Soft Robotics

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MIT Splash 2022

Contents

About Me

Happy to chat about my experiences, going from high school to college, and more!

- Grew up around Boston
- Actually attended Splash when I was your age! As well as Spark when I was in middle school
- Went to Tufts for my degree in Computer Science
- Then did a Masters in Medical Robotics at Imperial College London
- Now doing my PhD in Mechanical Engineering at Boston University
- Hobbies: learning languages, D&D, sci-fi and fantasy, photography

London

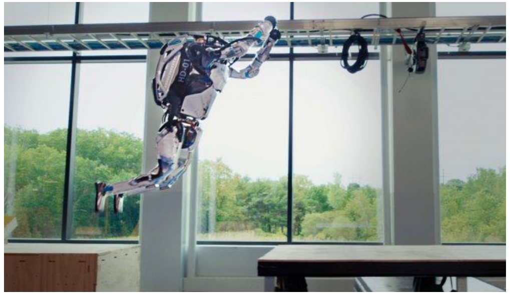
Boston

Robots

- “A robot is an autonomous machine capable of sensing its environment, carrying out computations to make decisions, and performing actions in the real world.”

  -- [What Is a Robot? *IEEE*]

C-3PO
(Credit: Wikipedia)



Atlas (Credit: Boston Dynamics)

Sparrow (Credit: Amazon)

Robots - example

Roomba (Credit: insider.com)

Take the idea of a chore robot:

- What are some common chores our robot could do?
  - What are some features the robot should have to accomplish these? *How many arms, how many eyes, how big should it be...*

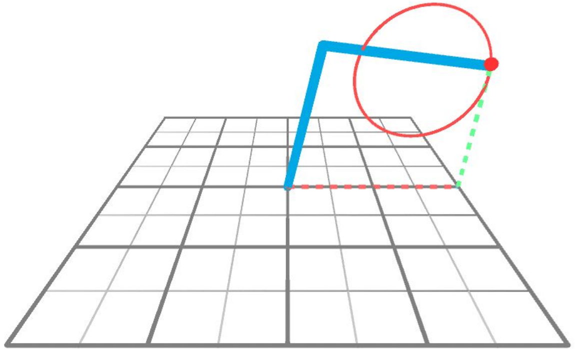
- Now, how may this robot need to be different to have around humans?
  - What are some ways you could make it better or even safer for humans?

Baymax (Credit: Disney via tenor.com)

Robots - current state

- Robots today are rigid, made of metal/plastic... why?
  - Easier to model and control (forward and inverse kinematics)
  - Resistant to damage
- However, they are limited
  - Not safe around humans
  - Not suitable to our dynamic world

Atlas (Credit: Boston Dynamics via giphy.com)

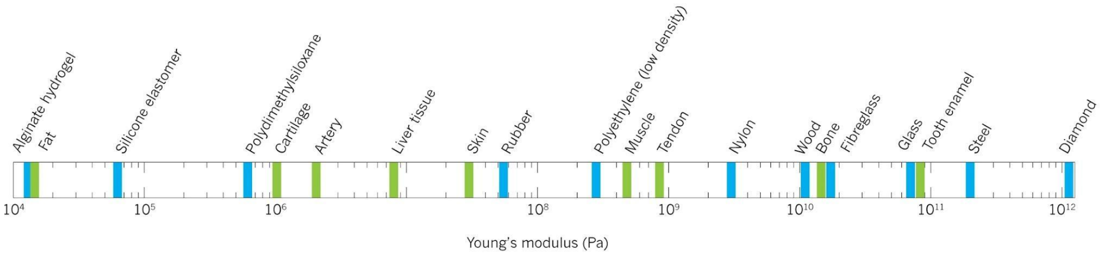


(Credit: Alan Zucconi, alanzucconi.com)

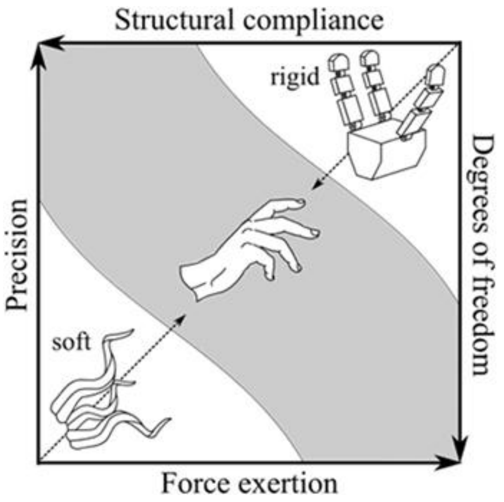
What is a soft robot?

Robots made of **soft**, **elastic**, or otherwise **compliant** materials (unlike metals and hard plastics)

- Sensing, making decisions, performing actions
- "...robots with new, bioinspired capabilities that permit adaptive, flexible interactions with unpredictable environments." -- Kim, S. *et al.* Trends Biotechnol., 2013



Rus, D. *et al.* Nature, 2015



Hughes, J. *et al.* Frontiers in Soft Robotics, 2016

What is a soft robot? cont.

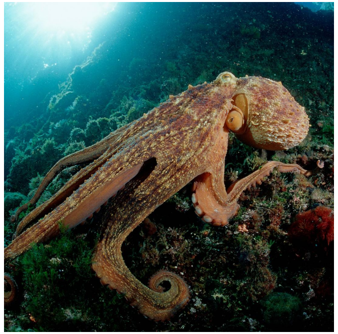
- Since they're made of soft materials, soft robots are **underactuated**
  - There are more degrees of freedom than there are actuators
- Can change shape to adapt
- Better at adapting to different environments/tasks
- More gentle materials prevent too much force being exerted (better safety)

Can you think of animals that might be good inspiration for a soft robot?

- What soft systems do you think would be interesting to replicate with technology?

