Myo electricity and 3D printing: a resource for revolutionary hand prosthetics.

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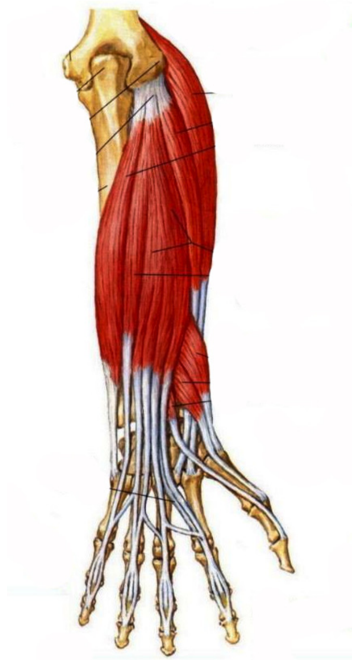
- **Introduction:**
  - Epidemiology
  - Commercial prosthetics
  - Scientific research
- The rehabilitation revolution
  - 3D modeling
  - 3D printing
  - Open source software & artificial intelligence
- A dexterous 3D printed hand
- Mechanical evaluation
- Tests with amputees
- Conclusion

Upper limb amputations: epidemiology and anatomy

- 41,000 subjects with a loss of an upper limb in US in 2005
- Most of upper limb amputations are at transradial level
- Hand muscles are mainly in the proximal part of forearm
- The remnant muscles can still be used to control a prosthesis

Atkins et al. 1996

Ziegler-Graham et al. 2008



Commercial hand prosthesis types

Cosmetic

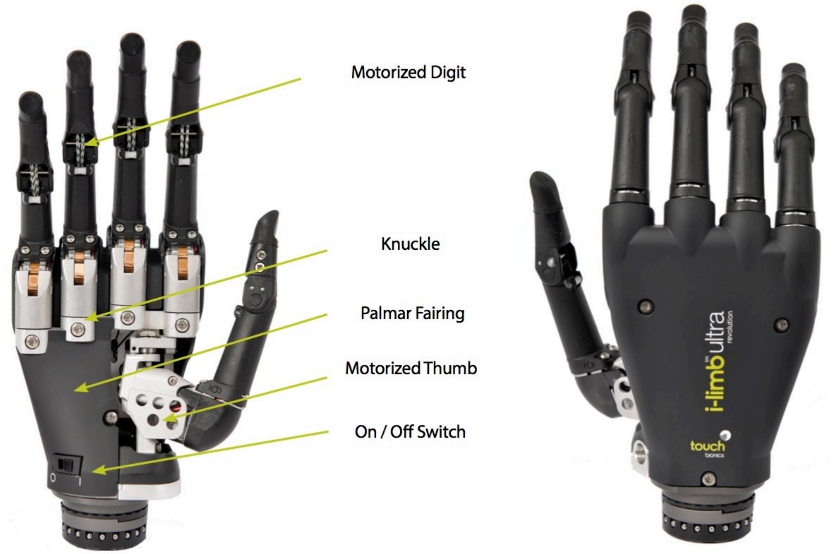
Myoelectric

Body-powered

Myoelectric prosthetics: market

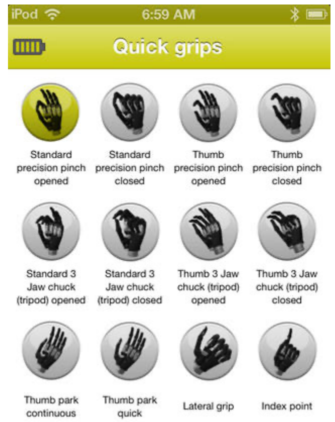
Pros: mechanically advanced hands

- Rotating thumb and wrist
- Up to 36 programmed movements



Cons: rudimentary control systems

- 2 sEMG electrodes (wrist flexion-extension)
- Movement changes via co-contraction, apps…
- No natural control



- First commercial pattern recognition systems available *(Coapt engineering)*

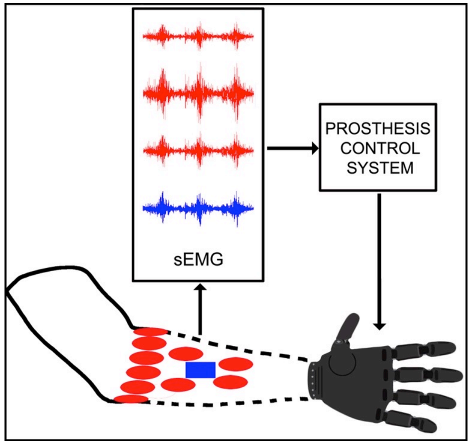
Many scientific results have not been translated to commercial systems due to control issues.

Atzori et al., Frontiers in Systems Neuroscience, 2016

sEMG prosthetics: scientific state of the art

Many scientific works presented:

- Proportional & simultaneous control (with supervised or unsupervised methods).
- Pattern recognition & movement classification.
- Multimodal data fusion (accelerometers, pressure sensors, computer vision, …).
- Neural interfaces for the bidirectional control of prostheses



