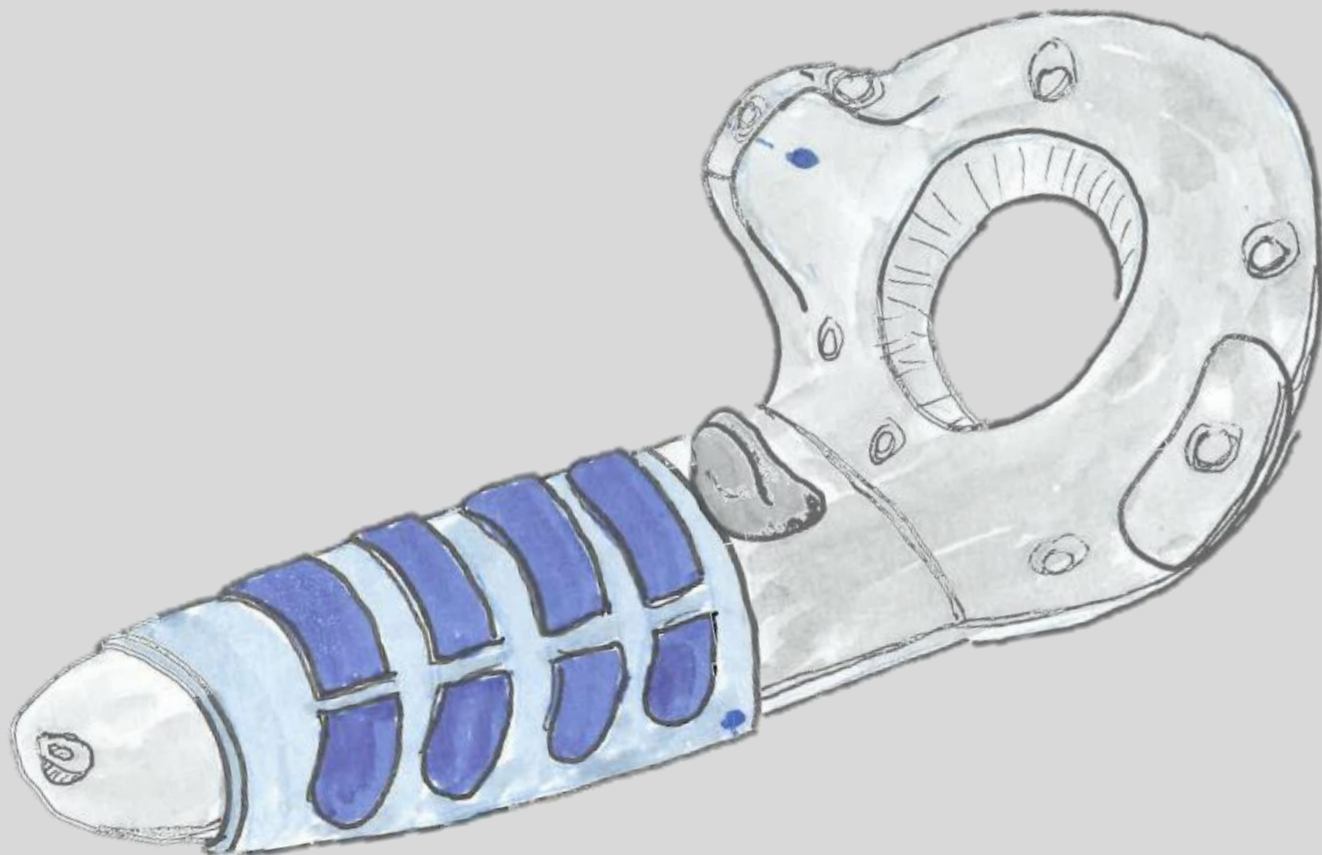
3. Variable-stiffness controller

4. Next steps

