Bio-Inspired Soft-Rigid Complex Robots

Turning Marerials into Intelligent Machines

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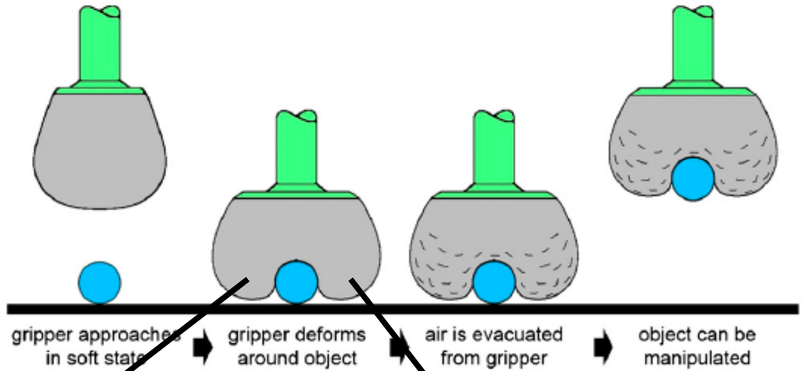
BIRL Bio-Inspired Robotics Lab

Problems of Robot Manipulation

- Cost
  (Humans are £10 per hour)
- Dexterity
  (Cut, trim, inspect, wrap in 5 seconds)
- Sensing
  (Visual and tactile sensing of variations)
- Physical contact
  (Self-healing/disposal surfaces)
- Creativity
  (Dealing with different situations every time)

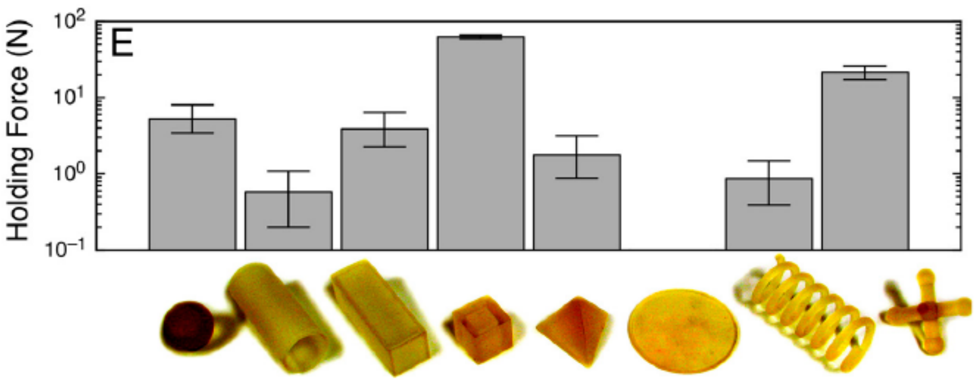
We need smart functional materials!

Universal Gripper



Elastic bag
(radius = 4.3 [cm], thickness = 0.3 [mm])

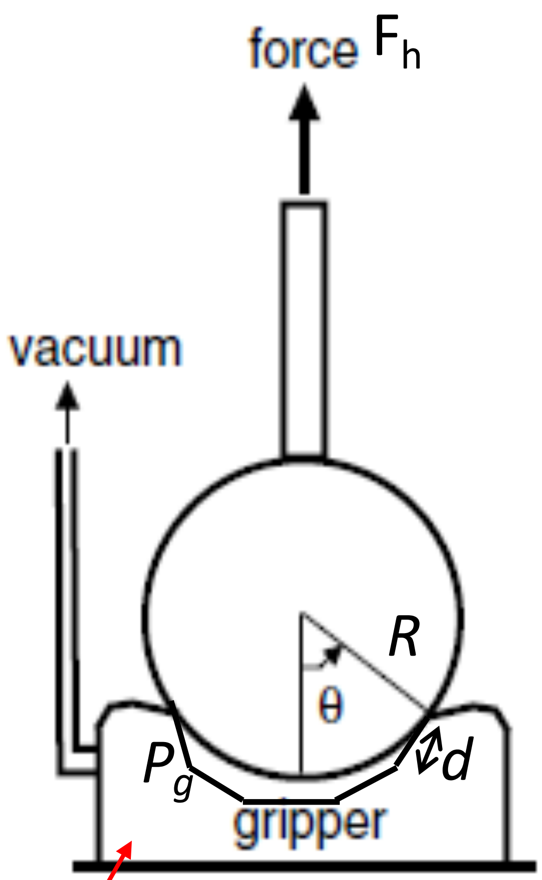
Inside: granular material
(ground coffee)



- Object is unknown
- Bang-bang control of vacuum

Brown et al (2010) *PNAS* 107 (44): 18809–18814

How Universal Gripper works



Particle Jamming

<u>Controller</u>

Push the gripper against the target object
Vacuum on to grip, and off to release

<u>Emergent behaviours by mechanical interactions</u>

$$F_h = F_s + F_f$$

Friction force

Sucking force

Holding force

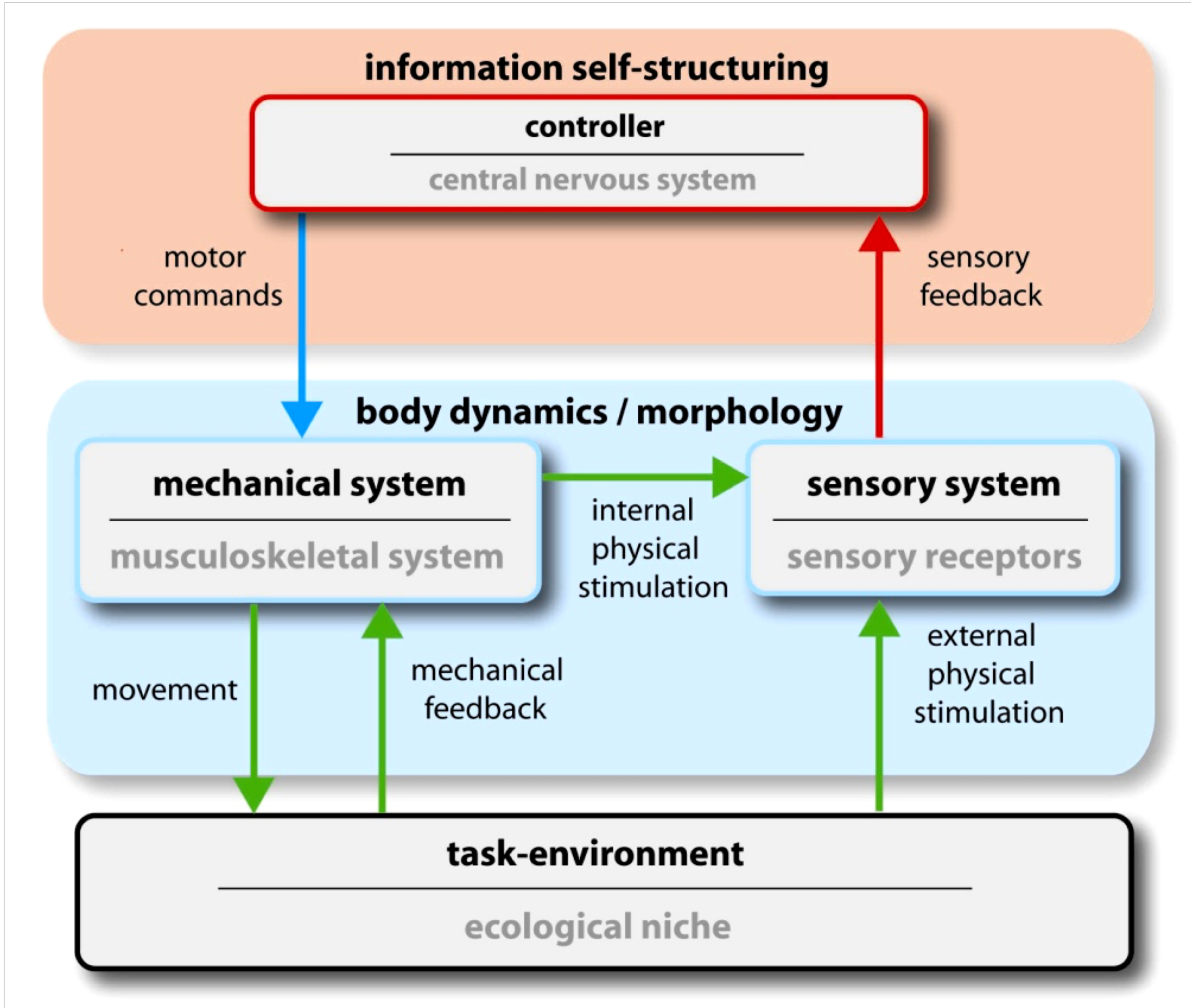
$$F_f = 2\pi R d \sigma^* (\mu \sin\theta - \cos\theta) \sin^2\theta$$