Octopus

- Almost completely soft creature
- 8 tentacles, capable of independent movement
- Highly coordinated creature

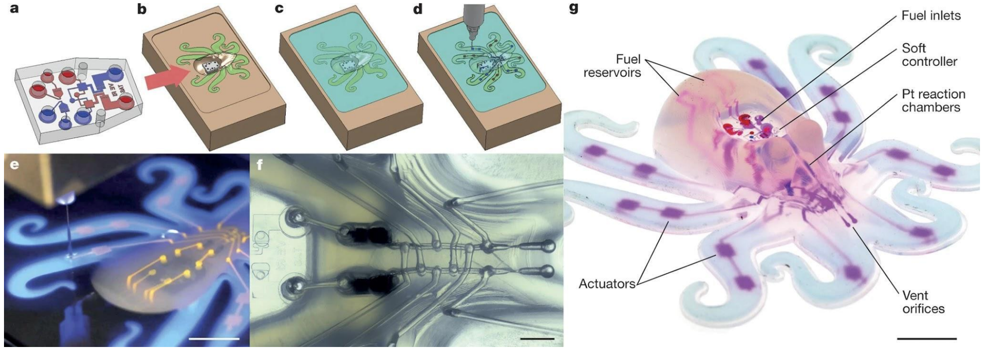


(Credit: The Atlantic)

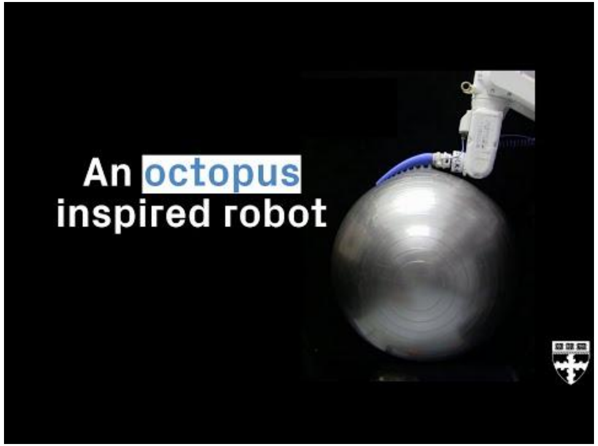
(Credit: James Wood via YouTube)

(Credit: Enoshima Aquarium via YouTube)

Octopus robots!

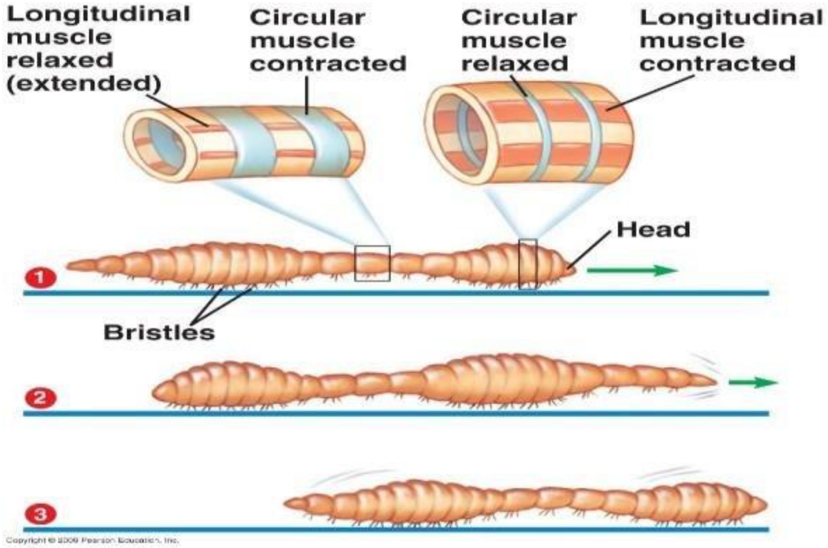


Wehner, M. *et al.*, Nature, 2016
[Video link]
[Vimeo video]



Xie, Z. *et al.*, Soft Robotics, 2020

Worms!

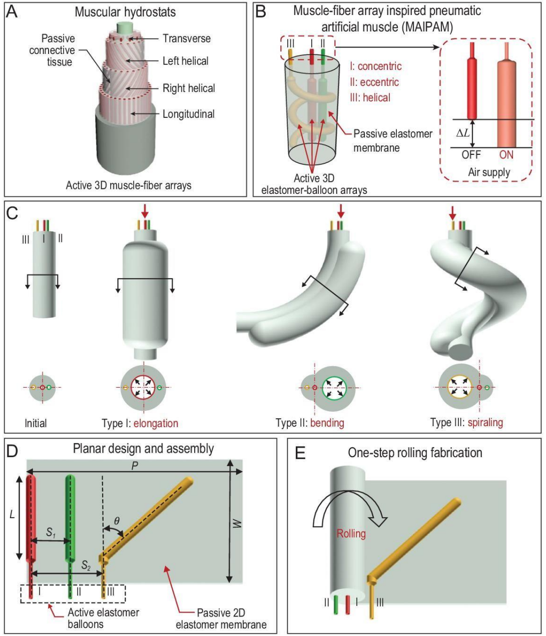


Niu, S. *et al.*, IEEE ROBIO, 2015

(Credit: Nuffield Foundation via YouTube)

This is called a **muscular hydrostat**

Elephants!

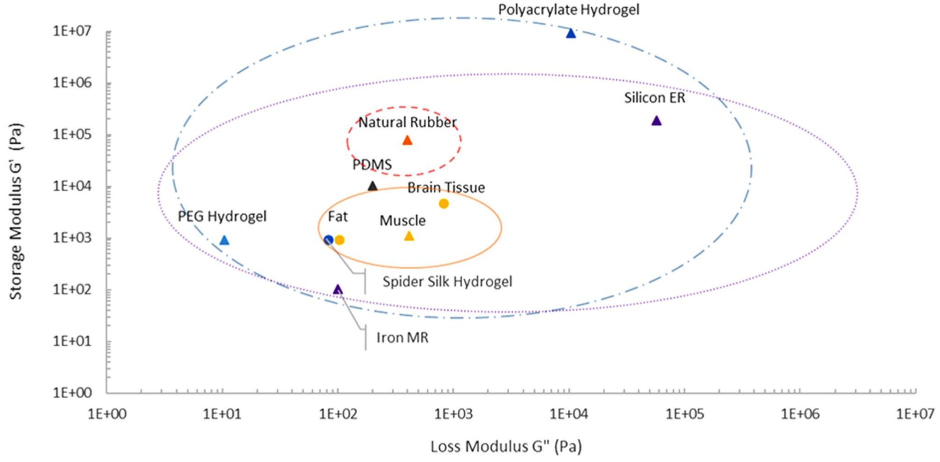


Zou, J. *et al.* National Science Review, 2021

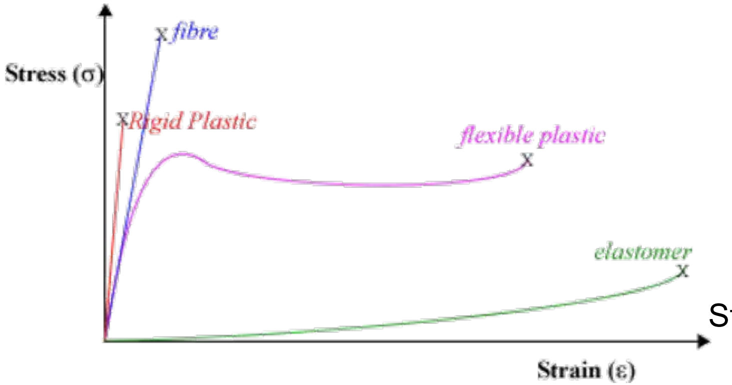
(Credit: Georgia Institute of Technology via YouTube)

