ProMain

Olivier Polit – Laurent Gallimard
Nicolas Jouandeau
Astrid Rubiano – Jose Ramirez

Laboratoire Energétique Mécanique Electromagnétisme

Université Paris Nanterre

50, rue de Sèvres, 92410 Ville d'Avray, France

Motivation

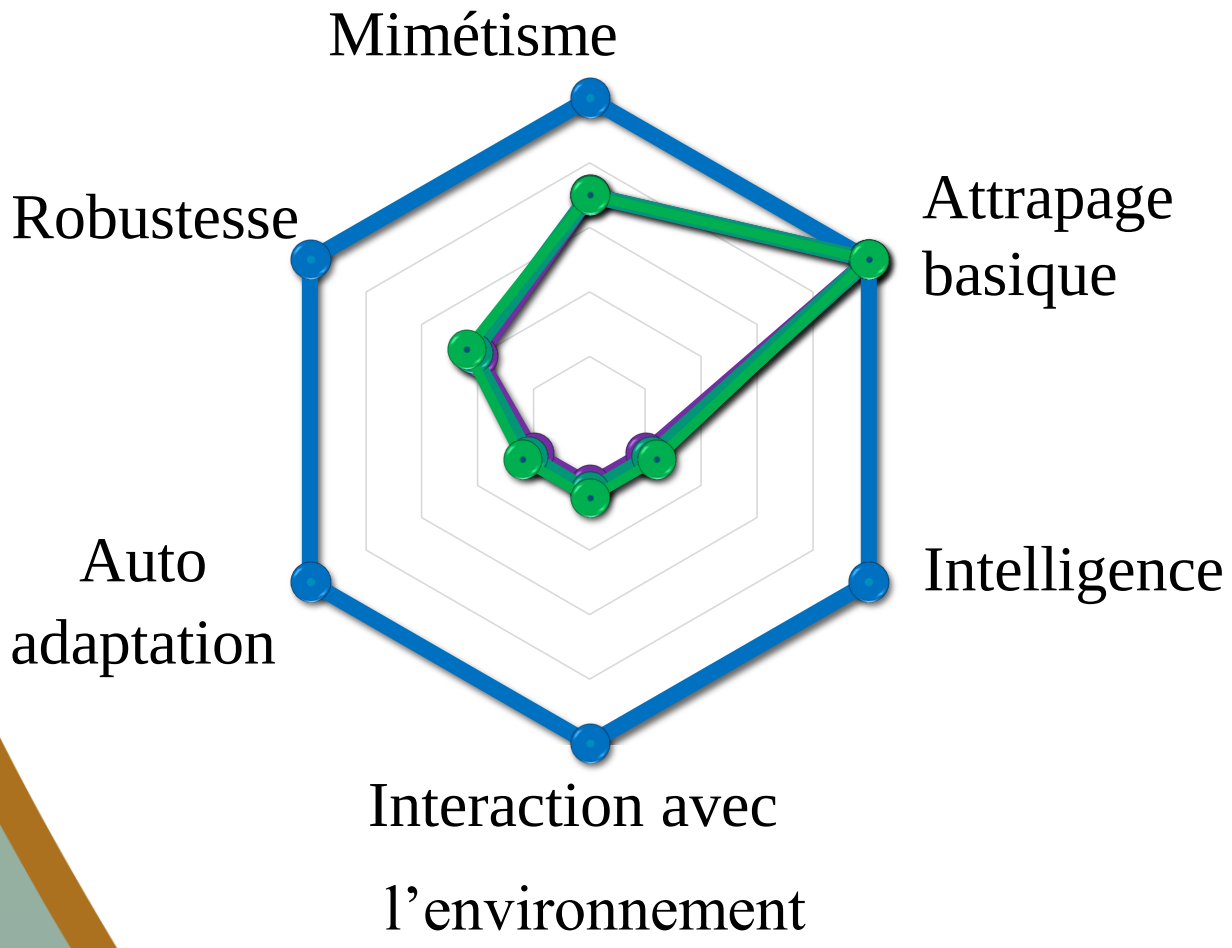
2009 – 2013

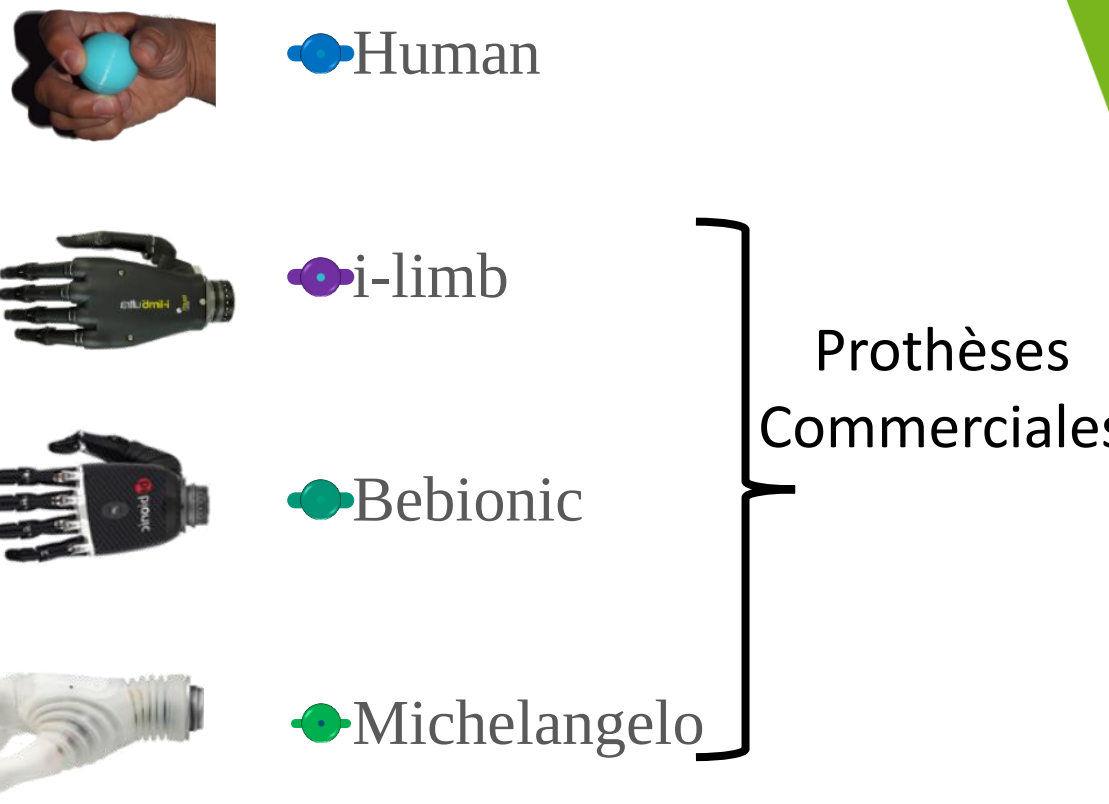
10 253 amputés

Solutions existantes

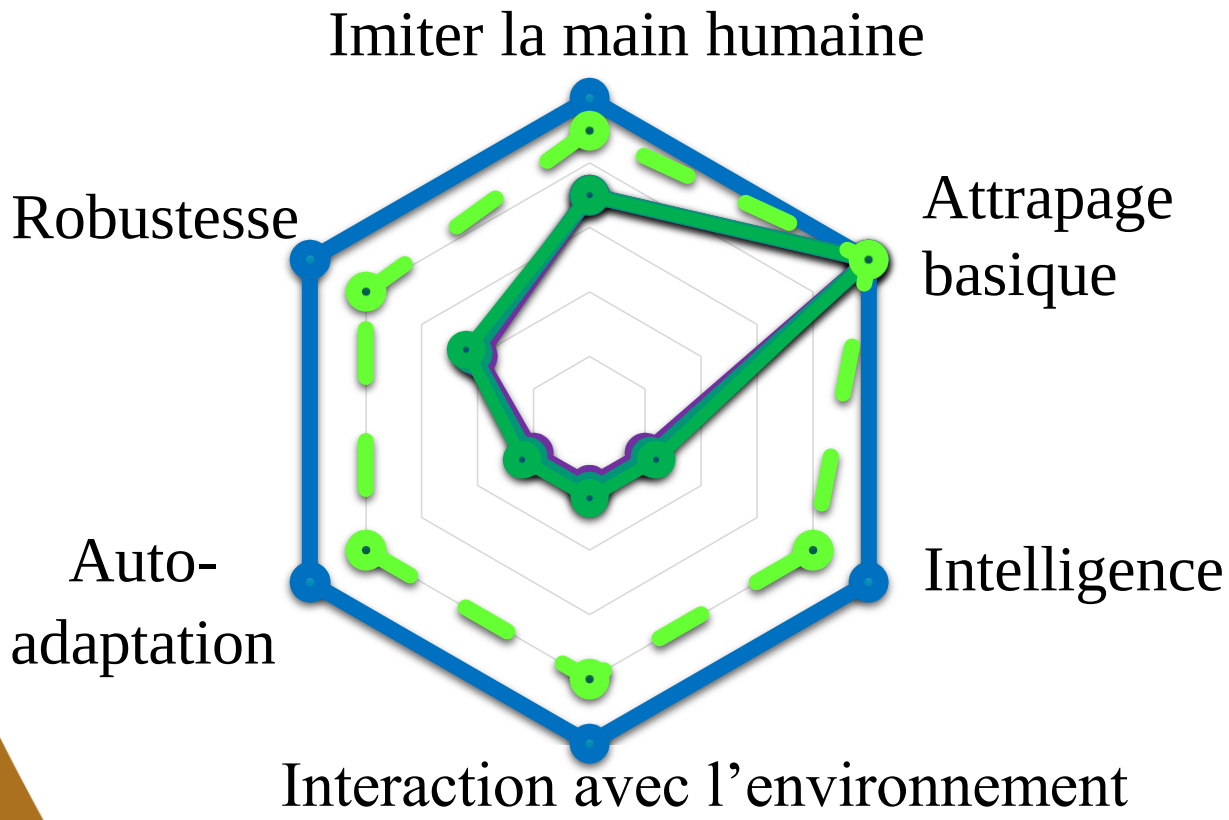
	Nom	DDL controlés	Nombre d'articulations	Type d'actionneur	Poids	Coût
	i-limb Ultra	5 (électriques) 1 (manuel)	11	électrique	550 g	25K€
	Michelangelo	4	6	électrique	600 g	40K€
	Bebionic Hand 3	5 (électriques) 1 (manuel)	11	électrique linéaire	600 g	15K€

