Smart control of a soft robotic hand prosthesis

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Motivation

2009 – 2013
10 253 amputees
(Vicepresidencia, 2013)

Commercial prostheses

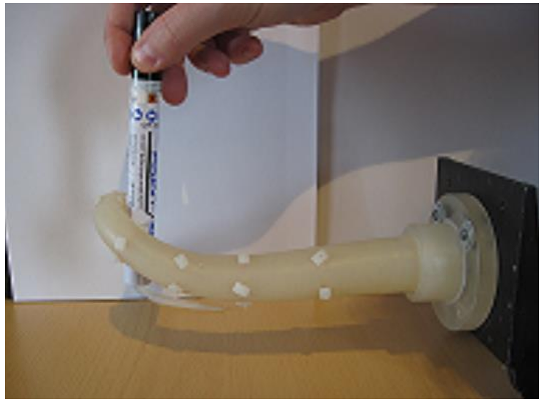
Michelangelo

Bebionic Hand 3

i-limb Ultra

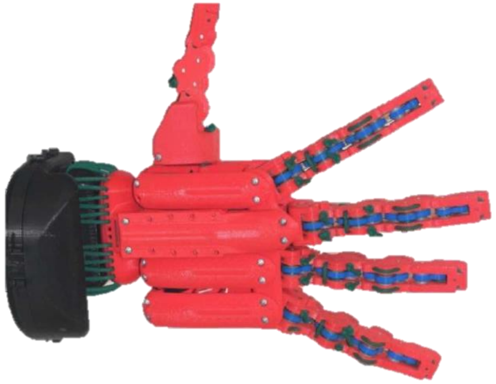
- Hard to use: difficult learning
- Low adaptability: rigid mechanism
- Low sensor capacity: limited to motor activity

Soft robotics



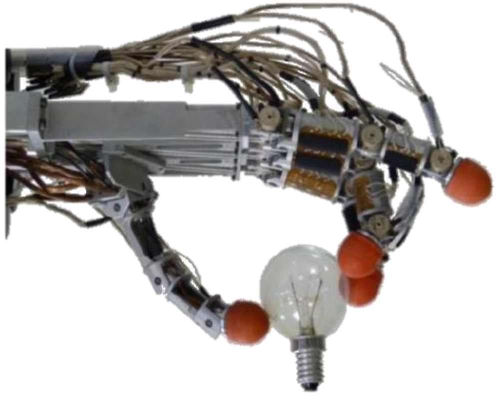
Octopus robot

(Calisti *et al*., 2010)



Pisa soft hand

(Godfrey *et al*, 2013)



ROBIOSS

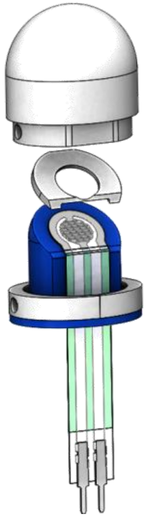
(Mnyusiwalla *et al.* 2016)

Unconventional materials, Elastic, Compliant

Target of the thesis

Our goal is to provide:

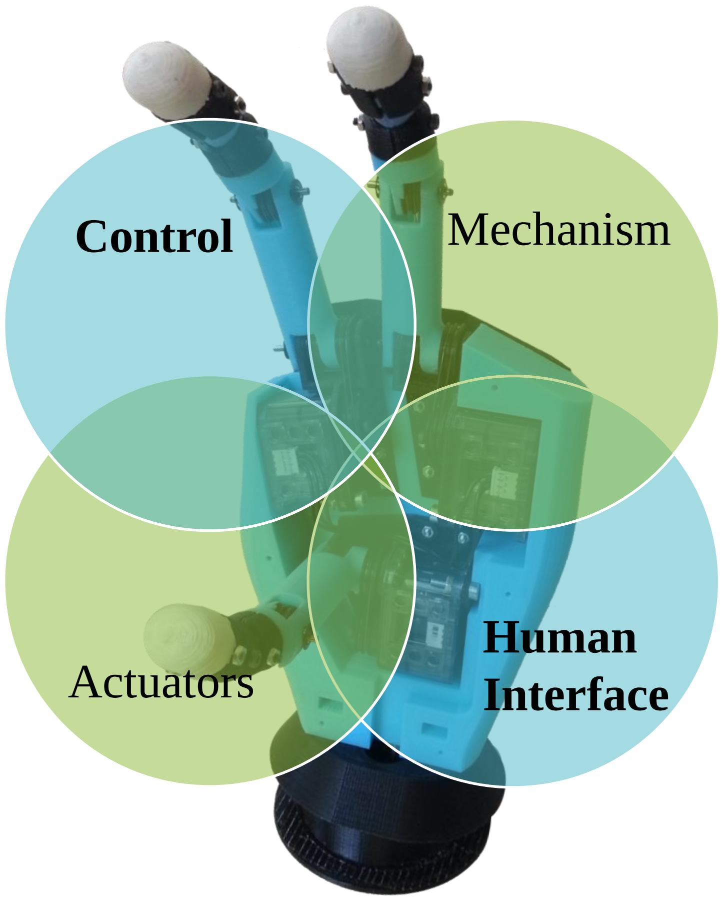
- A more intuitive human-prosthesis interface based on sEMG using a wearable device
- A soft fingertip for steady grasping
- Fingertip sensor for hybrid control
- Softness in robotic finger using soft materials



ProMain

The project has a highly multidisciplinary content, requiring a variety of skills that can be summarized below

- Data processing
- Robotics
- Artificial intelligence
- Embedded system
- Control
- Real-time computing

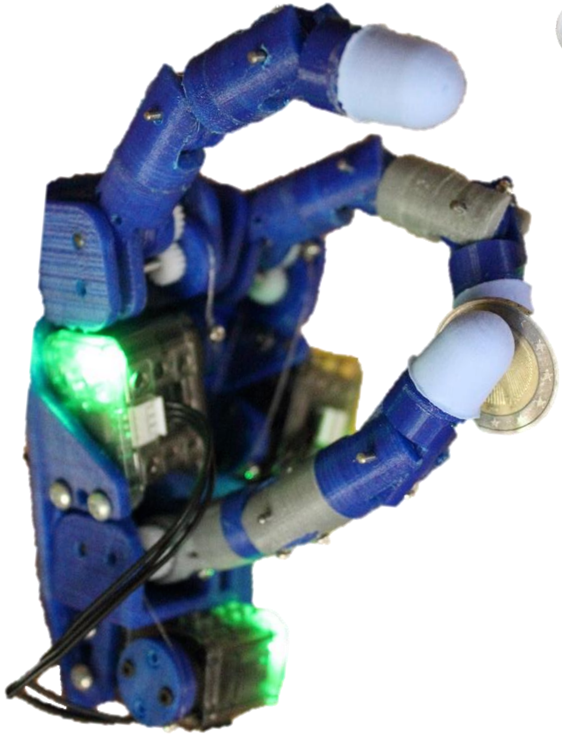


- Bio-mechanics
- Mechanical
- Modeling
- Numerical methods
- Multi-field coupling
- Smart materials
- Structural analysis

Outline

1. Introduction
2. Human hand interface
3. Hand prosthesis control
4. Development of a soft link
5. Conclusion and perspectives

ProMain hands

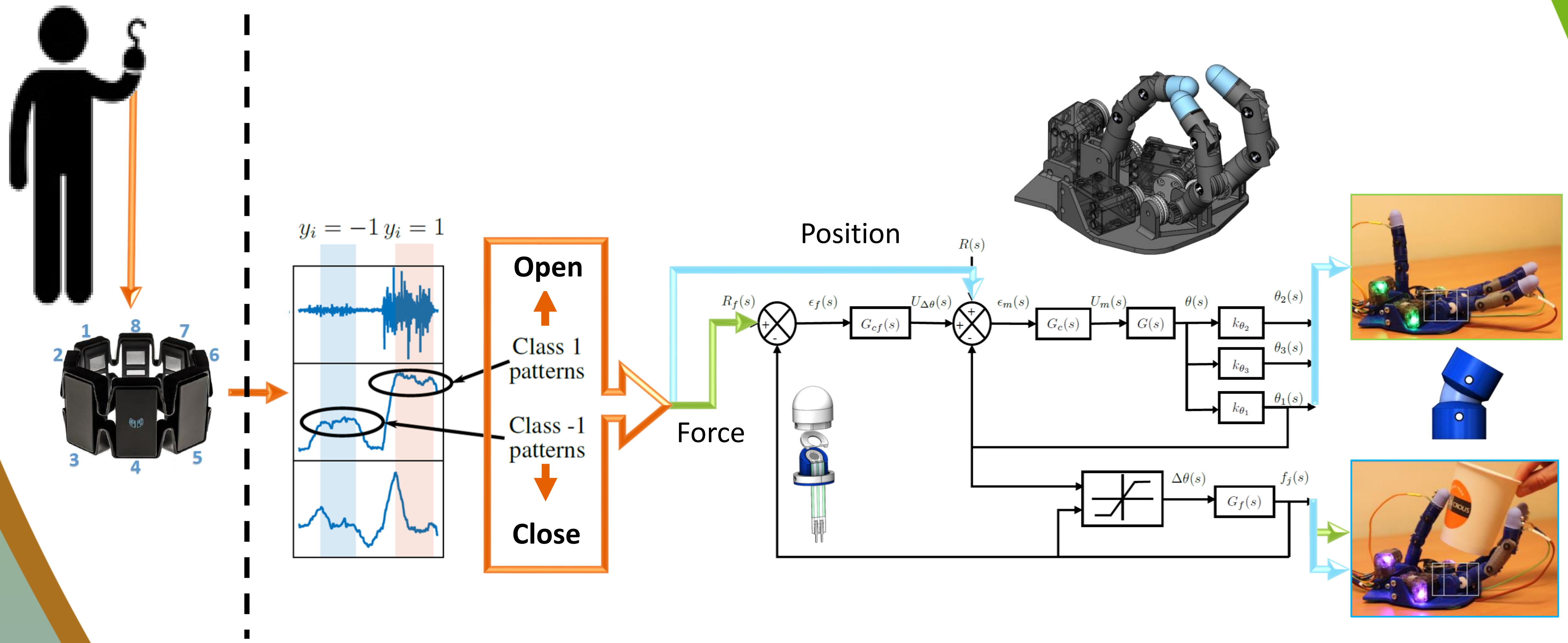


ProMain-I

ProMain-II

- Intuitive control based on sEMG
- Compliant (soft fingertip sensor and soft link)
- Modular
- 3D-Printed

New functional scheme



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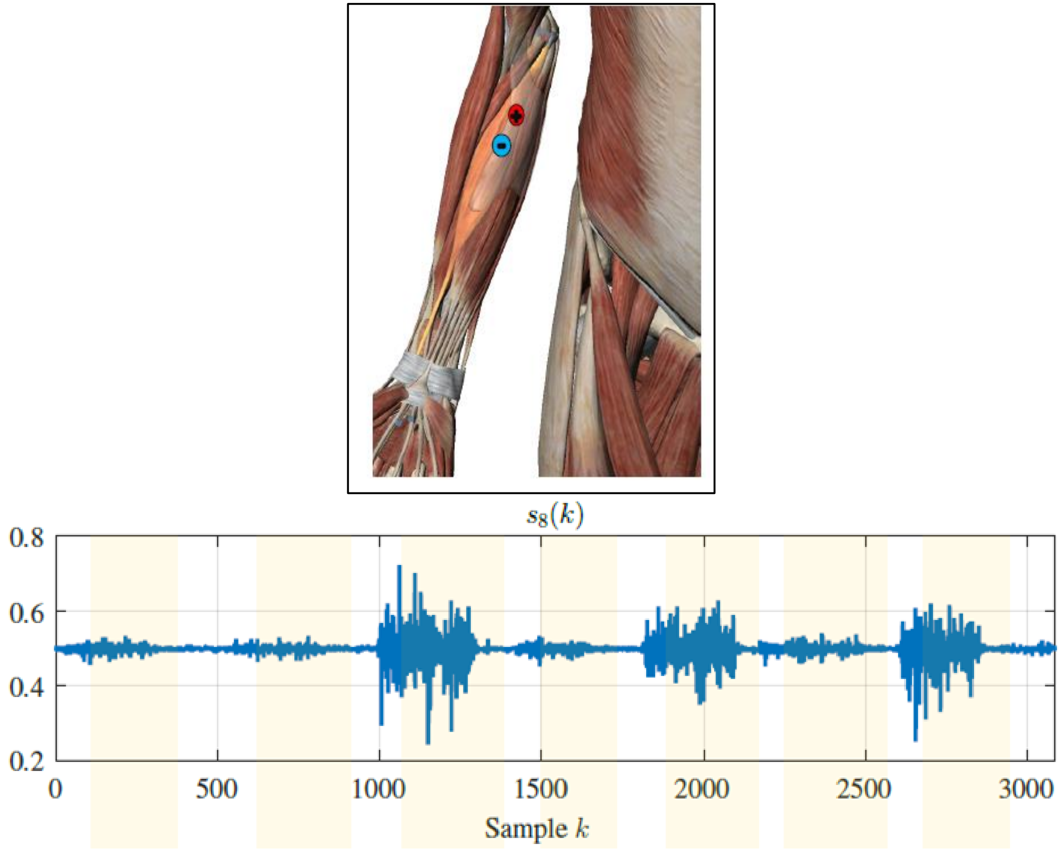
Electromyography signals (EMG)



- Produced during muscle contraction
- Contains movements information
- Superficial (sEMG) or intra-muscular (iEMG)

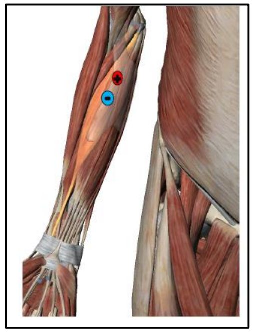
sEMG and Kinematic relation

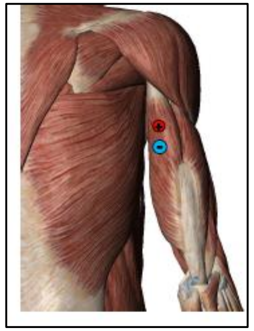
sEMG are carriers of information about subject's movements

Features from sEMG signal

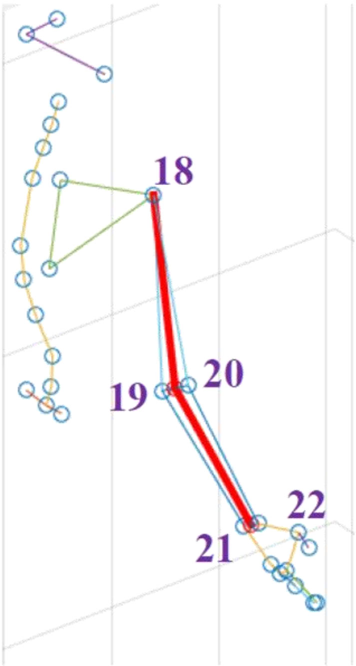
- Mean frequency (*MF*)
- Entropy (*H*)

