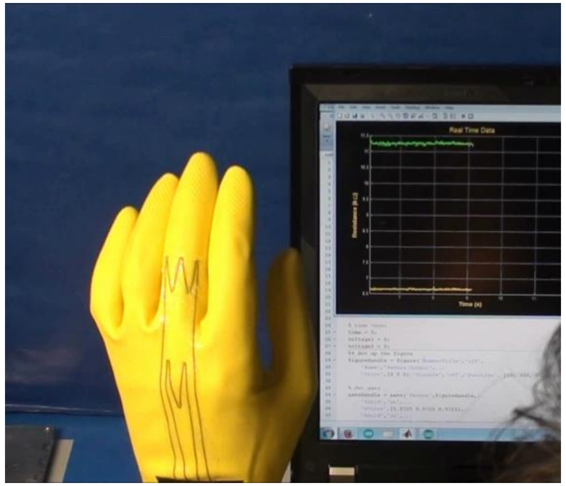
# Bottom-up design and control methods for adaptive robotic systems

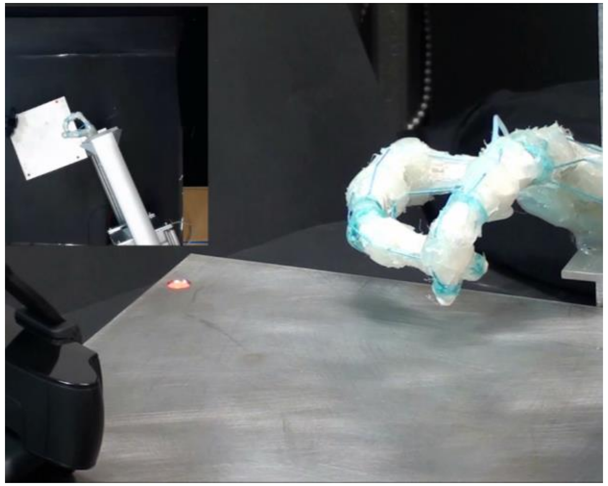
## Design Principles for Soft-Rigid Hybrid Robotic Grippers