Axes de développement des prothèses de main



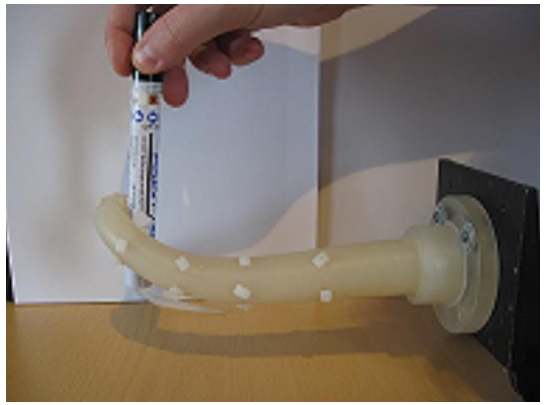


Amélioration des capacités d'une prothèse de main



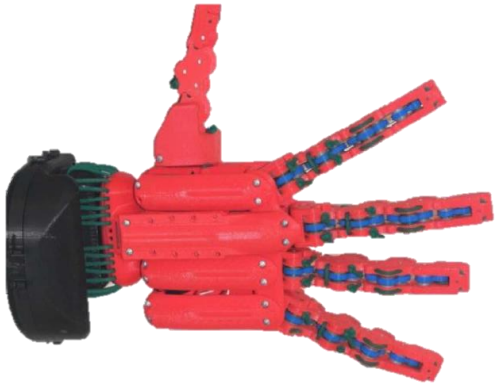
- Emuler l'**adaptibilité** de la main humaine
- Développer des **mécanismes plus adaptés**
- Utilisant **matériaux intelligents** et la **robotique douce**
- Améliorer les **actionneurs**

Robotique douce



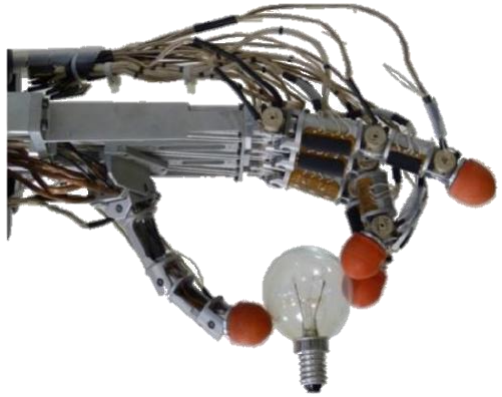
Octopus robot

(Calisti *et al*., 2010)



Pisa soft hand

(Godfrey *et al*, 2013)



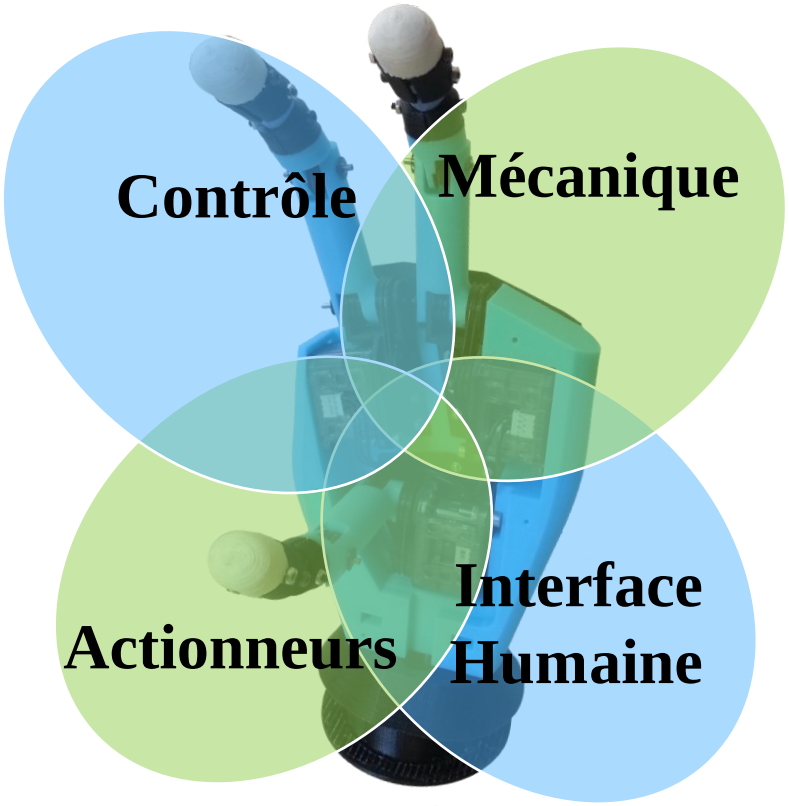
ROBIOSS

(Mnyusiwalla *et al*. 2016)

Matériaux intelligents, élastiques et adaptables

Contexte

ProMain



TECHNISCHE UNIVERSITÄT DRESDEN

Université Paris Nanterre

UPL UNIVERSITÉ PARIS LUMIÈRES

UNIVERSITÉ PARIS 8 VINCENNES-SAINT-DENIS

UNIVERSIDAD MILITAR NUEVA GRANADA

cogitobio

Equipe scientifique

Olivier Polit

Laurent Gallimard

Michele D'Ottavio

Thomas Wallmersperger

Nicolas Jouandeau

Jose Ramirez

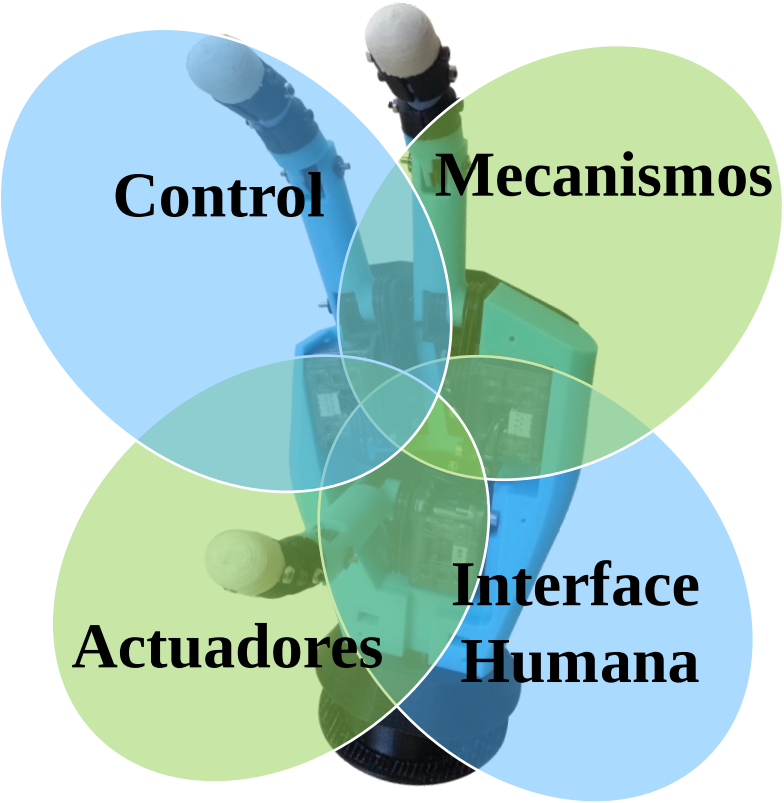
Astrid Rubiano

Aurélien Scola

ProMain

Le Projet nécessite une approche pluri-disciplinaires et requière les compétences suivantes

- Traitement de données
- Robotique
- Intelligence Artificielle
- Systèmes embarqués
- Contrôle
- Calcul temps réel



- Biomécanique
- Mécanique
- Modélisation
- Méthodes Numériques
- Couplage multi-champs
- Matériaux intelligents
- Calcul de structures

Gestes d’attrapage les plus utilisés

Envolvente medio

Herramienta ligera

Prismático a 4 dedos

Prismático a 3 dedos

Prismático a 2 dedos

Disco de precisión

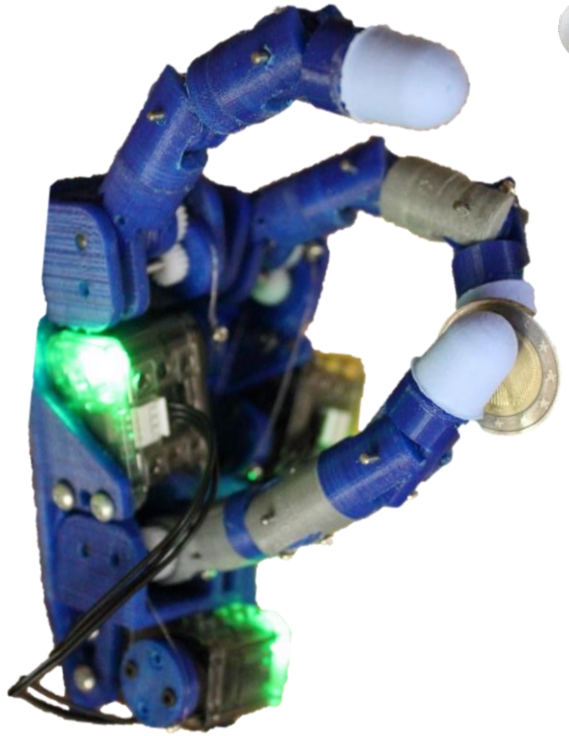
Trípode

Pouce	VF1	VF2	VF3
Rot (Abd)	I	II-III II-V	
Rot (Abd)	I -	II-V	P
Rot (Abd)	I	II-III	

- **Pouce en abduction**
- **Trois doigts**
- **Doigts II-V dans la même position**

Trois doigts se révèlent suffisant pour ces gestes de préhensions

ProMain: Main de précision
86% de l’activité quotidienne



ProMain-I

ProMain-II

- Faible coût
- Faible consommation électrique
- Prototypage rapide
- Avec/Sans matériaux intelligents
- Qui s’adapte au patient et non l’inverse

Prothèse de main : ProMain-I

- **Trois doigts:** nécessaires pour réaliser les attrapages sélectionnés
- **Sous-Actionné:** réduit la taille, le poids et la consommation énergétique.

Préhension

Préparation

Exécution

Aduction abduction

Chassis Passif

Flexion extension

Doigts actifs

- Pouce en abduction
- Angle entre index et majeur = 15°

- Les doigts effectuent une rotation de 90° durant le mouvement

ProMain-I

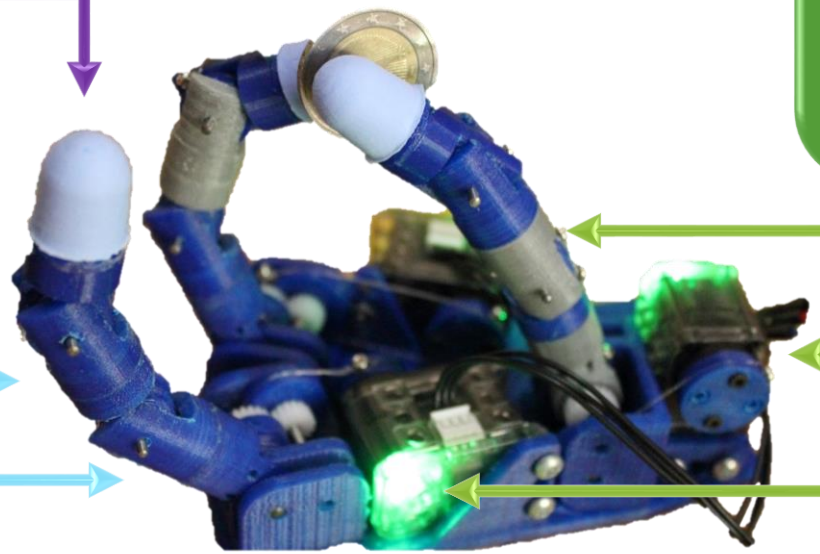
Capteur souple à chaque doigt

- Sous-actionné
- Tendons élastiques
- Contrôle hybride en force et position

Distal (DP)