$$F_s = P_g A^* = \pi R^2 \sigma^* (\mu \sin\theta - \cos\theta) \sin^3\theta$$

P_g, d, θ are all automatically set by soft body

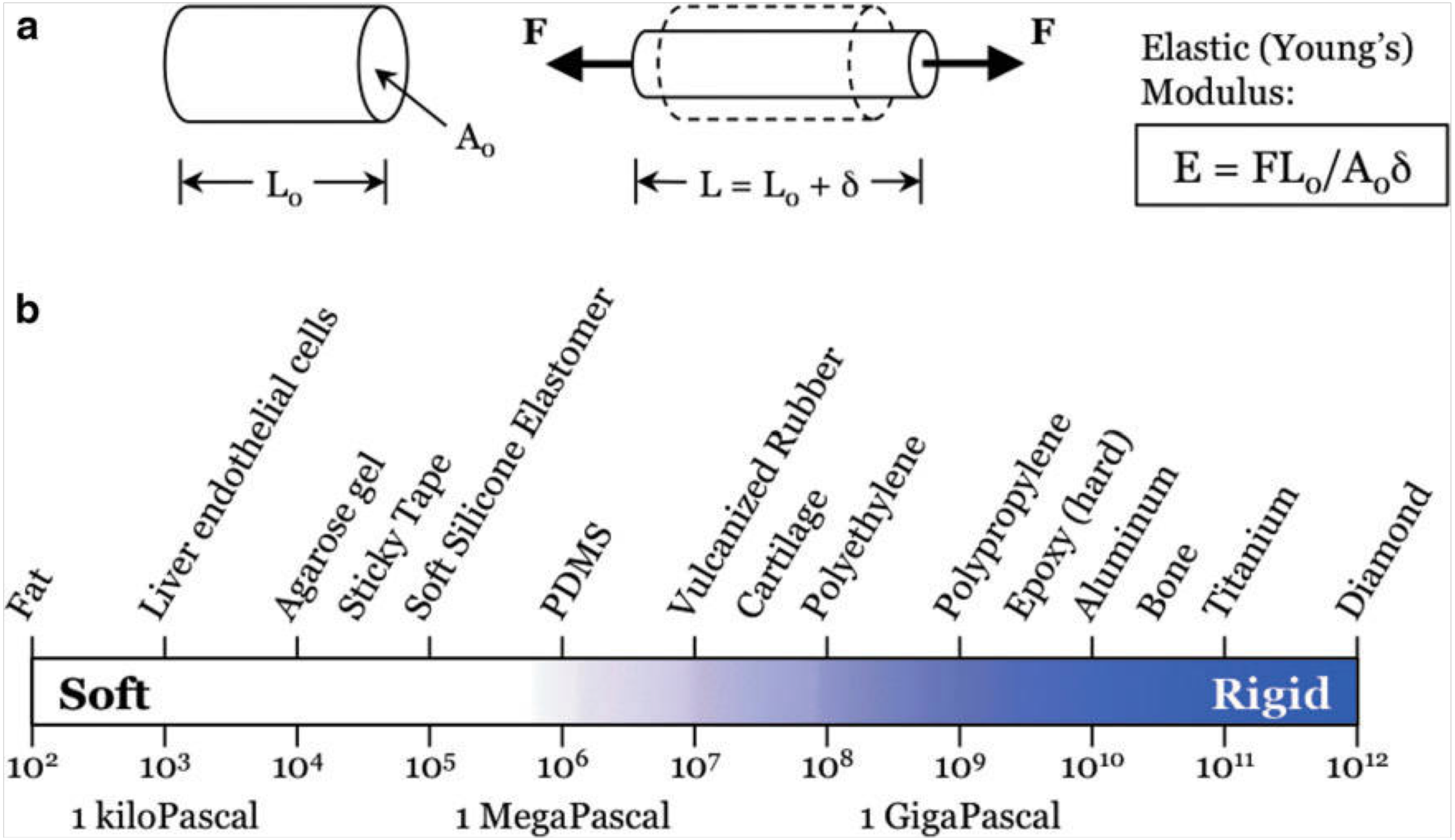
Brown et al (2010) *PNAS* 107 (44): 18809–18814

Embodied Intelligence

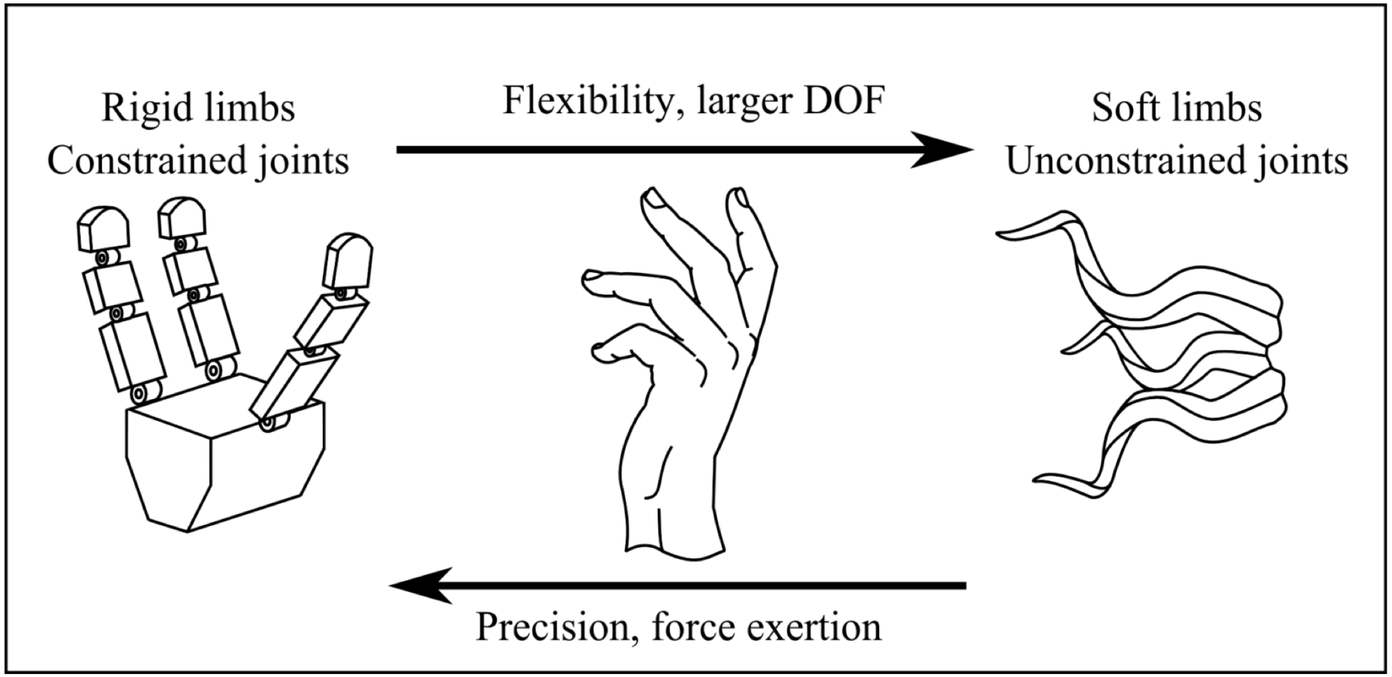


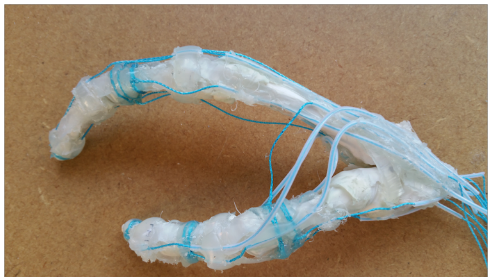
[Peifer, et al. Science 2007]

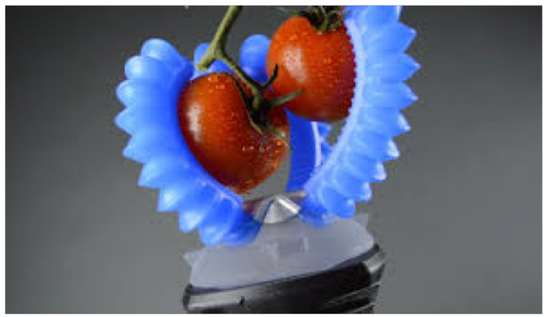
Young’s Modulus as a Measure of Softness