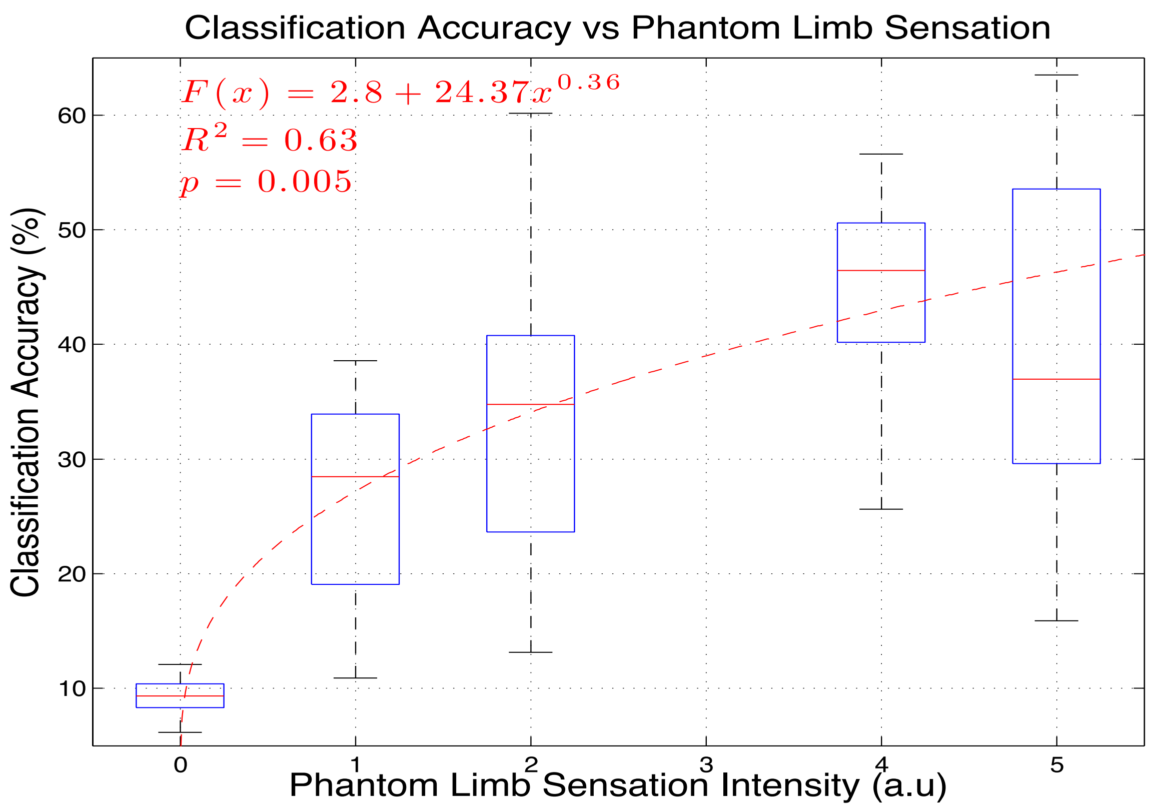
Few results translated to the market:

- Control systems not sufficiently robust or difficult to use

Atzori et al., Frontiers in Systems Neuroscience, 2016

Clinical parameters influence the capability to control the muscles in the stump

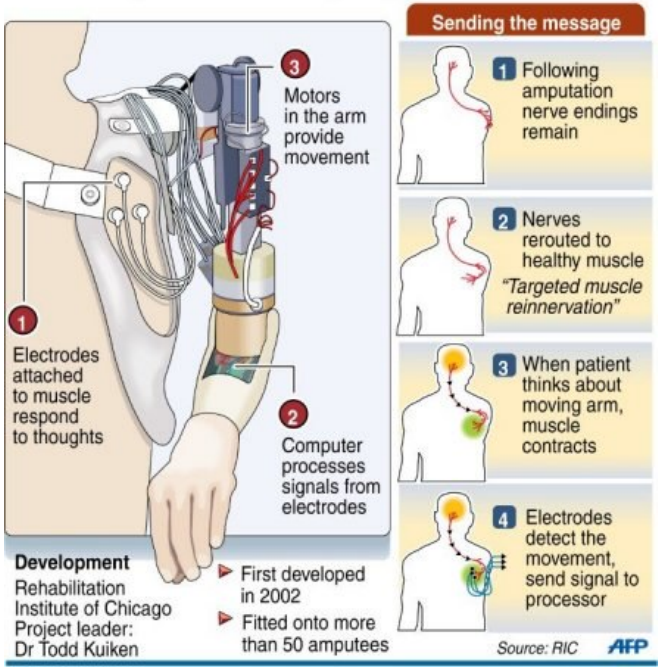
- sEMG activity related to 40 hand movements was analysed
- Amputees can repeat the movements with up to 65% accuracy
- Higher phantom limb sensation leads to better control of the muscles



Atzori et al., Journal of Rehabilitation Research and Development, 2016

Targeted muscle reinnervation

- Target muscle is denervated and reinnervated with residual nerves of the amputated limb. EMG signals of the target muscle are used to drive a motorized prosthetic device.
- Developed by Dr. Todd Kuiken (Northwestern University and Rehabilitation Institute of Chicago) and Dr. Gregory Dumanian (Northwestern University Division of Plastic Surgery)
- Economics and invasiveness



Kuiken et al., PNAS, 2007

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The rehab revolution

The prosthetics market is expensive

It is not sufficiently big to absorb big investments, leading to high costs *e.g.:*

- *dexterous prosthetic hands: > 50’000 $*
- *Exoskeletons: > 100’000 $*

Modern technology make development easier, faster & cheaper:

- 3D modeling
- Additive manufacturing & rapid prototyping
- Open source software & artificial intelligence

- Reduce prototyping costs
- Reduce testing costs
- Comply with national law requirements only when necessary

Technology factors: 3D modeling

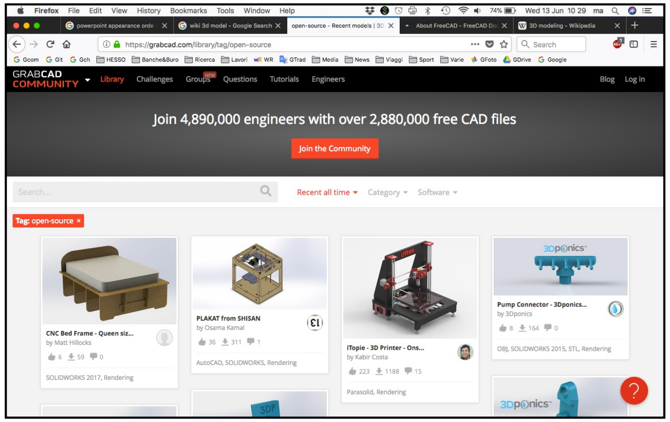
Definition

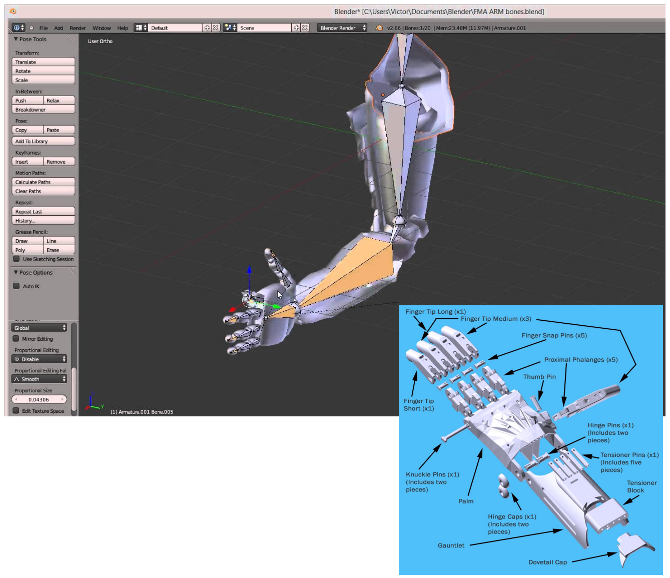
Process of developing mathematical representations of objects in three dimensions via specialized software