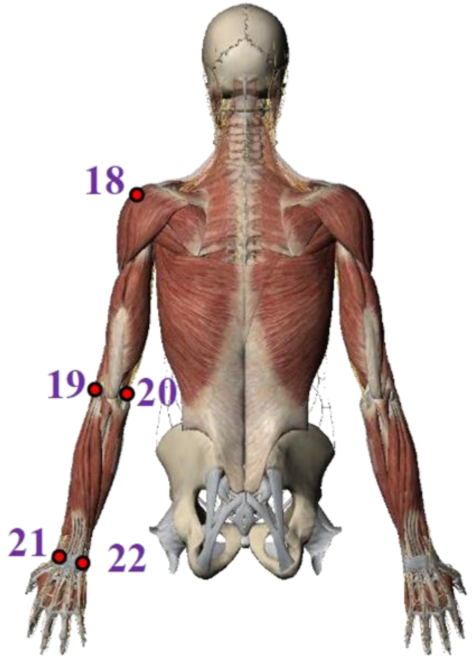
(A. Rubiano *et al*. 2015)



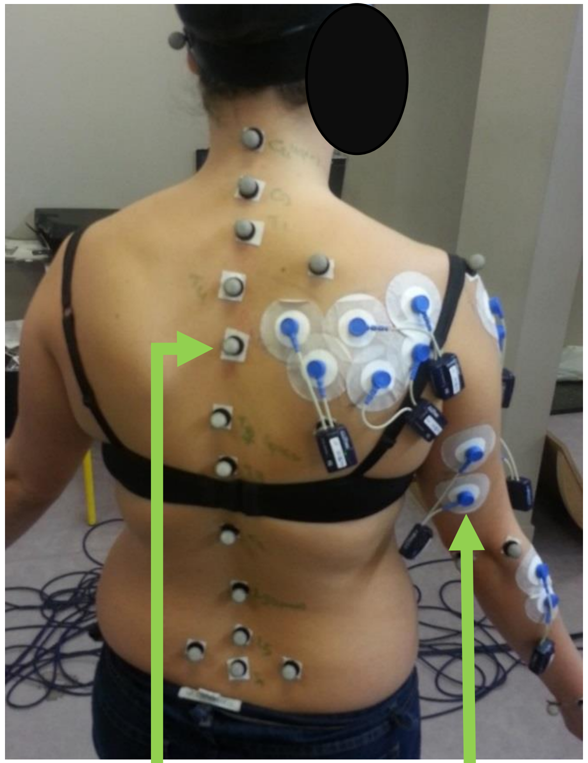


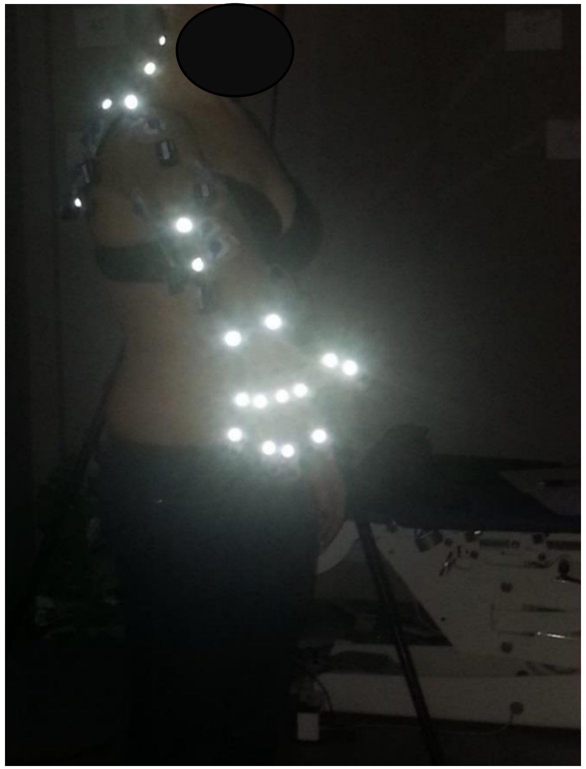
Upper limb movements





Experiment: Materials





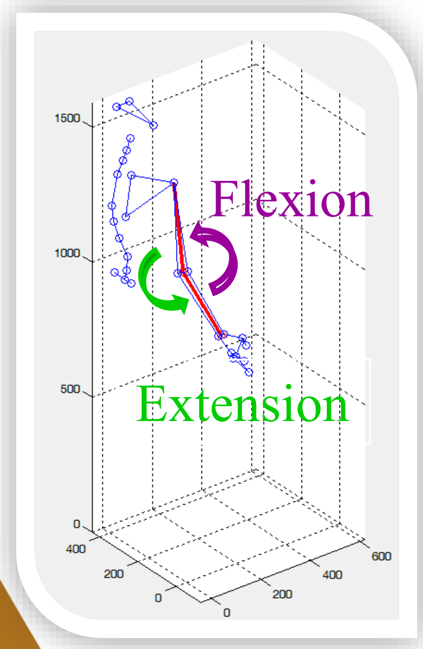
Markers sEMG

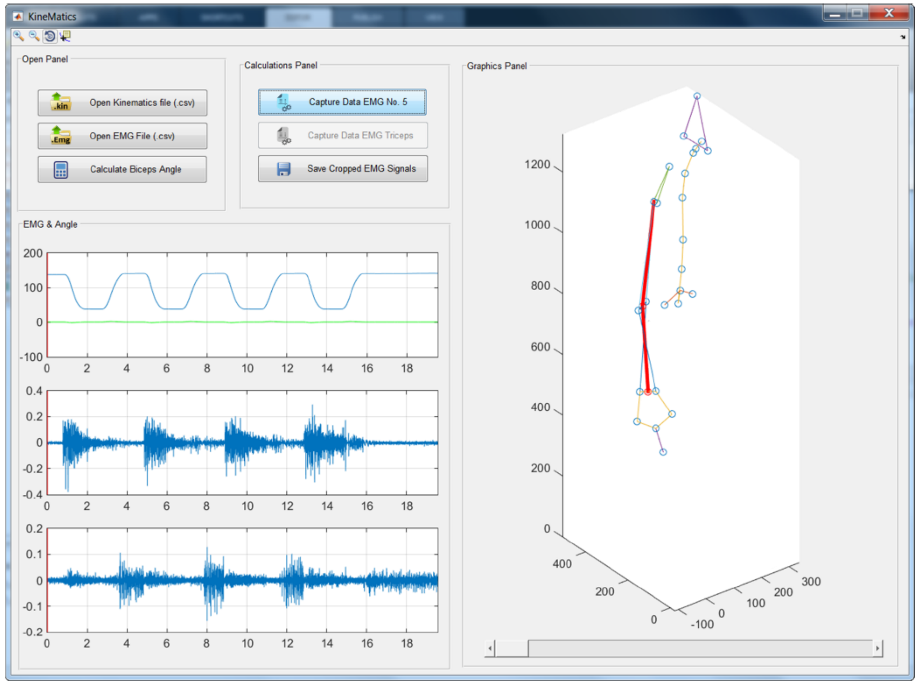
VICON Camera

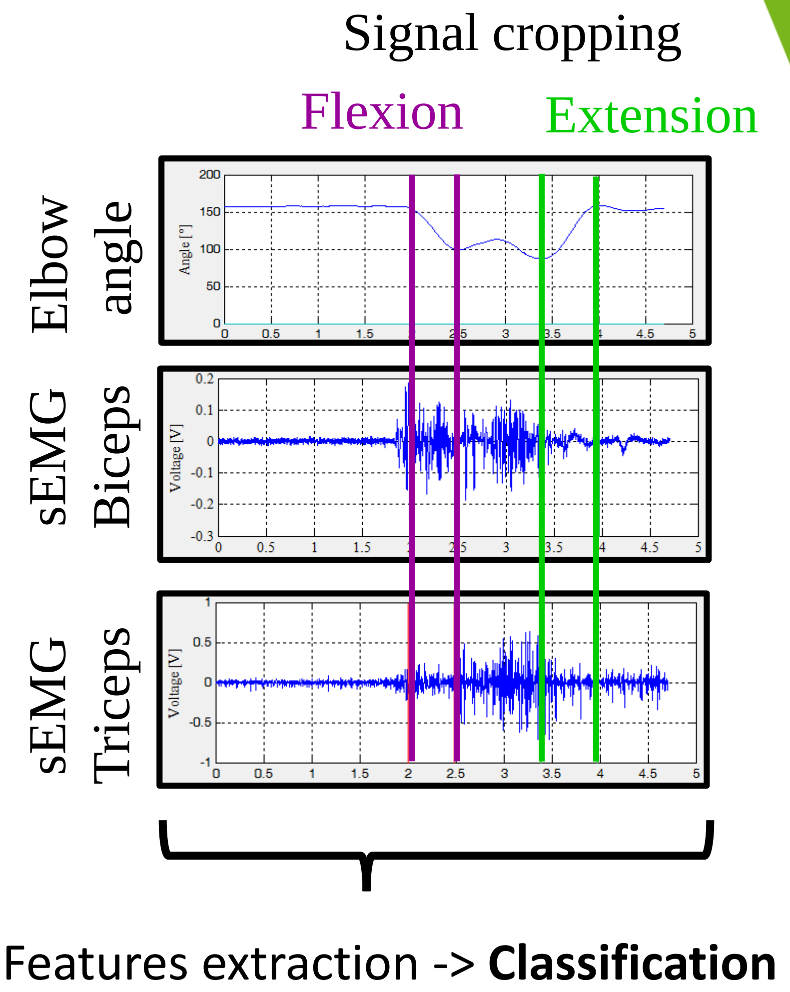
Acquisition

Experiment: Data processing

- 3 Subjects performing elbow flexion an extension
- Measures of sEMG produced by Biceps and Triceps muscle
- Features extracted from cropped signals are used in movement classification



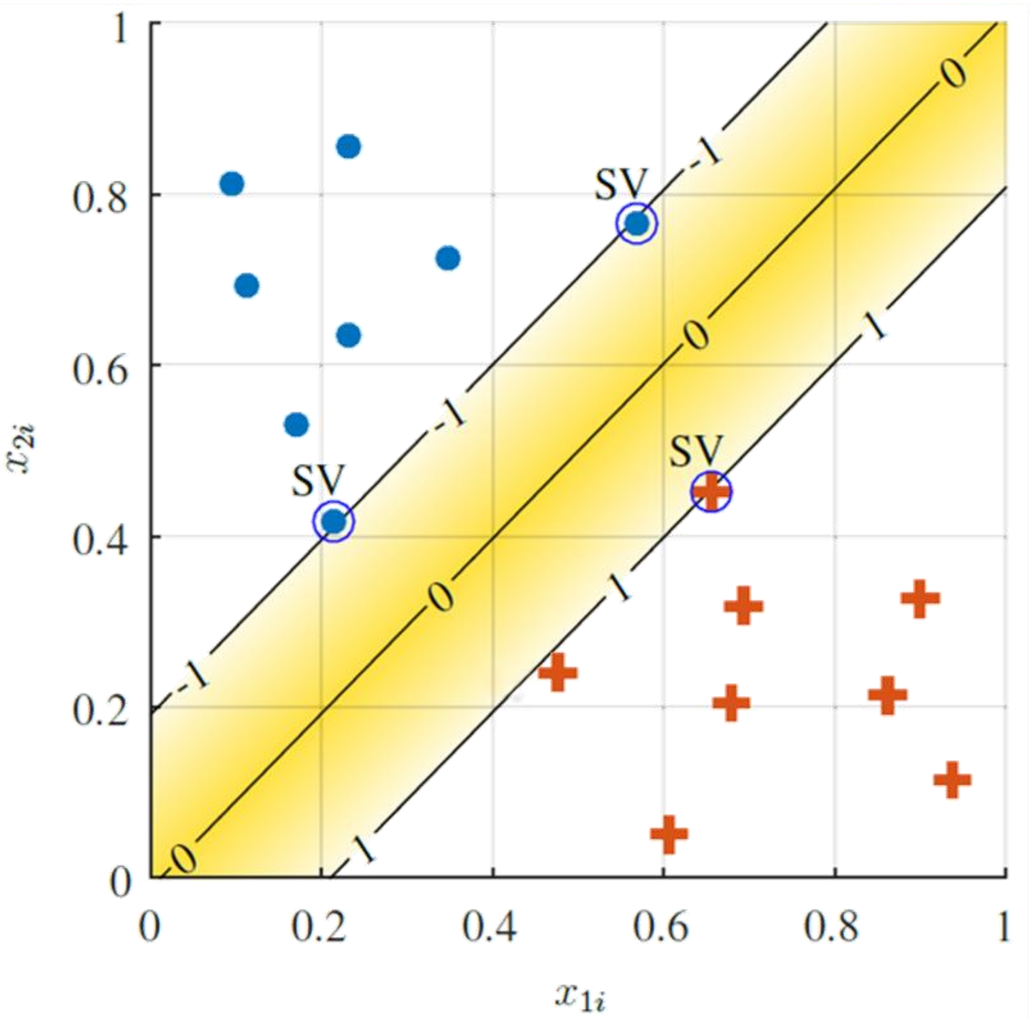




Movement classification based on myoelectric signals

Support Vector Machines
(Cortes and Vapnik, 1995)
(Boser, *et al.* 1992)

(i) Supervise learning model
(ii) Find an separator hyperplane that has the largest possible margin
(iii) Formulation of optimal margin
(iv) Linear, soft margin, non-linear