Soft-Rigid Hybrid Robot



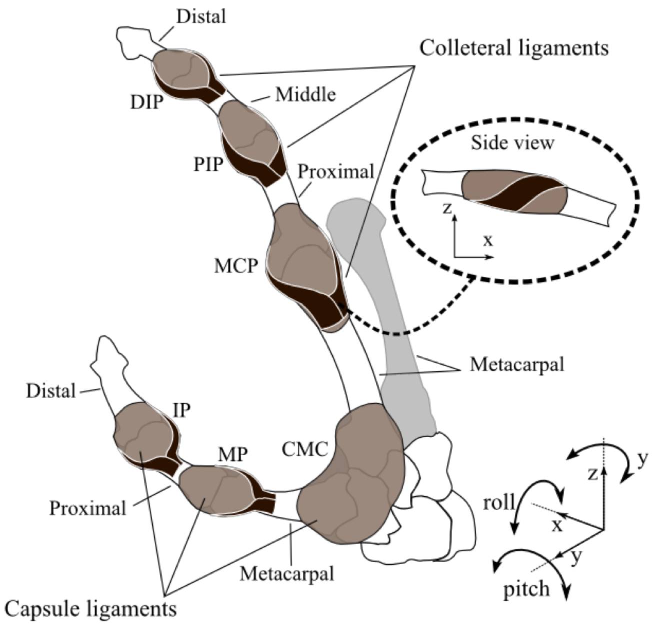


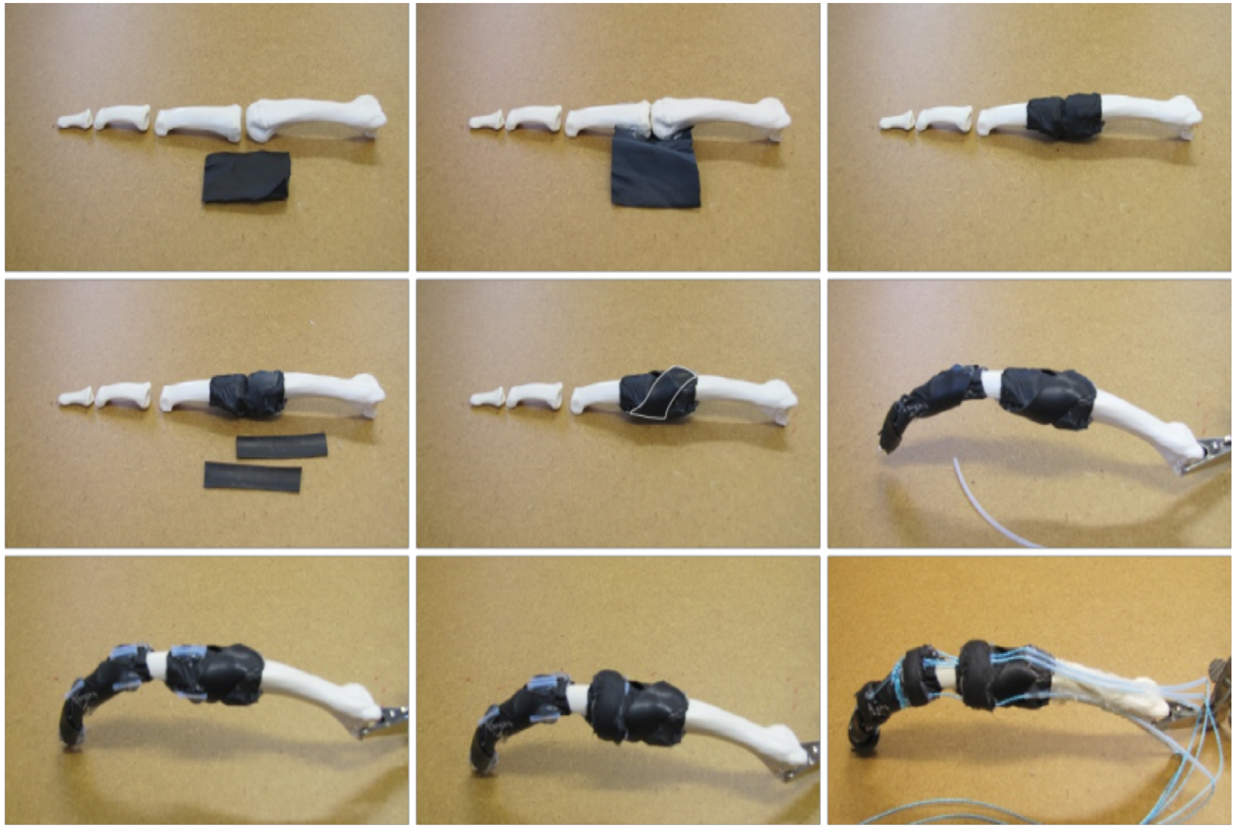


[Hughes, et al. Robotics and AI, 2016]

Anthropomorphic Robot Fingers

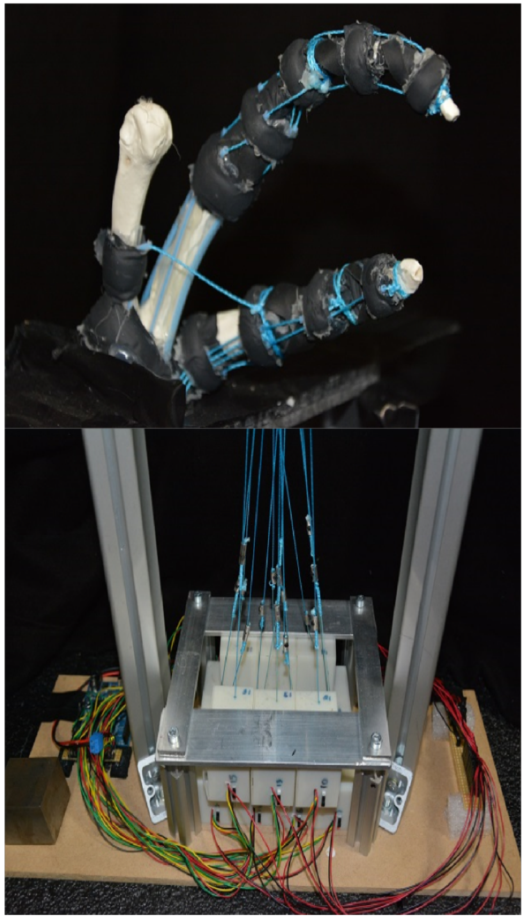
Structural hierarchy
- Rigid bones
- Continuum passive joints
- Membrane capsule ligament
- Fixation ligament
- Rotation limit ligament
- Tendon tubes
- Actuated tendons



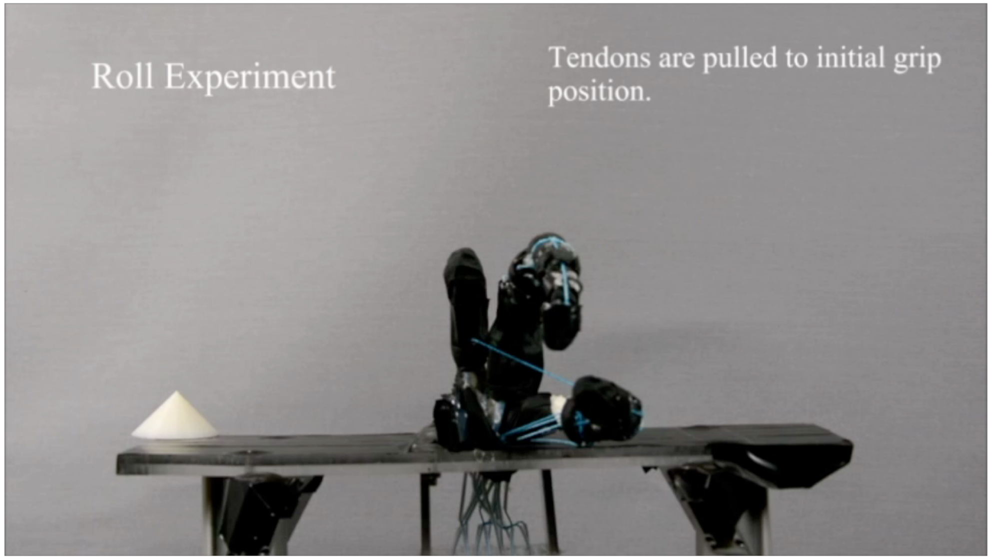


Designed and experimented by Utku Culha (Bioinsp. Biomimet. 2016)

Anthropomorphic Robot Fingers



14 servomotors connected through Bowden cables to 2.5 fingers

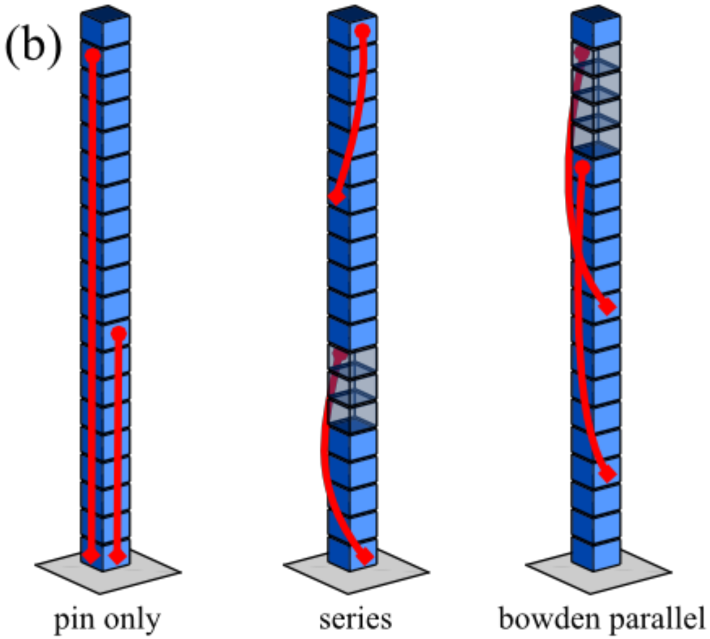


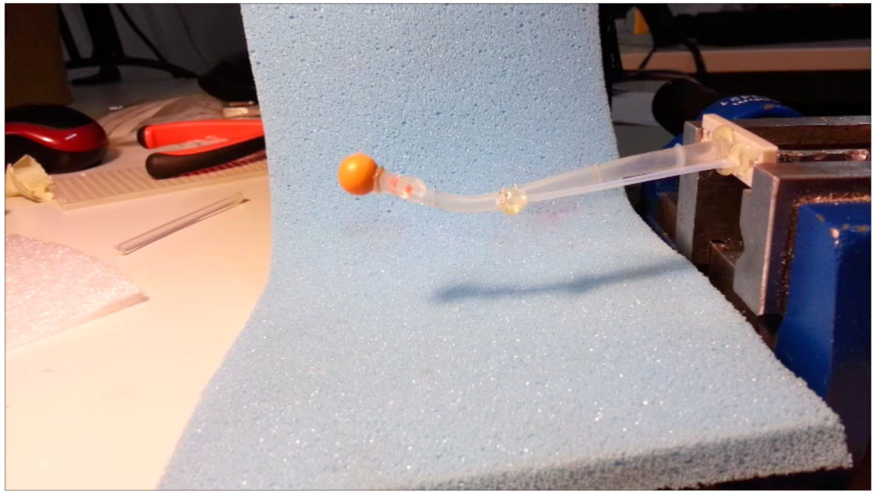
Designed and experimented by Utku Culha (Bioinsp. Biomimet. 2016)