Soft robots - materials

- Compromise between softness and integrity
- Common materials include:
  - Silicone
  - Flexible plastics
  - Fabrics
- Inspired by biological materials

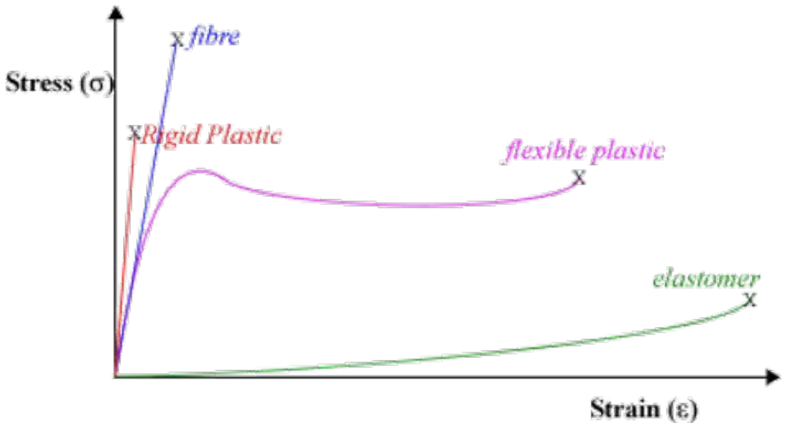


Coyle, S. *et al.*, Extreme Mechanics Letters, 2018



Stress/strain graph (Credit: Luís Rita via Medium)

Soft robots - review of stress vs strain



Stress/strain graph (Credit: Luís Rita via Medium)

Stress: the force applied to a material, divided by the material's cross-sectional area.

$$\sigma = \frac{F}{A_0}$$

σ is stress
F is force
A_0 is the original cross-sectional area

Strain: the deformation or displacement of material that results from an applied stress.

$$\varepsilon = \frac{L - L_0}{L_0}$$

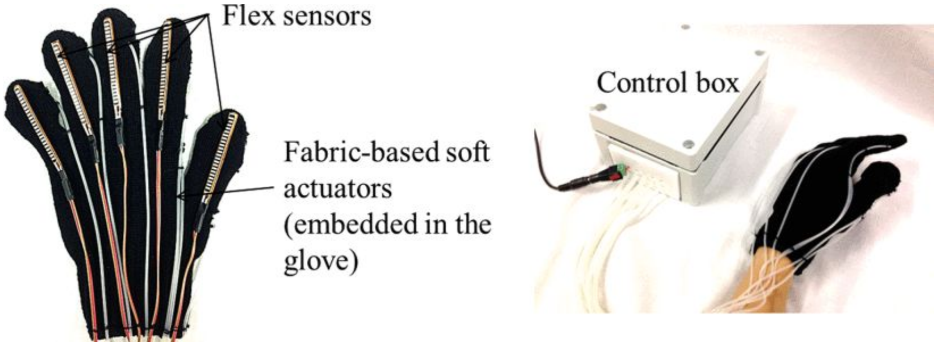
ε is strain
L is length after the load is applied
L_0 is the original length

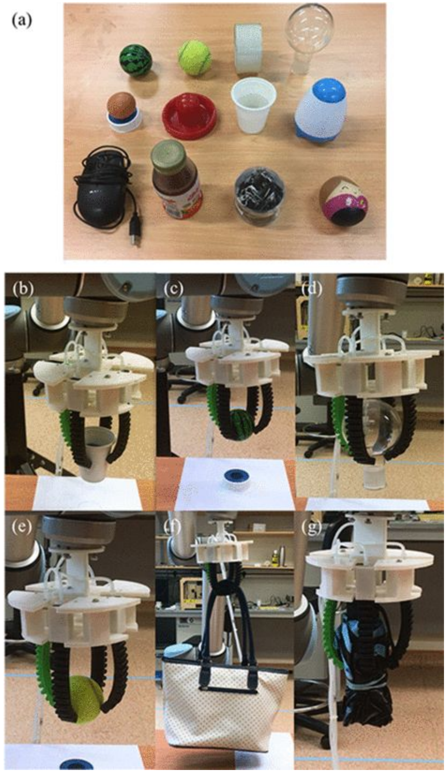
Stress and strain explanation (Credit: Danielle Collins via Linear Motion Tips)

Soft robots - materials

Fabrics

- Made up of fibers, which combine to form interesting structures
- Easy to use in projects
- Strong





Low, J H. *et al.*, IEEE Robotics and Automation Letters, 2017

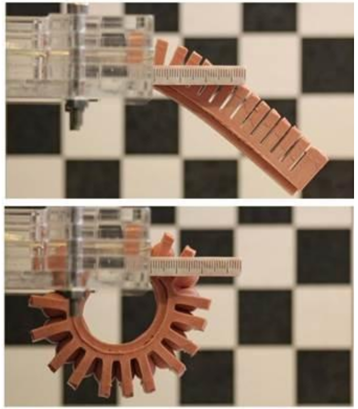
Soft robots - actuation

Pneumatics/hydraulics (fluidic actuation)

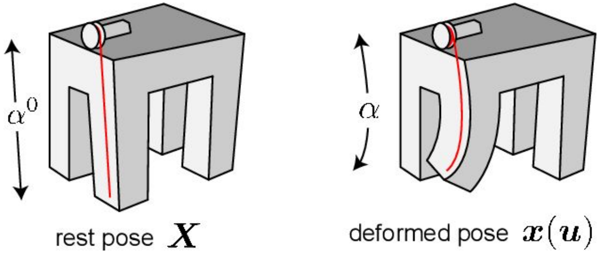
- Use air or liquid pressure to force closed chamber into a particular shape