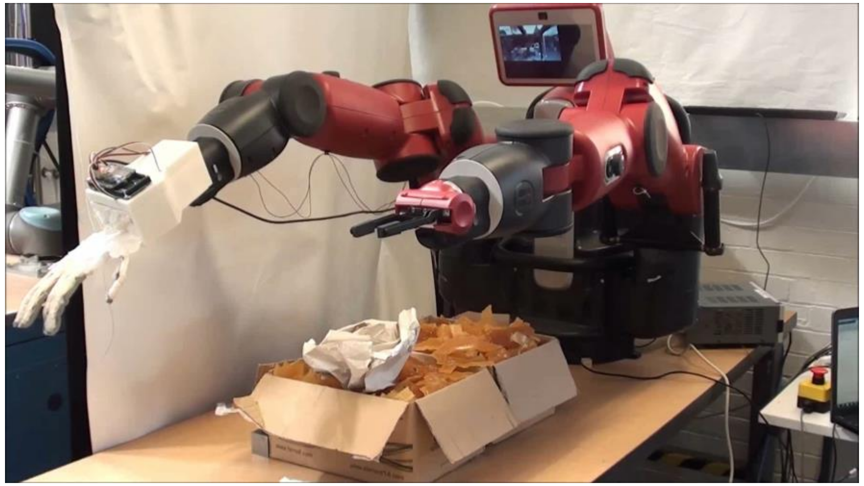
Dr. Utku Çulha

*Senior Researcher*, Learning Systems and Robotics Lab

Chair of Safety, Performance and Reliability of Learning Systems





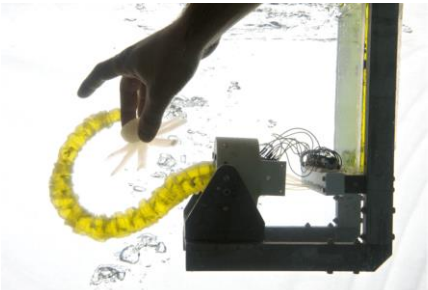


**HANDSFORUM**

Optimization

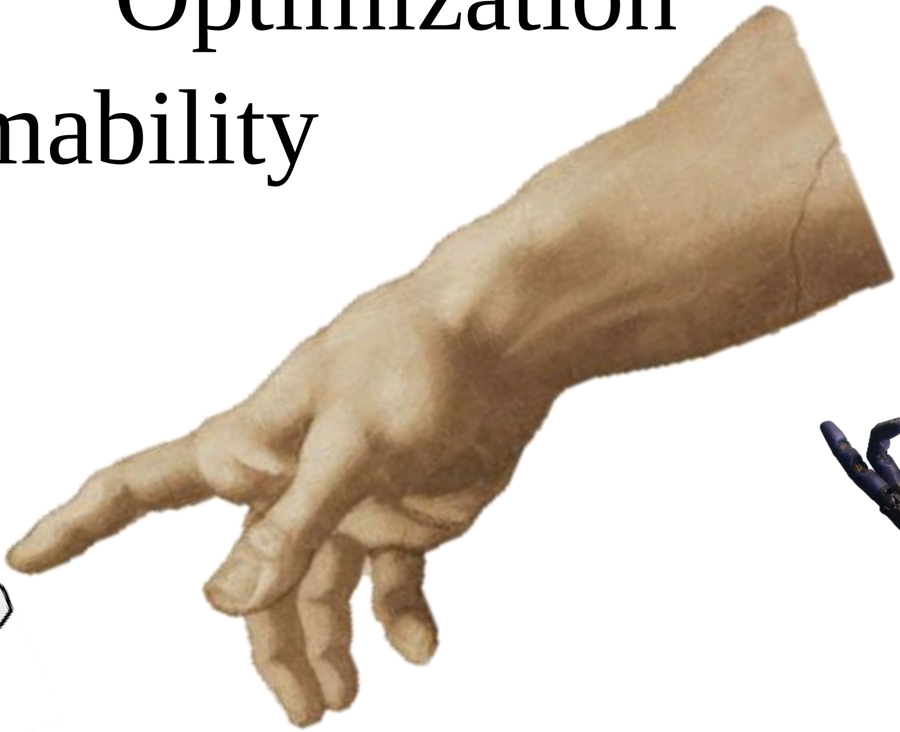
Top Down

Programmability



Soft Octopus Arm, SSSA Pisa

Autonomy



Boston Dynamics

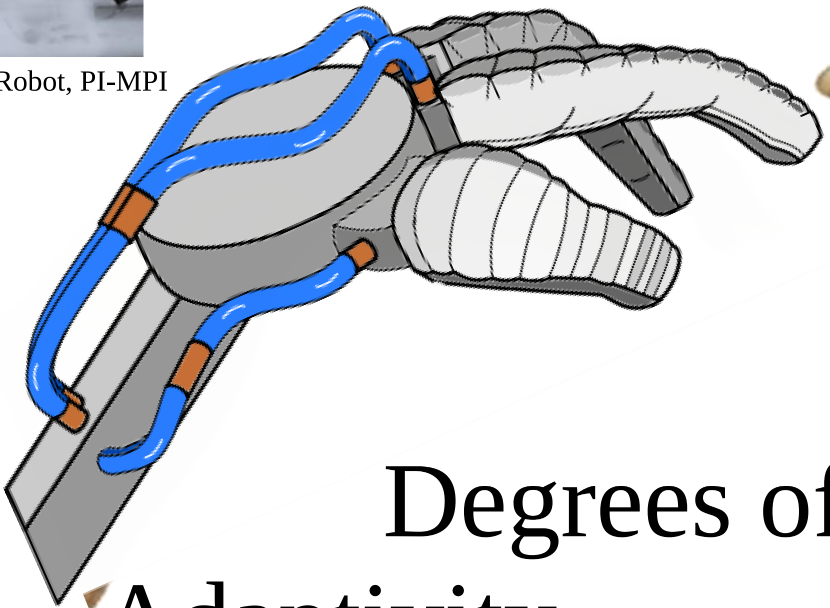
Soft Magnetic Robot, PI-MPI

Shadow Hand

iRobot Roomba

KiloBots, Harvard University

Modularity



Bottom Up

Degrees of Freedom

Adaptivity

Star Wars

# Research Scope

**Human hand as the manifestation of research focus on adaptive robots**

### Hybrid Robotics

- Functional material integration
- Accessible, repeatable, adaptive fabrication methods
- Task-tailored morphology, actuation, and sensing

### Self-Assembly

- Design and control exploration
- Distributed task-handling
- Outreach to physics, biology, and materials science