Medial (M)

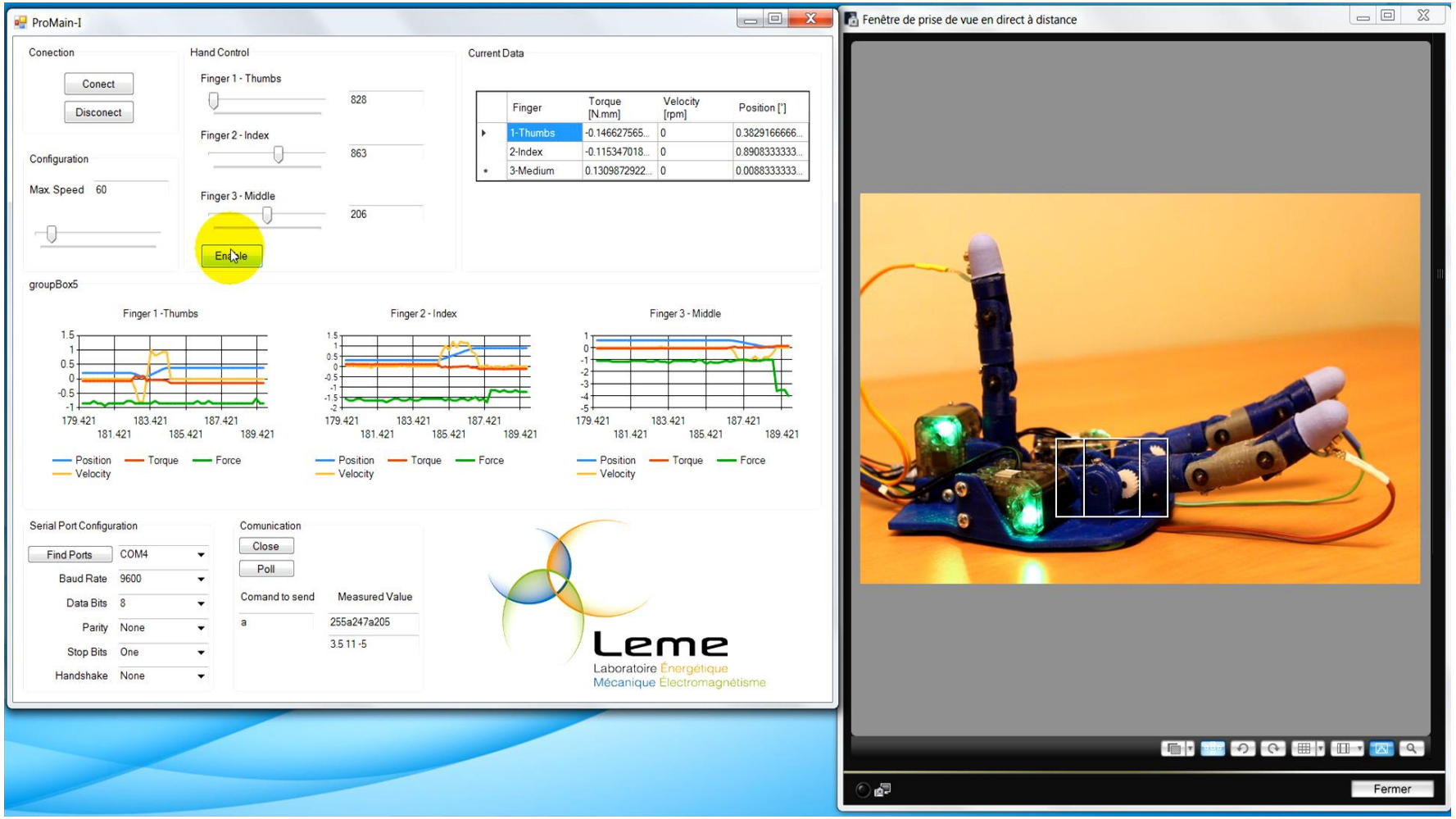
Proximal (PP)



Servomoteurs

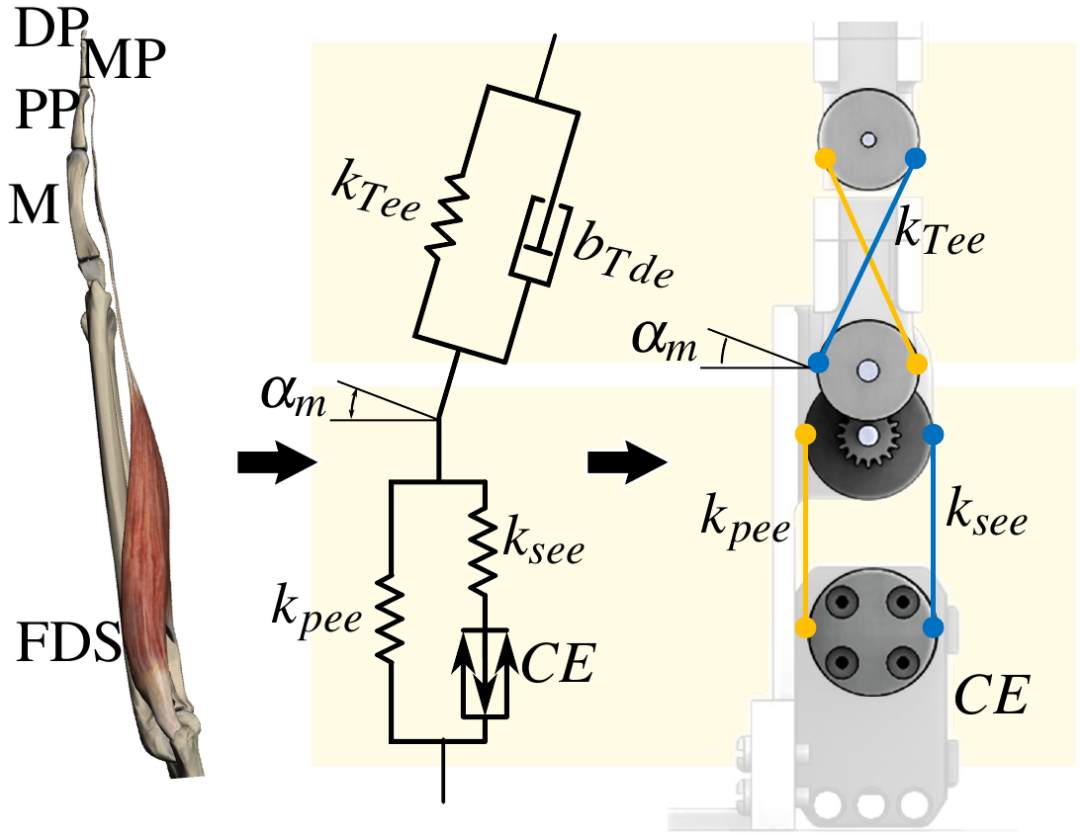
Ajustable → Modulable → Impression 3D

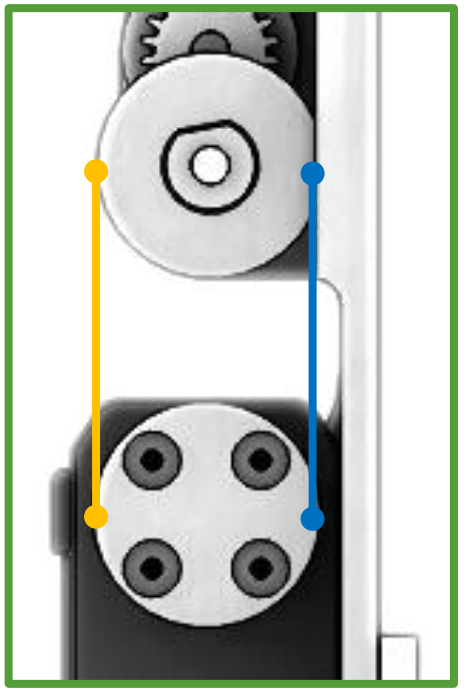
Promain-I

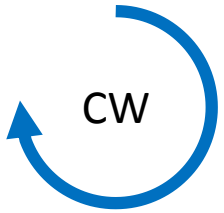


(video)

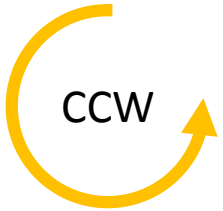
Innovation: Mécanisme épicyclique élastique bio-inspiré



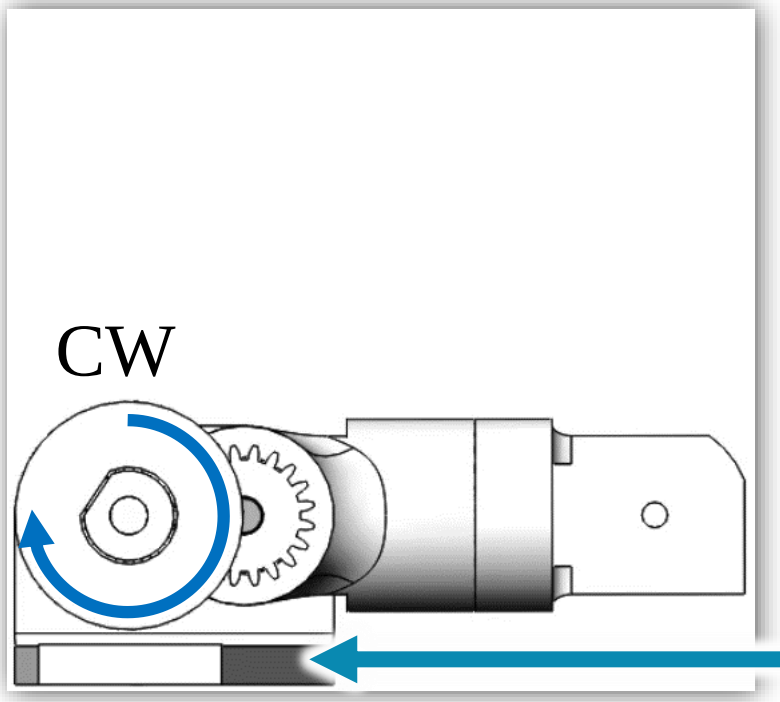




- Flexion
- Extension



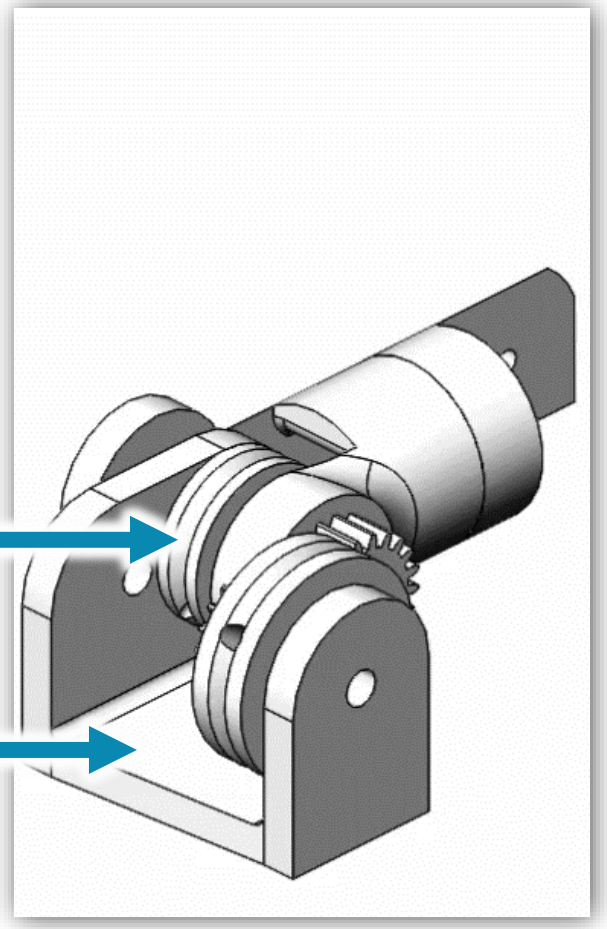
Innovation: Actionnement de la phalange proximale