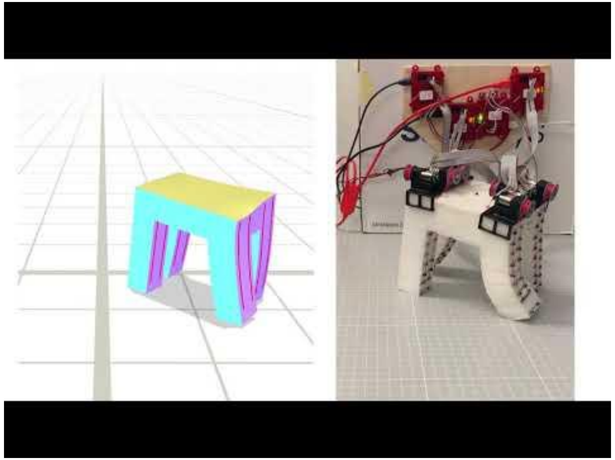
Cables

- Attached to critical points along robot, and cause movement when pulled



Polygerinos, P. *et al.* IROS, 2013





Bern, J. *et al.*, Robotics: Science and Systems XV, 2019

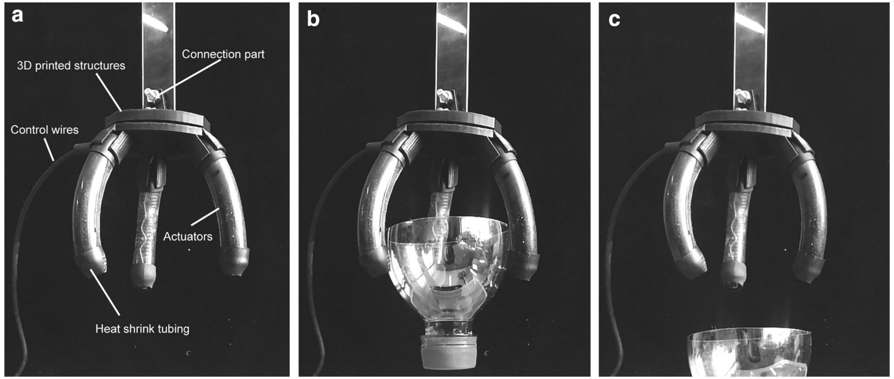
Soft robots - actuation

Shape Memory Alloys (SMAs)

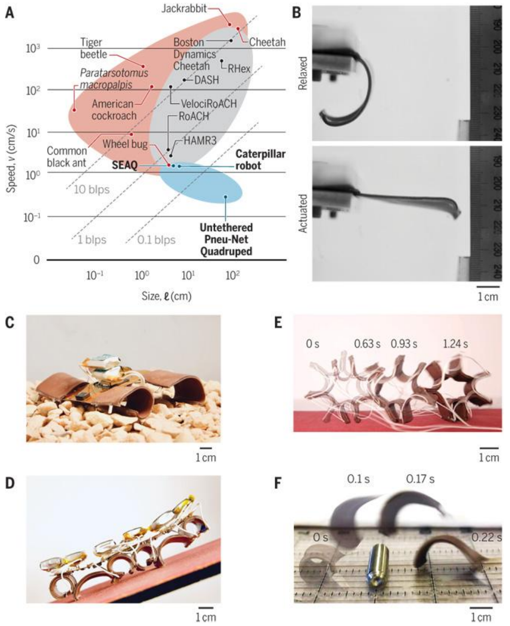
- Return to “memory” of a specific shape when reheated

Dielectric Elastomers (DEAs)

- “Sandwich” of two electrodes between an insulator; when a voltage is applied, the thickness decreases and the area increases



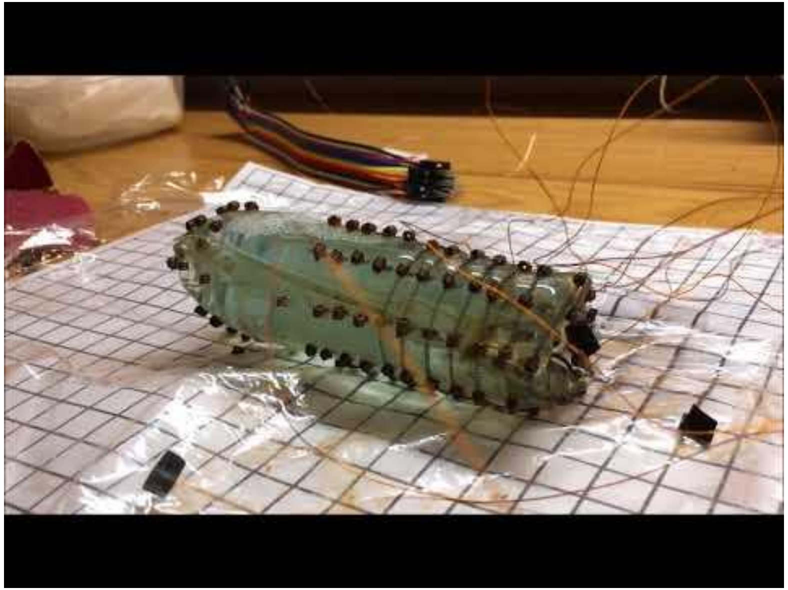
Li, J. *et al.,* Soft Robotics, 2019



Huang, X. *et al.,* Science Robotics, 2018

Soft robots - actuation

Another Shape Memory Alloy robot

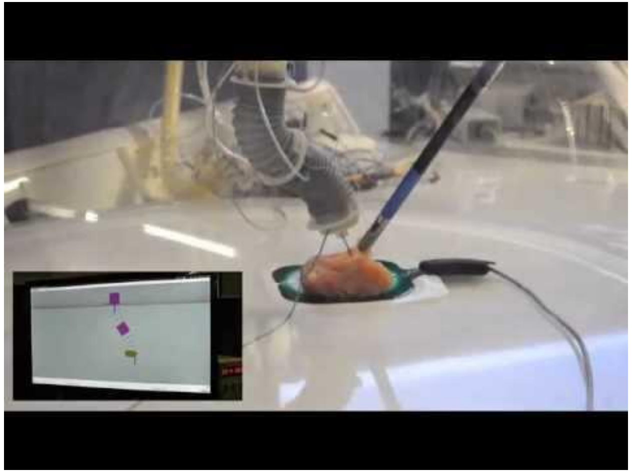


Lee, J., Wierzbanowski, C. and Young, H. Soft Robotics Toolkit, 2018

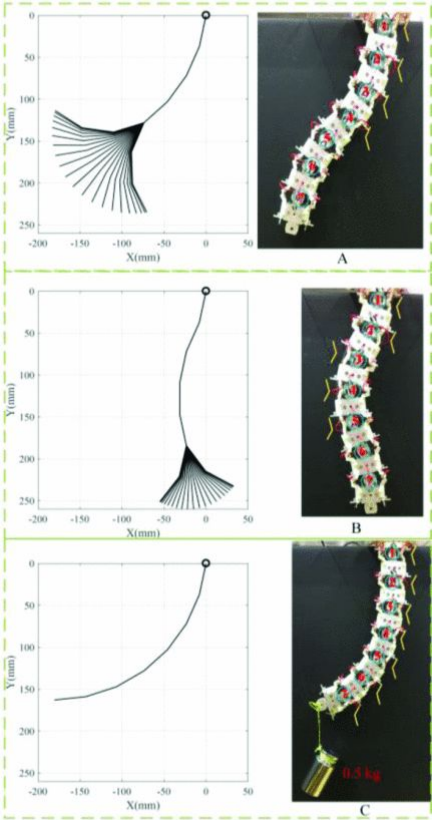
Soft robots - actuation

Variable stiffness

- Isolated stiffening control of select sections of a robot to achieve new actuation