### Machine Learning

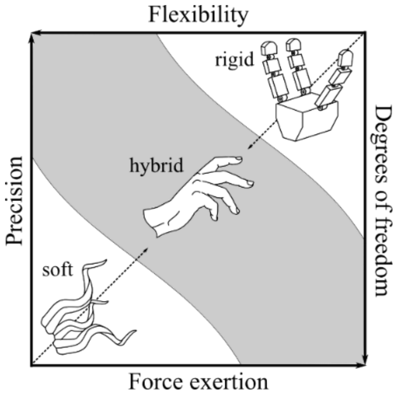
- Kinematics, dynamics, and task learning
- Adaptive control learning
- Optimization and exploration

Images are adapted from 3D Molier International.

# Research Focus: Hybrid (Soft & Rigid) Robotics

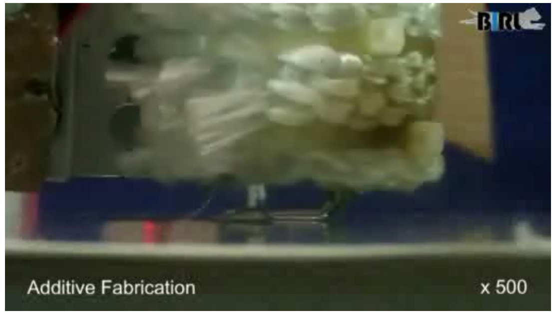
The **design**, **modeling**, **fabrication**, and **control** of robots that embody soft and rigid materials establish the structural foundation for physical robotic adaptation.

### Robot Design



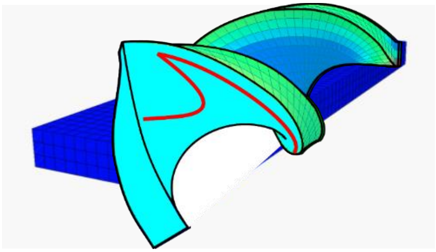

- Bioinspired design elements
- Target-oriented morphology
- Design exploration

### Materials and Prototyping



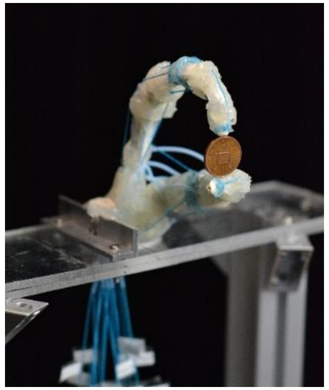

- Accessible, reproducible, reliable materials
- Easy-to-learn 3D printing, rapid prototyping
- Active collaboration on functional materials

### Modeling & Control



- Data-driven & analytical methods
- Experimental robotics
- Controller learning & optimization