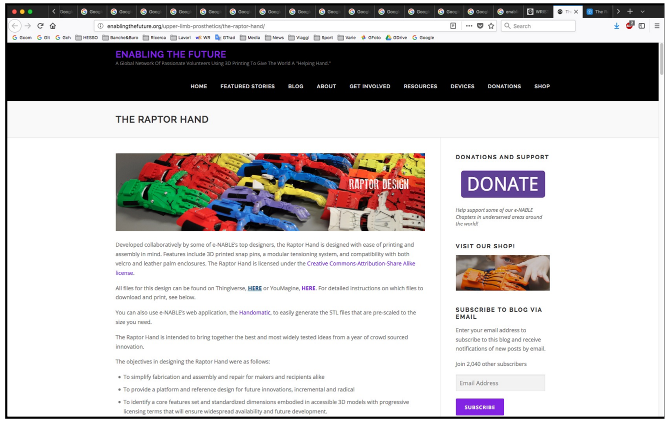
Features

Growing open source communities worldwide (also for rehabilitation)

Design is made not only by professionals, but **by many people including users**







Technology factors: additive manufacturing & rapid prototyping

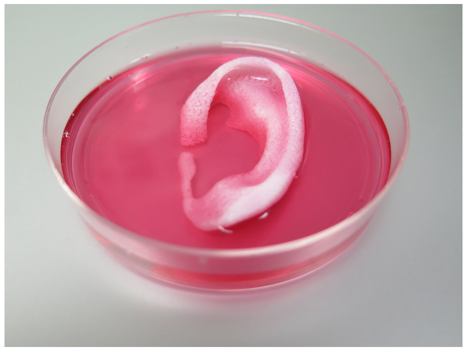
Definition

Processes in which material is joined under computer control to create a 3-dimensional object

Features

Many materials: polymers, composites, metals and biological

Applications: industry, domestic use, medical use, healthcare, food, human cells production, rehabilitation



Technology factors: open source software & artificial intelligence

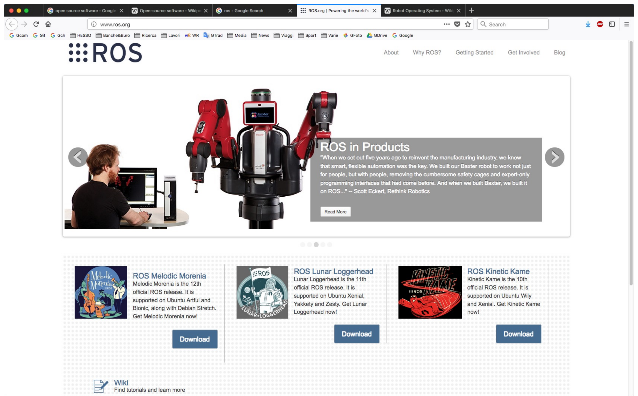
Definition

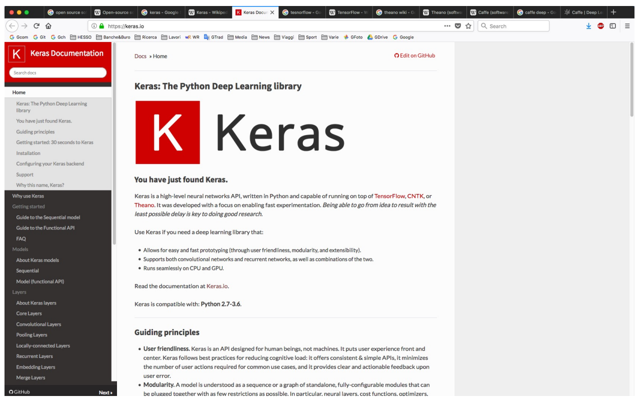
Computer software with source code released under licenses that grant users the rights to study, change and distribute the software.

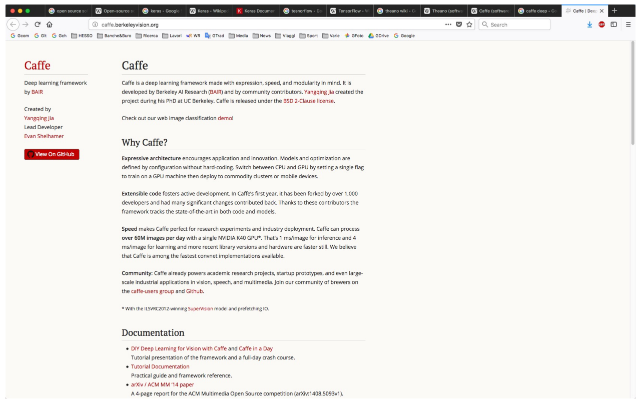
Features: many different domains, including

Robotics: Robot Operating System (ROS) is a software framework for robot software development.

Artificial Intelligence: e.g. deep learning frameworks such as Caffe, Keras, TensorFlow or Theano.





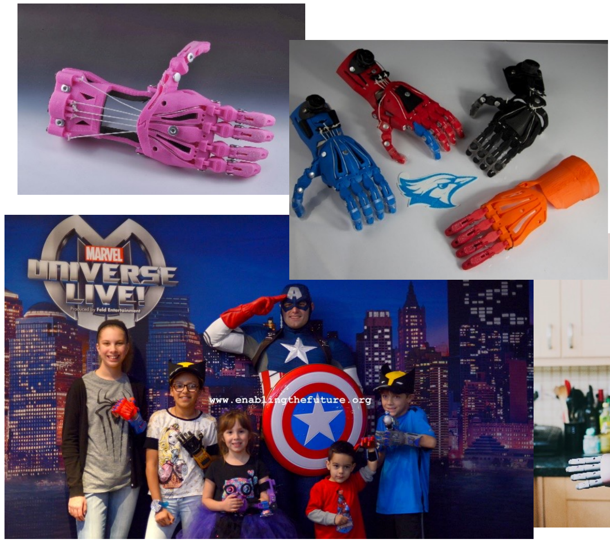


3D printed hand prosthesis: an overview

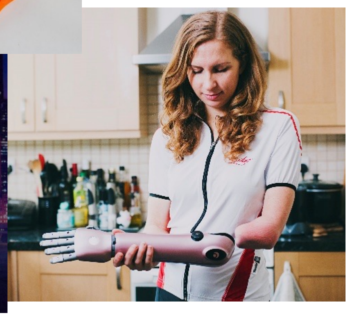
Open source 3D models are increasingly being released, even for dexterous prostheses