(video)

Poulie fixée au chassis

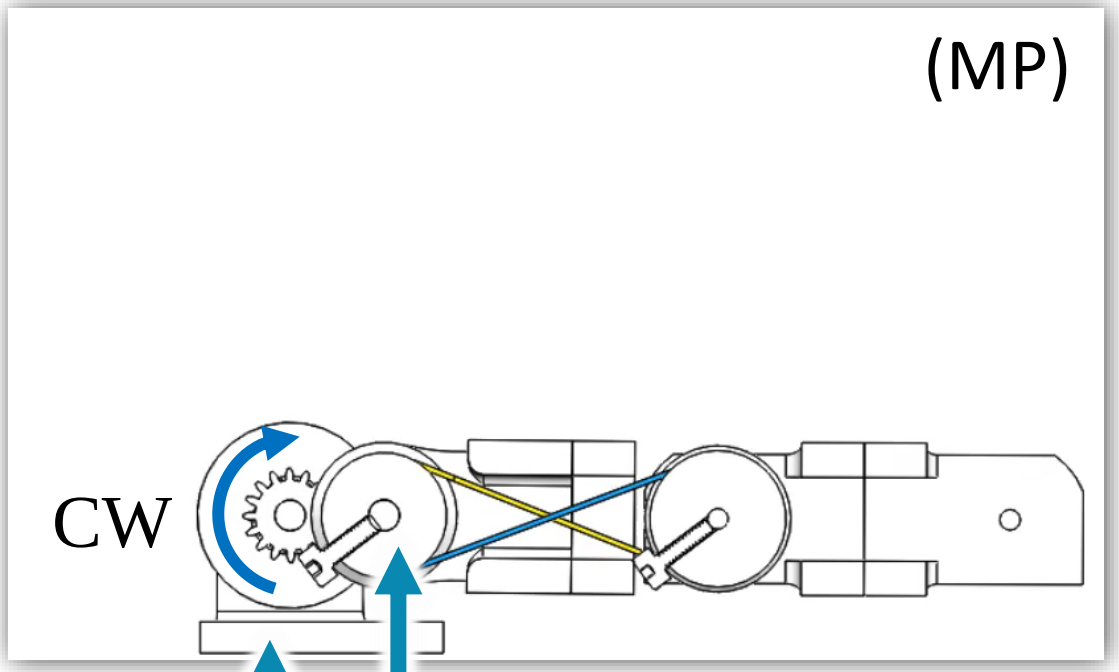
Chassis



(video)

Mouvement sous-actionné des phalanges mediale (MP) et distale (DP)

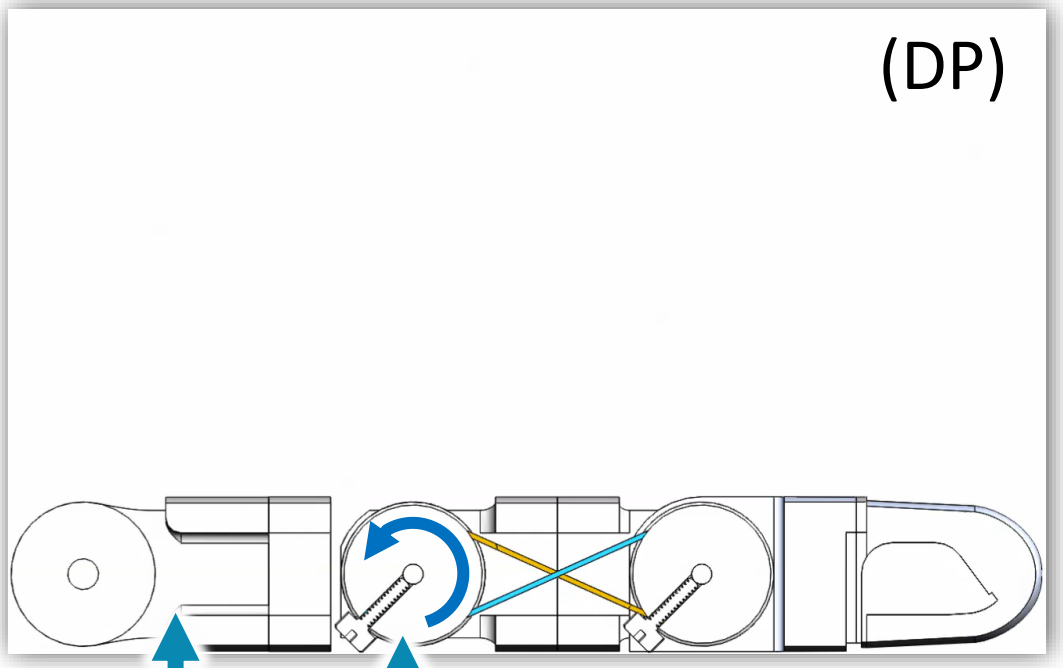
(video)



Chassis

Fixé au chassis

(video)



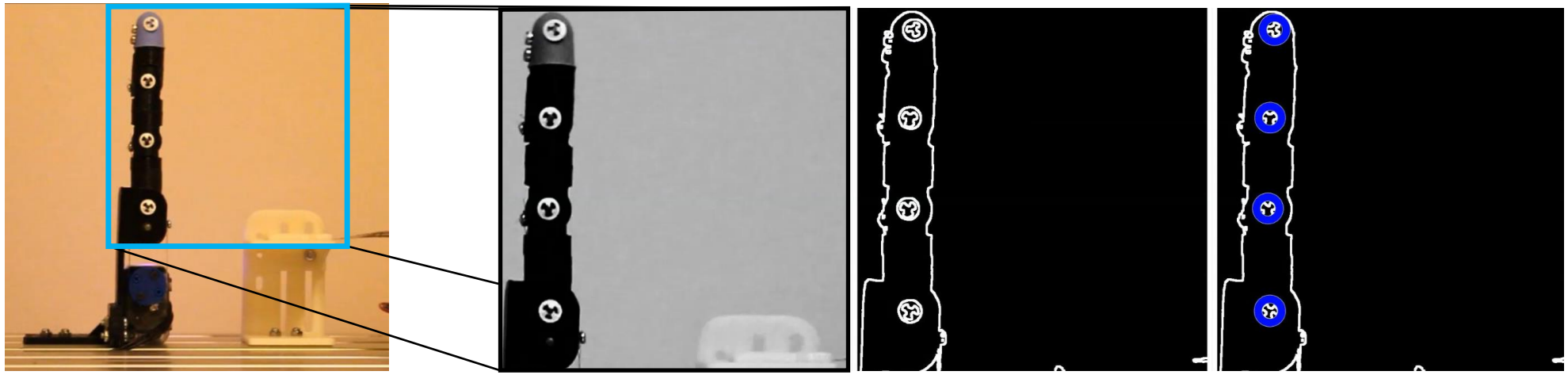
Flexion

Phalange proximale (PP)

Fixé à PP

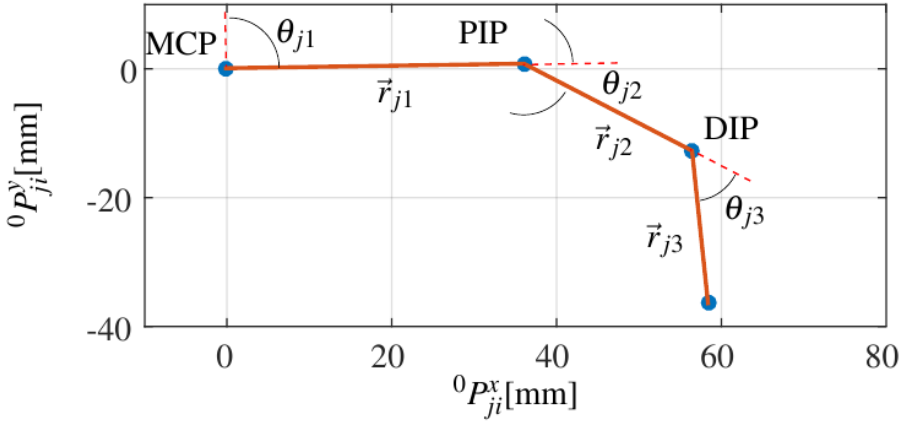
Validation expérimentale du modèle cinématique du doigt

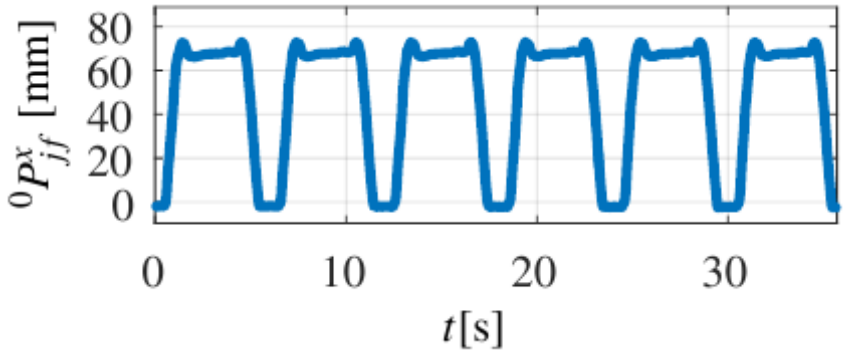
(video)



(video)