### Adaptive Manipulators

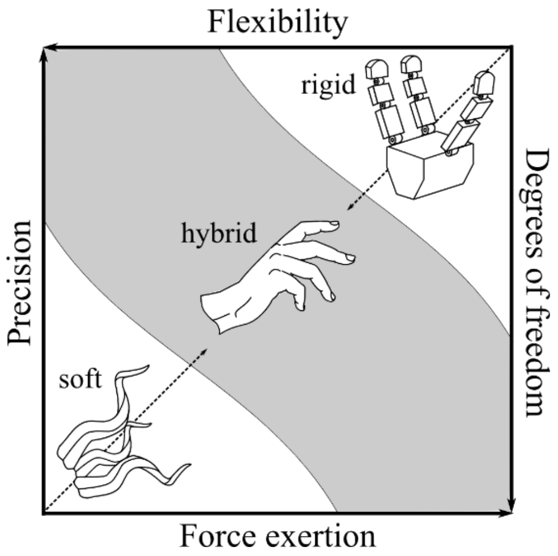


- Soft actuation and sensing
- Hybrid materials
- Learning of tasks and controllers
- Applications in assistive systems, agriculture, and HRI.

Design principles for soft/hard hybrid robotic grippers

## The design space of the manipulators

The hybrid manipulator lies in the middle of the design space as it is a combination of soft and rigid materials. Different materials and designs yield specific advantages over others. We identified four design principle to produce such a manipulator.



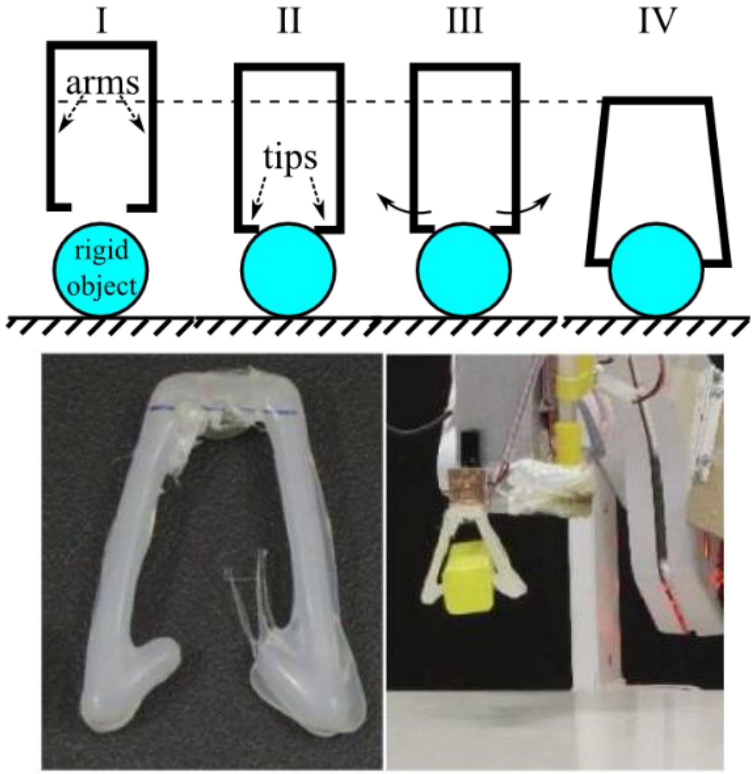

Articulated Link Structure → Soft/Tendon Actuation → Differential Stiffness → Guided Soft Joints