- ✓ AFFORDABLE
- ✓ CUSTOMIZABLE
- ✓ EASY TO MAINTAIN
- ✓ EASY TO UPGRADE

- ✗ ROBUSTNESS
- ✗ PERFORMANCE

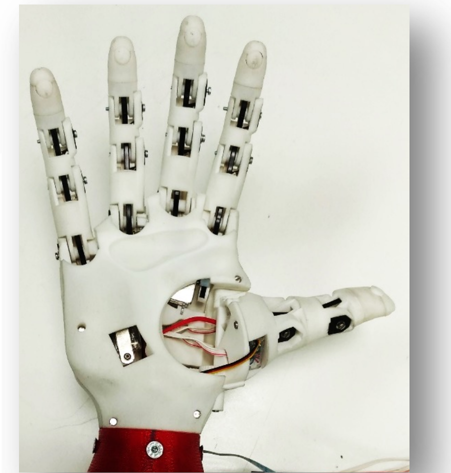


http://www.enablingthefuture.org



https://openbionics.com

http://exiii-hackberry.com



https://blinclab.ca/

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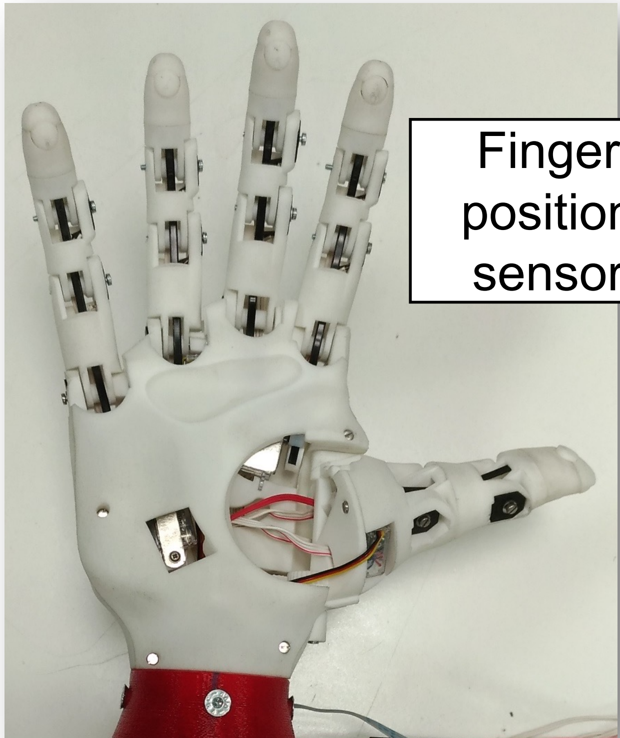
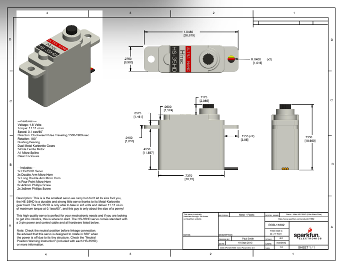
The Humanoid, Anthropometric, Naturally Dextrous intelligent (HANDi) Hand

Force sensor on fingertips



Finger position sensor

6 Servomotors



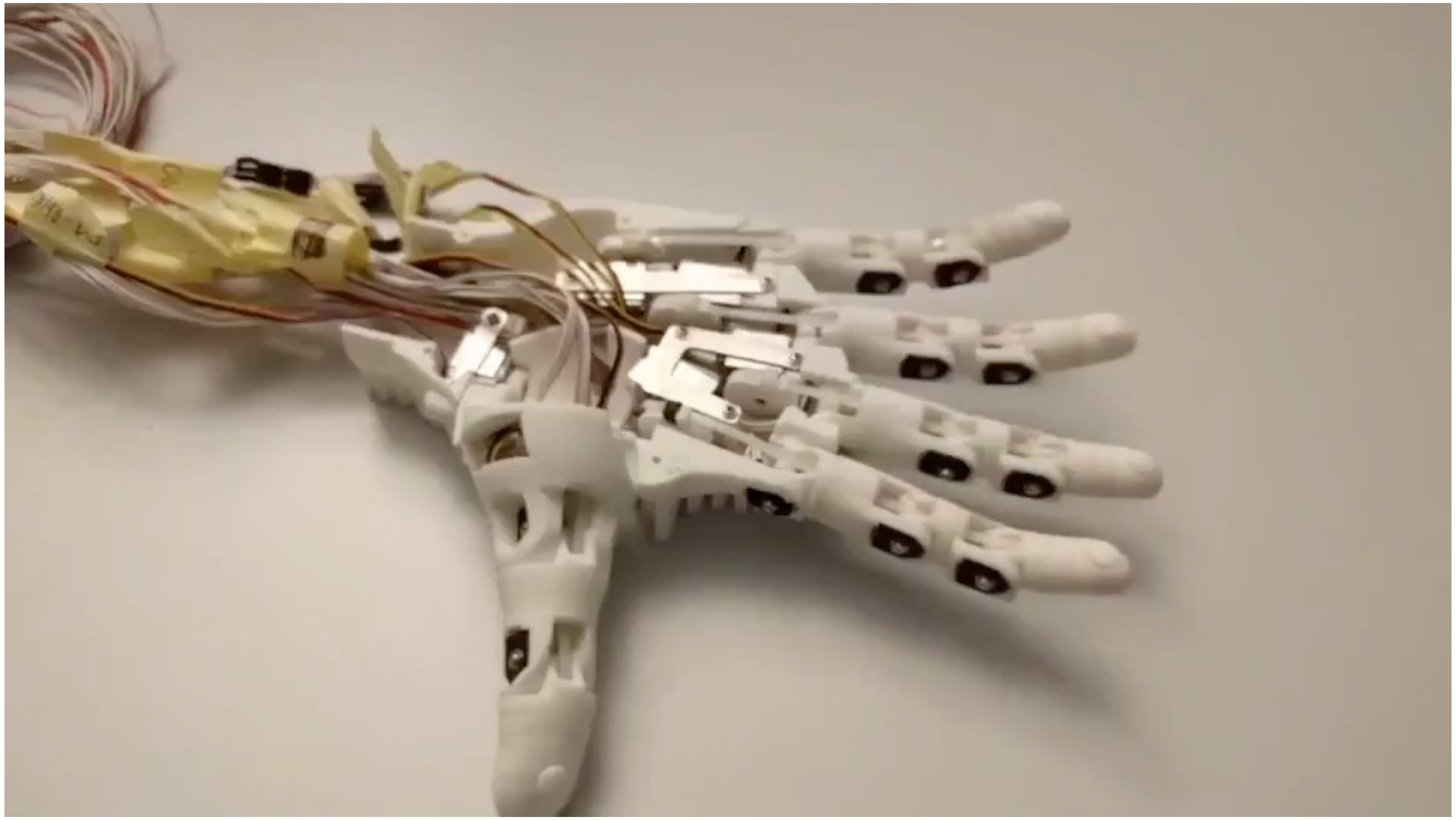
Item	Specification
Size	Anatomical Proportions
Mass	256 g
Max Payload	500 g
Finger Speed	Full close in 0.43 s
Grip Force	4.2 N
Prototype Cost	$ 800