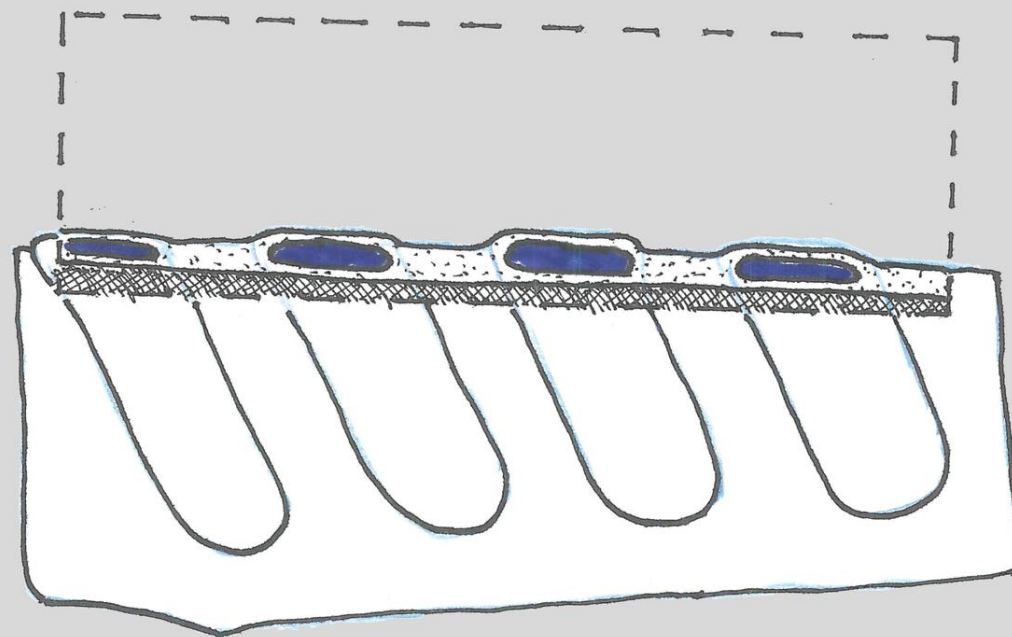
# Haptic feedback design challenges:

1. High force actuators
2. Many degrees of freedom
3. Scalable manufacturing

# Fluidic Elastomer Actuators (FEAs) for haptic feedback



Rubber sleeve with many actuators



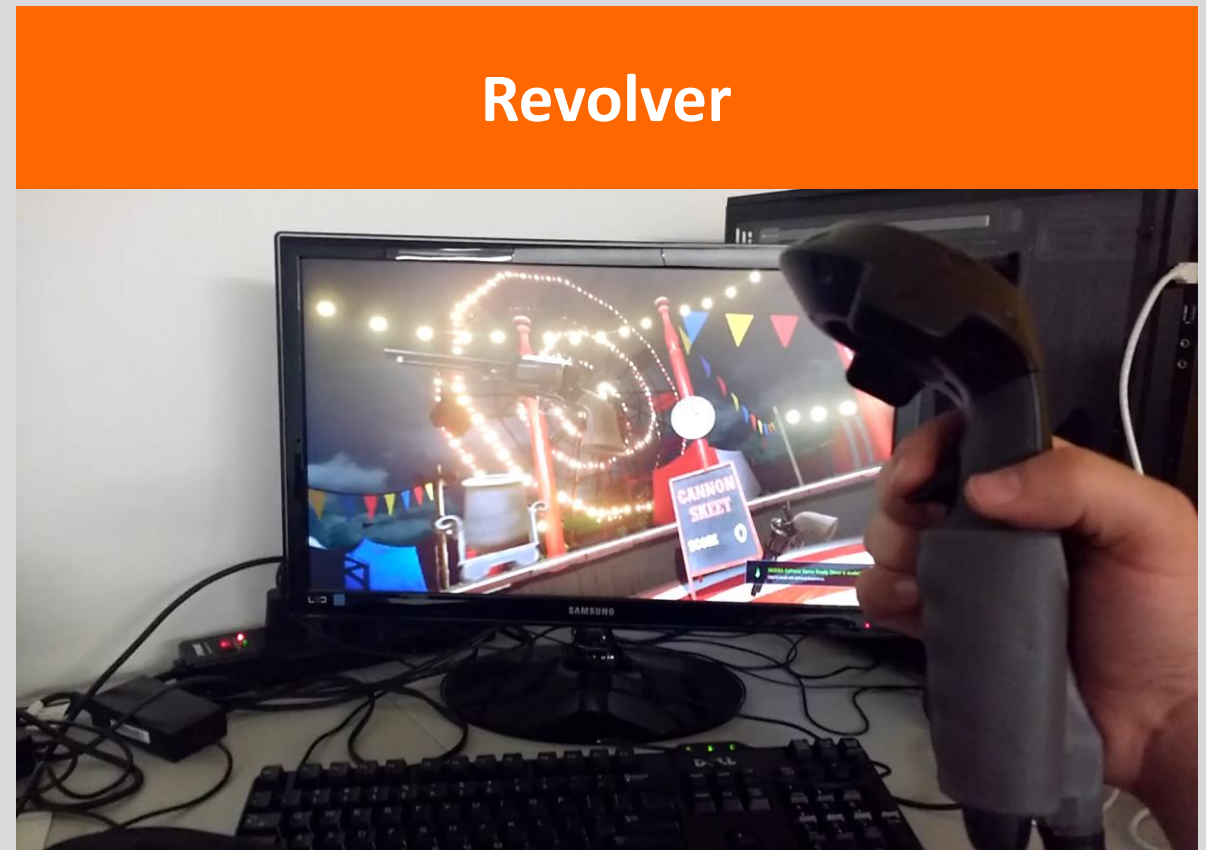