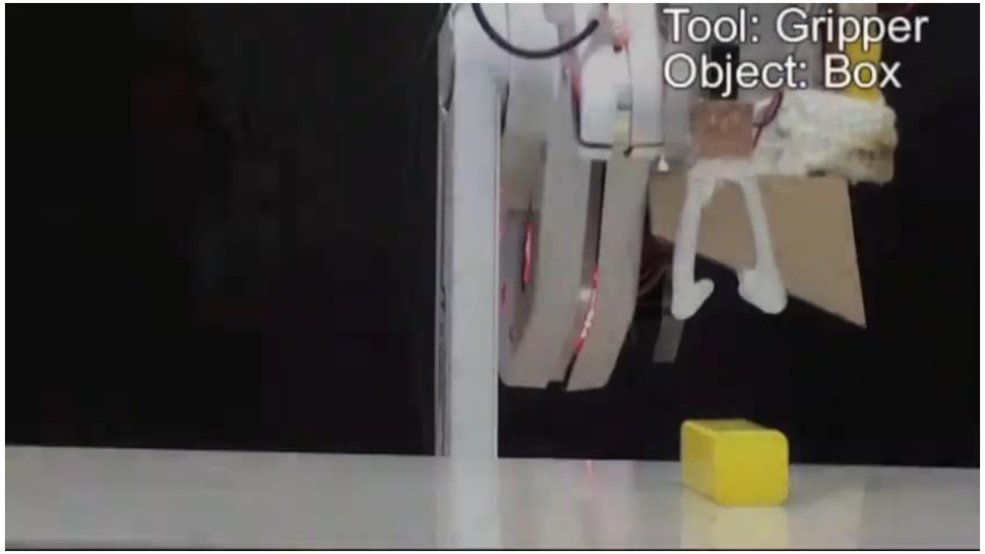
Culha, U. et al., *Soft Robotics: Trends, Applications and Challenges*, Springer, pp. 87-94, 2017.

# Design principles for soft/hard hybrid robotic grippers

## 1. Articulated Link Structure

Being able to generate **form** and **force closure** on objects enables manipulators to achieve complex interactions. Articulated links further enable "in-hand manipulation" when actively actuated.



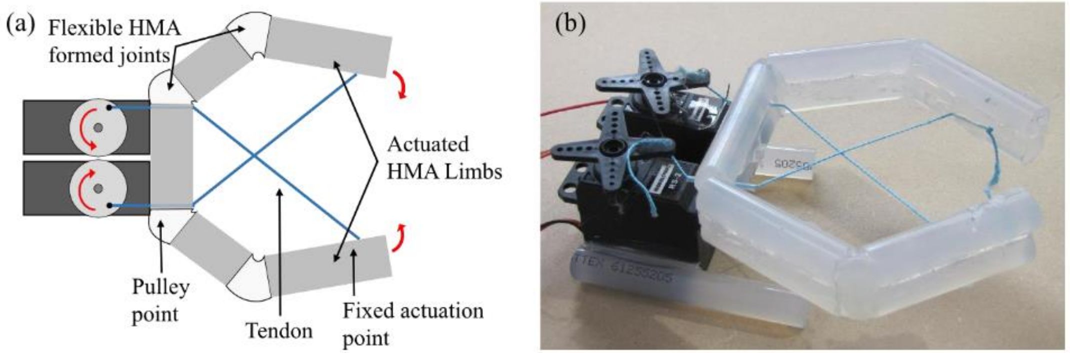




- Grasping is still possible with passive compliance.
- The morphology of the links define the manipulation space.
- External forces can be utilized to help with manipulation.

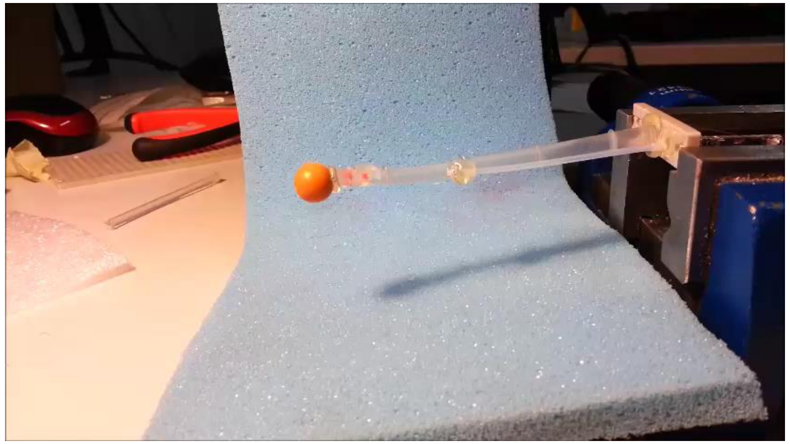

Brodbeck, L. et al., in *IEEE/RSJ Int. Conf. Int. Robot. (IROS)*, pp. 1428-1433, 2012.
Wang, L. et al., *J. R. Soc. Interface*, 11, p. 20140827, 2014.
Culha, U. et al., *Soft Robotics: Trends, Applications and Challenges*, Springer, pp. 87-94, 2017.