Cianchetti, M. *et al.*,
Soft Robotics, 2014



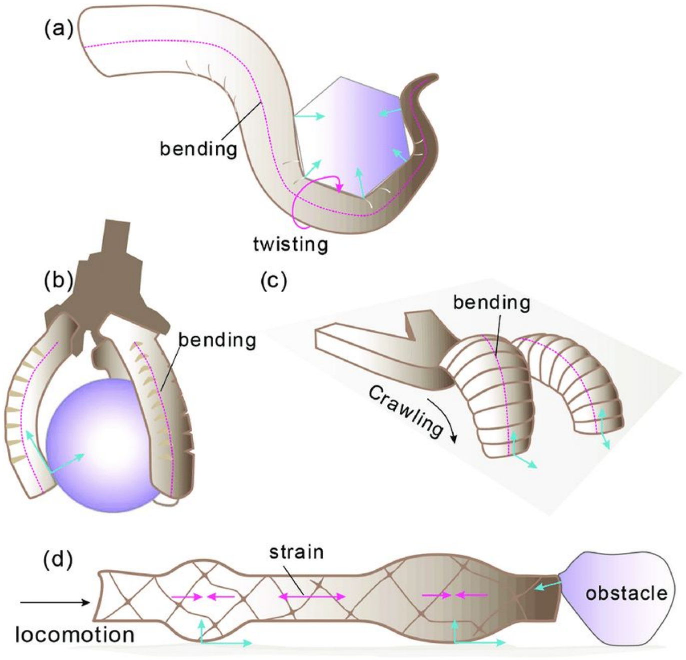
Zhong, Y. *et al.*, ICRA, 2020

Soft robots - sensing

Why do we want this?

What properties do we want to sense?

- Pressure/force on the robot
- Temperature
- Robot position, bending
- Contact force (what is the robot touching)



Wang, H., *et al.*, Advanced Science, 2018

Soft robots - sensing

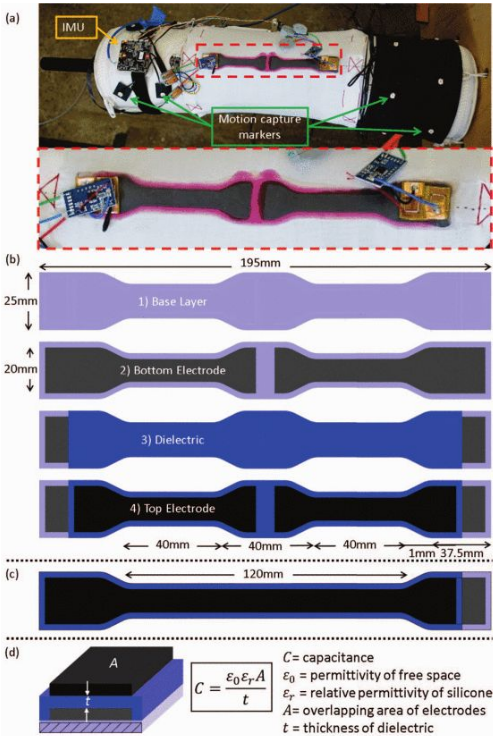
Flex/bending sensors

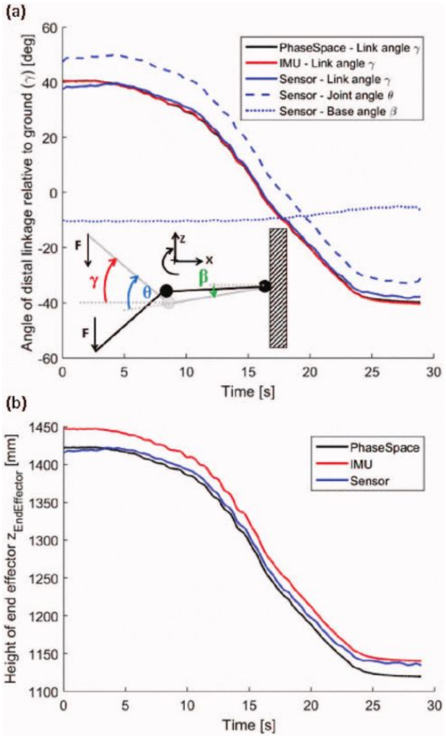
- Use electrical properties to measure change
- Resistivity: when material is strained, resulting in a change in resistance
- Capacitance: strain on conductive material changes the length or area, resulting in a change in resistance

Equation of voltage: V = I R

Rewritten to have R by itself: R = V / I

R, as defined for a cylinder: $R = \frac{V}{I} = \rho * \frac{L}{A}$



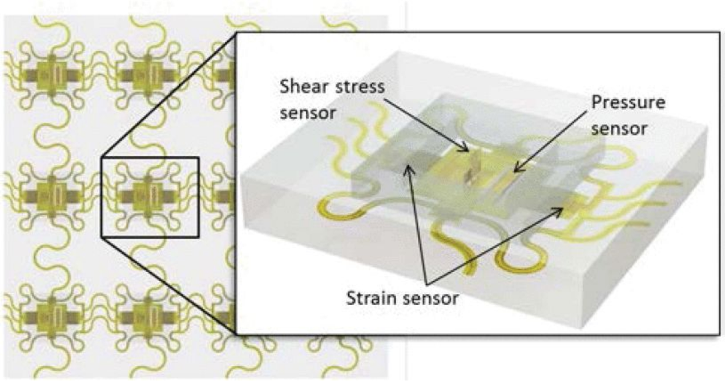


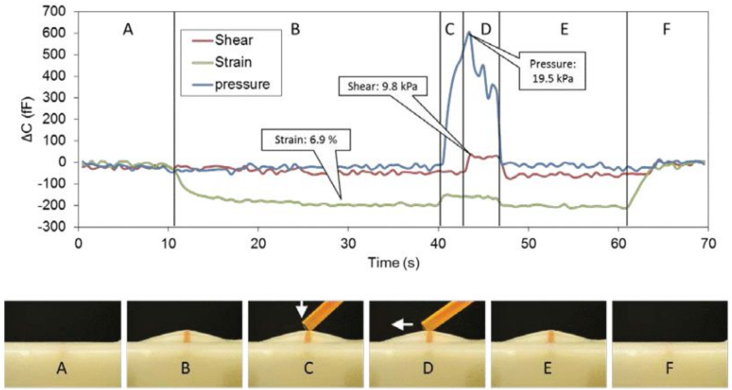
Yuen, M. C., *et al.*, ICRA, 2017

Soft robots - sensing

Stress/strain sensors

- Describe physical interactions with environment (pushing, stretching, bumping, shearing, and so on)