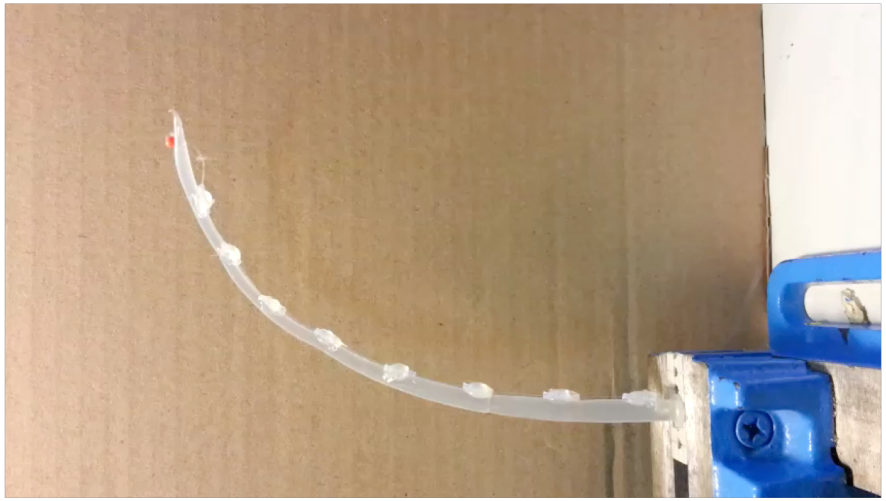
Soft Structure Actuation

Boden mechanisms for soft actuation

- Over-redundancy through tendon-driven remote actuation
- Under-actuated control of continuum bodies
- Passive dynamics of musculoskeletal structures

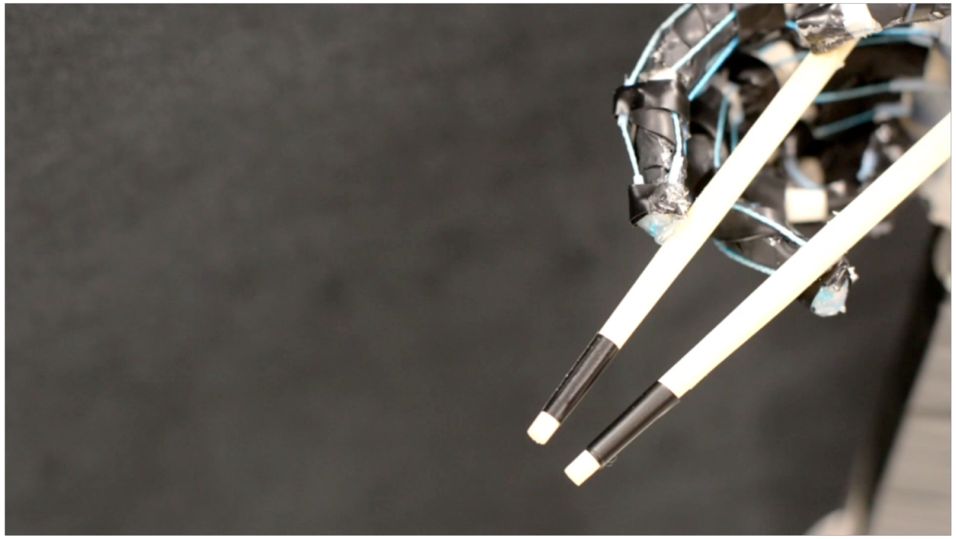


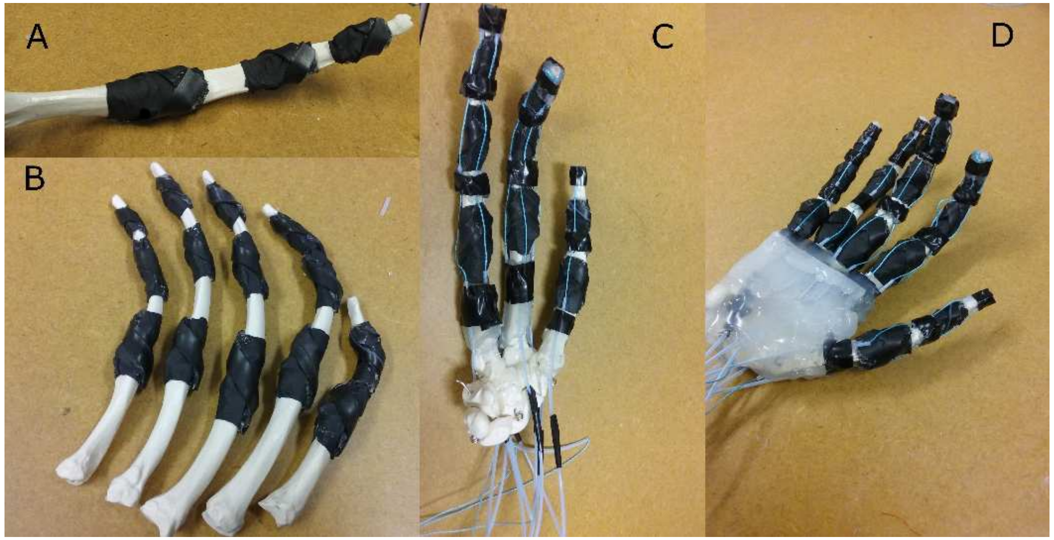




[Design and experiment by Culha]