Classification of extracted features during elbow flexion and extension

Features extraction

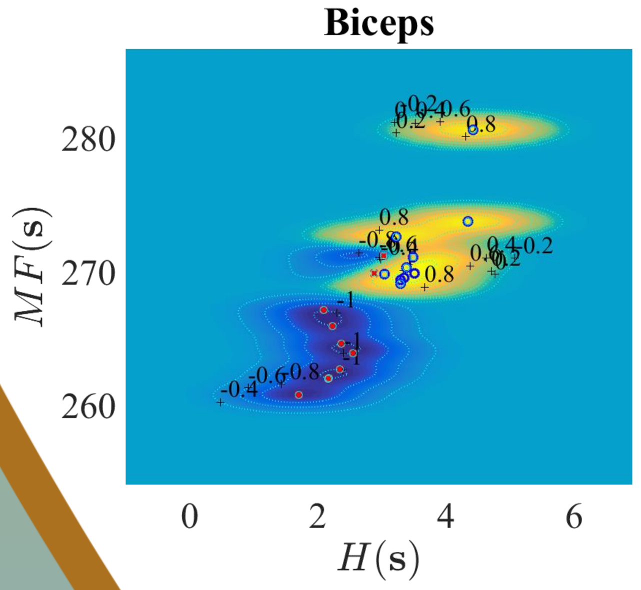
- Mean Frequency
- Entropy

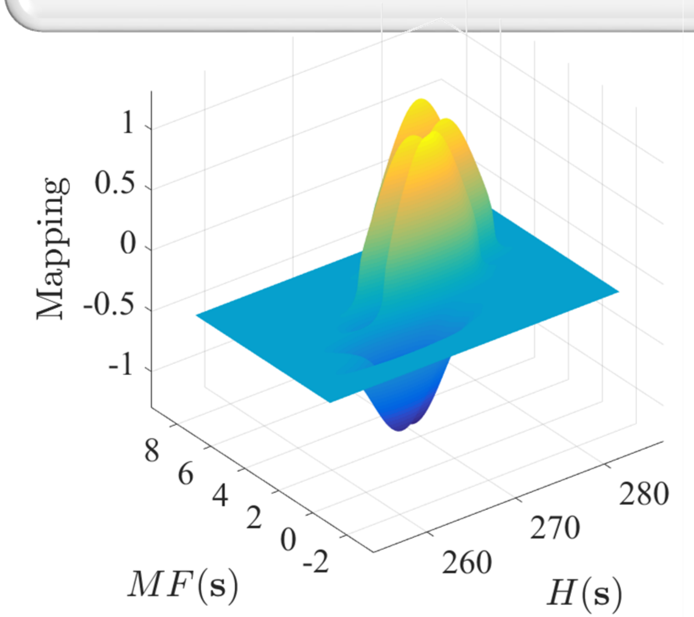
Classification

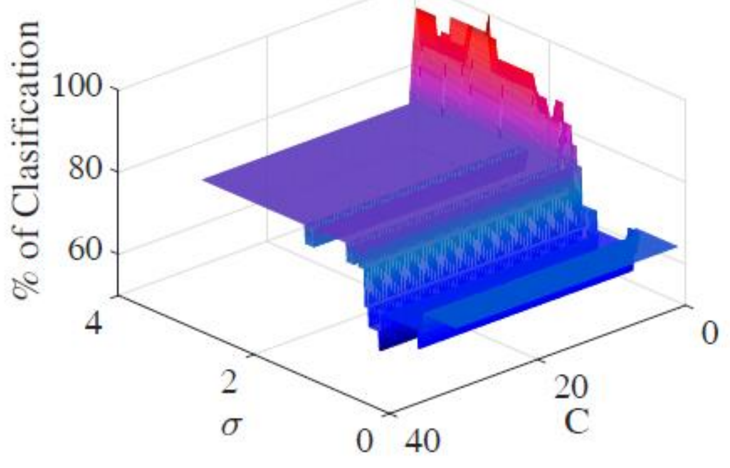
- Non-linear SVM with kernel radial basis function
  - Training (13.63%)
  - Testing (new subject)

Results

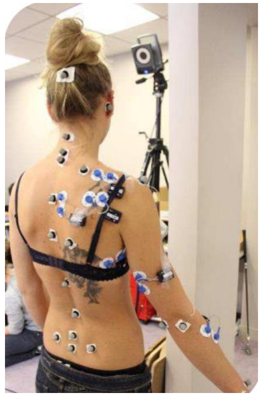
- SVM parameters C and σ
- Classification success 99.99%







Grasping gesture out of laboratory conditions



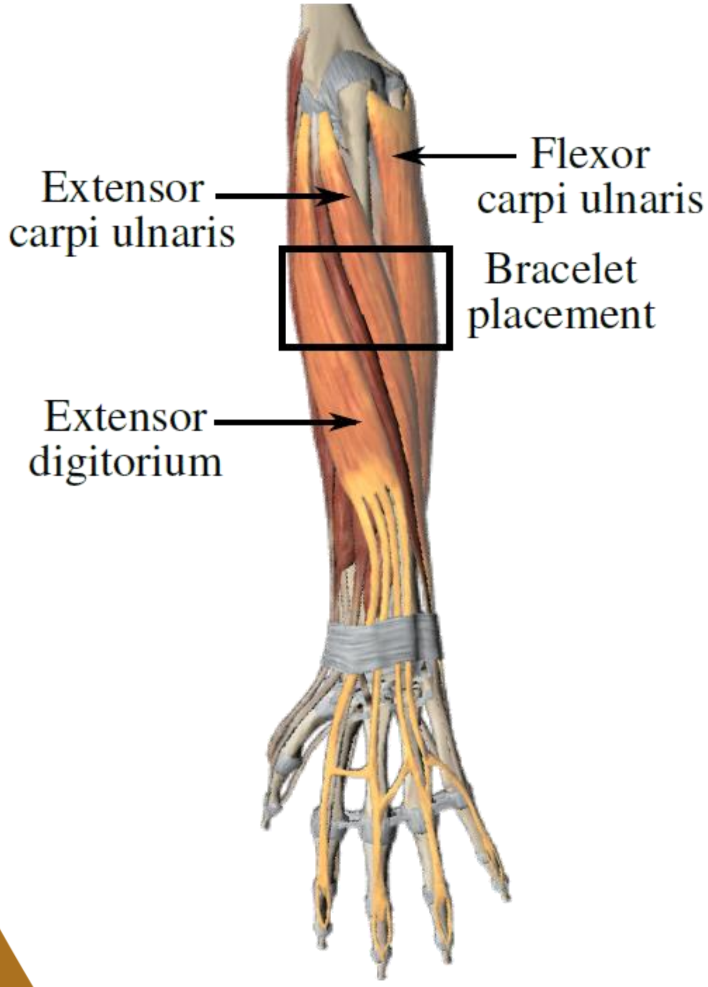
Upper limb movement (elbow flexion – extension)

- In motion caption laboratory conditions: wireless sEMG
- Motion detection: VICON
- 2 electrodes and 2 features: Feature space of 4 dimensions

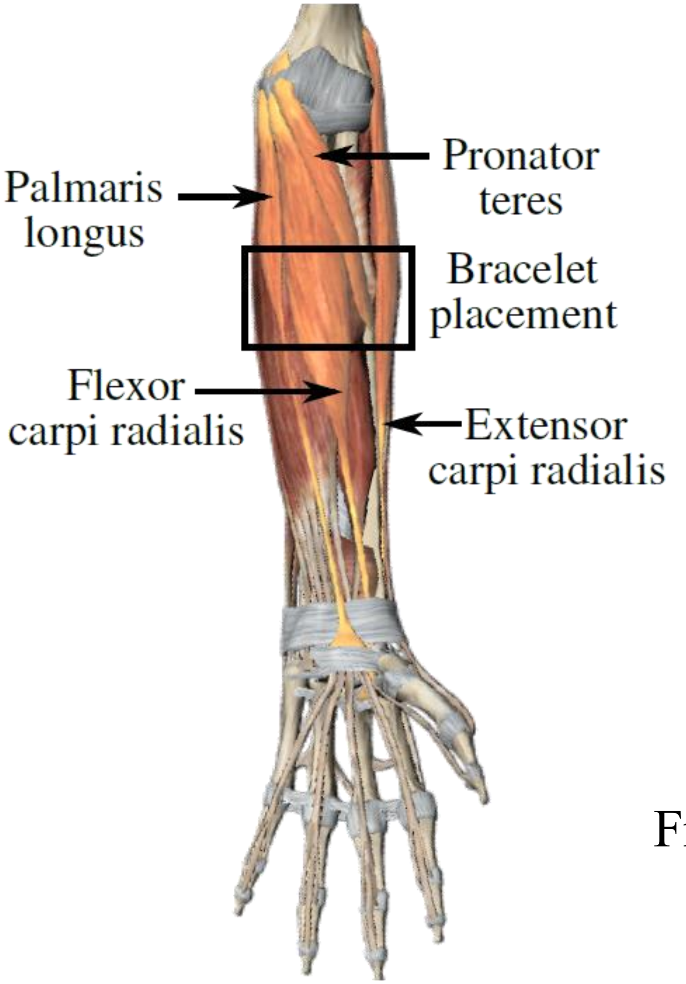
Grasping gesture (open - close hand)

- Out of laboratory condition: wearable device MyoArmband™
- No motion detection: algorithm required to detect motion inception
- 8 electrodes and 1 feature: Feature space of 8 dimensions

MyoArmband™ sEMG sensor



(a) Frontal muscles.



(b) Posterior muscles.

From 2 features (H, MF) dual channel
To 1 feature (H) 8 channels

Grasping recognition: Hand open – close

Identification of movement inception

↓

Measure of produced information rate: Entropy

↓

Entropy flow

Recognition of prehension patterns

↓

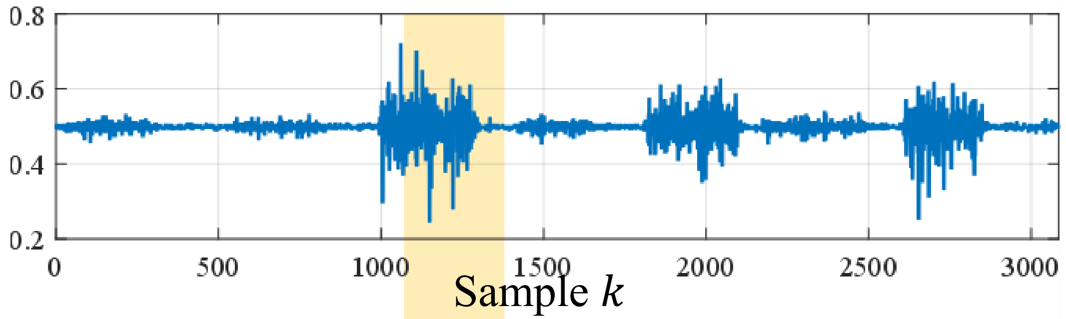
Feature Extraction: Measure of produced information rate

↓

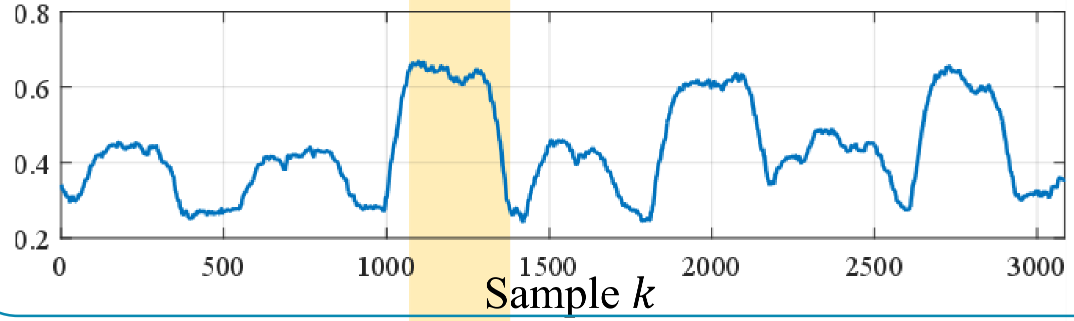
SVM classifier

- Training
- Utilization

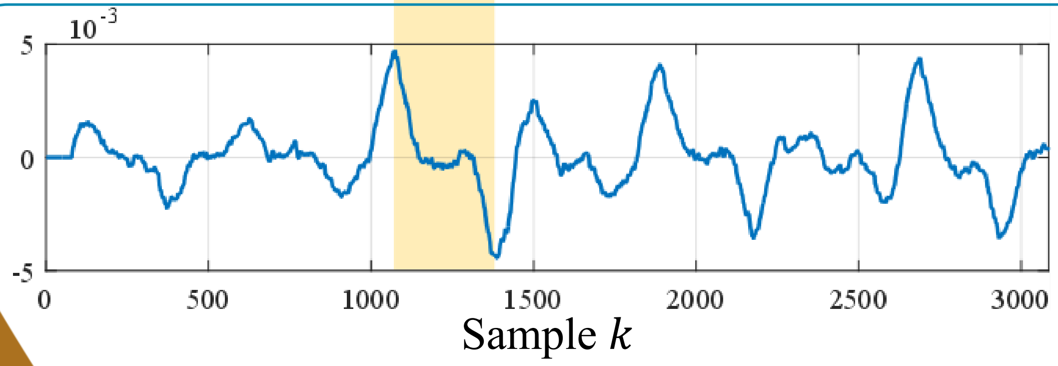
Identify movement inception



sEMG $\boldsymbol{s}_8(k)$



Measure of produced information rate: entropy $H(k, \boldsymbol{s}_8)$



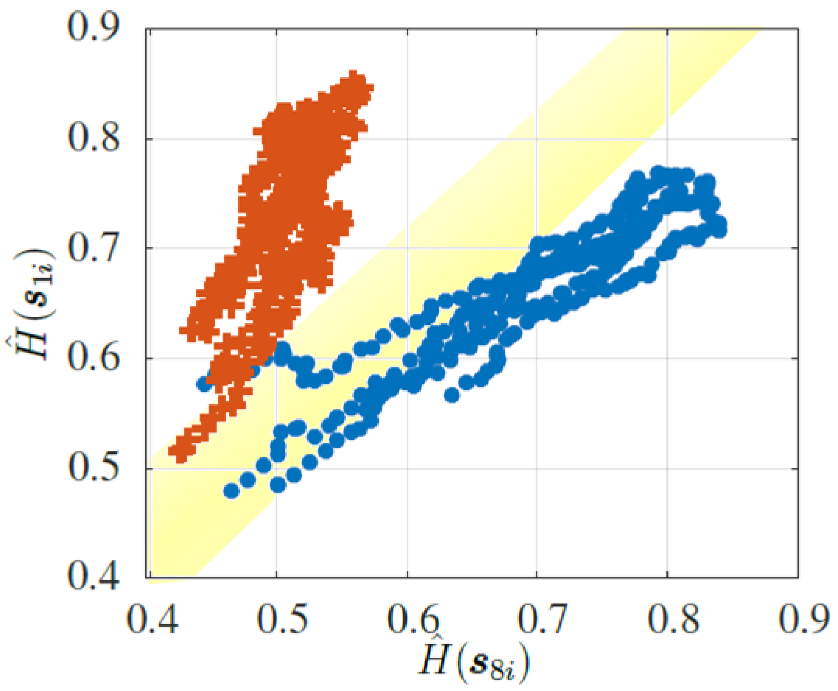
Entropy flow: derivative of entropy $\dot{H}(k, \boldsymbol{s}_8)$ with respect to the time

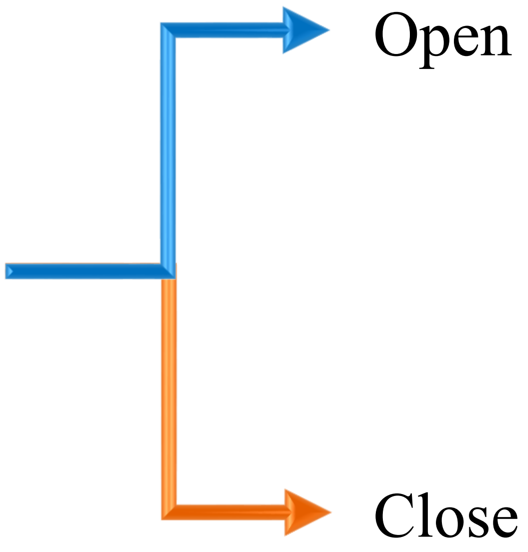
Recognition of prehension patterns

Feature space $\mathcal{X} \in \mathbb{R}^8$ composed of the normalized entropies $\widehat{H}(\boldsymbol{s}_{1i})$ to $\widehat{H}(\boldsymbol{s}_{8i})$