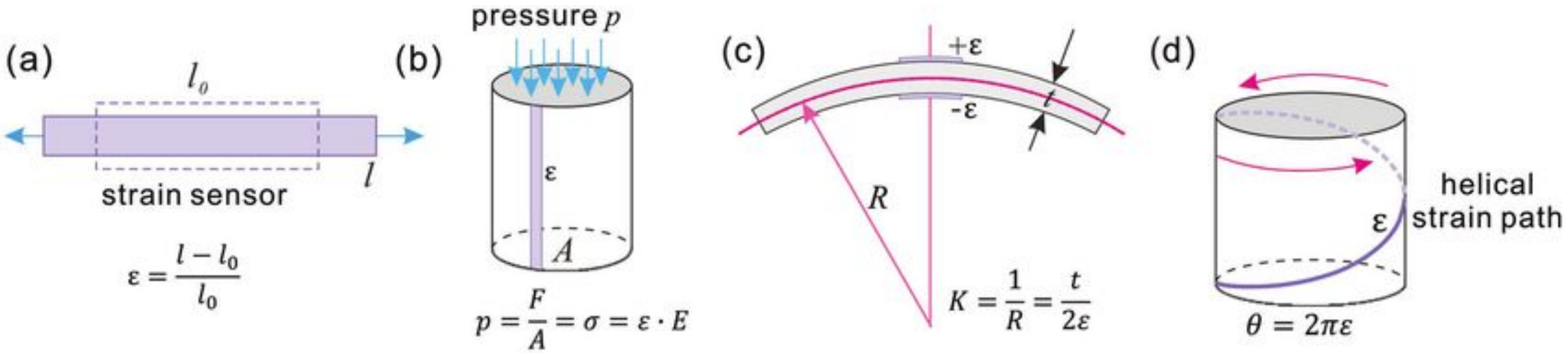
Zhang, Z. F., *et al.*, IEEE Sensors Journal, 2013

For your interest: [Wolfram demo of balancing forces]

Soft robots - sensing

Stress/strain sensors

- Different ways these can be configured to achieve different data

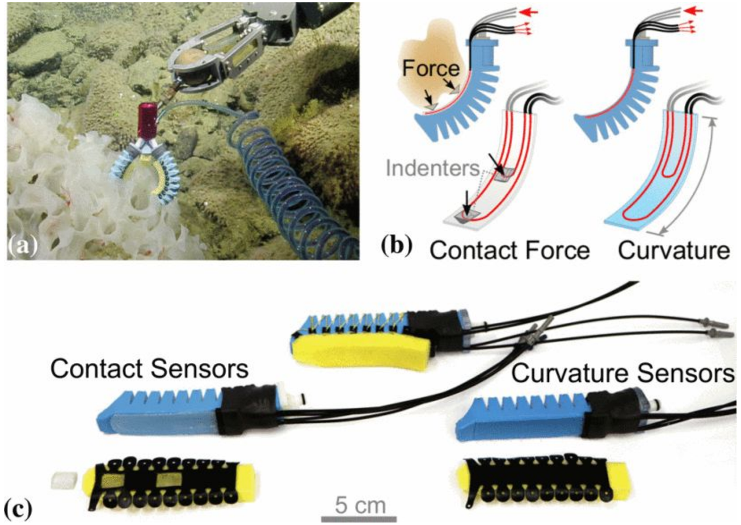


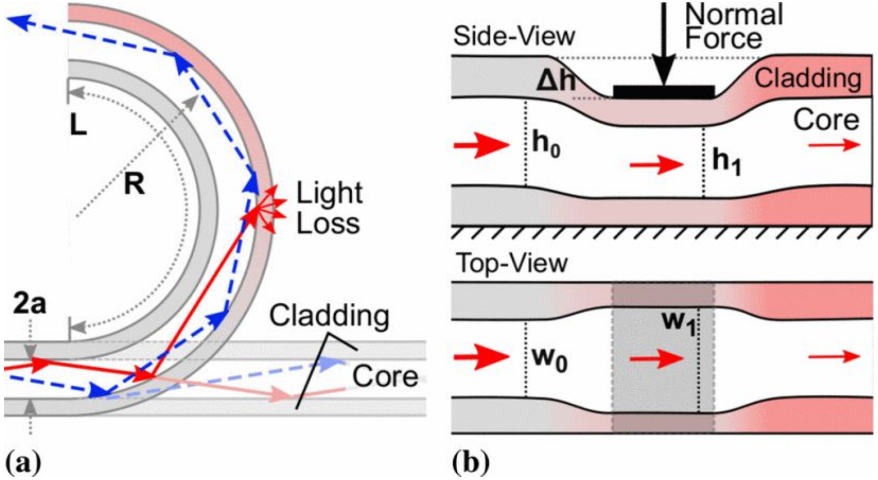
Wang, H., *et al.*, Advanced Science, 2018

Soft robots - sensing

Optical sensors

- Shoots light through a space
- When the material around it bends and deforms, there will be loss of light signal



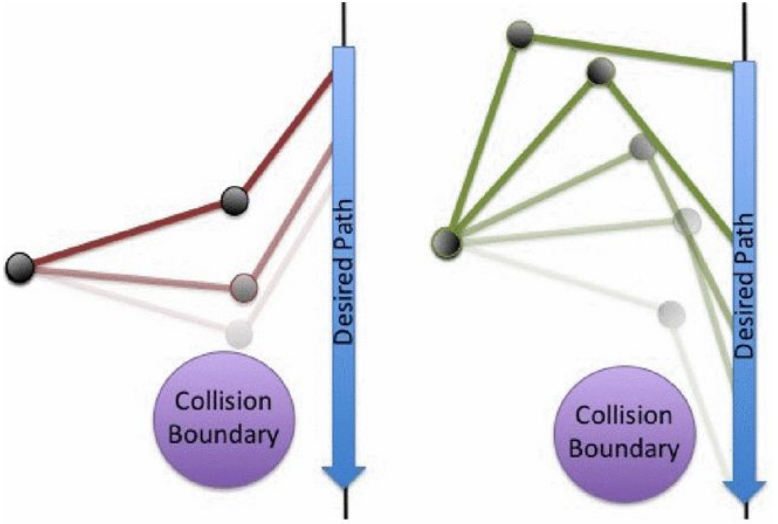


Teeple, C. *et al.* IROS, 2018

How do we model soft robot motion?

Can we use the same methods as with regular robots?

- We could, but we would be missing out on the fundamental differences between them



(a) Poor Planning (b) Good Planning

Bodily, D. M., *et al.*, ICRA, 2017

How do we model soft robot motion?