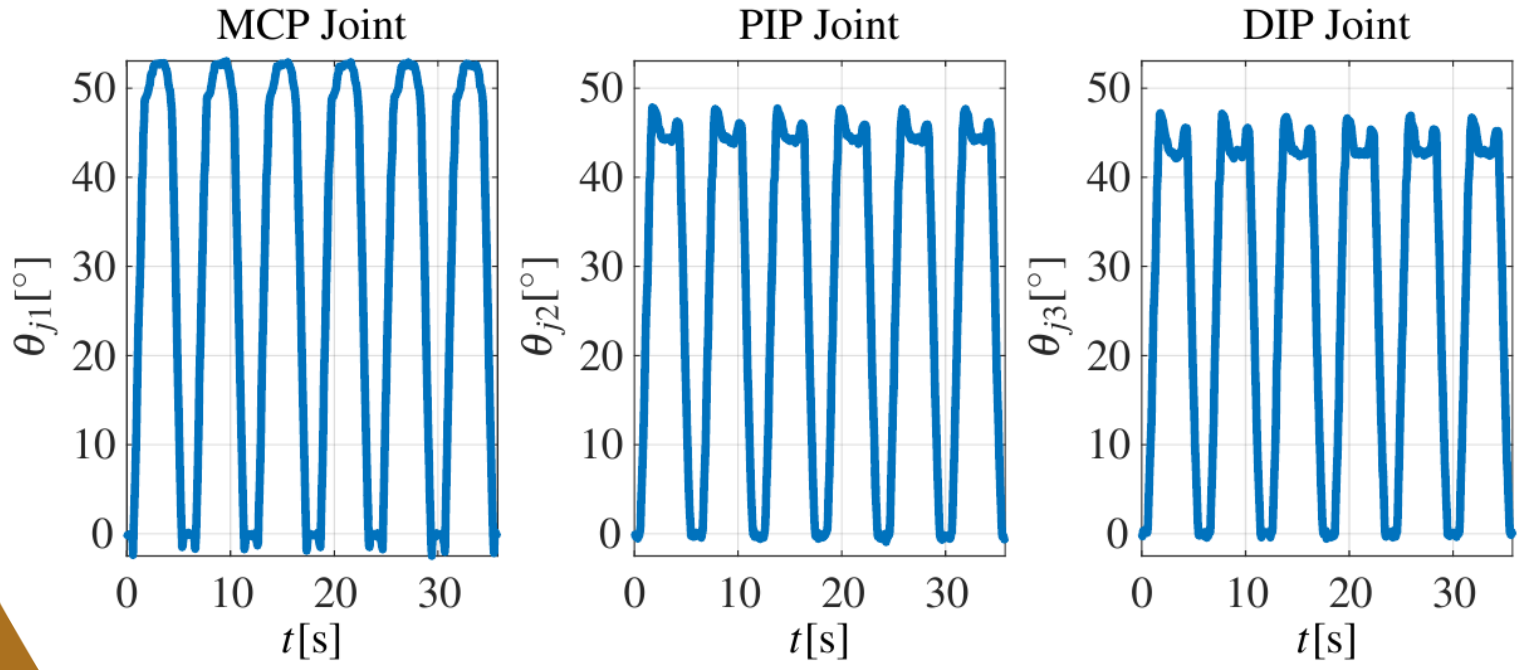
$$\theta_{j2} = \theta_{j3} = 0.9\,\theta_{j1}$$