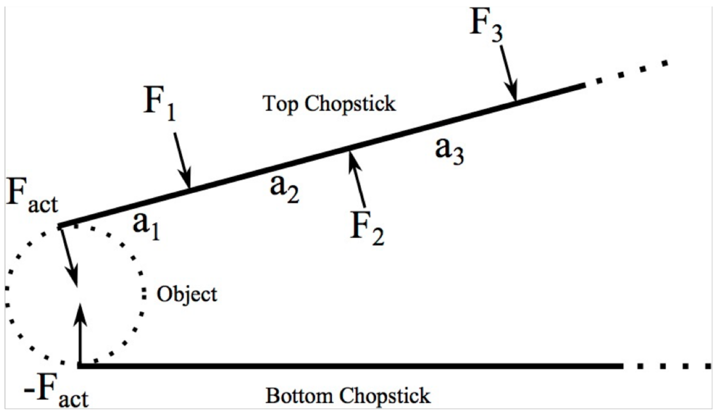
Muscle Synergies

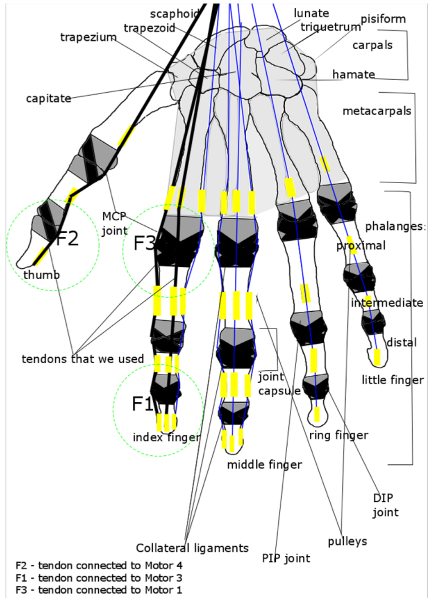




Demonstration of 10 different objects with the same 1D control of motors

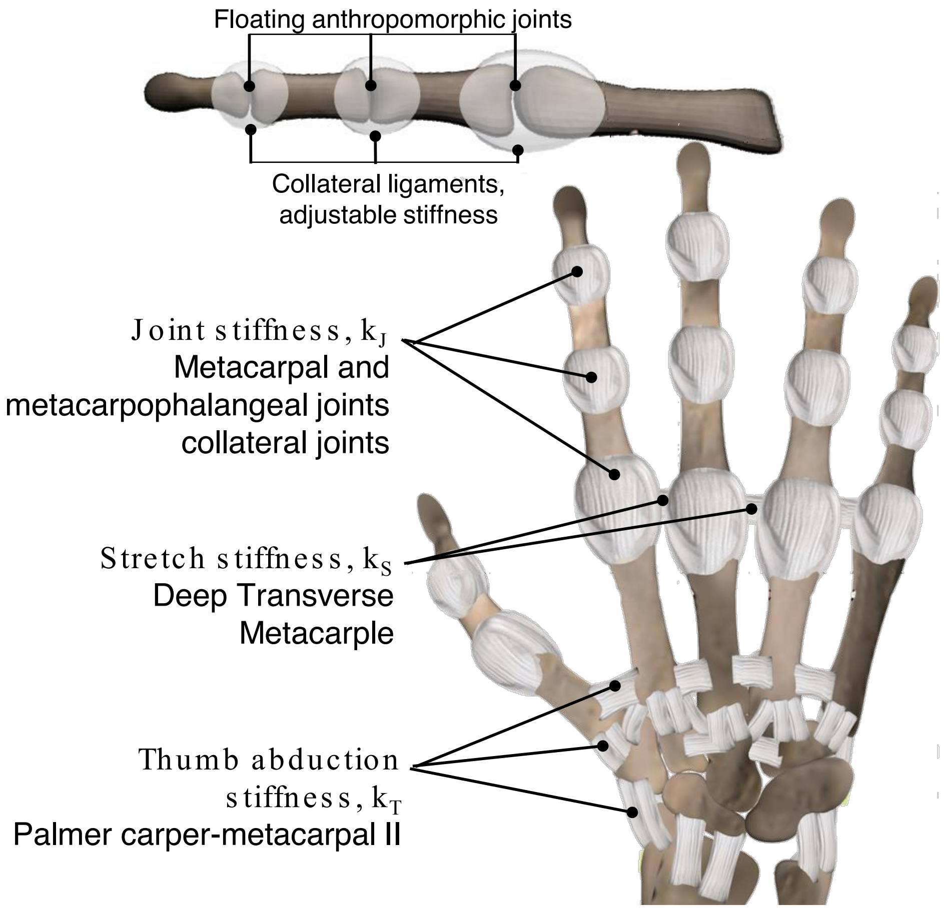
1 DoF is enough when "<u>muscle synergy</u>" is exploited

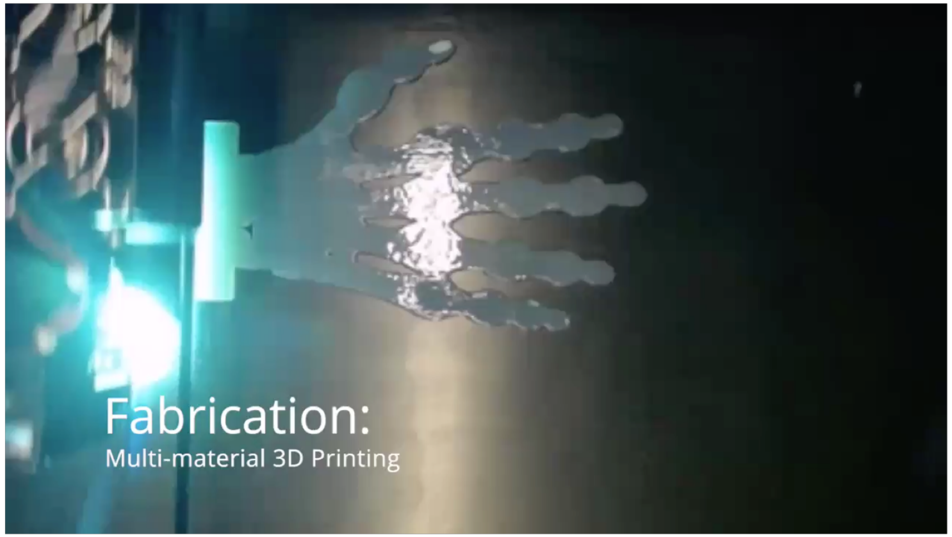


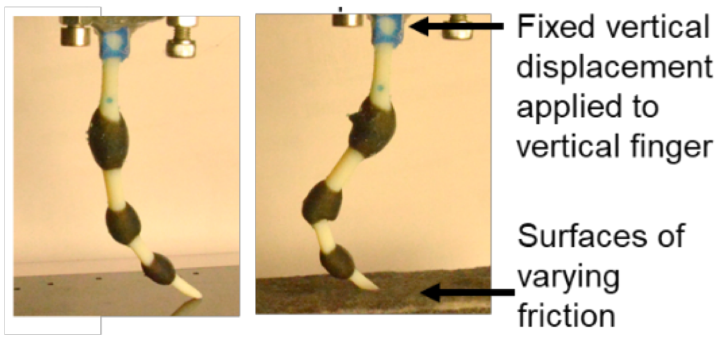


[M. Chepisheva et al. SAB2016]

3D-Printed Passive Skeleton Hand



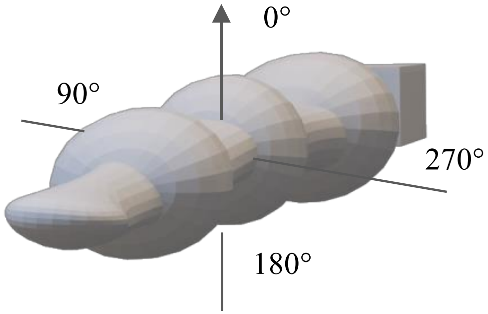


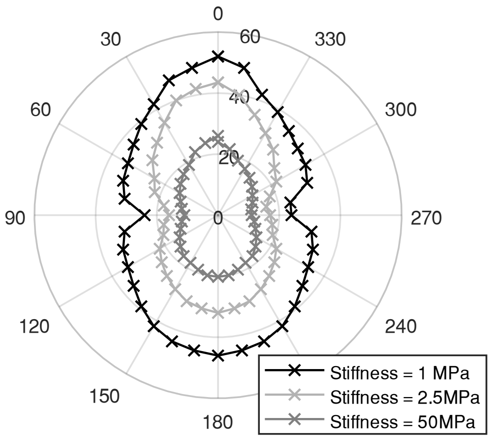


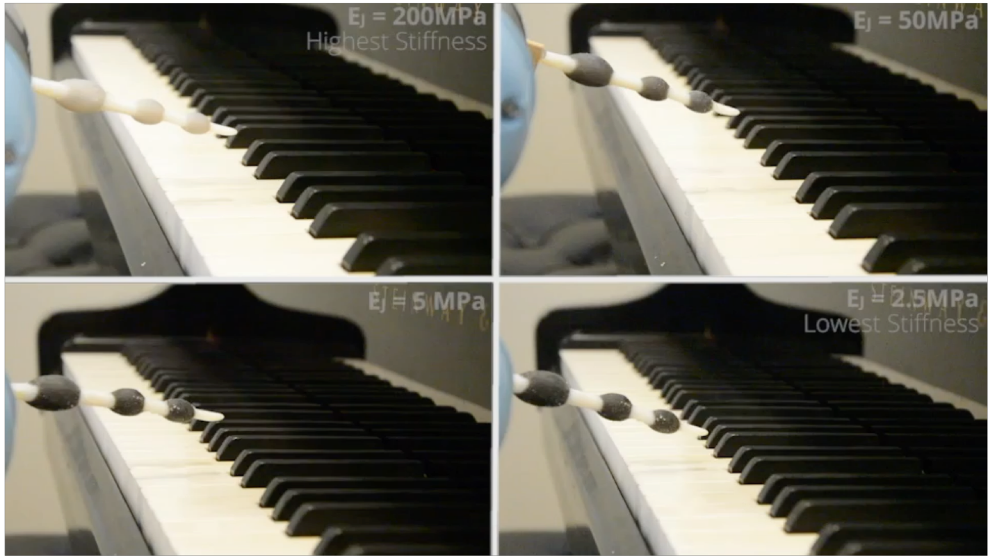
Skeleton Materials
Bones: VeroWhite (~100MPa)
Ligaments: TangoBlack (~1MPa)

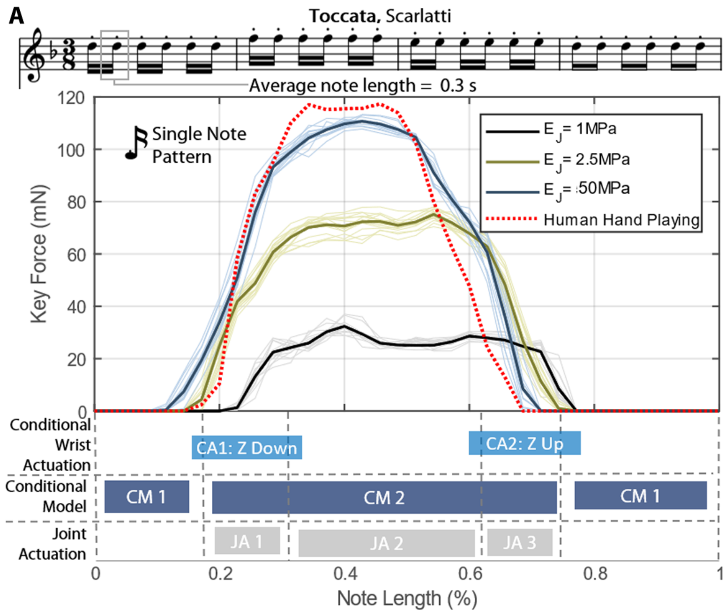
[Hughes, et al. Science Robotics 2018]