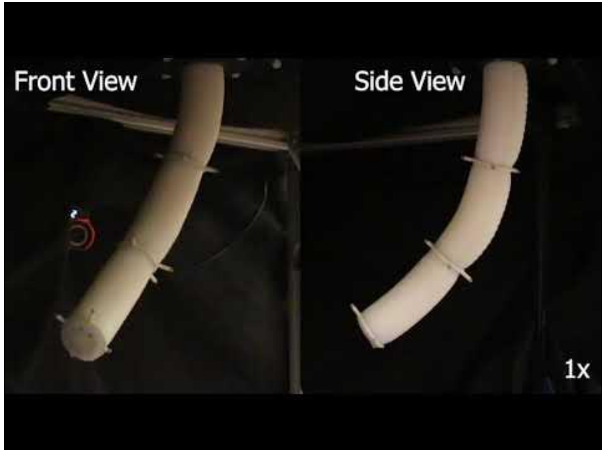
Certain assumptions can/have to be made in certain situations, and these are what we use to model soft robots

- Pseudo-rigid body model
- Constant curvature
- Cosserat rod theory
- FEM models

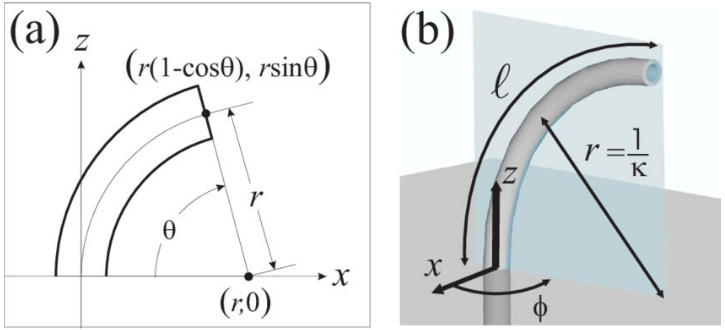
How do we model soft robot motion?

Constant curvature

- Assume that robot bending always follows the radius of a circle
- Makes the math easier



Katzschmann, R., *et al.,*RoboSoft, 2019

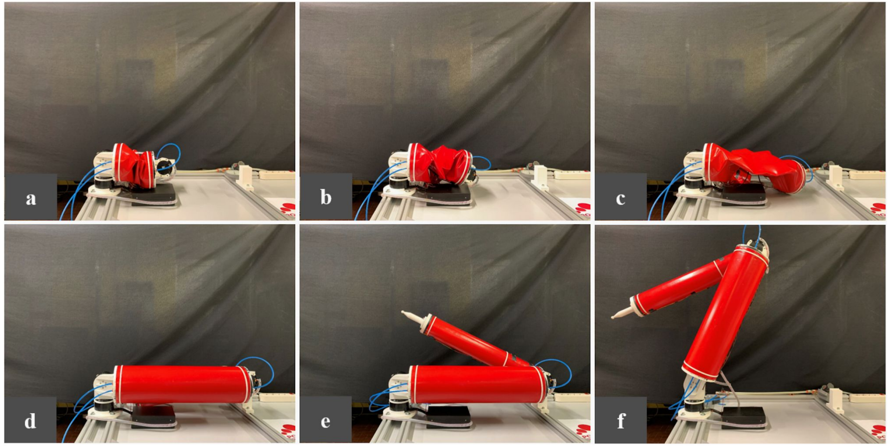


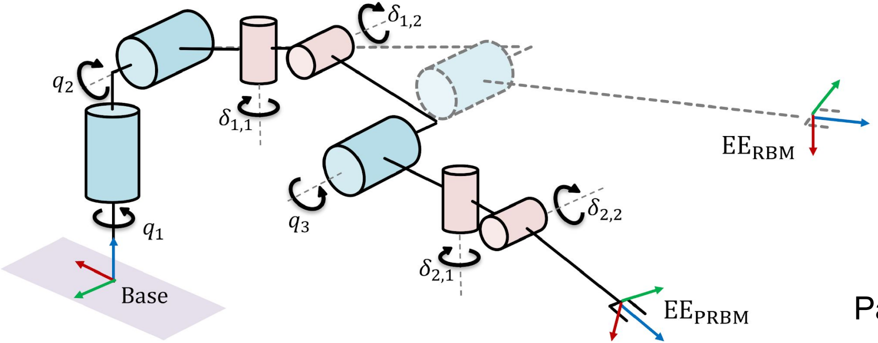
Webster, R., and Jones, B., International Journal of Robotics Research, 2010

How do we model soft robot motion?

Pseudo-rigid body model

- Can be used for robots that are rod-like (long and continuous)
- Effectively an approximation of a rigid robot with springs at each joint (to represent the “soft” aspect)



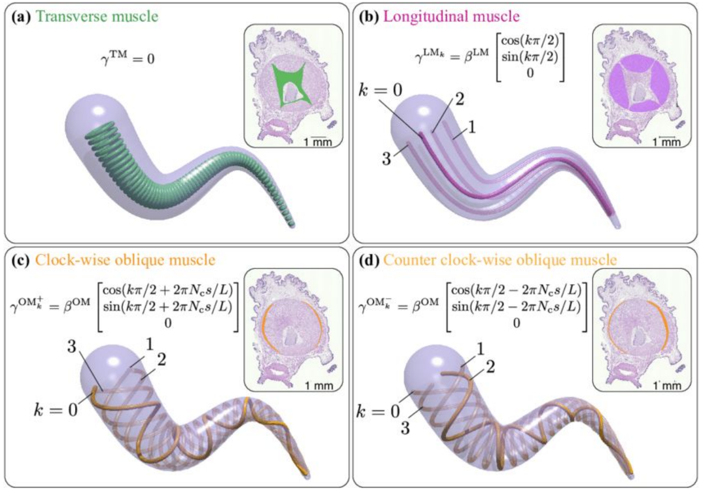


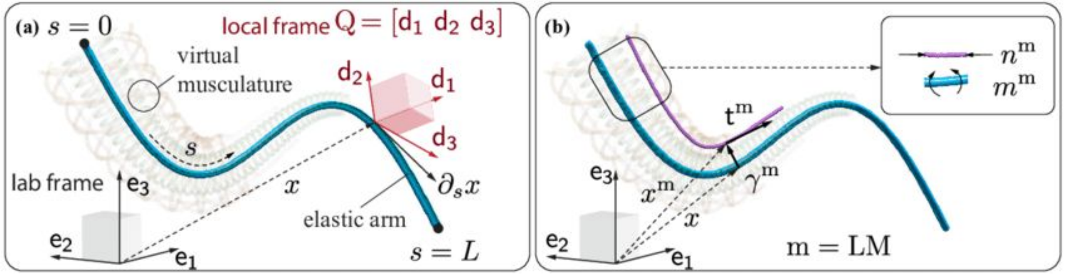
Palmieri, P., *et al.*, Frontiers in Bionic and Flexible Robotics, 2022

How do we model soft robot motion?