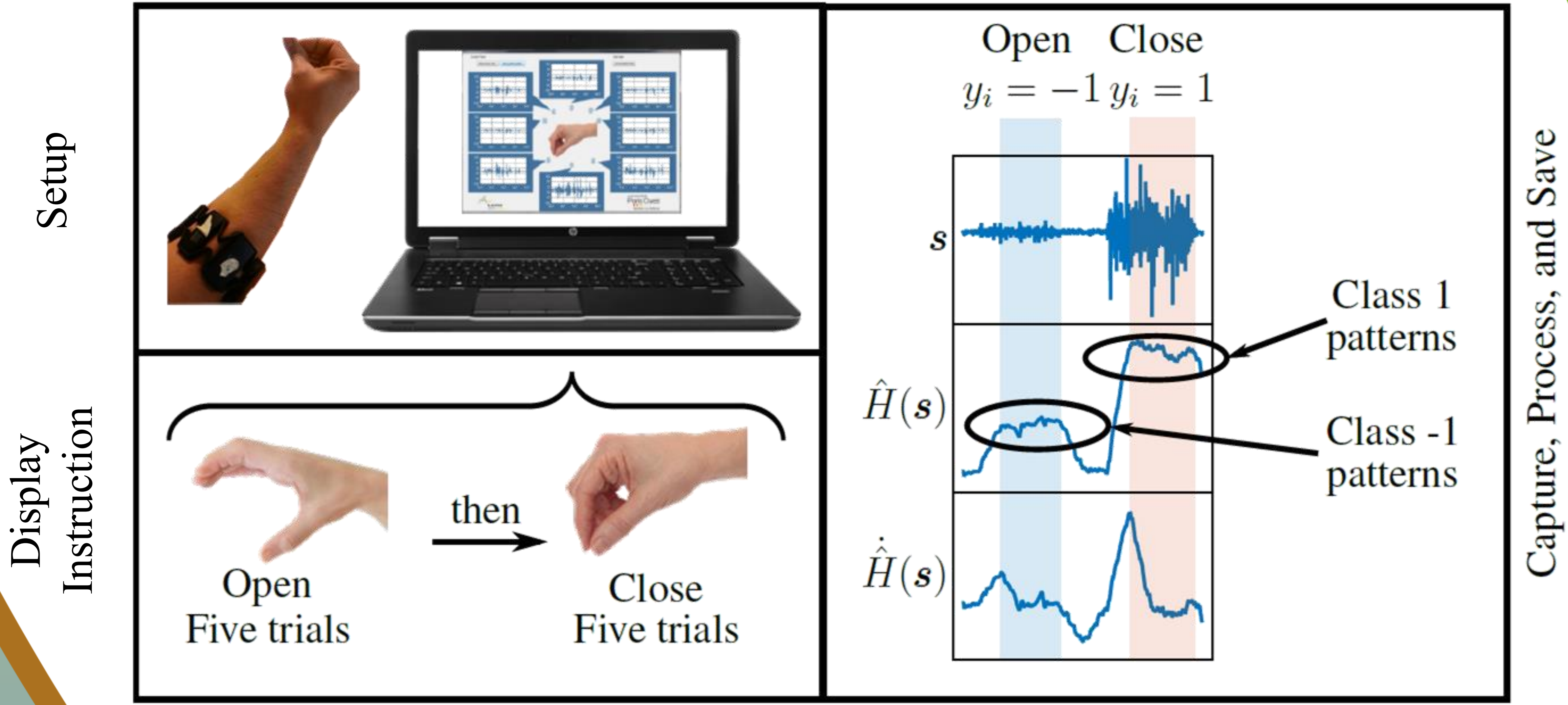
Pattern | Soft margin SVM | Gesture grasping

$$\boldsymbol{x}_i = \left\{ \begin{array}{c} \hat{H}(\boldsymbol{s}_{1i}) \\ \hat{H}(\boldsymbol{s}_{2i}) \\ \vdots \\ \hat{H}(\boldsymbol{s}_{7i}) \\ \hat{H}(\boldsymbol{s}_{8i}) \end{array} \right\}$$

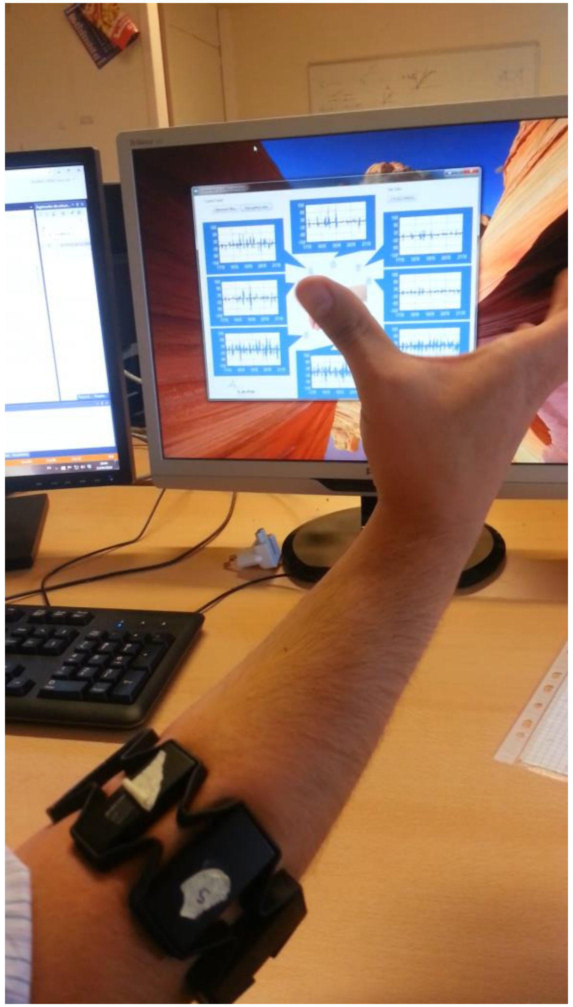




Experimental analysis and model validation



Results of grasping gesture recognition



Mean success rate: 97.5%

Subject	Open trials		Close trials		Overall	
	Trials	Success [%]	Trials	Success [%]	Trials	Success [%]
1	20	100	20	100	40	100
2	20	95	20	100	40	97.5
3	20	100	20	90	40	95

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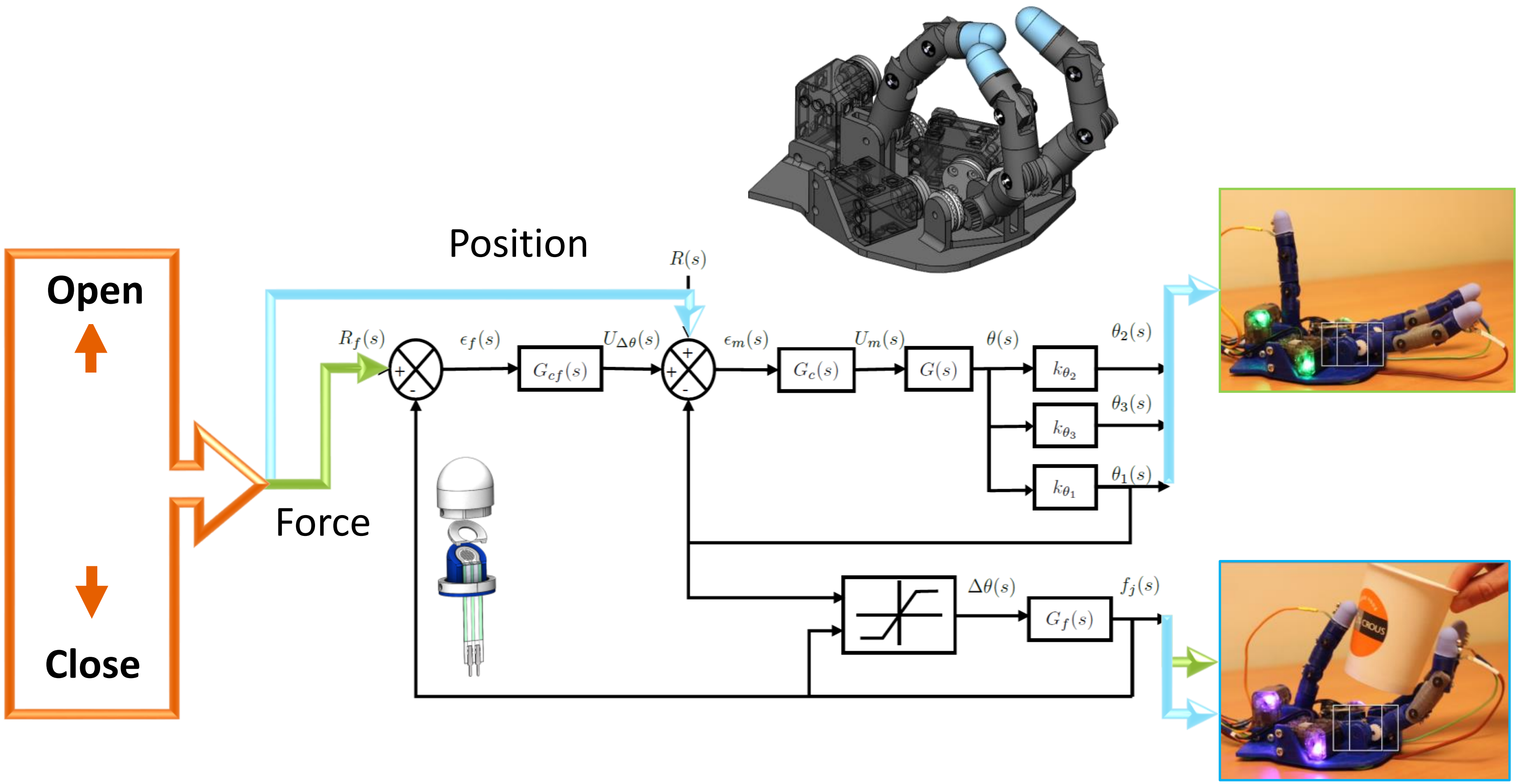
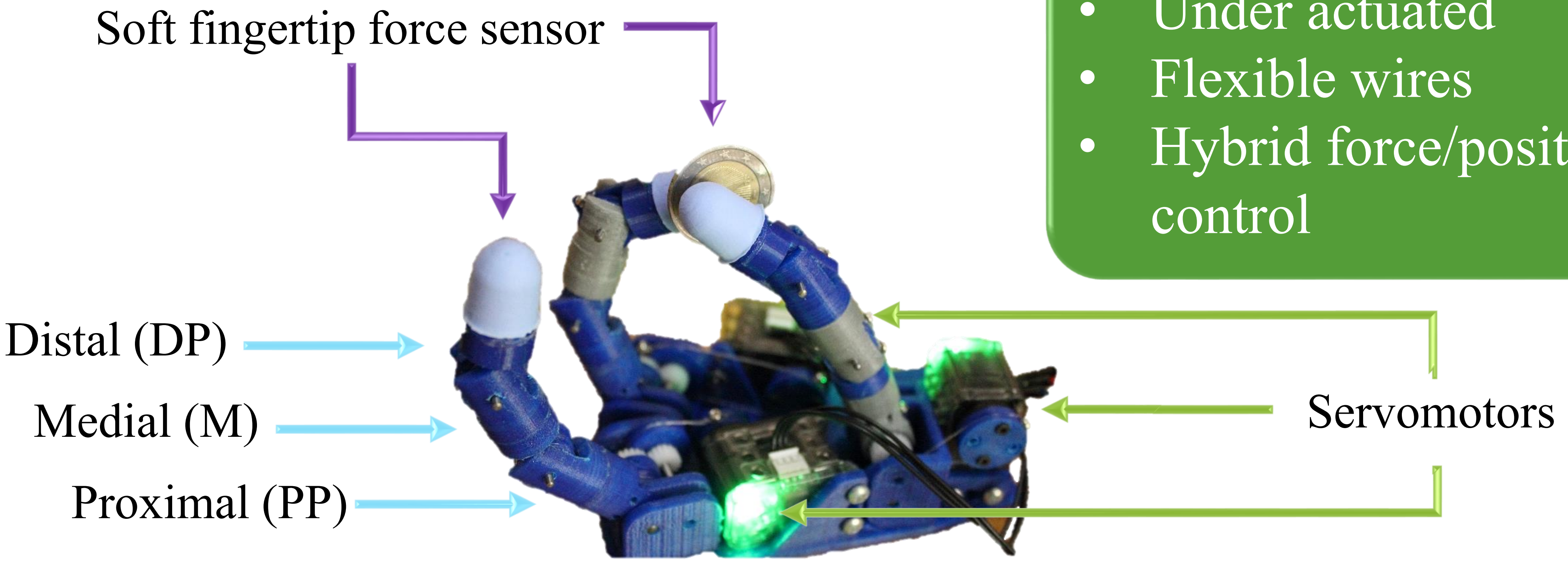
Hand prosthesis control