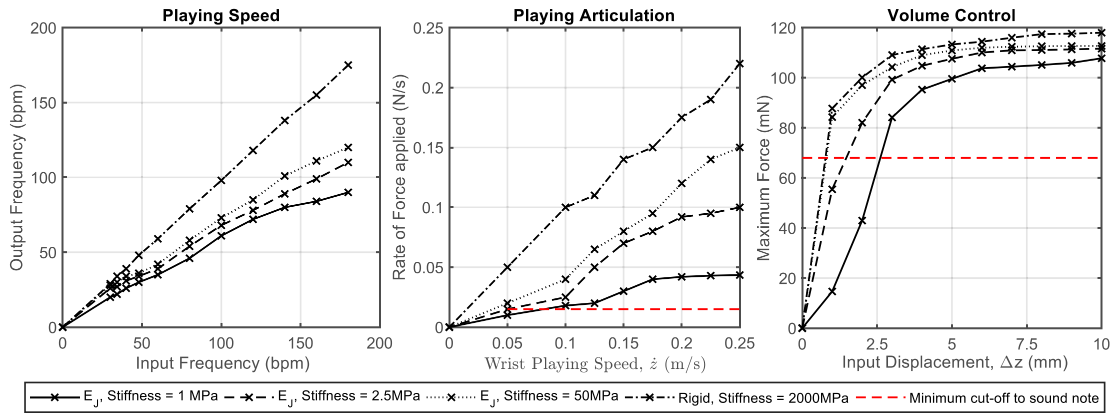
Single Finger Behaviours





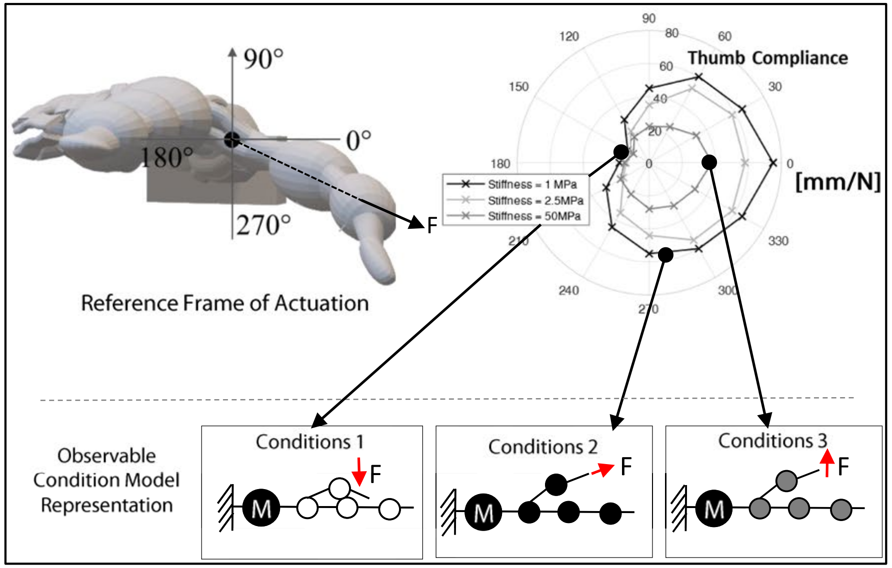


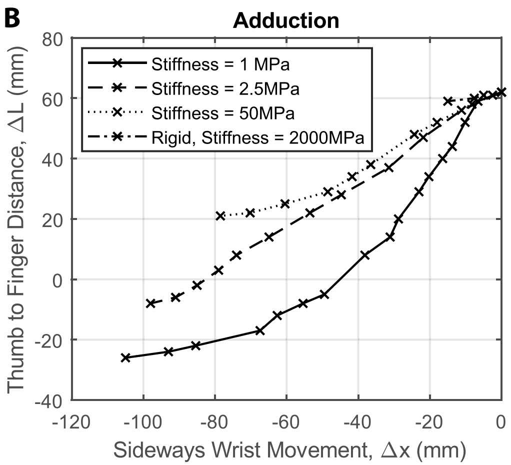


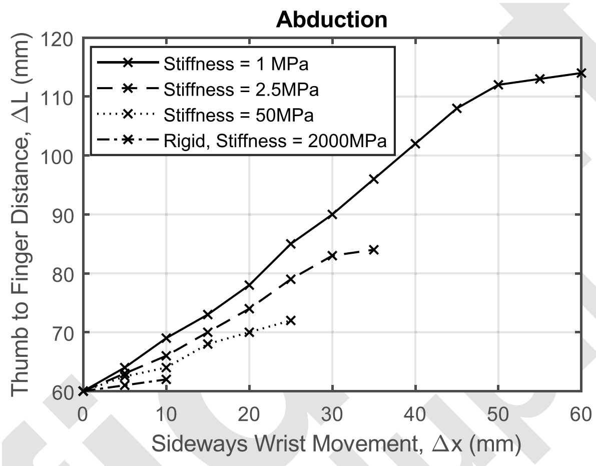


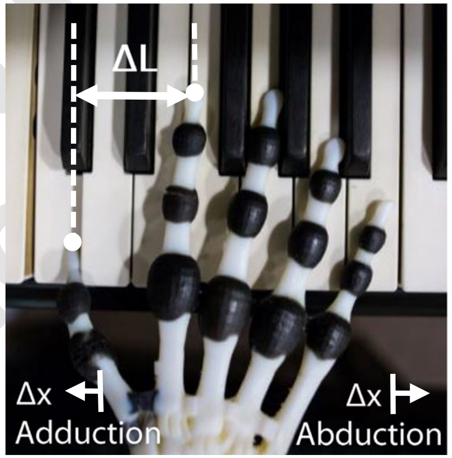
[Hughes, et al. Science Robotics 2018]

Thumb Adduction/Abduction









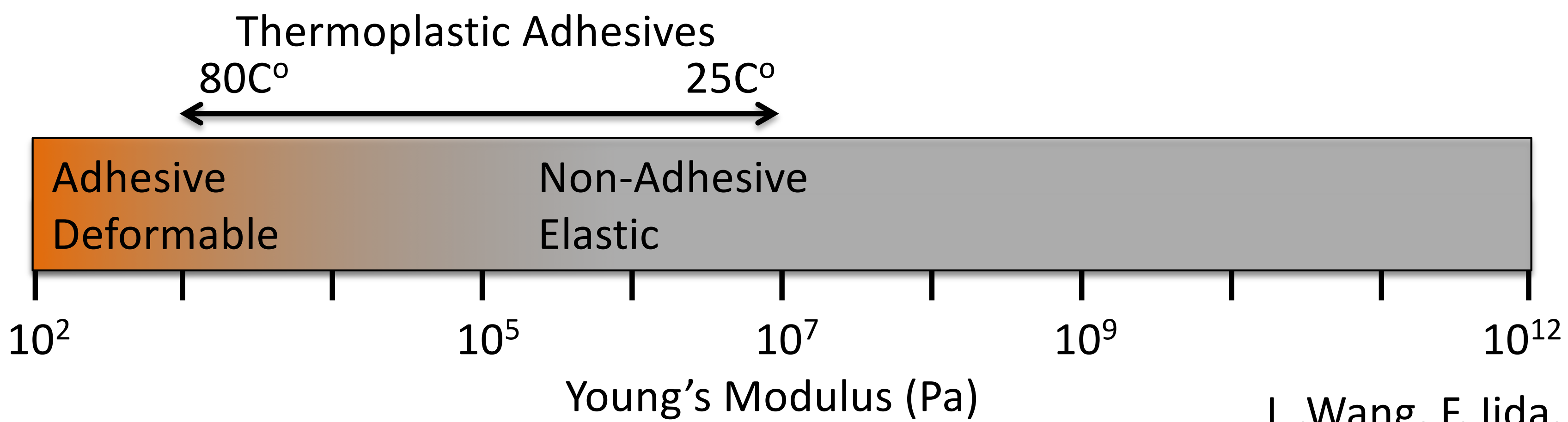
[Hughes, et al. Science Robotics 2018]

Hot Melt Adhesives as Soft Functional Material

Bonding Strength to Different Substrates

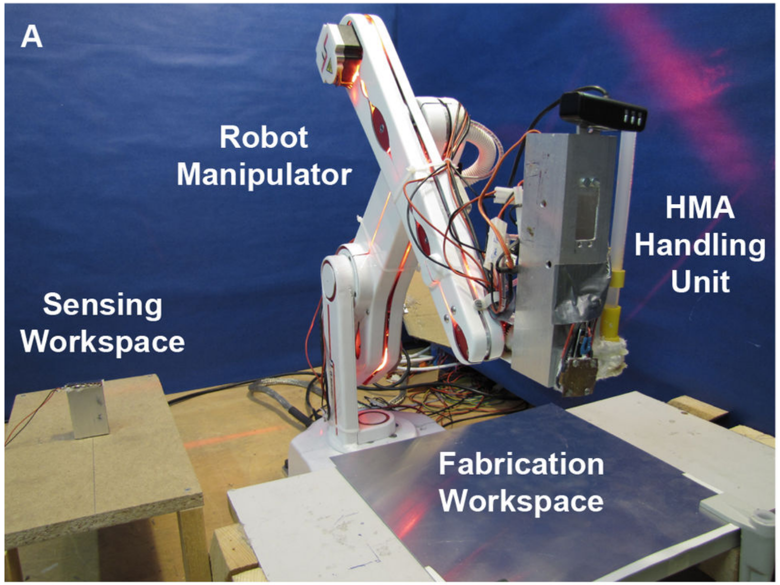
HMA's Bonding Strength with Various Materials