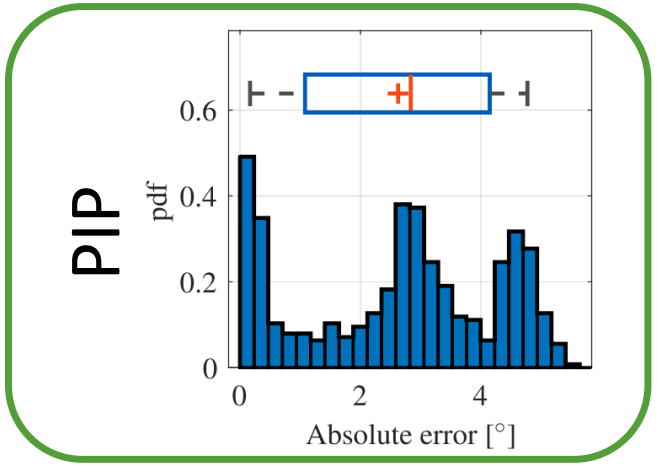


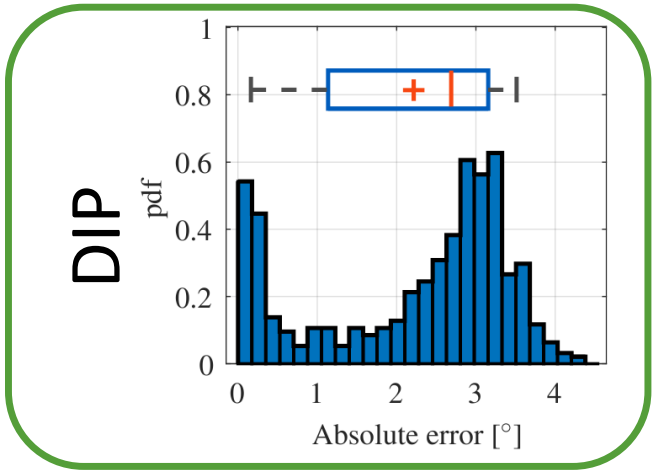


Analyse de la rotation des articulations

$$\theta_{j2} = \theta_{j3} = 0.9\,\theta_{j1}$$

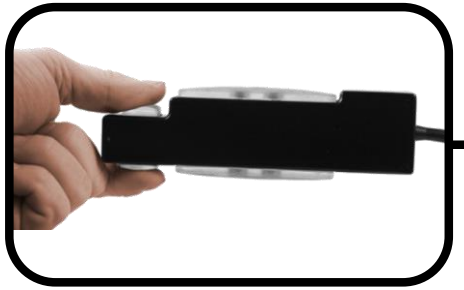




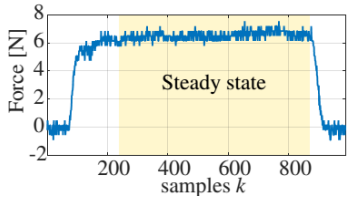


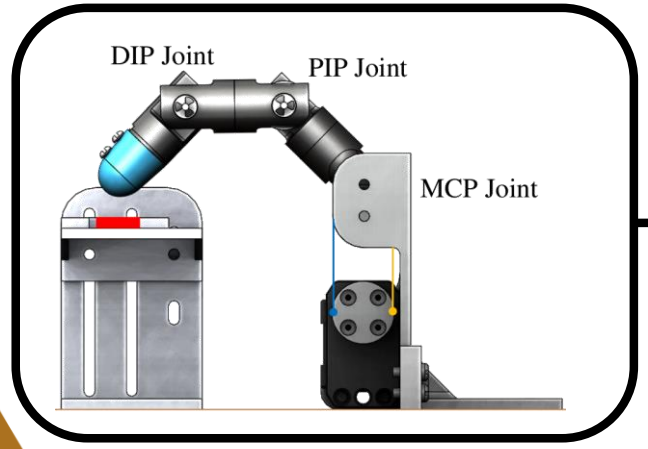
Cahier des charges de l'actionnement

Mesures dynamométriques

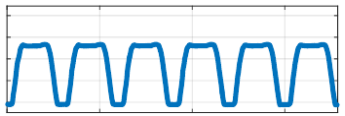


$4.78\text{N} \leq F_j \leq 6.70\text{N}$

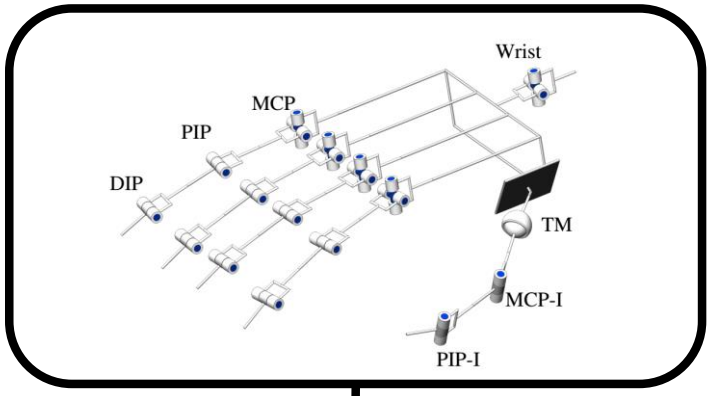




$\{q\}, \{\dot{q}\}, \{\ddot{q}\}$



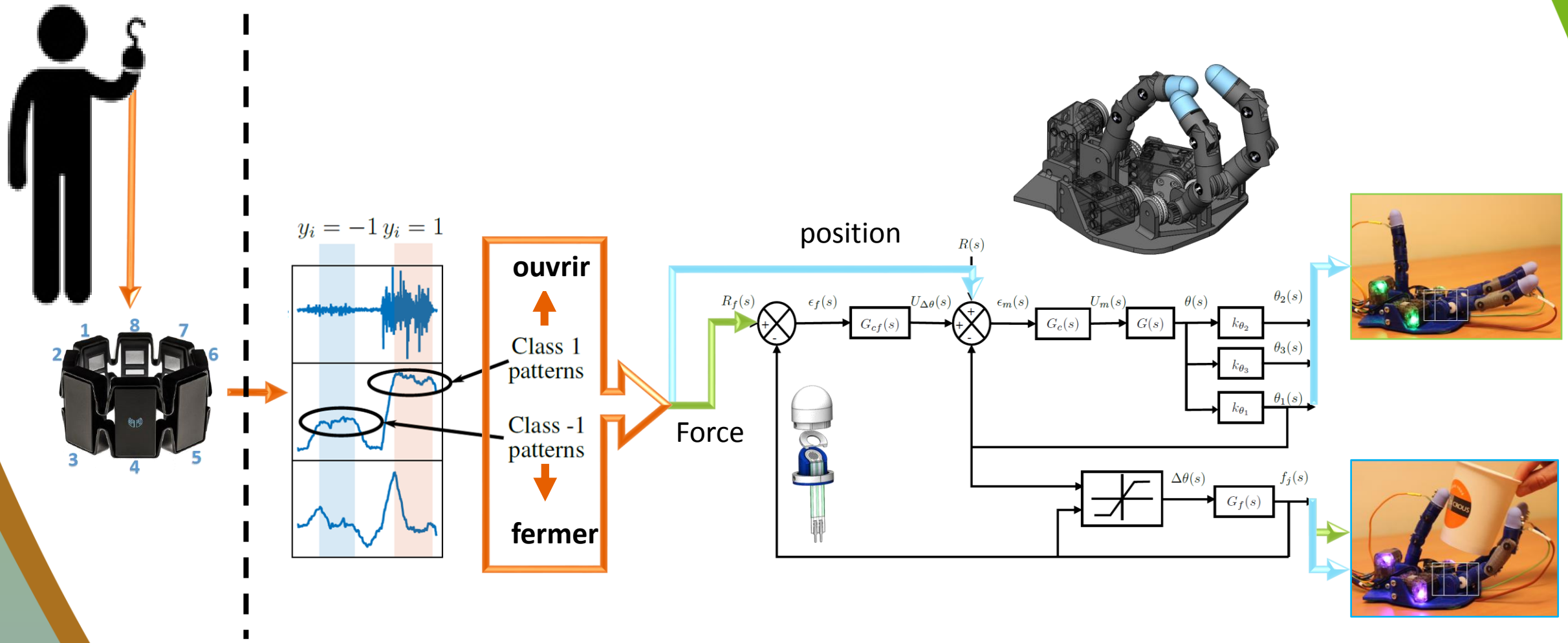
Cinématique + Dynamique



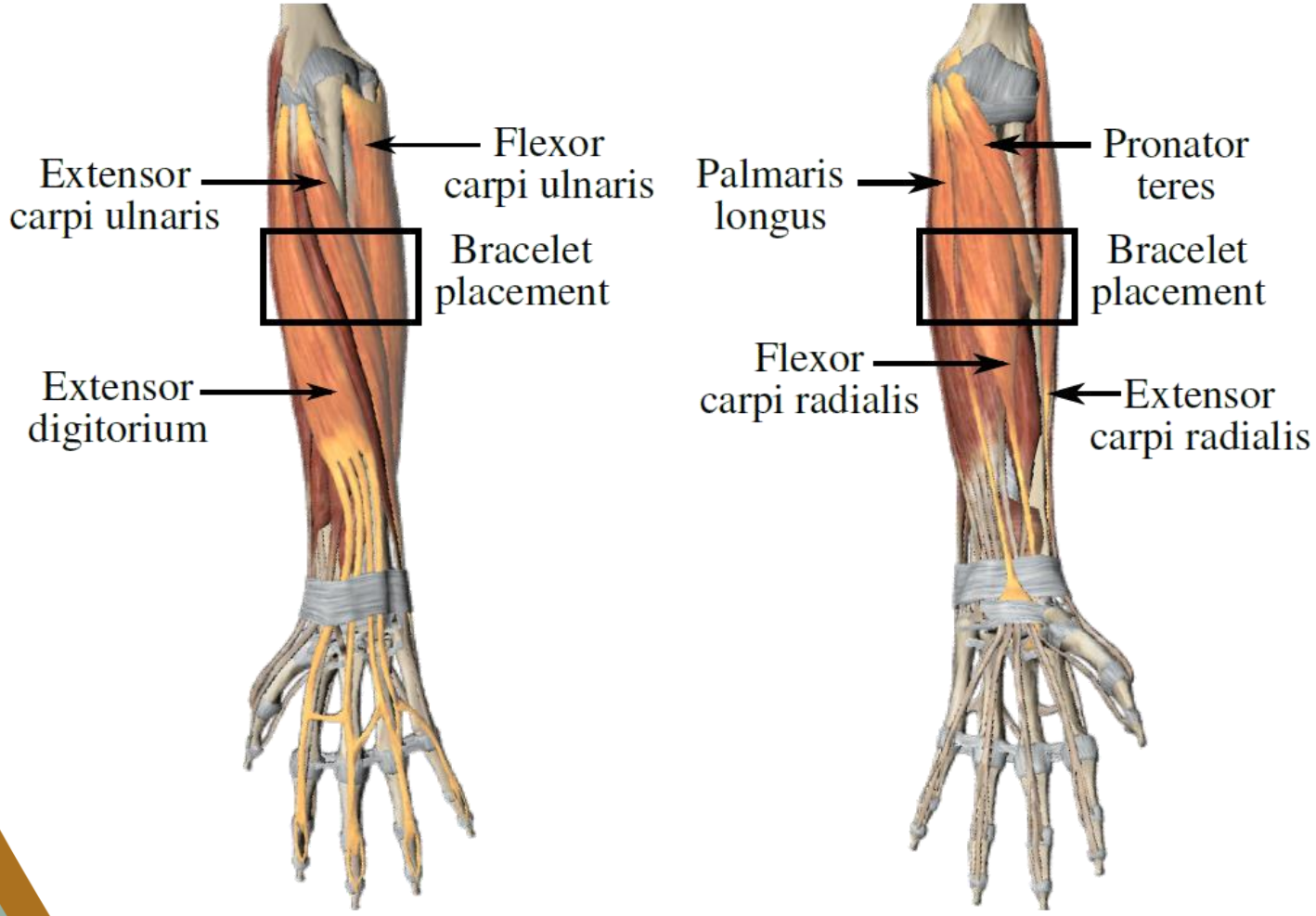
Temps d'activation: [0.18s, 0.45s]
Rotation des articulations: 90°

Couple : [124.7Nmm,175.8Nmm]

Schéma fonctionnel du contrôle



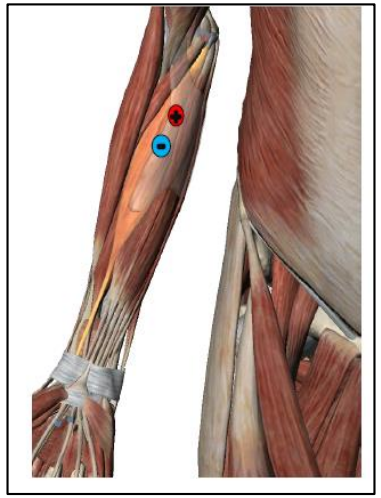
Expérimentation: capteur MyoArmband™ sEMG

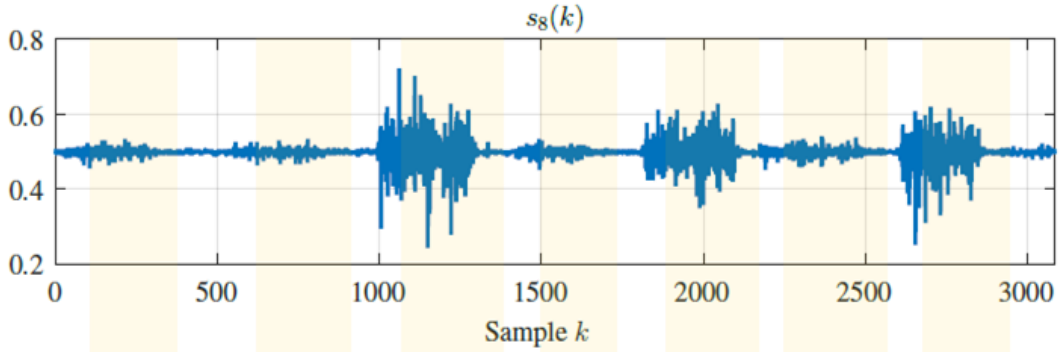


(a) Frontal muscles. (b) Posterior muscles.

Extraction d'une caractéristique (H)
8 capteurs

Signaux Electromiographiques (EMG)





- Se produisent durant la contraction du muscles
- Contiennent les informations sur le mouvement
- En superficie (sEMG)

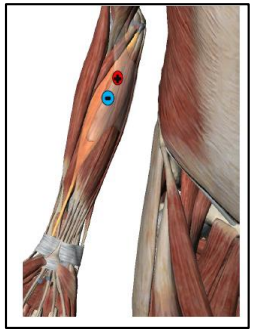
sEMG et cinématique

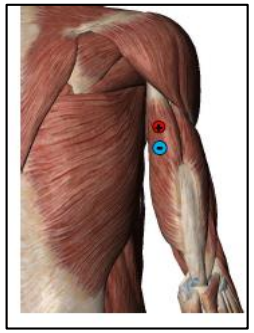
Les sEMG portent les informations du mouvement réalisé par une personne

Caractéristiques extraites des sEMG

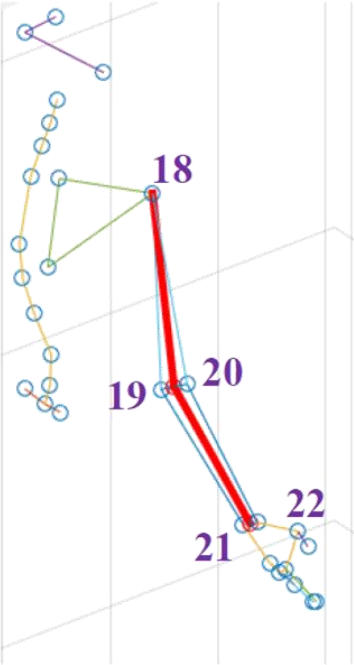
- Entropie (H)
- Dérivée de l'Entropie ()

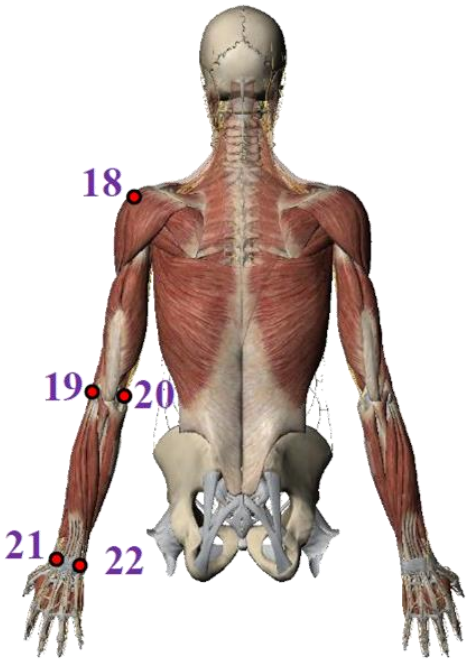
(A. Rubiano *et al*. 2015)