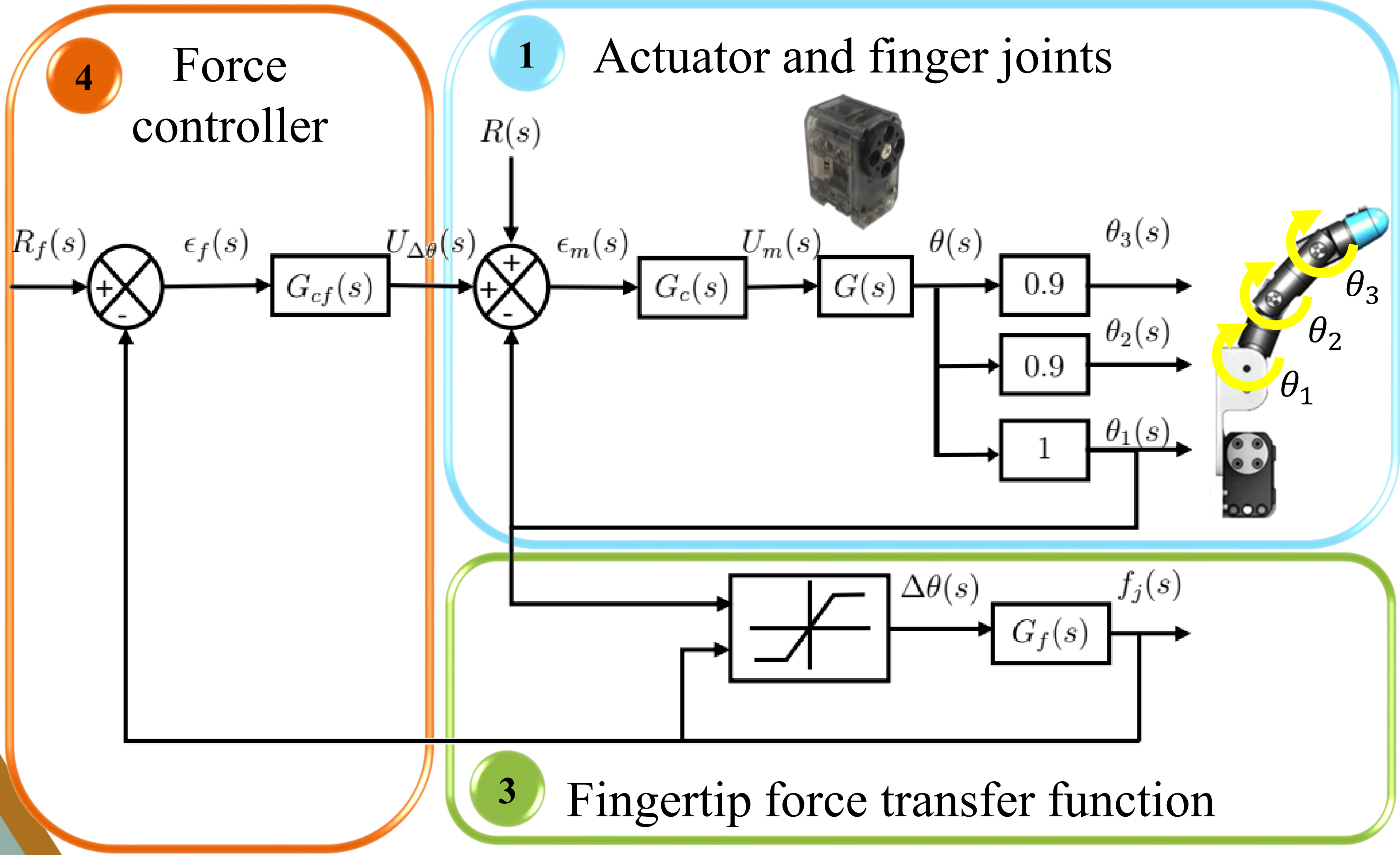
ProMain-I hand



- Under actuated
- Flexible wires
- Hybrid force/position control

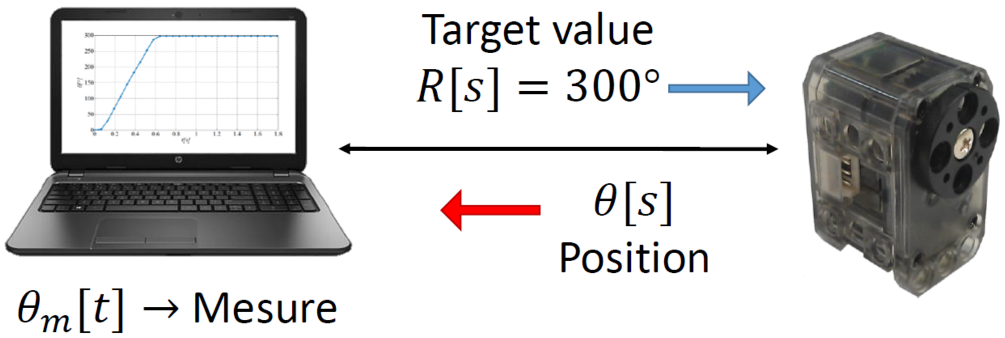
Compliant → Modular → 3D-Printed

Block-diagram of ProMain-I hybrid control

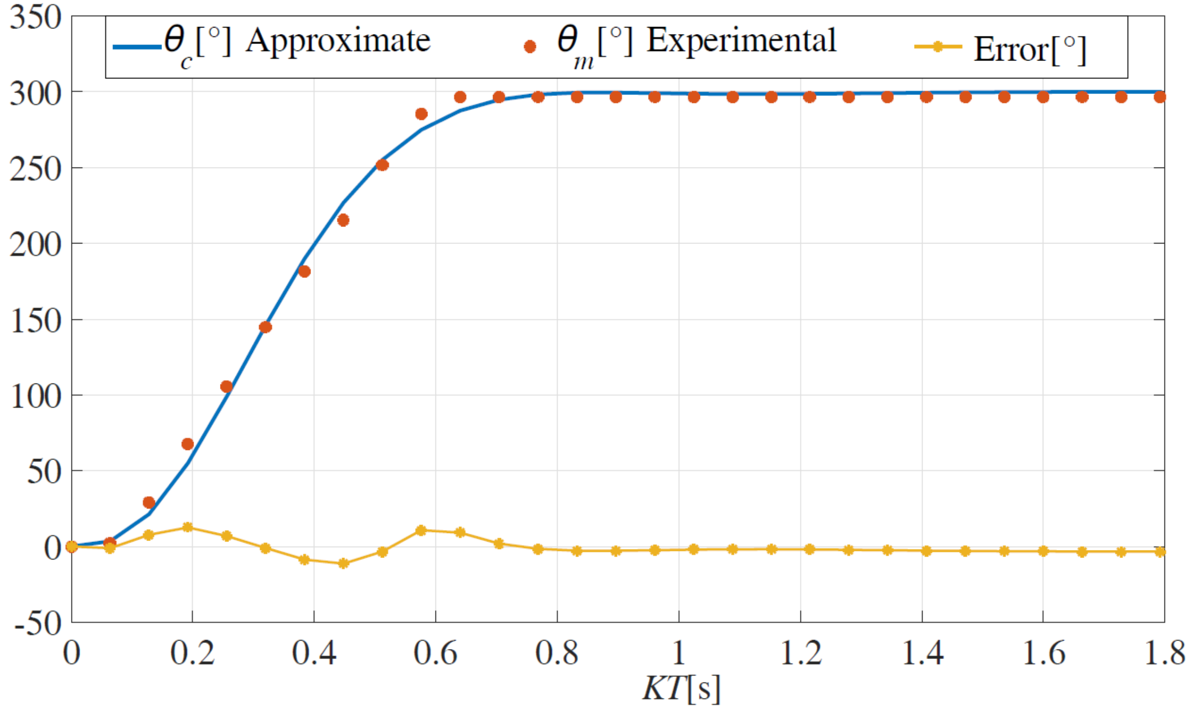


Actuator parametric identification

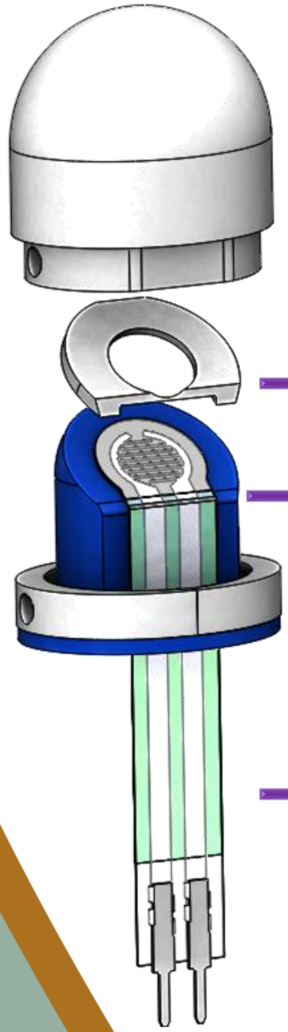
1



Parameters	Symbol	Value
Rotor inertia	J_M	0.0483
Inductance	L	0.0164
Resistance	R	0.2168
Ball bearing	b_c	0.0931
Motor constant	K_T	0.2677



Soft force fingertip sensor



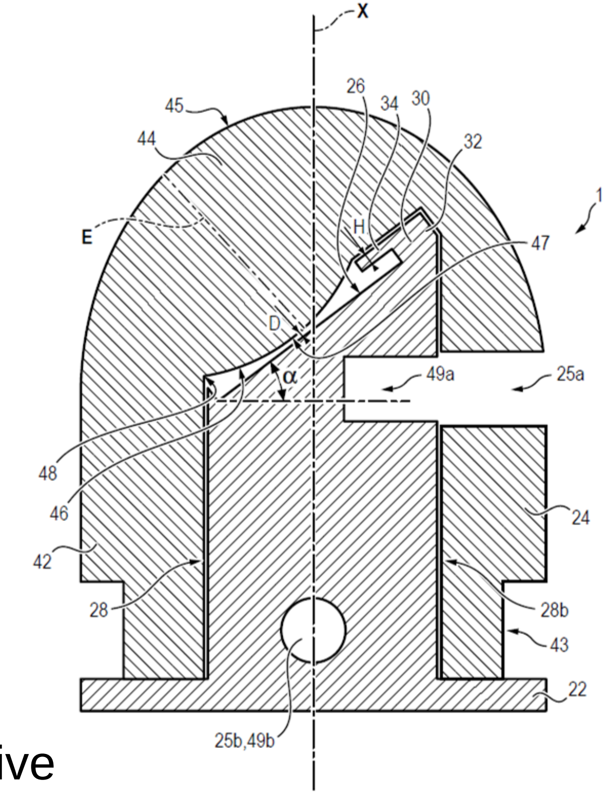
Soft cover

Fixation ring

Bone

Support ring

Force Sensor Resistive



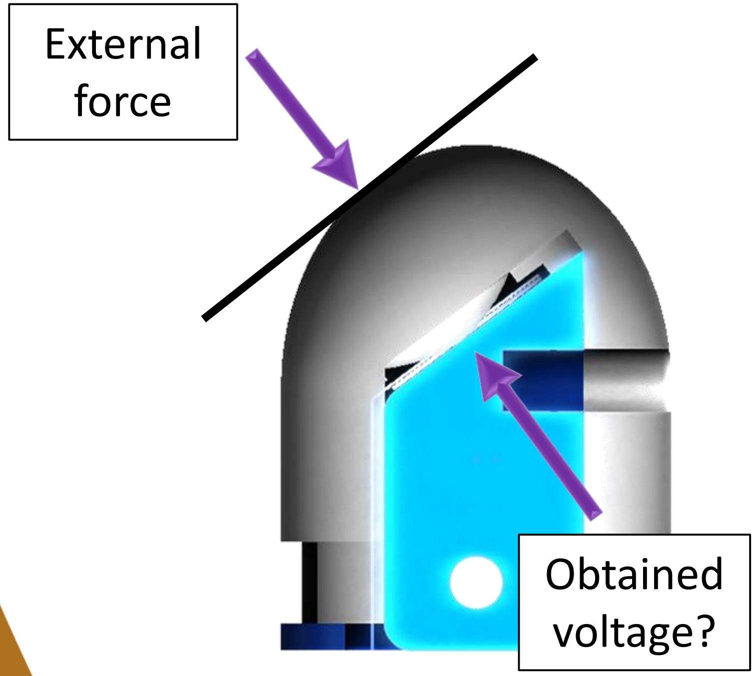
2

- Compliant
- Measure force in the fingertips

Patent N 1655991
Application June 2016

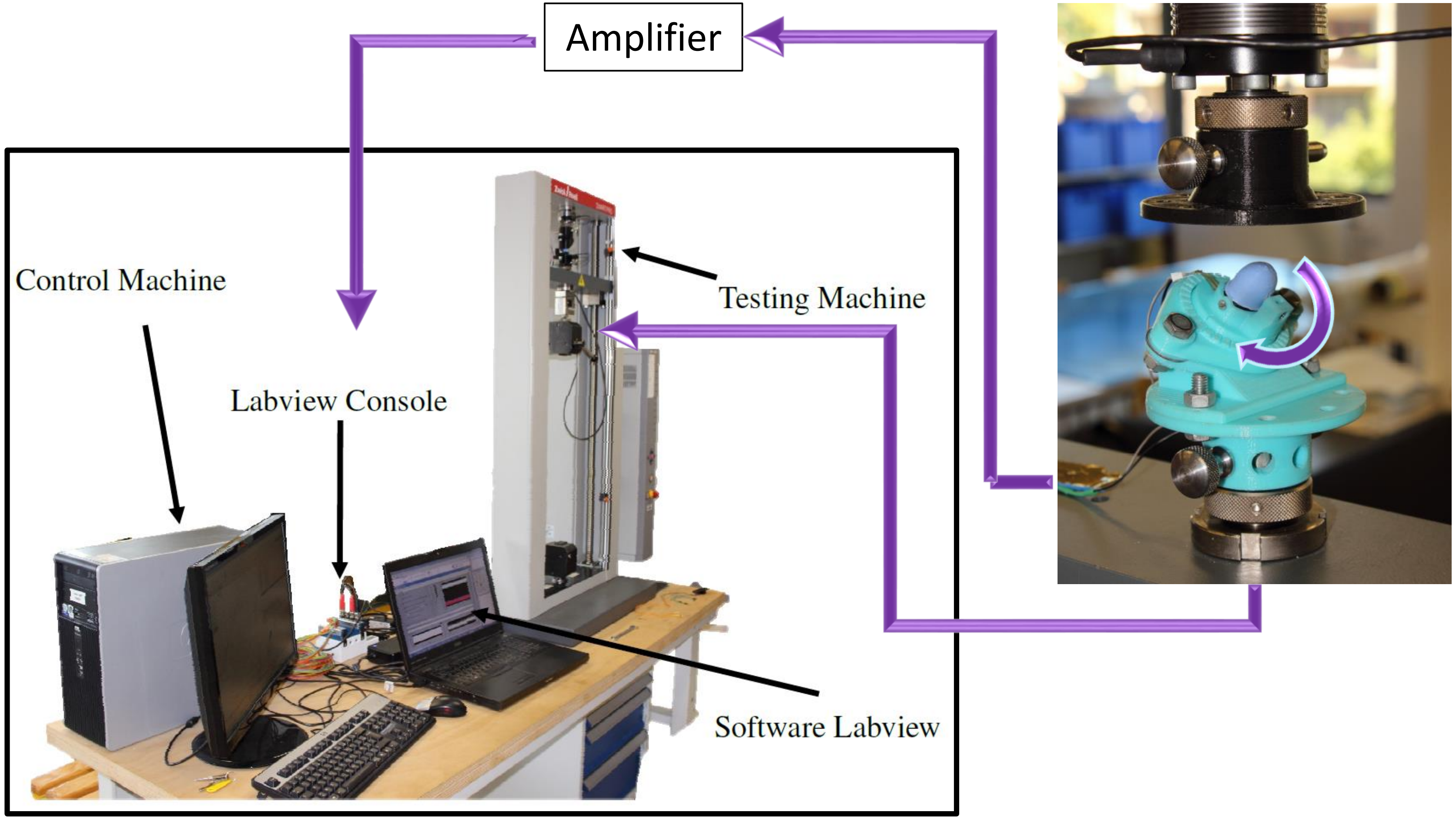
Soft fingertip characterization

2



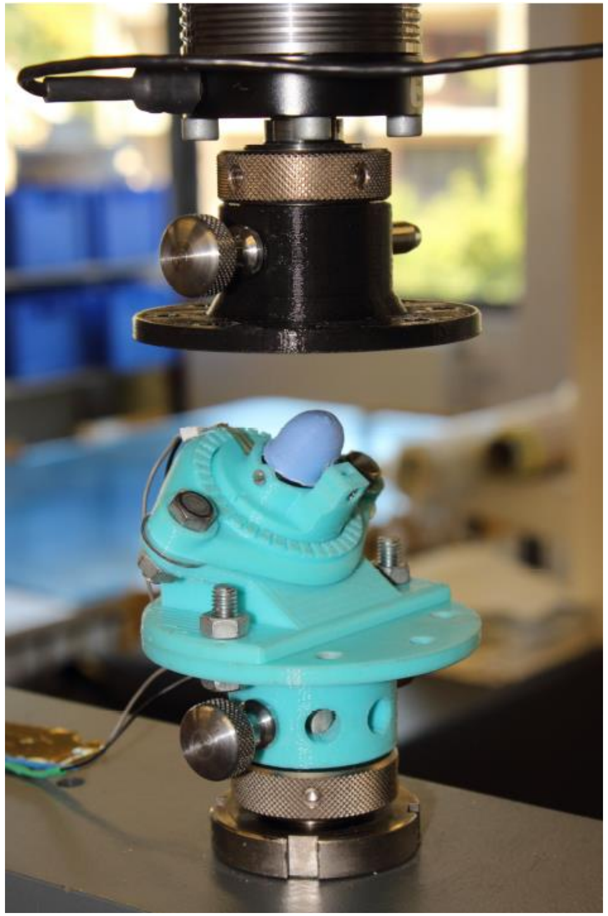
Test performed using two materials for the soft cover:

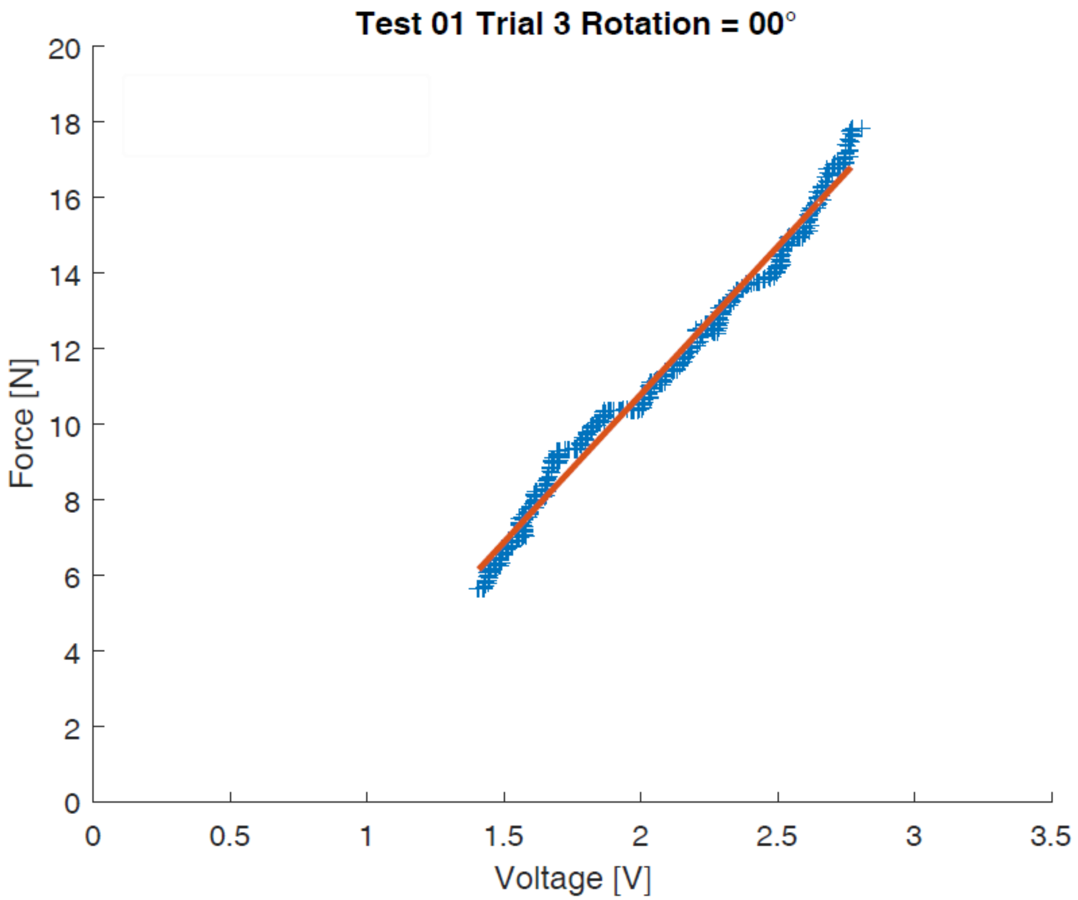
- RTV3535
- RTV127



Experimental result using RTV3535

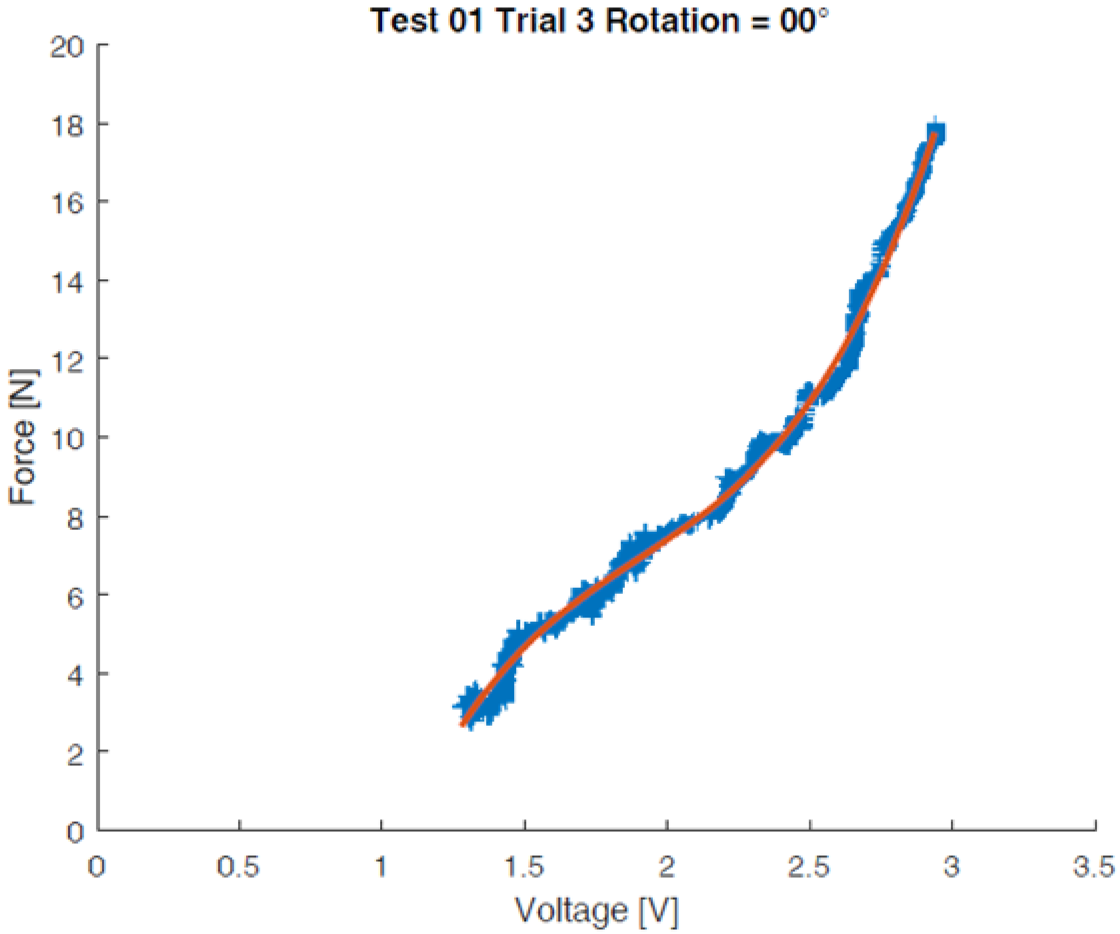
2





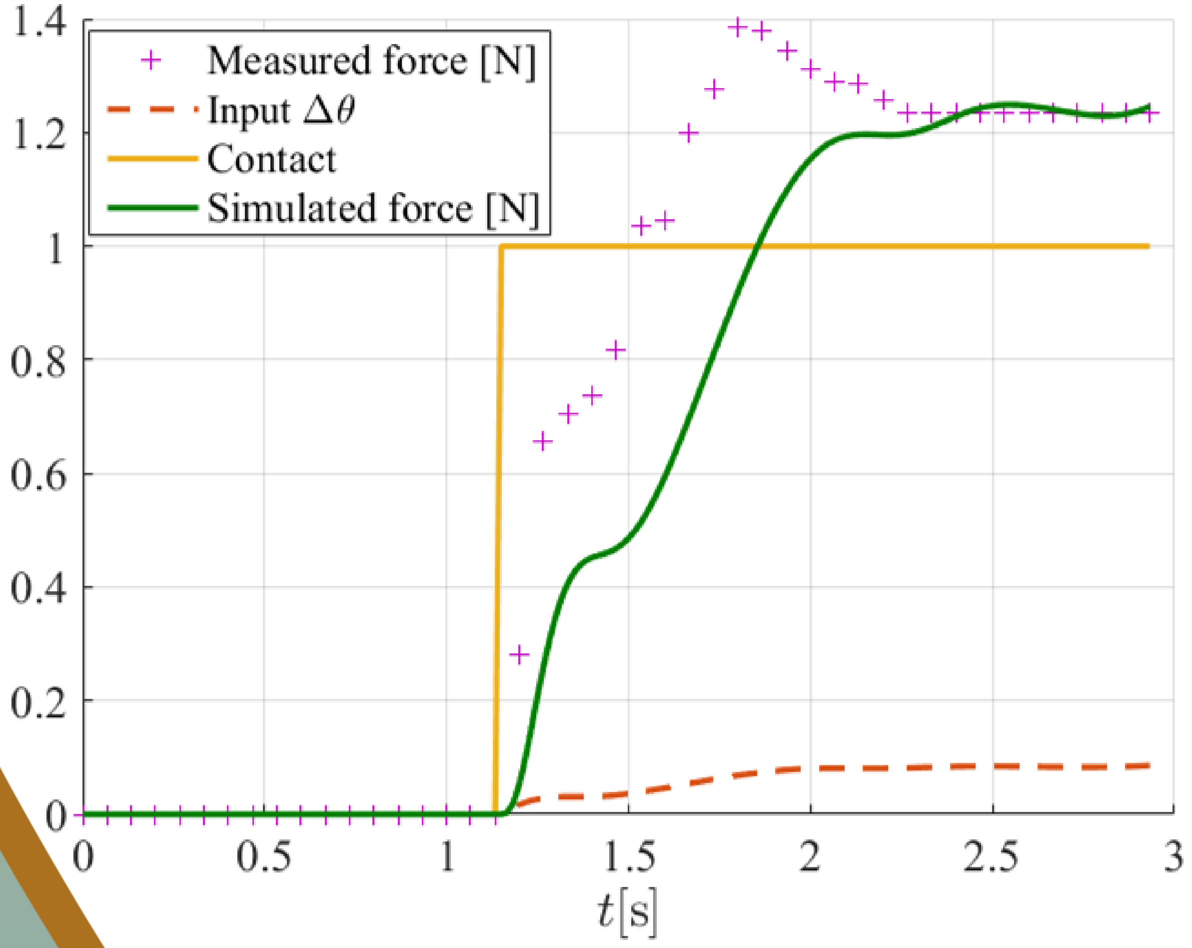
Experimental result using RTV127

2



Fingertip force identification

3



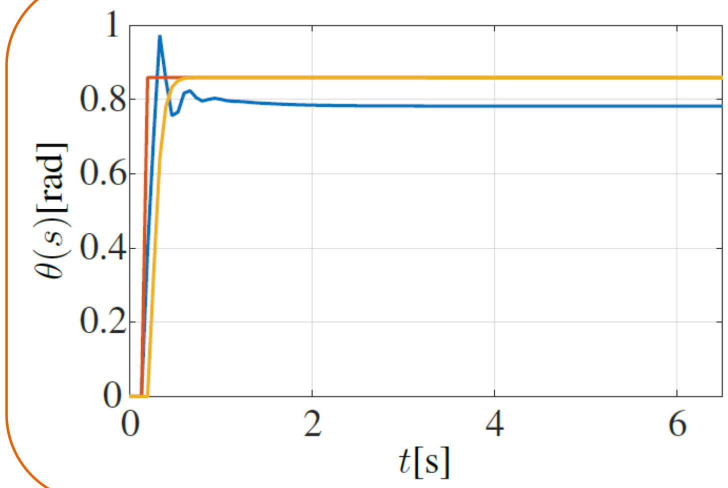
Non parametric identification

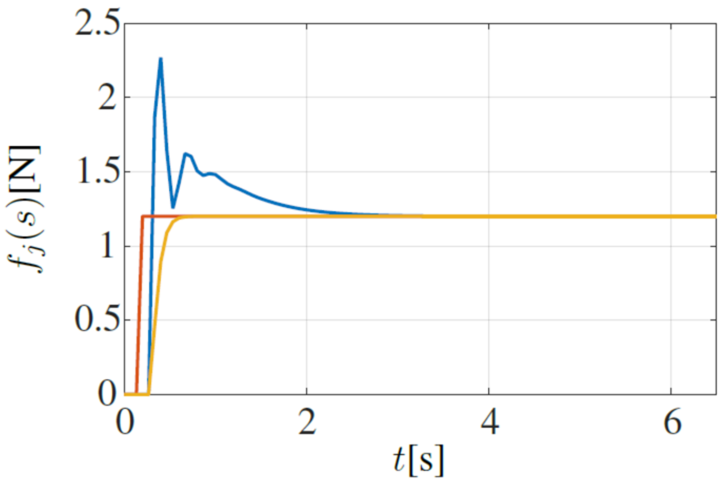
$$G_f(s) = \frac{f_j(s)}{\Delta\theta(s)} = \frac{13.2669}{s^2 + 26.5338s + 217.2671}$$

Constants	**Symbol**	**Values**
Gain	k_{op}	30.0
Damping ratio	ζ	0.9
Natural frequency	w_{n_f}	14.741