Cosserat rod theory

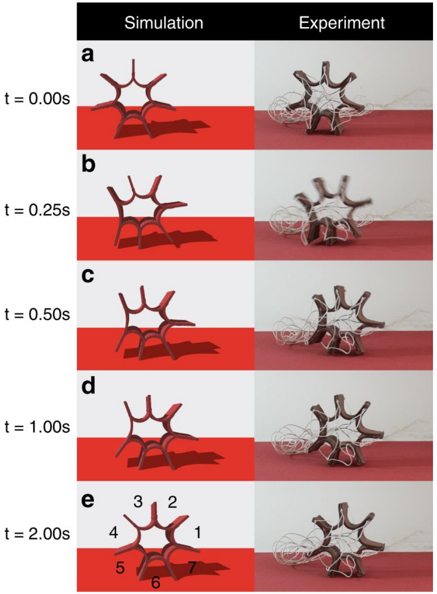
- Mathematical modeling of slender rod under assumption that they are much longer than their radius

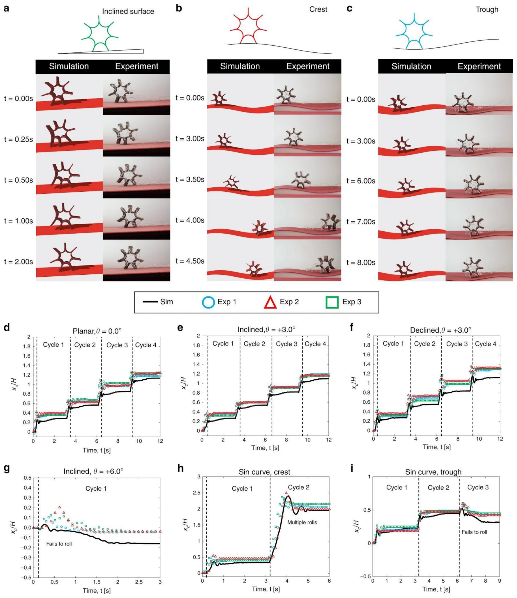




Chang, H-S., *et al.*, preprint, ResearchGate, 2022

How do we model soft robot motion?





Huang, W., *et al.*, Nature Communications, 2020

Finite Element Modeling (FEM)

- Using a computer to divide a big problem into many many smaller problems
- Solving them, then combining the solutions

What are some drawbacks of soft robots?

- Where do we commonly see these soft living organisms?
  - *Hint: where do octopuses[1] live?*
- Difficult to model/control
- Materials have different properties than typical robots, so their interactions with the environment and objects must be considered
- Generally less powerful, in terms of exertable force
- Generally have to be “small”
- Each actuation and sensing method have their own pros and cons

[1]Yes, the plural of “octopus” is “octopuses”.

What are soft robots useful for?

- Manipulating soft/delicate things
- Safe interaction with humans, being around humans in general
- Can accomplish trajectories/maneuvers that rigid robots cannot
  - Tight spaces
  - Weird object shapes
  - Changes in environment
- Can be adapt to wider variety of tasks and environments
- Resist damage and forces

What are soft robots useful for? cont.

Here are just a few fields soft robotics could be applied to in the future:

- Wearable and assistive/rehabilitative robots
- Underwater applications
- Medicine (surgery)
- Commercial fruit/item picking (agriculture)
- Search-and-rescue
- Space

Soft robots today

Most of the work does in soft robotics is in research (both at universities and at companies)

Many companies doing soft robotics are startups, because the field is only now starting to gain traction

- What is a startup? Basically, a company in the initial stages of business, where they have an idea but need money

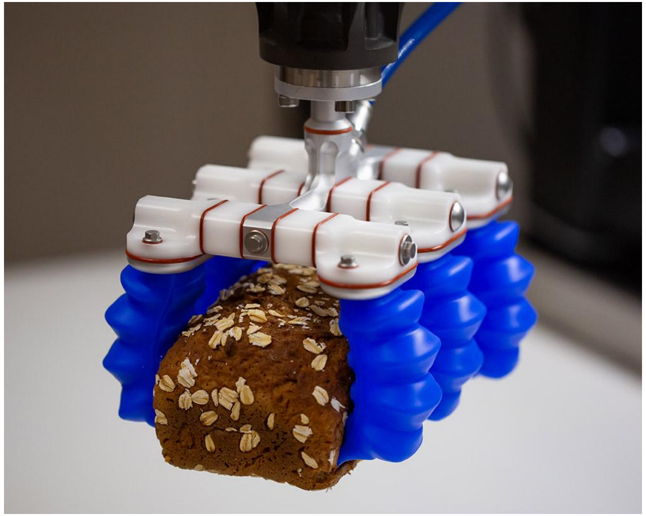
Startup information (Credit: Mitchell Grant via Investopedia)

Soft robots today - food/agriculture

Soft Robotics, Inc.

- Soft robot grippers for better manipulation

(Credit: Soft Robotics, Inc.
via The Robot Report)

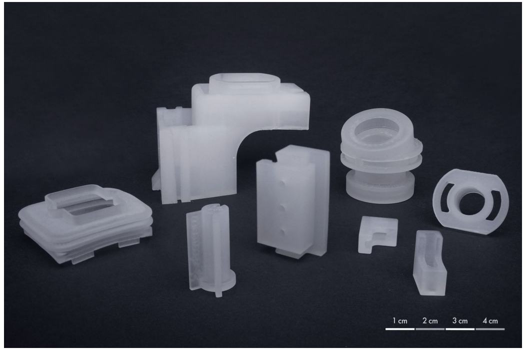


(Credit: Soft Robotics, Inc.)

Soft robots today - silicone 3D printing

Spectrolast

- Printing silicone enables rapid prototyping and development
- Industrial as well as medical applications



(Credit: Spectroplast)

Soft robots today - hazardous areas

Squishy Robotics

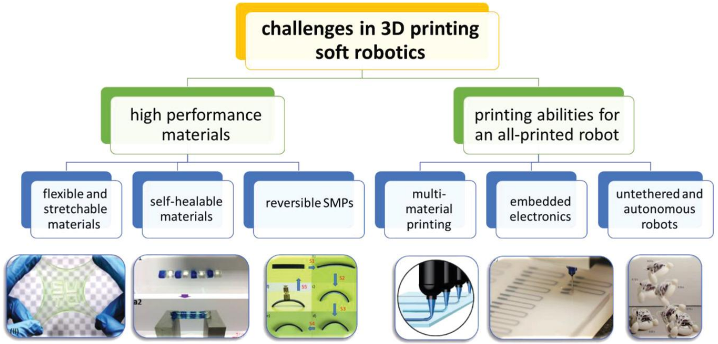
- Deployable robots with sensor arrays for gathering information in hazardous areas
- Uses design based on concept of tensegrity

(Credit: Squishy Robotics)

The future of soft robots

Many avenues of improvement for the field:

- Actuation
- Sensing
- Modeling
- Fabrication



Sachyani, E. *et al.*, Advanced Materials, 2021

Companies are starting to show interest in soft technologies!

And there's so much more to explore...

Questions