## 2. Soft Actuation – Tendon Driven Links

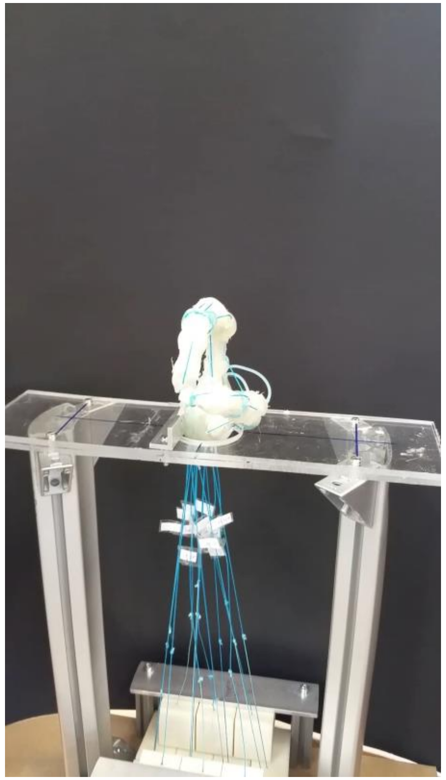
It is desired to have **low inertia** for a hybrid manipulator to achieve delicate and soft interactions. This requires the actuation mechanism to **transfer forces** to the target actuation point without hindering the softness of the manipulator.




(a) Hot-melt adhesive (HMA) based “fingers” and “joints” are actuated with (b) “tendons” with more flexible axes of motion.



Bowden cables can transfer the point of actuation over relatively soft links.



A slightly more complex setup.

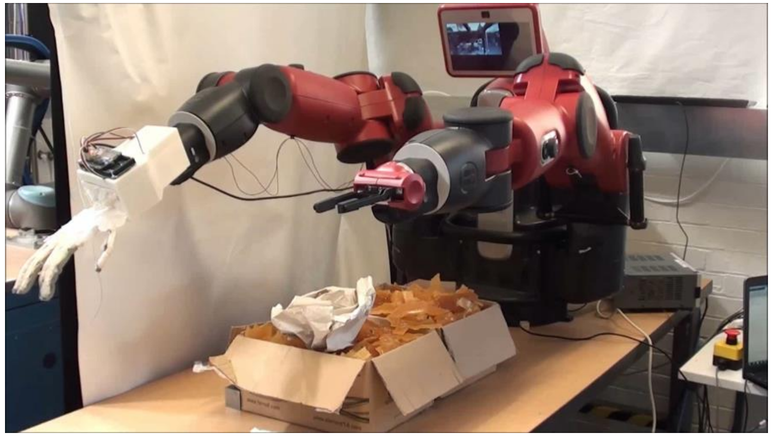
Culha, U. and Iida, F., *Bioinspiration and Biomimetics*, 11(2), p. 026001, 2016.
Culha, U. et al., *Soft Robotics: Trends, Applications and Challenges*, Springer, pp. 87-94, 2017.

# Design principles for soft/hard hybrid robotic grippers

## 3. Differential Stiffness via Multiple Materials

The hybridity of soft and rigid sections can be achieved through combining materials with different **mechanical stiffness**. We can therefore define the motion and physical adaptation of a manipulator just via material selection.


(a) Wooden links are connected to each other with (b) HMA to form soft joints and finger pads with “sponge” to assist form closure. (c) Palm is reinforced with rigid materials to apply necessary forces during grasping.