Results for hybrid force position control

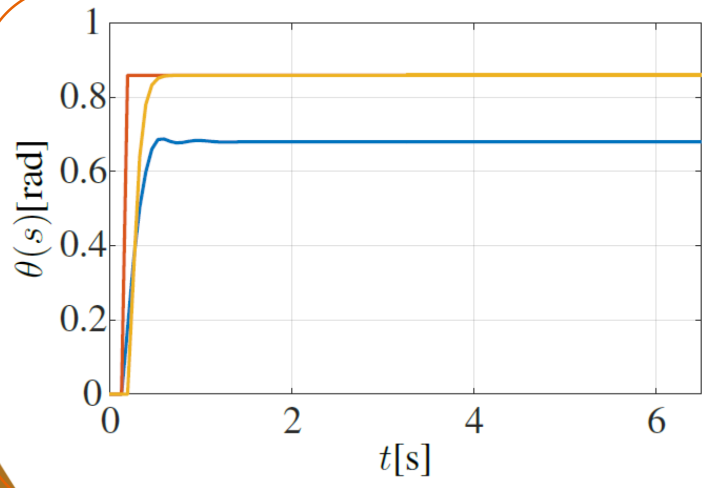
4

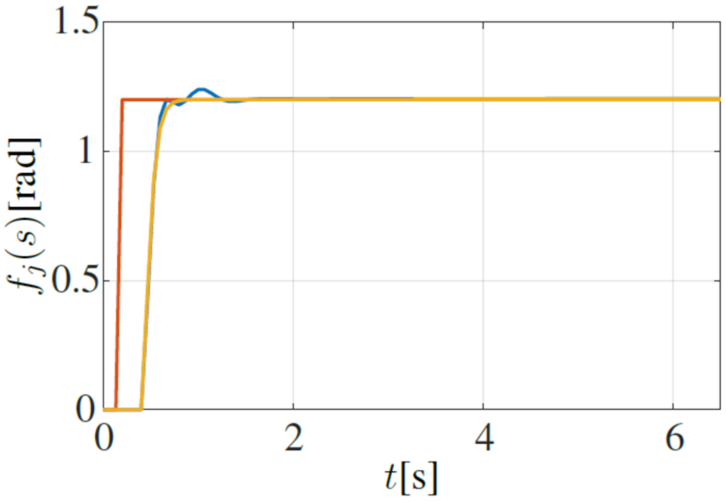




Position control

Desired response
Obtained response
Step input





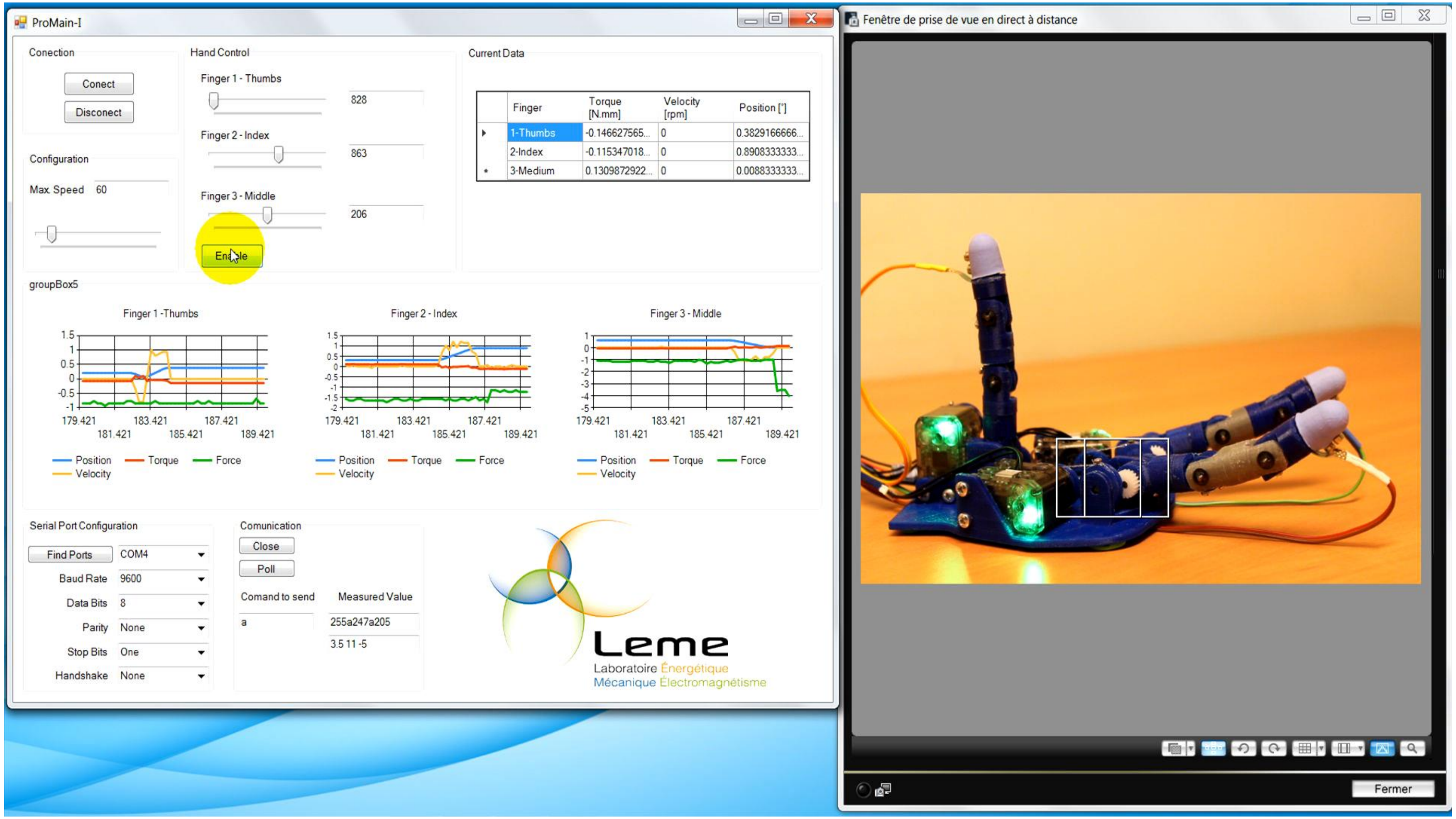
Hybrid control

Desired response
Obtained response
Step input

Resulting movements

- Classical grasping gestures
- Precision grasping gestures
  - Lateral pinch
  - Precision disk
  - Prismatic 3 fingers
  - Tripod
- Power grasping gestures
  - Medium wrap
  - Power disk

Classical Grasping Gestures



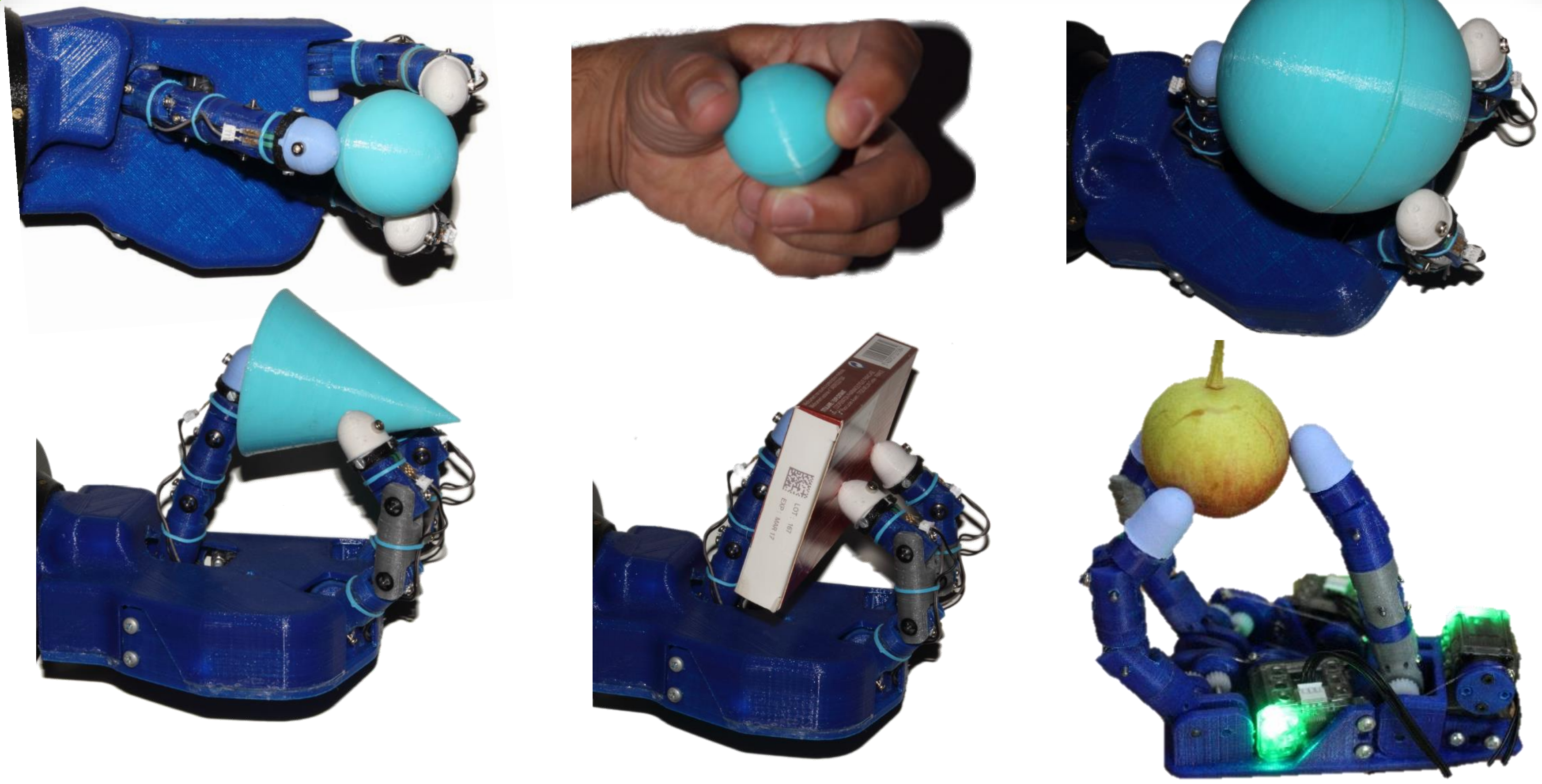
Precision Grasping Gestures (1)

Lateral pinch

Precision Disk

Prismatic 3 fingers

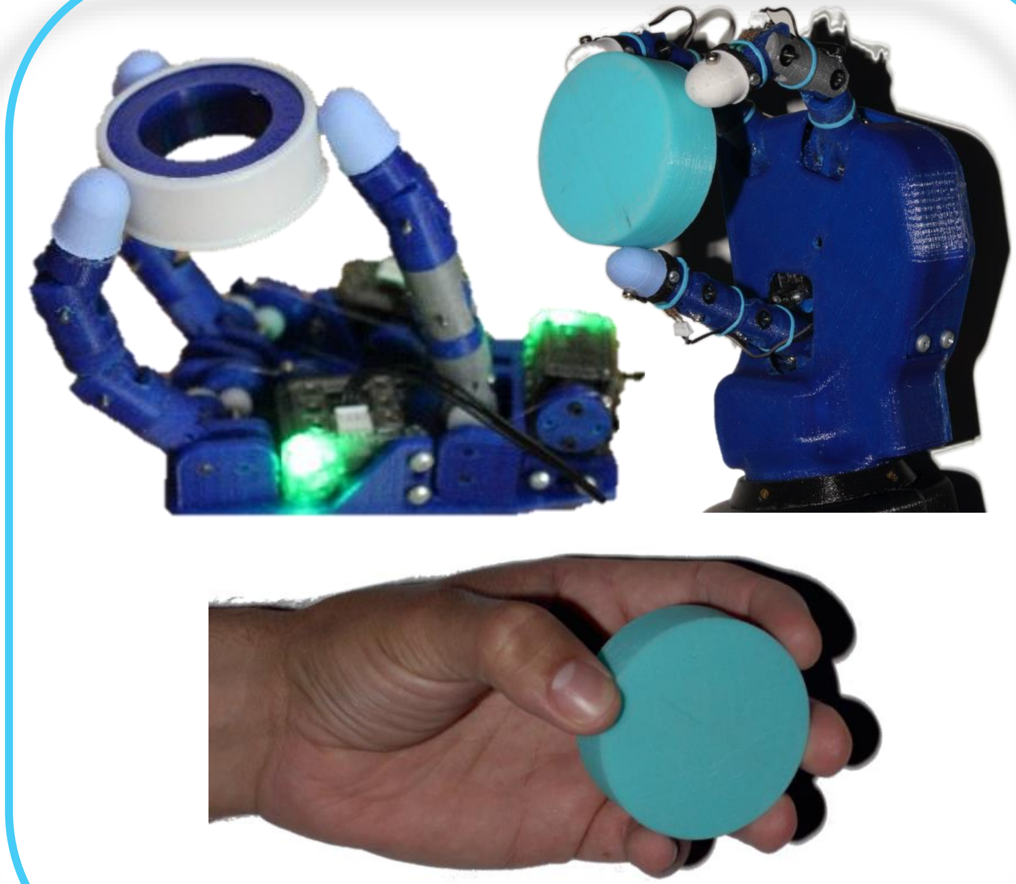
Precision Grasping Gesture (2)