The HANDi Hand is an open-source project developed and released by the Bionic Limbs for Improved Natural Control (**BLINC**) **Lab** from the **University of Alberta**, Canada

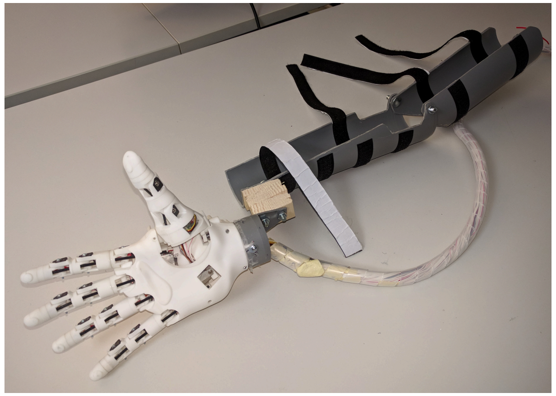
- Multi-articulated
- Highly sensorized
- Inexpensive
- Designed for research applications and machine learning-based control systems

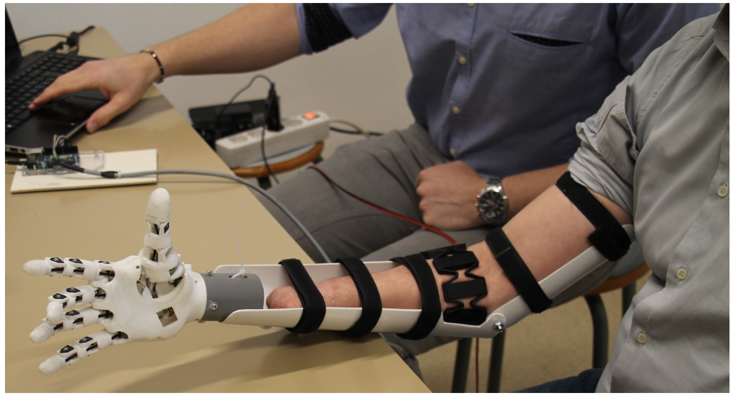
[Brenneis, D. J. A et al., MEC'17]

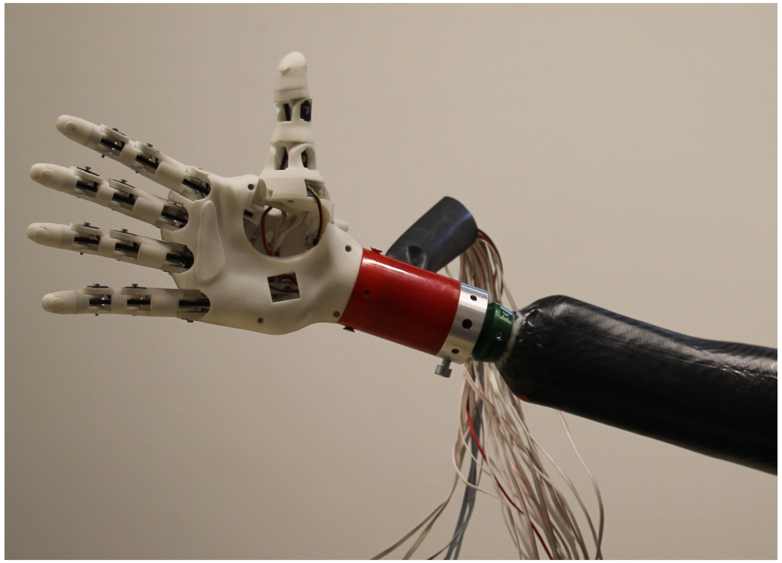
The Humanoid, Anthropometric, Naturally Dextrous intelligent (HANDi) Hand