Independent control



# Integration with NVIDIA's VR Funhouse

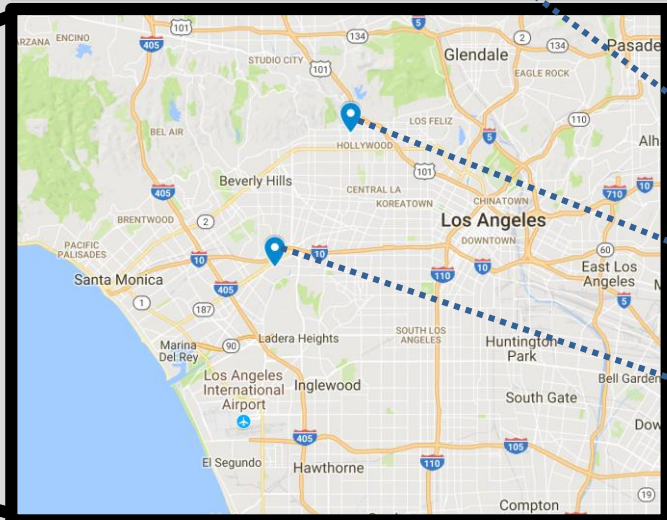
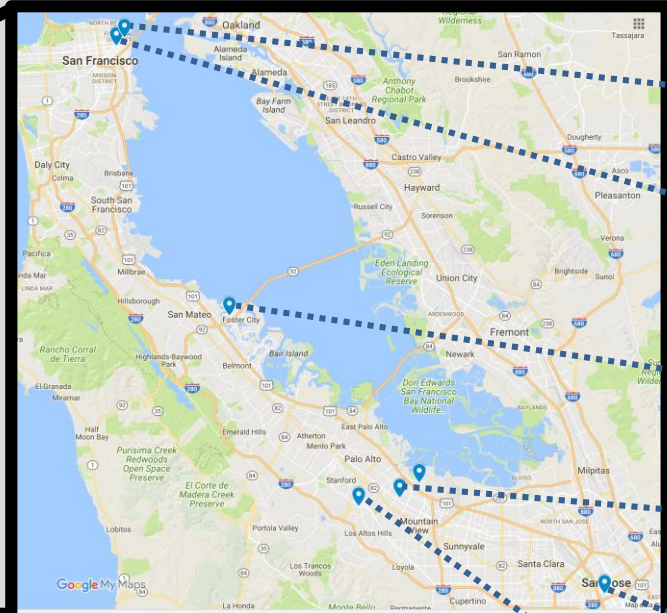
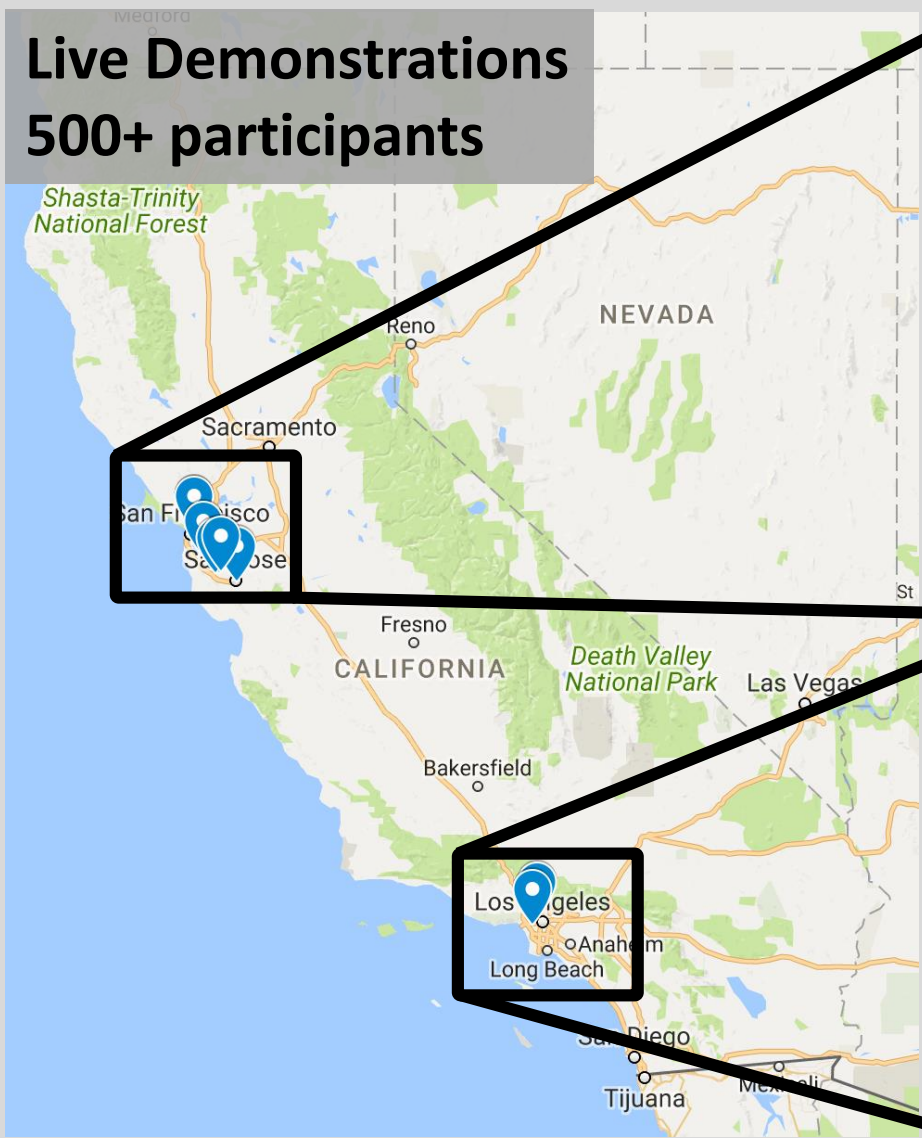