Tripod

Power Grasping Gesture

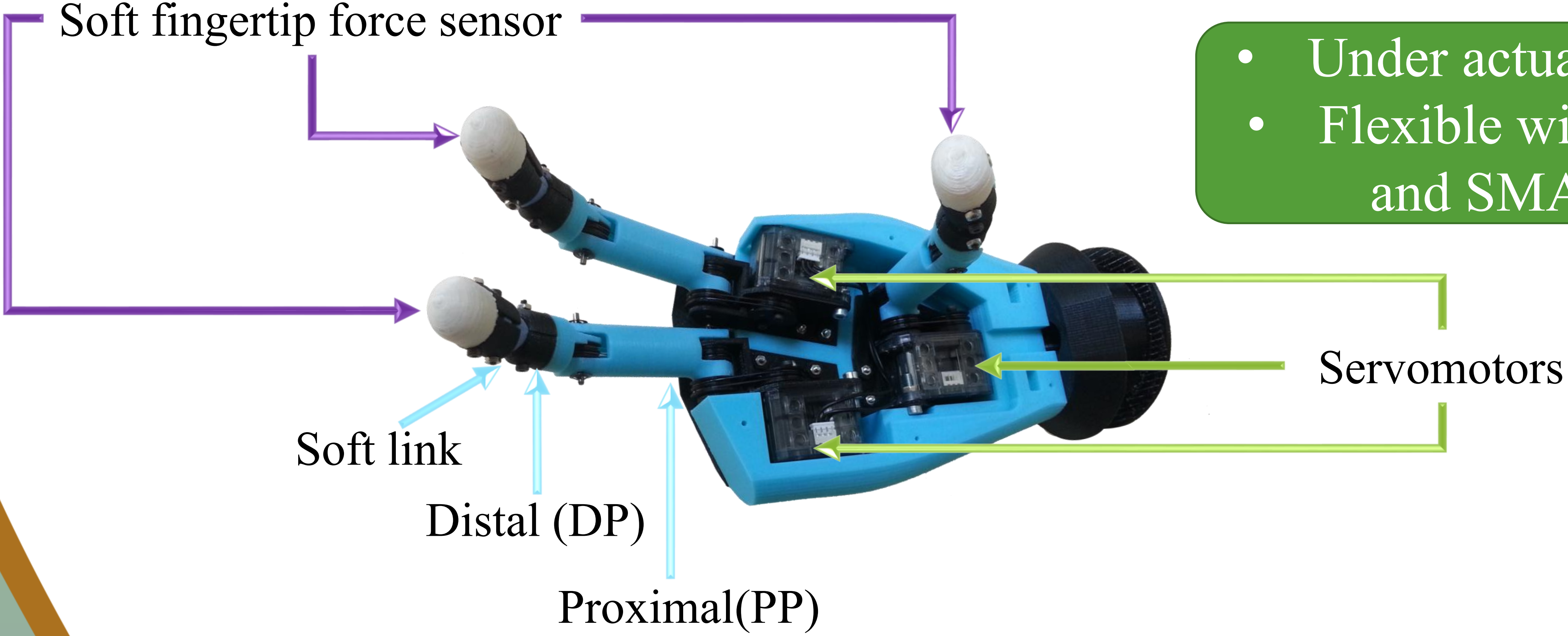
Medium Wrap



Power Disk

Outline

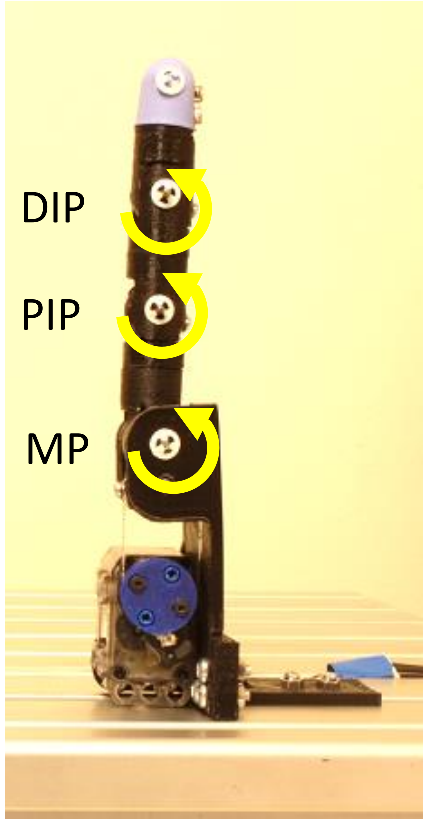
ProMain-II

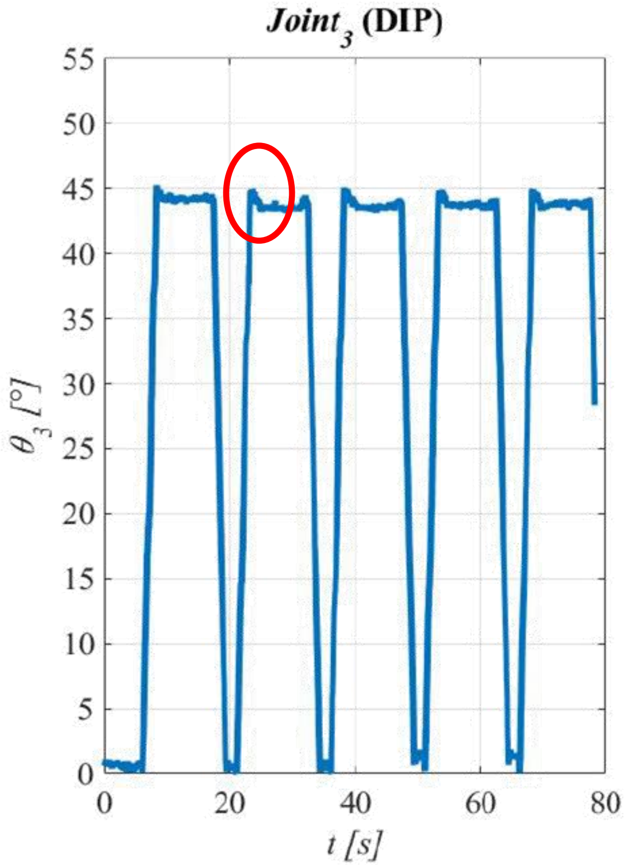


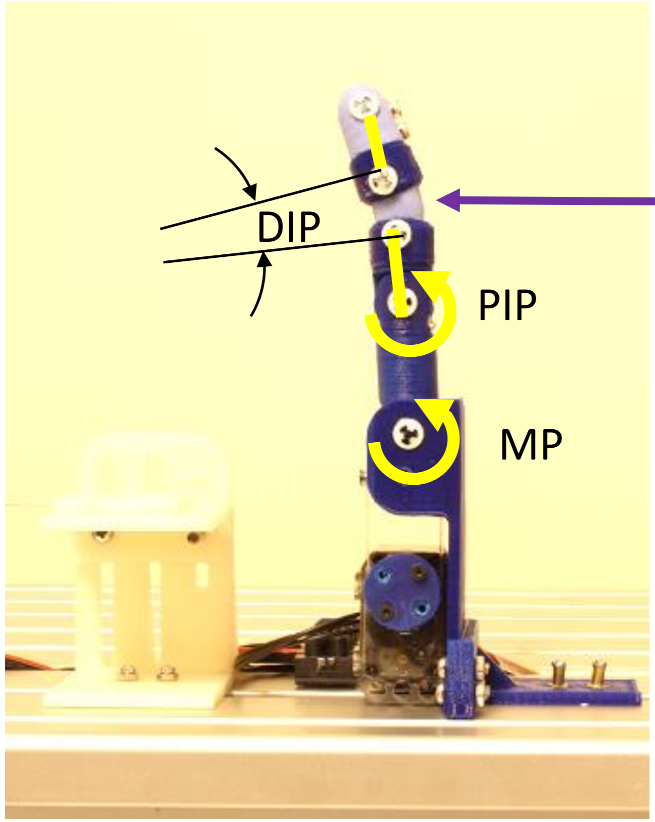
- Under actuated
- Flexible wires and SMA

Compliant → Modular → 3D-Printed

Development a soft link



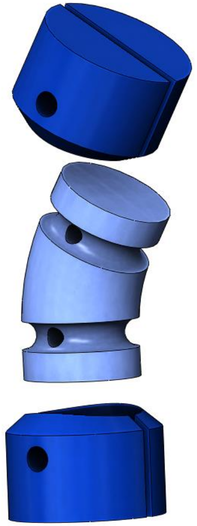




Soft link

Adaptable
Functional
Versatile

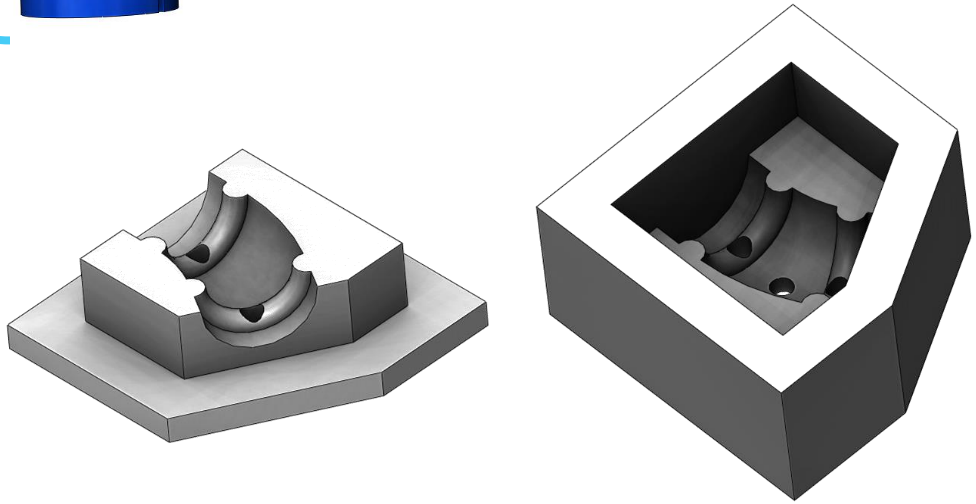
Soft link design



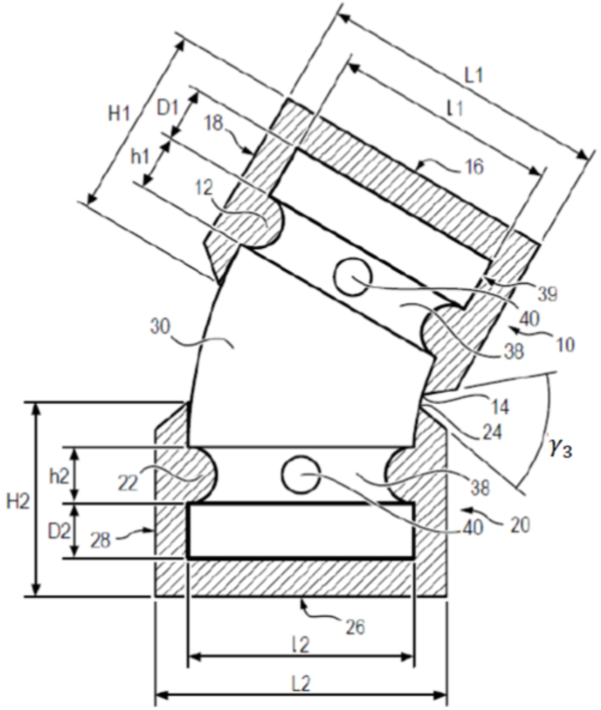
Rigid: PLA

Soft: RTV 3535

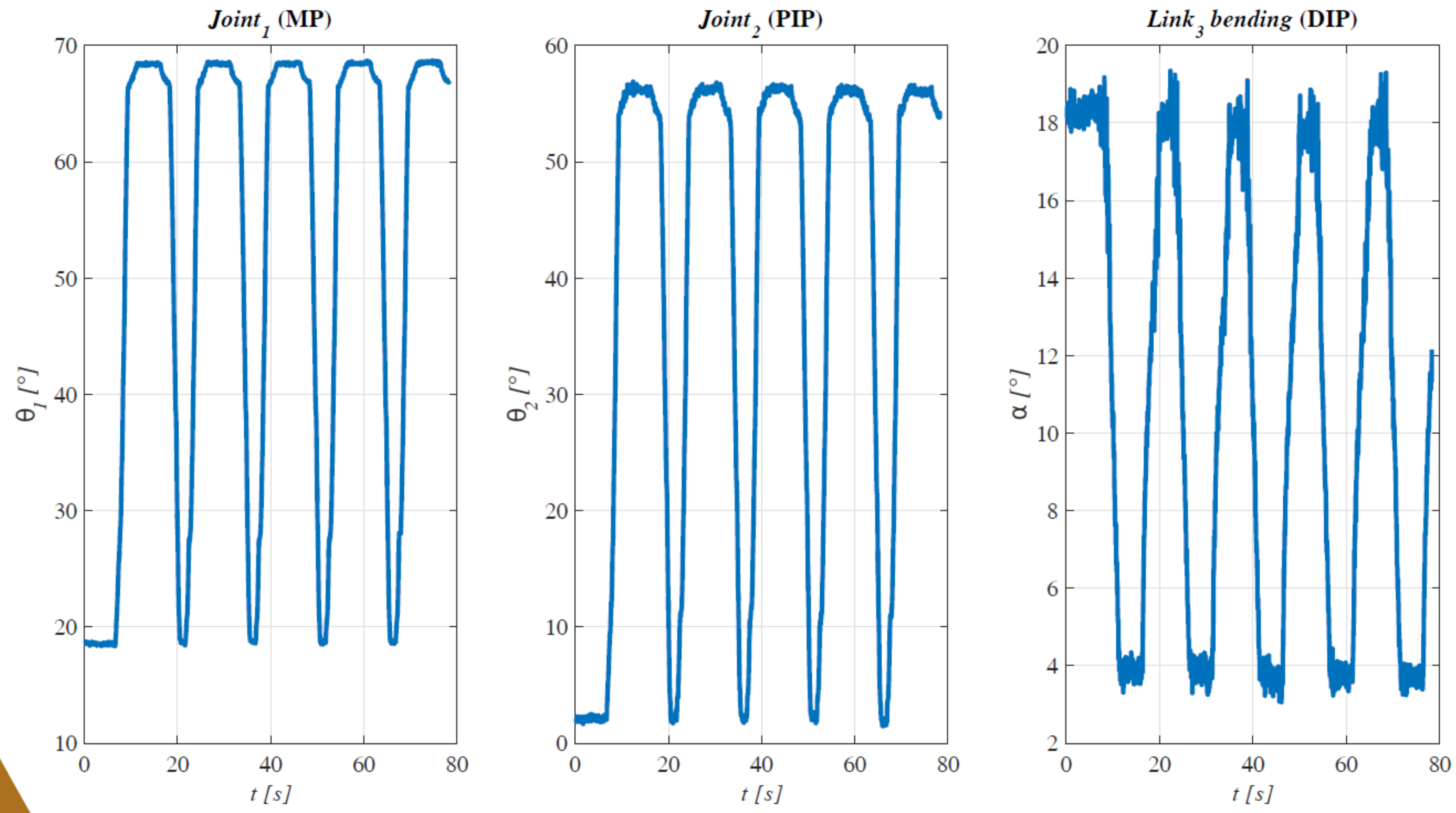
Rigid: PLA

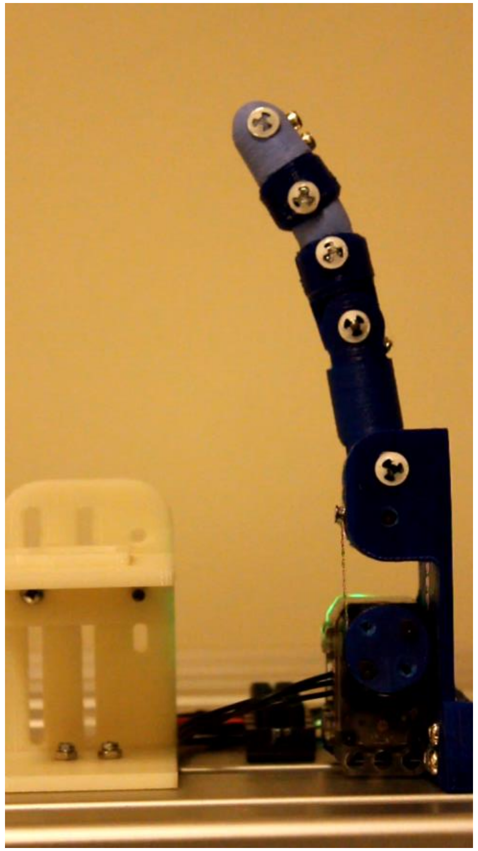


The initial bending angle improves grasping



Angles performed during flexion/extension soft robotic finger





Conclusion

Kinematic Vs sEMG	• Features extraction • Features behavior
Wearable movement recognition	• Entropy based analysis • Out of laboratory conditions • 97.5% classification success
Smart control of soft prosthesis	• Hybrid controller • Fingertip force sensor
ProMain-II hand	• Soft link

Perspectives

Validation with amputated patients	• Test ProMain hands in amputated patients • Add feedback force sensation to patient
Control of ProMain-II	• Introduce a control law for smart materials
Hand movements	• Classify individual fingers movements • Recognize force level with sEMG

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Smart control of a soft robotic hand prosthesis

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