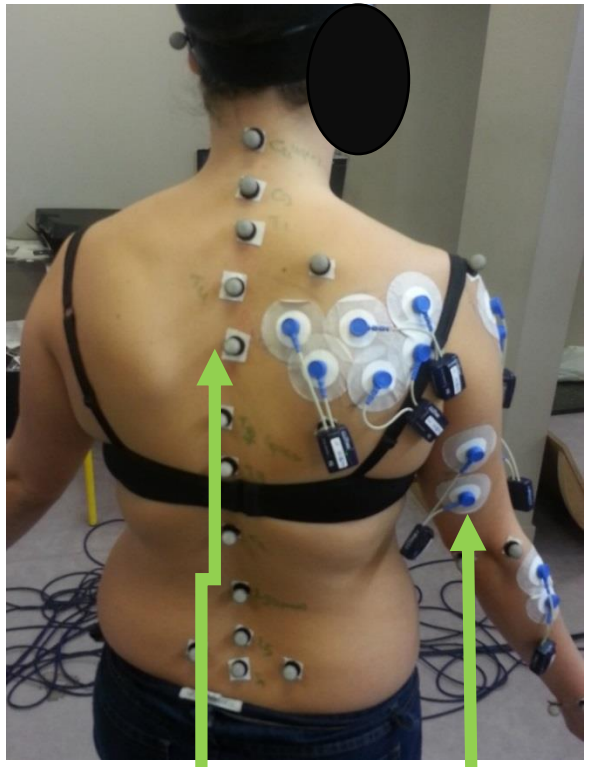


Mouvement du membre supérieur



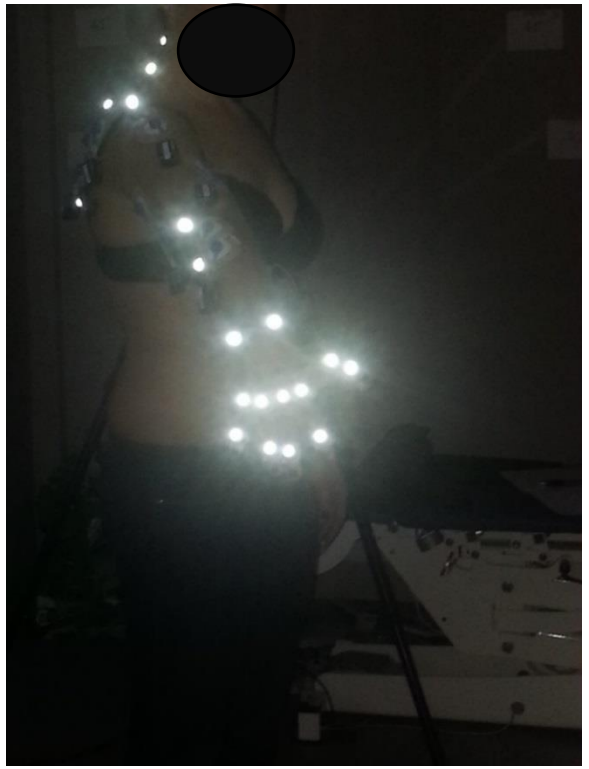


Expérimentation



Marqueurs sEMG

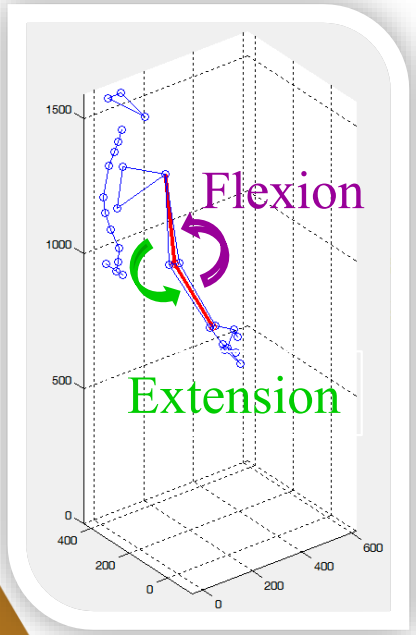
Caméra VICON

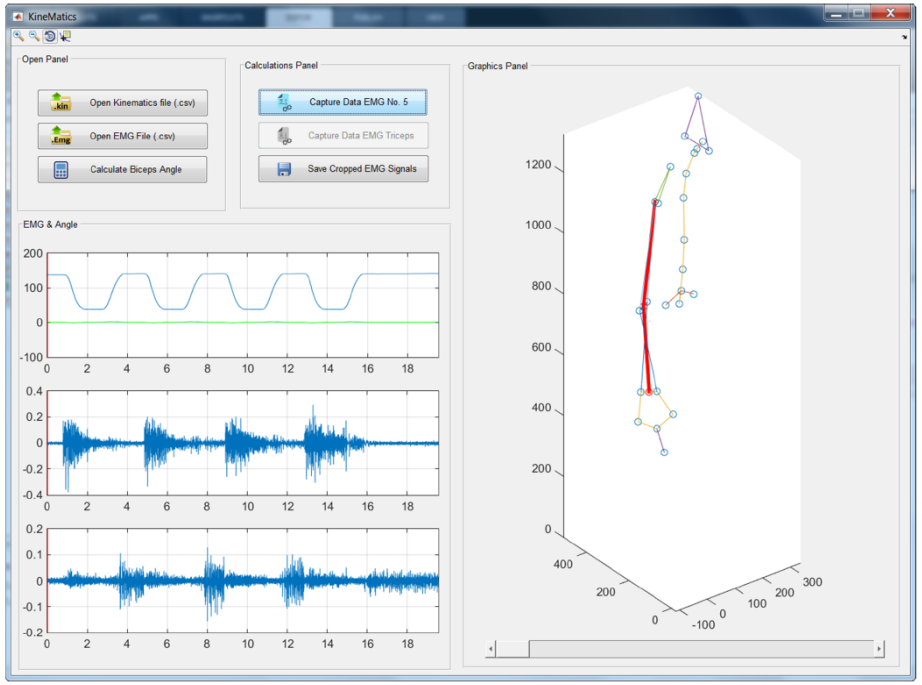


Aquisition

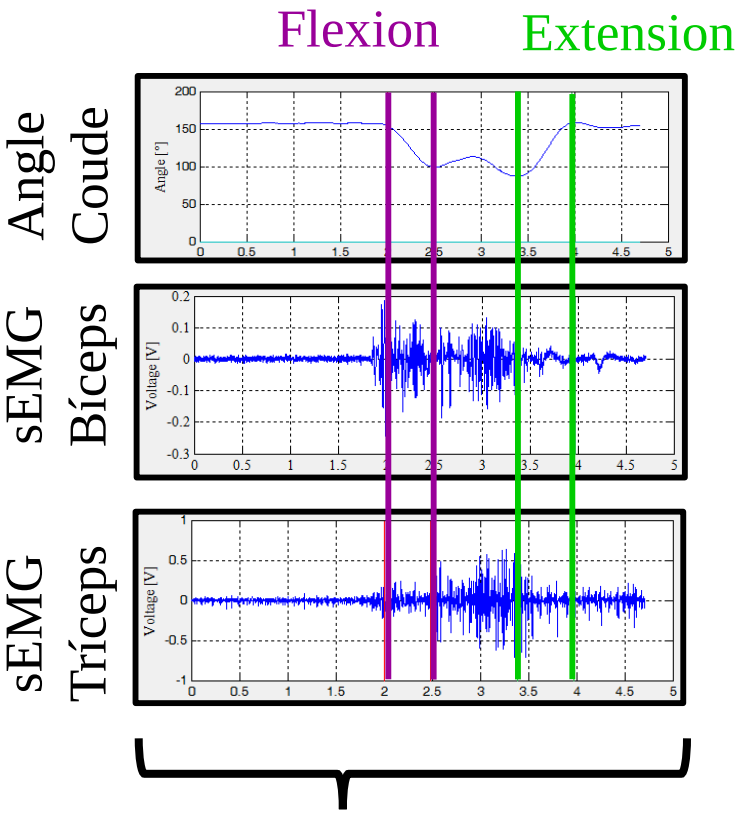
Traitement des données expérimentales

- Trois sujets réalisent flexion et extension du coude
- Acquisition des sEMG du bIceps et du triceps
- Extraction des caractéristiques des signaux produits durant le mouvement





Sélection des signaux



Caractéristique-> **Classification**

Classification des mouvements

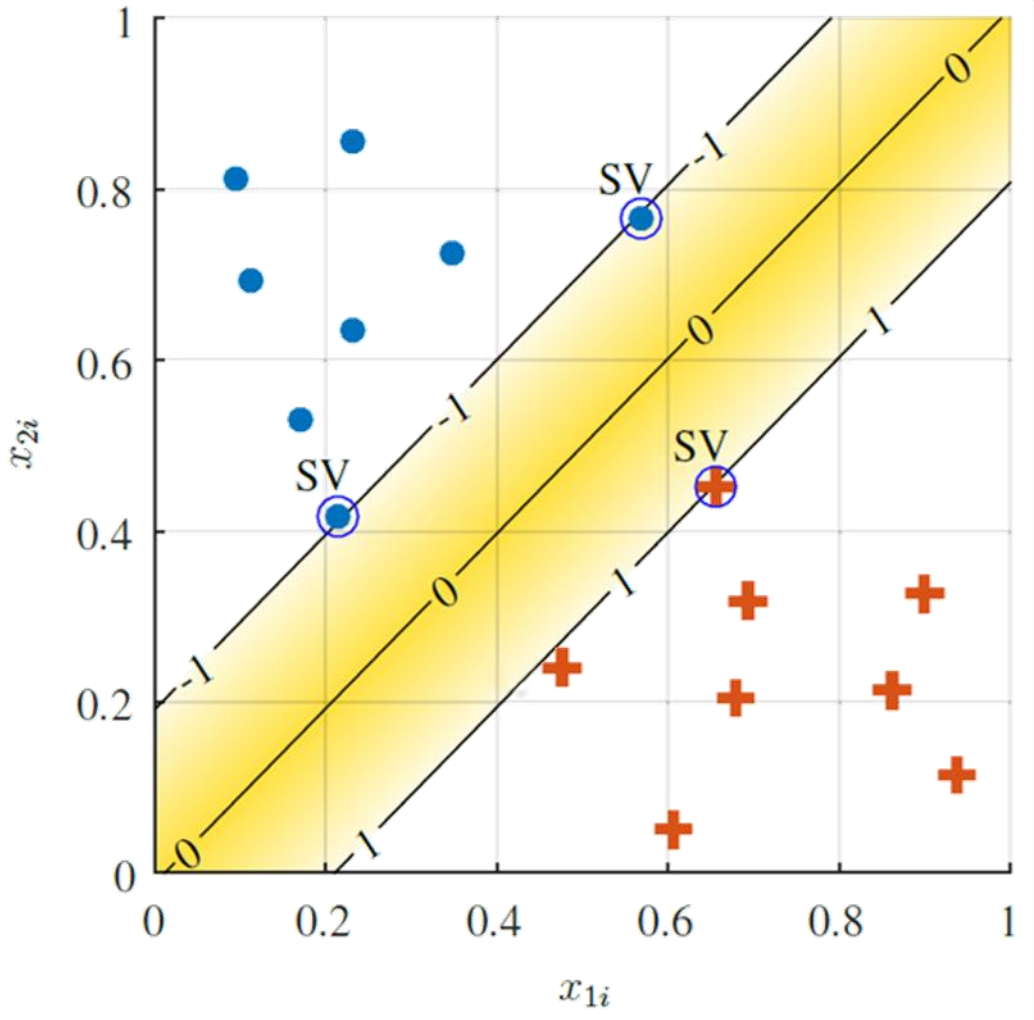
Support Vector Machines
(Cortes and Vapnik, 1995)
(Boser, *et al.* 1992)