Material	Clamping σ^c (MPa)	Shear σ^s (MPa)
HMA	6.2-26.1	N/A
Peltier element ceramic	0.1-0.2	0.1
Stone	0.2-0.3	0.2
Normal steel	0.3-0.4	0.4-0.5
Anticorodal hard aluminium	0.6-0.7	0.9-1.0
Copper ETP	0.9-1.0	1.3-1.5
Roof batten fir wood	1.5-2.5	4.3-5.2
Window glass	>2.0	>2.0

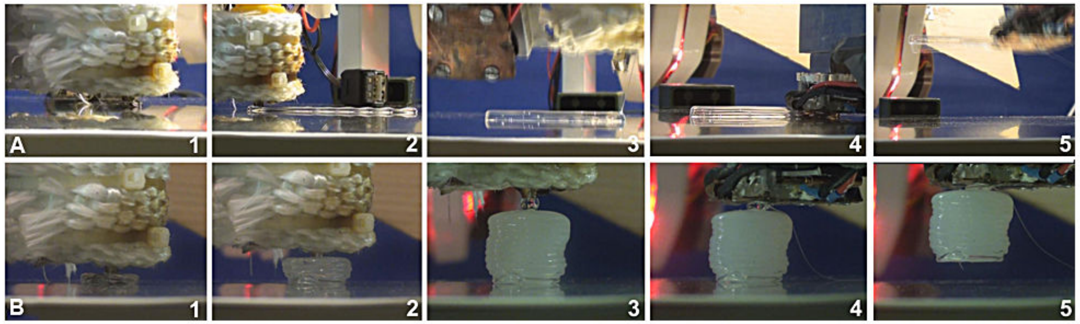


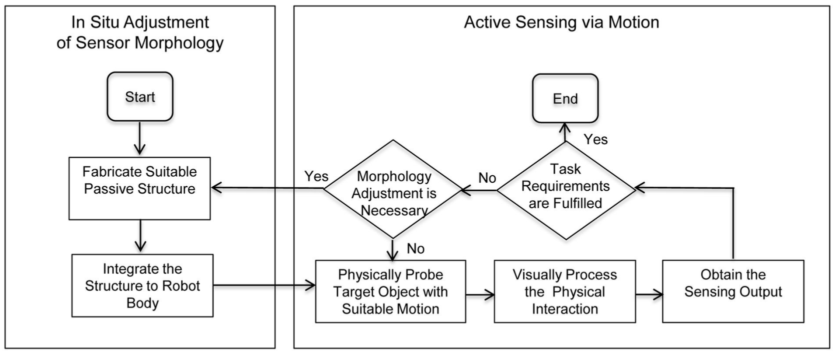
L .Wang, F. Iida, 2012

Adaptation of Sensor Morphology



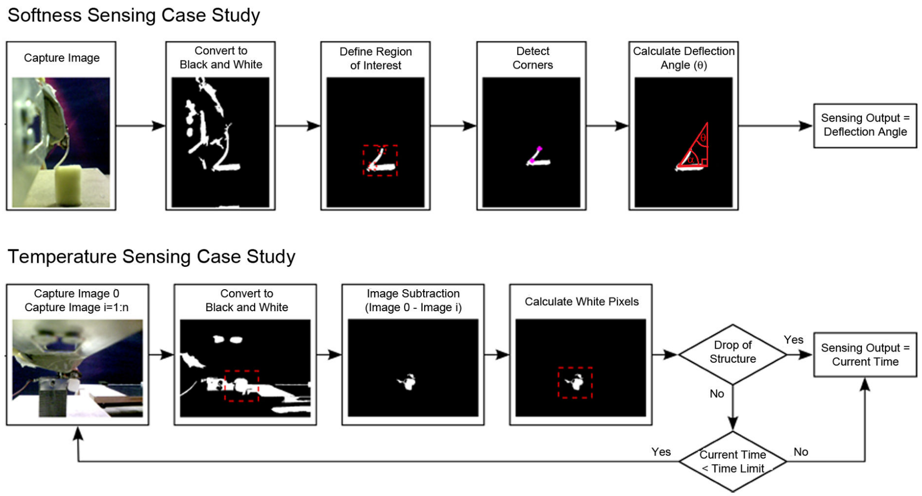
Morphology construction processes





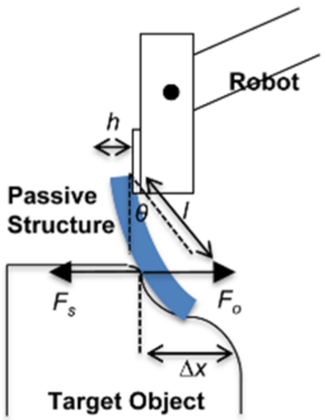
Fabrication Sensing

Camera image processing



[Nurzaman et al. 2013 PONE]

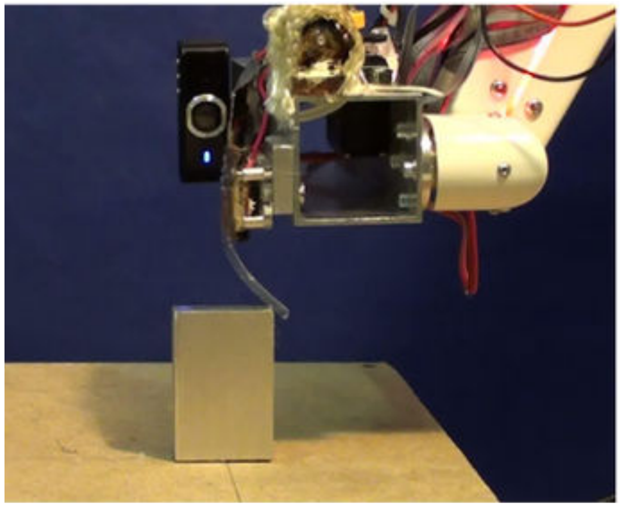
Adaptive Sensor Morphology (1/2)

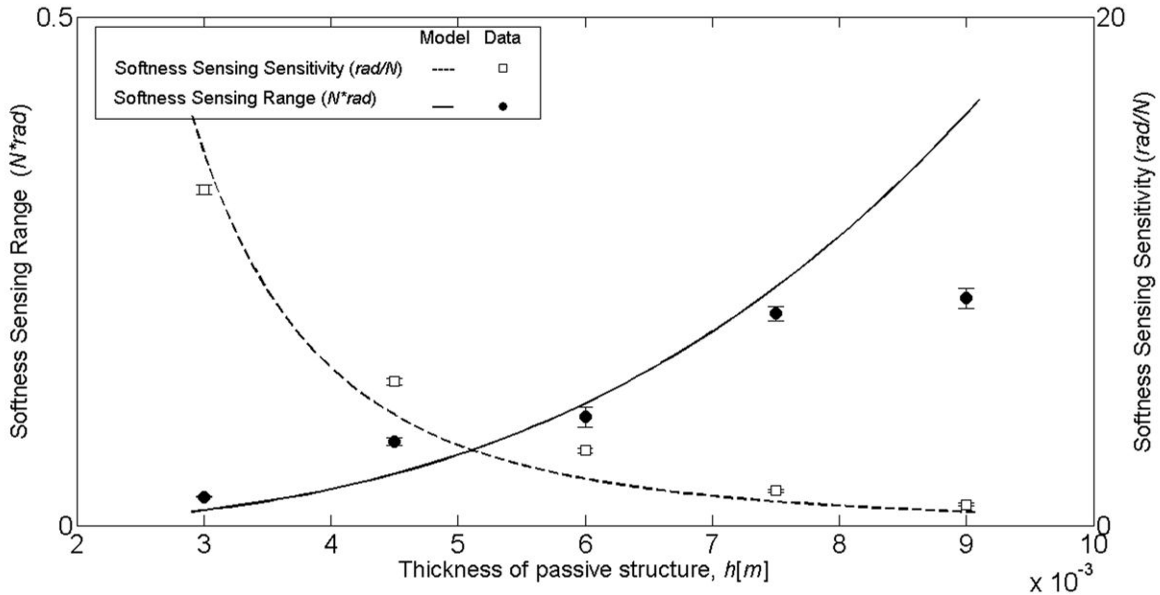


$$F = \frac{Edh^3}{6l^2}\theta \qquad (\,0 \le \theta \le \theta_{\max}\,)$$

Sensing range: $R_F\left(d,l,h\right) = \frac{Edh^3}{6l^2}\theta\Big|_{\theta=\theta_{\max}}$