Sockets development

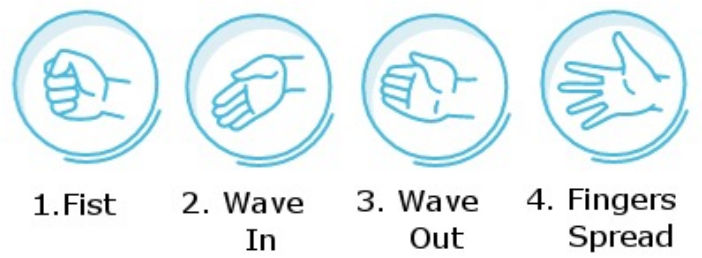






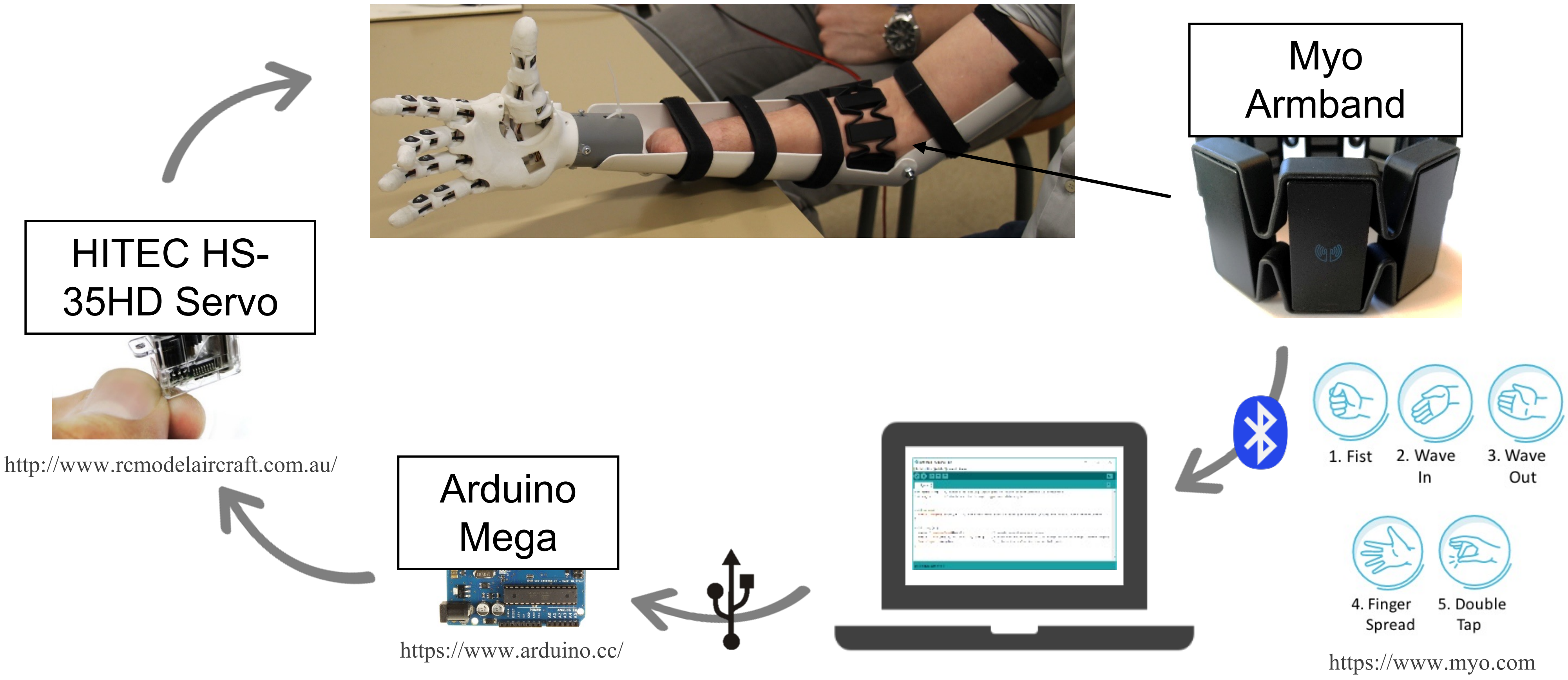
Real time control tests by amputees

- Thalmic Myo armband (~ 150 €):



	Fist	Wave In	Wave Out	Fingers Spread	Overall
Sbj 1	100%	88.9%	100%	100%	97.2%
Sbj 2	88.9%	77.8%	11.1%	88.9%	66.7%
Sbj 3	100%	66.7%	33.3%	0.0%	50.0%

Dexterous control of the 3D printed hand prosthesis



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3D printed hand prosthesis kinematic and structural evaluation & reinforcement

- Hand kinematics was compared with real hand
- Hand structure was modelled and analysed to improve robustness

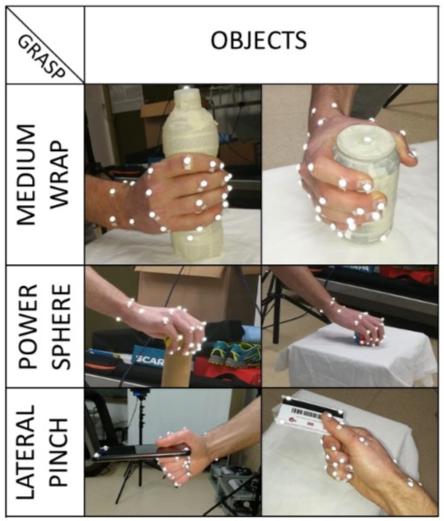


Fig. 4.14: Object's grasp performed with Real Hand.

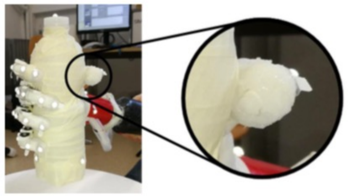


Fig. 5.14: Bottle grabbing with focus on mistouching of the thumb's fingertip.

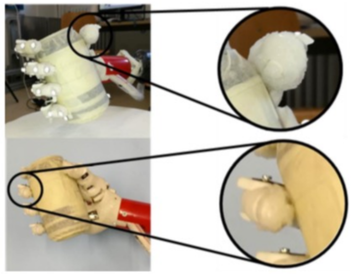
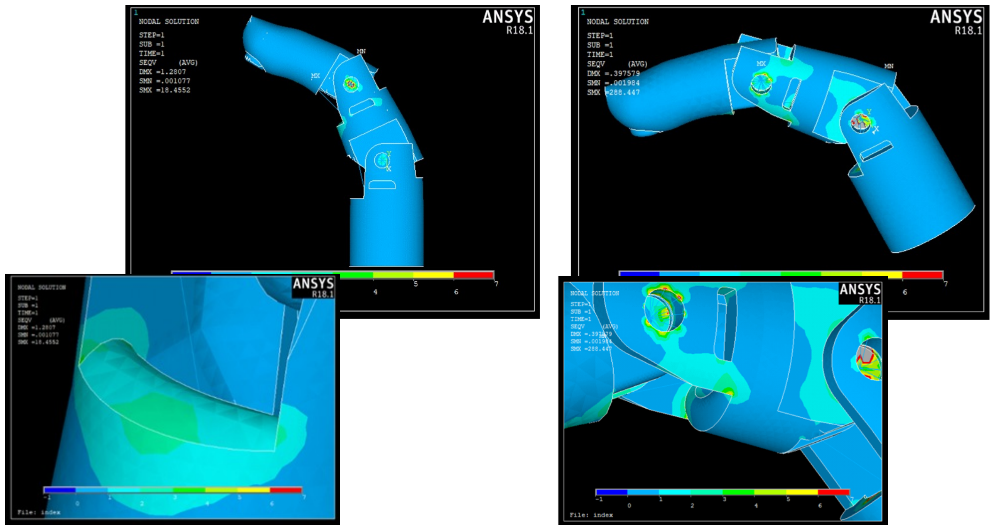


Fig. 5.15: Can grabbing with focus on mistouching of the thumb's and middle's fingertip.