**Goo Gun**



**Revolver**

Live Demonstrations  
500+ participants



**This soft rubber sleeve has  
12 in**



# Outline:

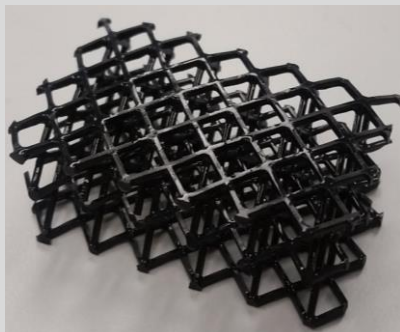
1. Motivation

2. OmniPulse

3. Variable-stiffness controller

4. Next steps

# Shape-shifting, variable compliance controllers



## Shape-shifting, variable compliance controllers



# Outline:

1. Motivation

2. OmniPulse

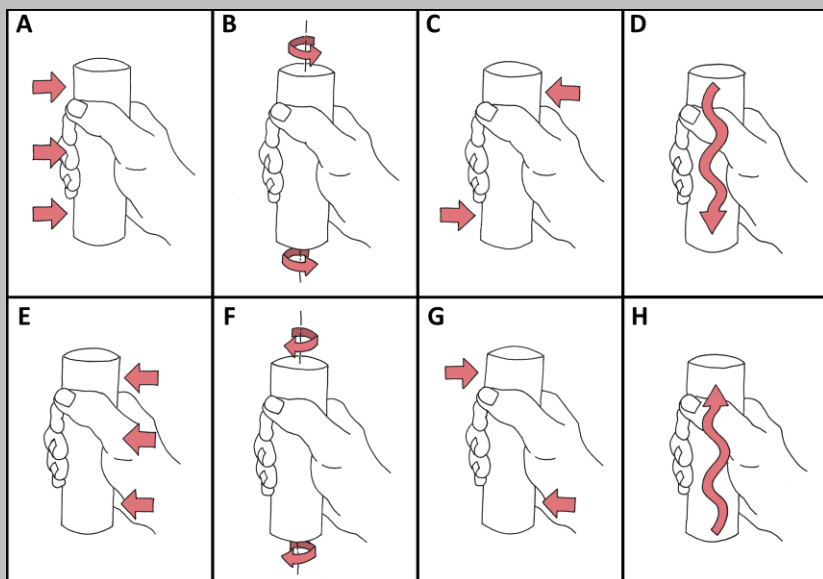
3. Variable-stiffness controller

4. Next steps, learned from I Corps

# Next steps

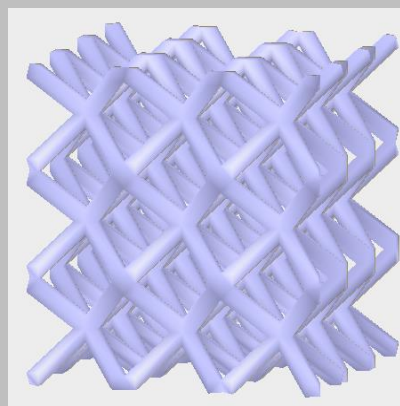
## OmniPulse

- Collaborating with Houston Claire and Malte Jung to develop user study:
  - Document the capabilities of FEA-driven haptic feedback
  - Quantify impact on user experience

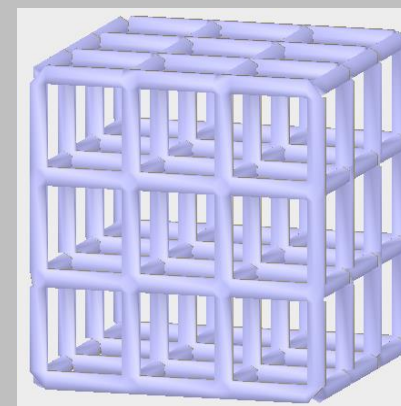


## Variable-stiffness controller

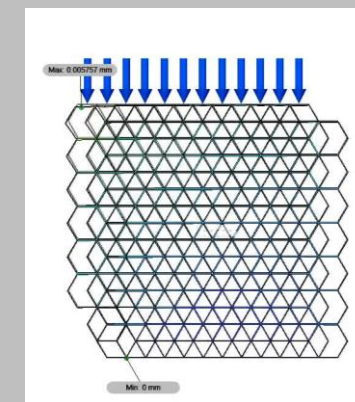
- Increase the stiffness range of the controller by systematically exploring variations to the internal lattice.
  - **Objectives:**
    1. Create a more compliant structure in the unpressurized state
    2. Maintain shape while pressurized to higher pressure.



BCC



Simple Cubic



# Next steps

## Tendon Driven Actuator

- Electrically powered actuator that does not require air compressors, liquid CO<sub>2</sub> cartridges, or other cumbersome approaches for fluidic actuation



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