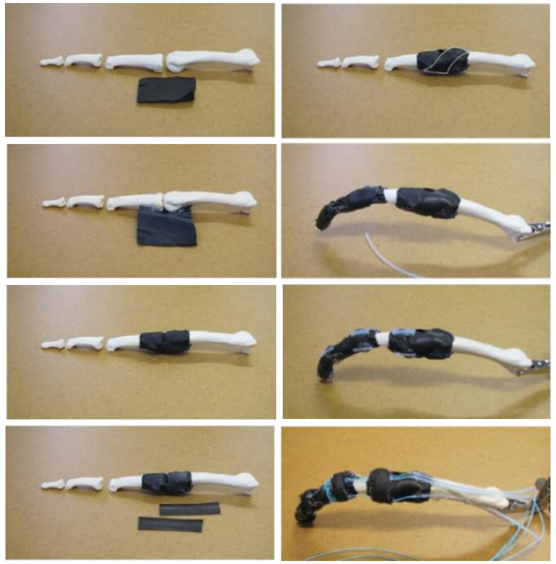


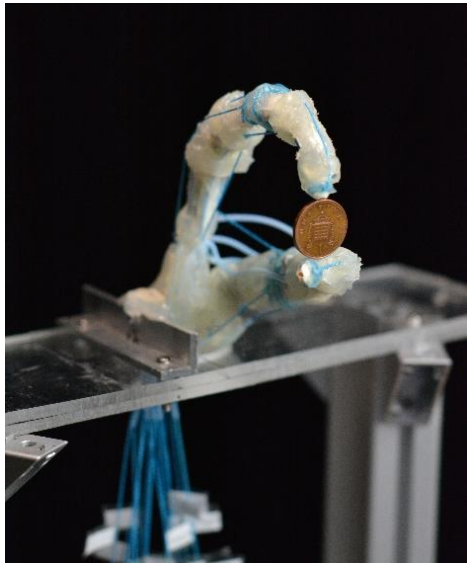

Culha, U. and Iida, F., *Bioinspiration and Biomimetics*, 11(2), p. 026001, 2016.
Chepisheva, M. et al., *in 14th Int. Conf. Sim. Adapt. Behav. (SAB)*, pp. 195-206, 2016.
Culha, U. et al., *Soft Robotics: Trends, Applications and Challenges*, Springer, pp. 87-94, 2017.

# Design principles for soft/hard hybrid robotic grippers

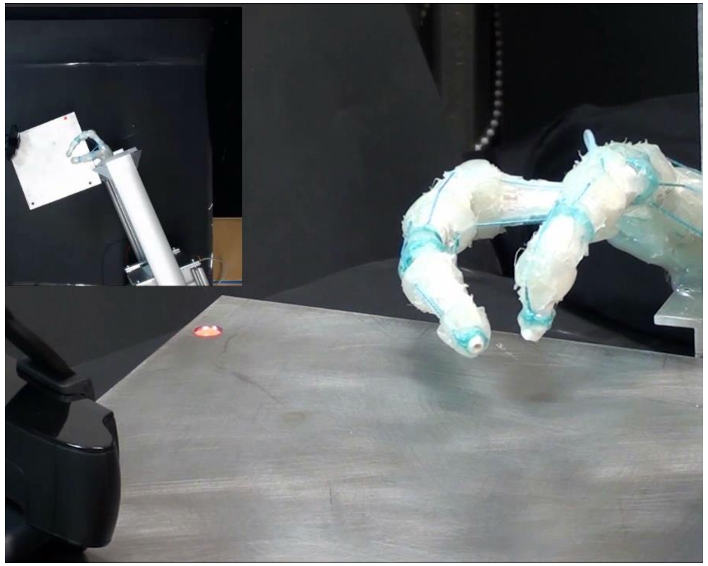
## 4. Guided Soft Joints

A soft joint allows motion in multiple directions, but it is challenging to control each axis. Guiding soft joints with the geometry of the link end regions and the routing of the tendons can establish a controlled actuation, while leaving room for physical adaptation.