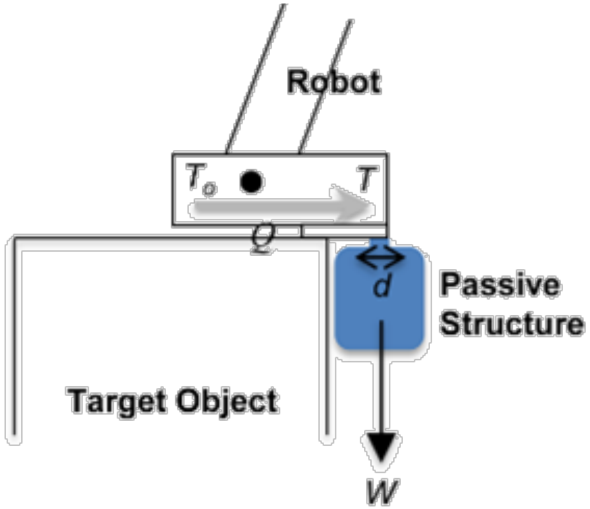
Sensitivity: $S_F\left(d,l,h\right) = \frac{d\theta}{dF} = \frac{6l^2}{Edh^3}$





[Nurzaman et al. 2013 PONE]

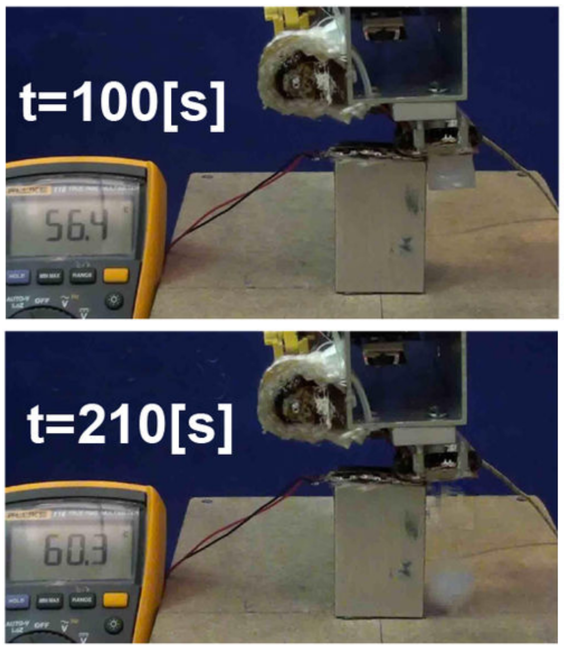
Adaptive Sensor Morphology (2/2)

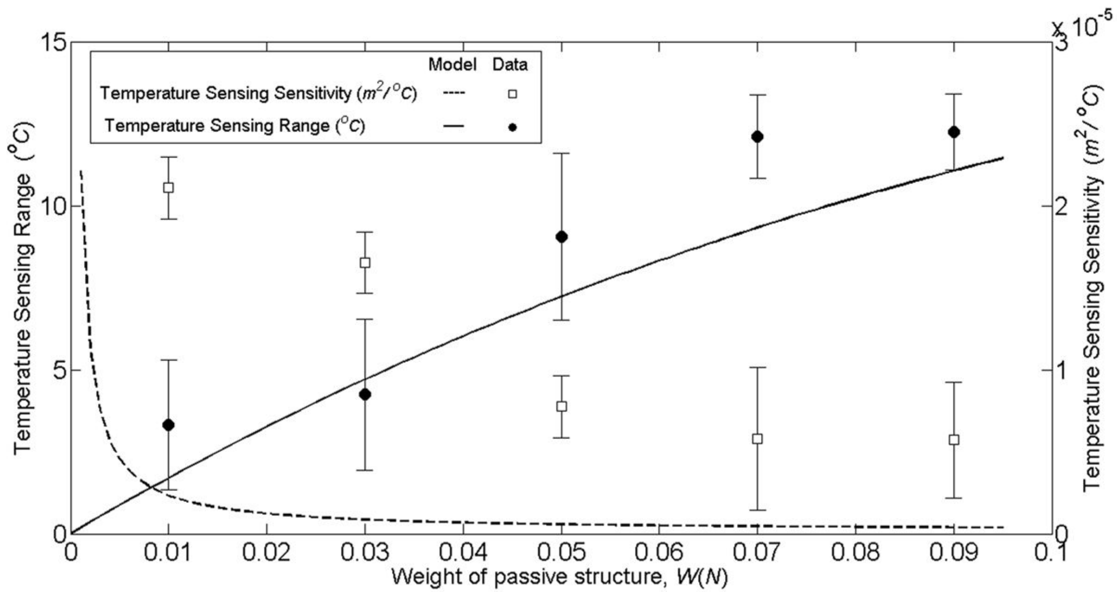


$$T = k_{T1}\exp\left(-k_{T2}B\right) \qquad B = \frac{W}{A} = \frac{W}{d^2} = \frac{mg}{d^2}$$

Sensing range: $R_T\left(W\right) = T|_{A=A_{\max}} - T|_{A=A_{\min}}$

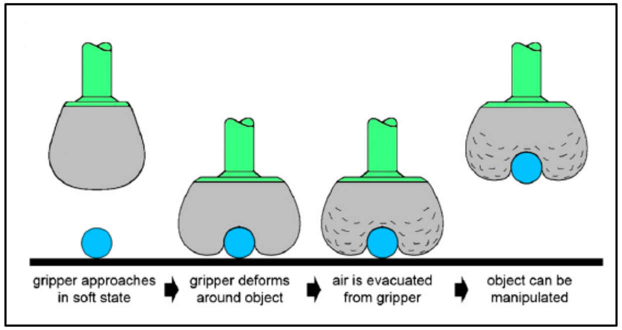
Sensitivity: $S_F\left(W\right) = \frac{dA}{dT} = \frac{A^2\exp\left(k_{T2}\left(\frac{W}{A}\right)\right)}{Wk_{T1}k_{T2}}|_{A=A_{\min}}$

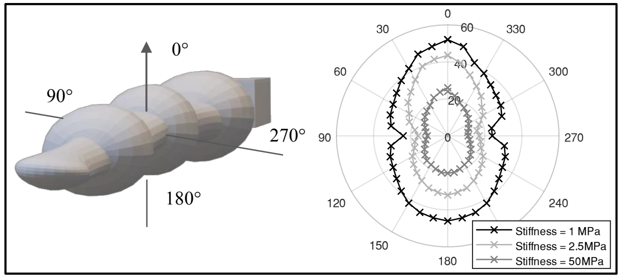


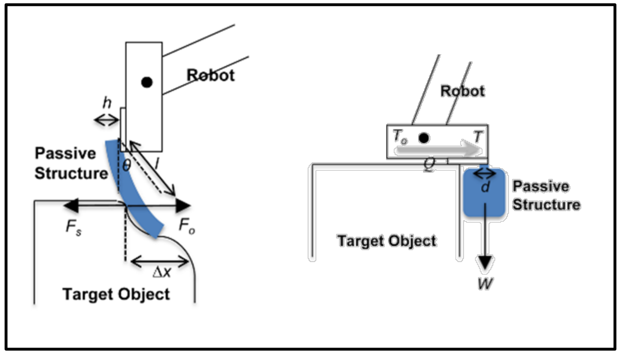


[Nurzaman et al. 2013 PONE]

Summary







- Design of Soft-Rigid Complex Robots is the grand challenge of robotics
- Math Design of Materials?
  - Soft-rigid phase transitions
  - Functional materials for actuation, motion control
  - Functional materials for sensing and computation

Pfeifer, R., Lungarella, M., and Iida, F. (2012). Communications of the ACM, 55(11): 76-87.

EPSRC Centre for Doctoral Training in Agri-Food Robotics: AgriFoRwArdS

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University of Cambridge

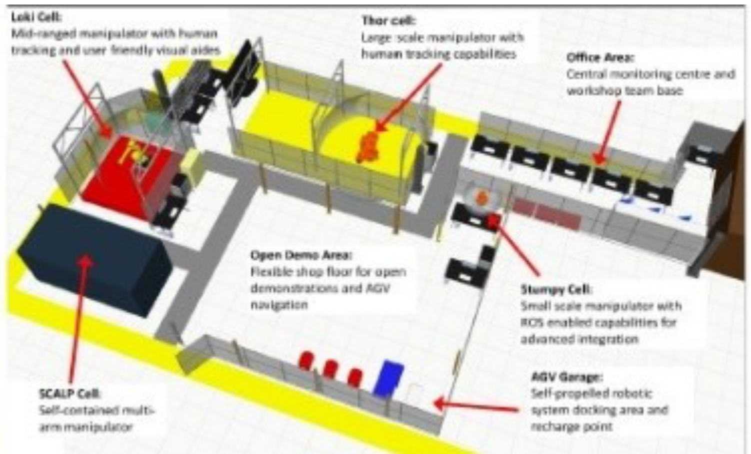
Fumiya Iida (CDT Deputy Director), Fulvio Forni, Roberto Cipolla

University of East Anglia

Richard Harvey, Graham Finlayson

MPhil/PhD POSITIONS AVAILABLE!

- 4 Year MPhil/PhD Interdiscplinary Training Programme
- 50 Studentships in 2019-2027 (20 for Cambridge)
- 40+ Academic supervisors from 3 institutions
- 23+ Industrial partners
- Budget: £6.6M (EPSRC) + £3M+ (industry support)



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http://softrobotics.org

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Thank you!

For publications, video, pictures, questions:

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