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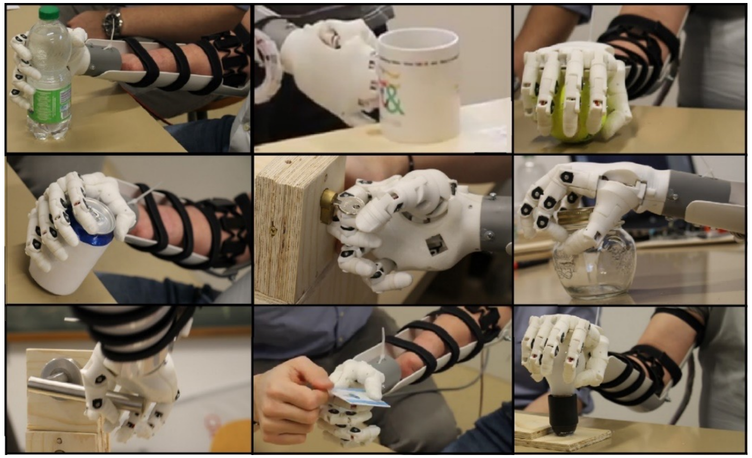
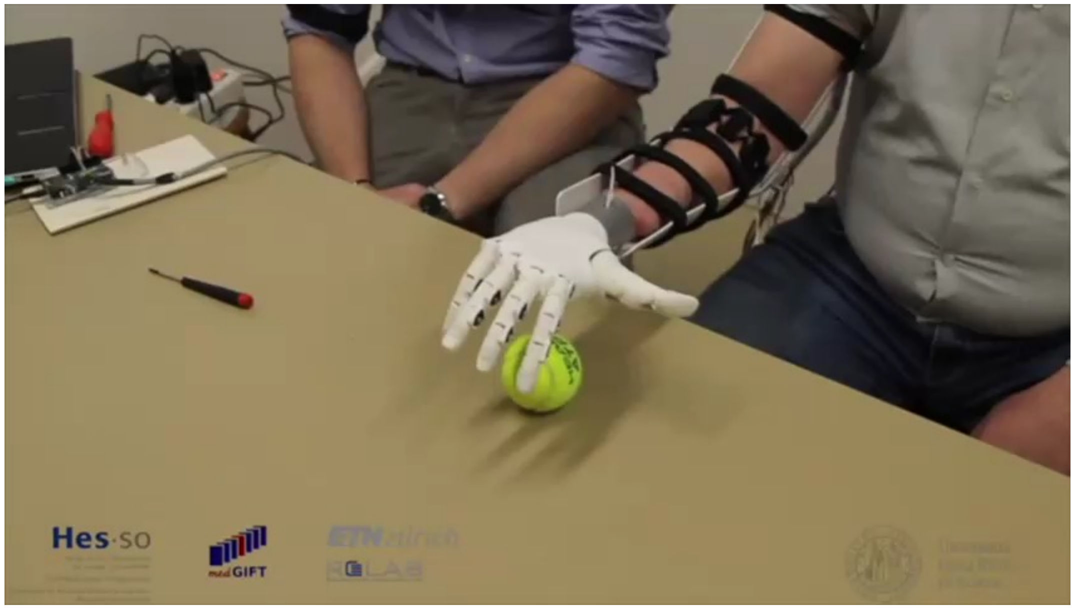
Functional tests with hand amputees