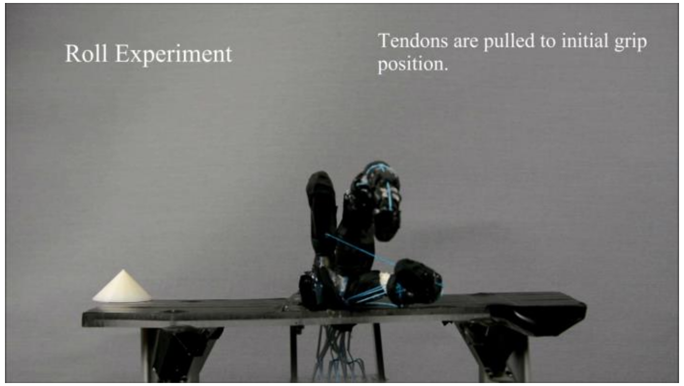


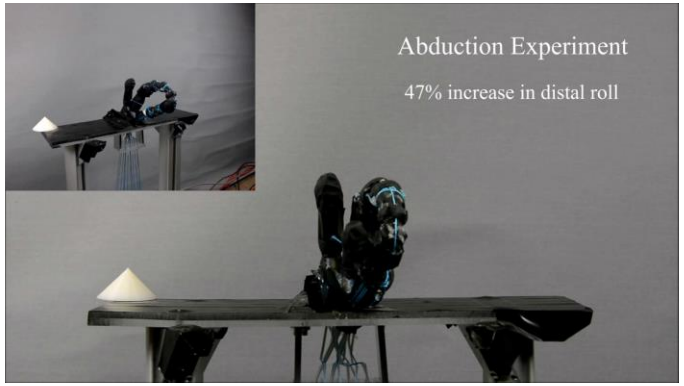


Stages of hybrid finger construction with soft/rigid materials, tendons, and guided joint architecture.



Energy (un)loading is possible with hybrid designs.




Culha, U. and Iida, F., *Bioinspiration and Biomimetics*, 11(2), p. 026001, 2016.
Culha, U. et al., *Soft Robotics: Trends, Applications and Challenges*, Springer, pp. 87-94, 2017.

# Is this useful?

## Technology transfer to affordable prosthetics

All the principles defined are easily applicable in robotics, but their direct transfer to prosthetics is questionable. Rather, they could serve as design guidelines.

- Articulated links → serve as the basis for simple designs e.g., Cybathlon Events in 2016, 2020 (https://cybathlon.ethz.ch/)
- Soft actuation → "intuitively" the natural choice but bio-mimicry is beyond question at this point.
- Differential stiffness → might allow for passive compliance with the expense of choosing correct materials.
- Guided joints → in the case of passive or under actuated designs, could expand the adaptation capabilities.

However, many key challenges are yet to be addressed, e.g., the biocompatibility, human interface, mass-production …

Developing "affordable" prosthetics is an "expensive" field of work.

# - Thank you -

BIRL Bio-Inspired Robotics Lab | ETH zürich | UNIVERSITY OF CAMBRIDGE

PHYSICAL INTELLIGENCE
MAX PLANCK INSTITUTE FOR INTELLIGENT SYSTEMS

Technische Universität München | TUM | MIRMI | LEARNING SYSTEMS & ROBOTICS LAB


Unterstützt von / Supported by
Alexander von Humboldt Stiftung/Foundation

Bundesministerium für Bildung und Forschung

Funded by
DFG Deutsche Forschungsgemeinschaft
German Research Foundation

erc European Research Council
Established by the European Commission

European Commission

Bayerisches Staatsministerium für Wirtschaft, Landesentwicklung und Energie

Bayerisches Staatsministerium für Wissenschaft und Kunst

REPUBLIC OF TURKEY MINISTRY OF NATIONAL EDUCATION

CyberValley