The

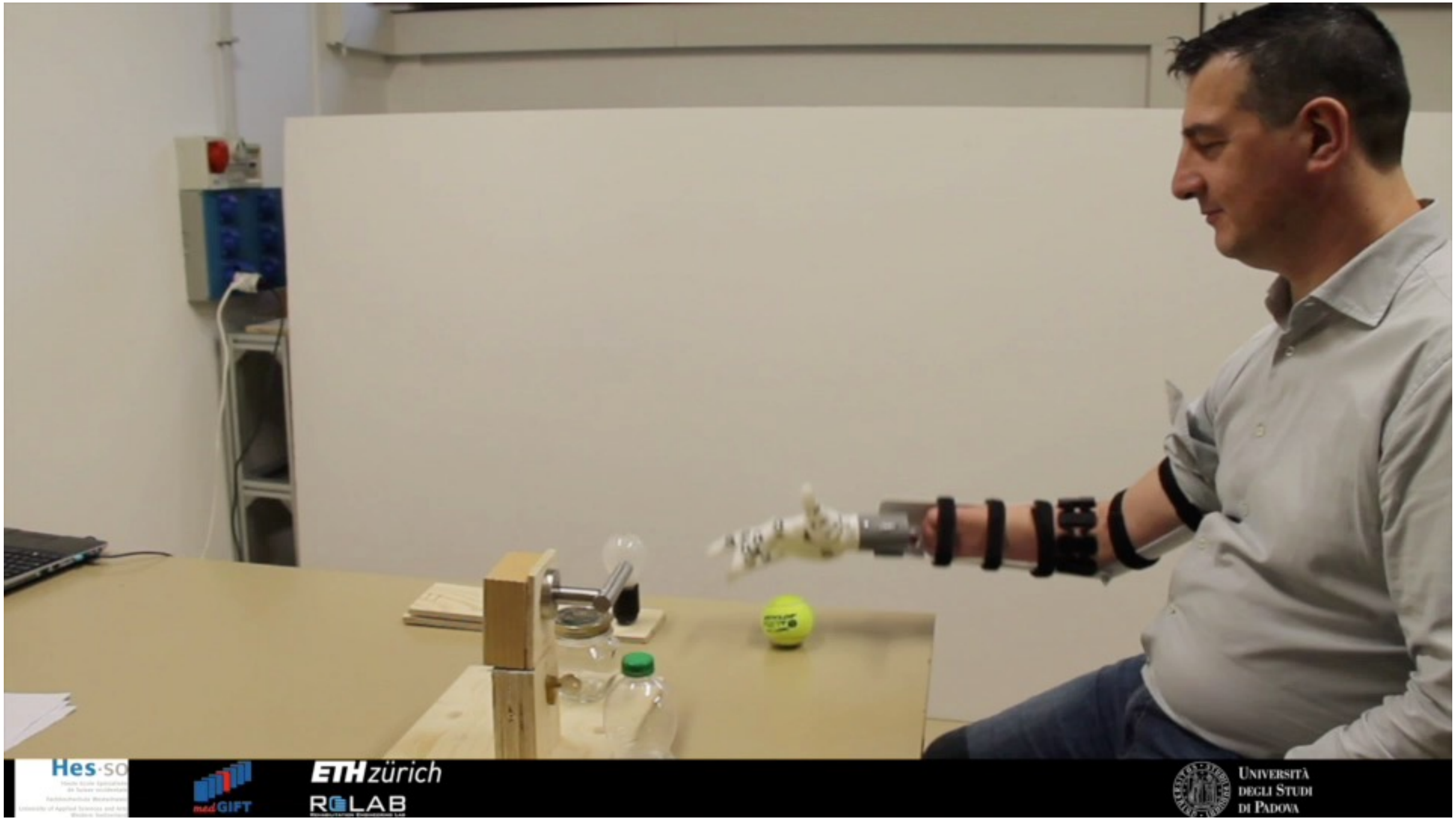


% OF FAILED ATTEMPT PER GRASP-TYPE (no training)			
	Medium Wrap	Power Sphere	Lateral Pinch
S1	45.45	7.69	33.33
S3	40.00	25.00	55.55



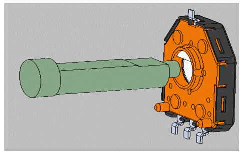
[Cognolato et al., BioRXiv'18]

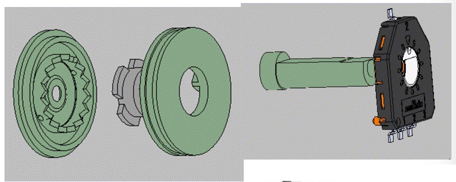
Control and test of a 3D printed hand prosthesis on amputees

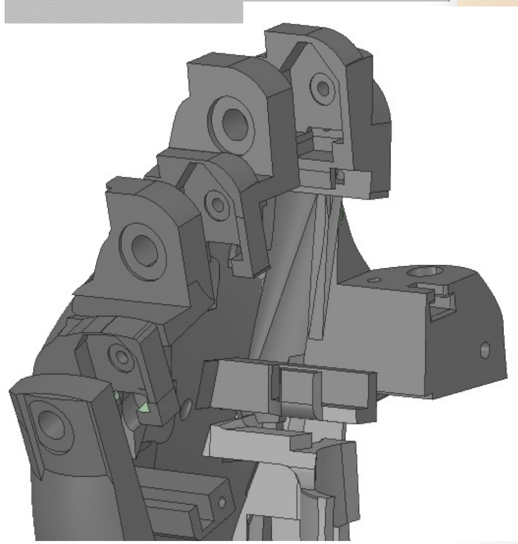


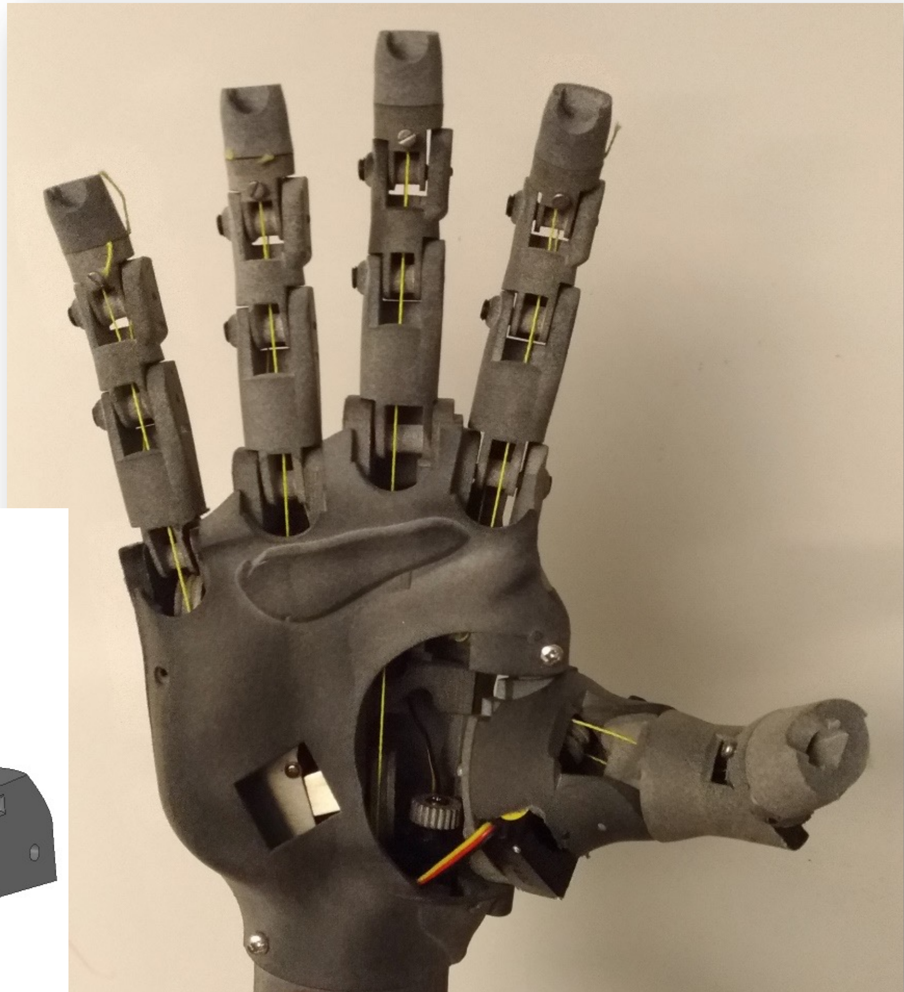
Cognolato et al., biorXiv 2018

Ongoing work: own prototype design









Several improvements:

- Different actuation
- Simplified geometry
- New thumb kinematic
- More robust and performing servos

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Take home message

- A robotics and rehabilitation revolution may be near (thanks to 3D printing and artificial intelligence)
- We are contributing to developing and testing new technologies
- The 3D printed hand real-life tests are extremely promising
- We are developing a more robust prototype to be used in real life conditions