(i) Apprentissage supervisé

(ii) Recherche de l'hyperplan séparateur optimal qui maximise la distance

(iii) Distance optimale

(iv) Linéaire, distance douce, non-linéaire



Classification des mouvements de flexion et extension du coude

Extraction des caractéristiques

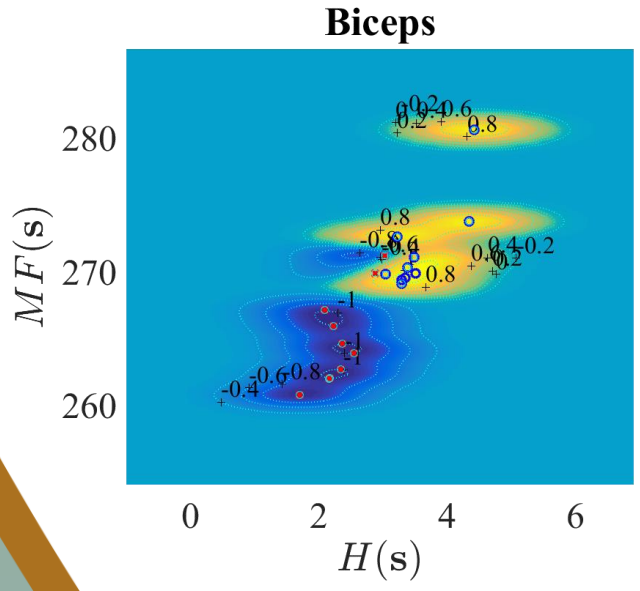
- Moy. Fréquence
- Entropie

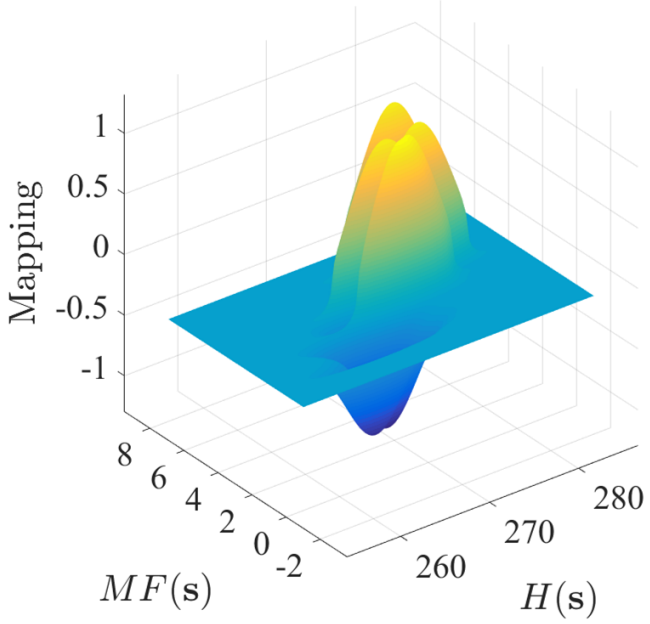
Classification

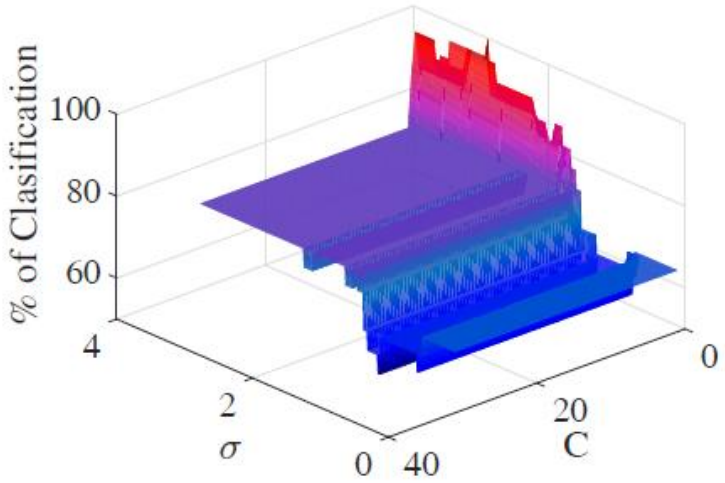
- SVM Non-lineaire avec fonction de base radiale
  - Entrainement (13.63%)
  - Test (Nouveau sujet)

Résultats

- Paramêtres SVM y
- Classifications réussies 99.99%



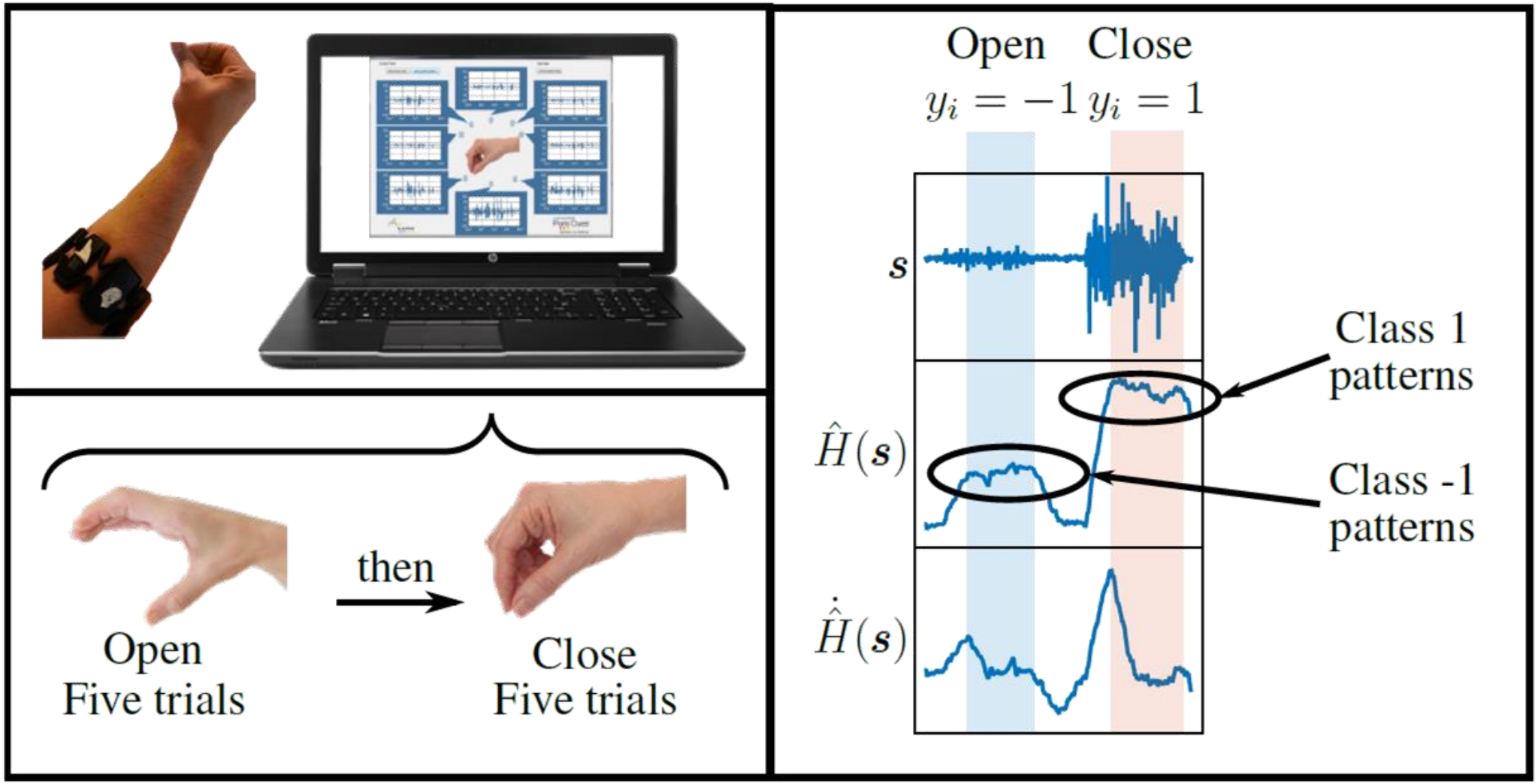




Analyse expérimentale et validation du modèle

Setup

Display Instruction



Capture, Process, and Save

Reconnaissance des modes d'attrapage

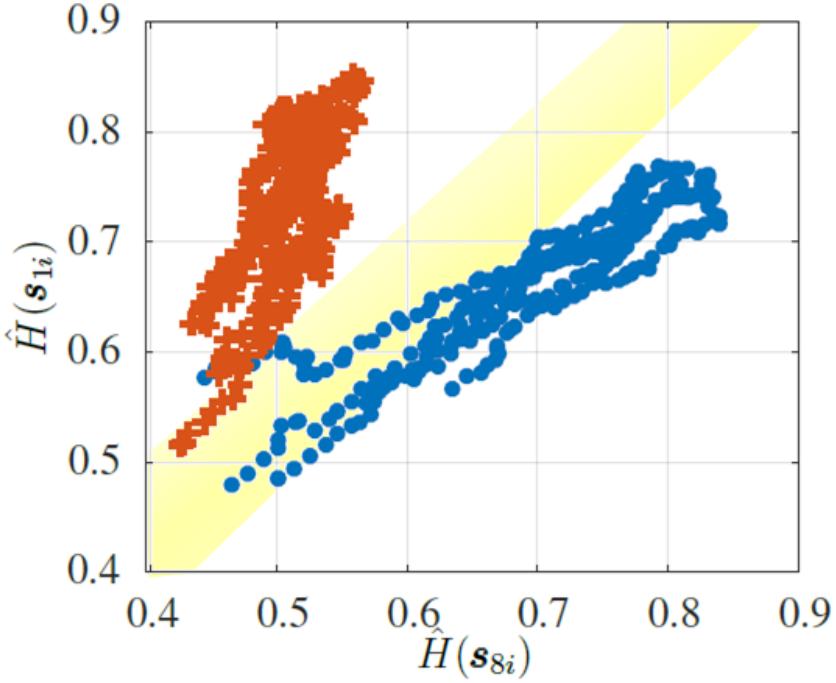
Espace des caractéristiques $\mathcal{X} \in \mathbb{R}^8$ composé des entropies normalisées

a

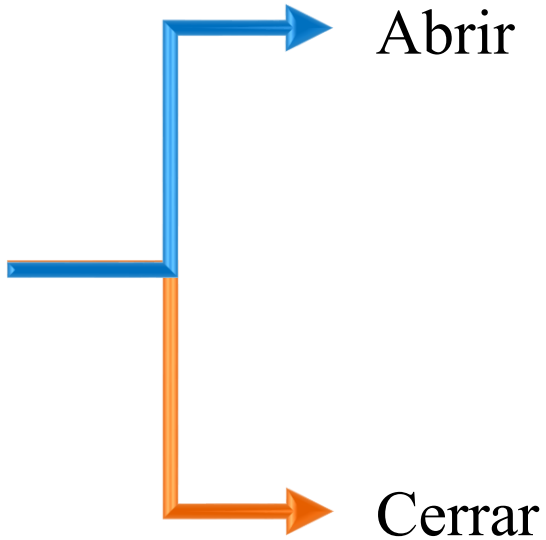
données

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

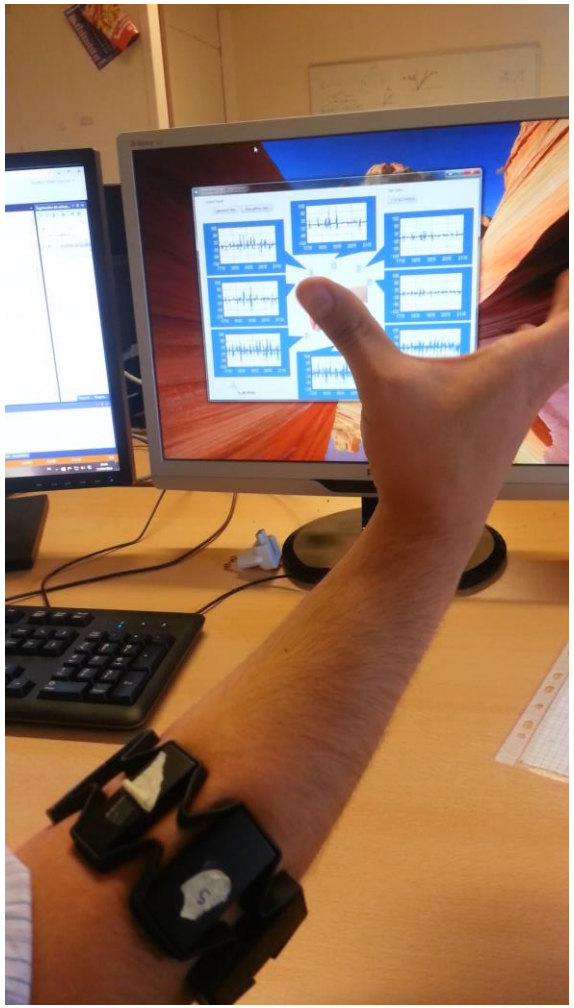
SVM de distance max



Reconnaissance



Résultat de la reconnaissance de l'attrapage



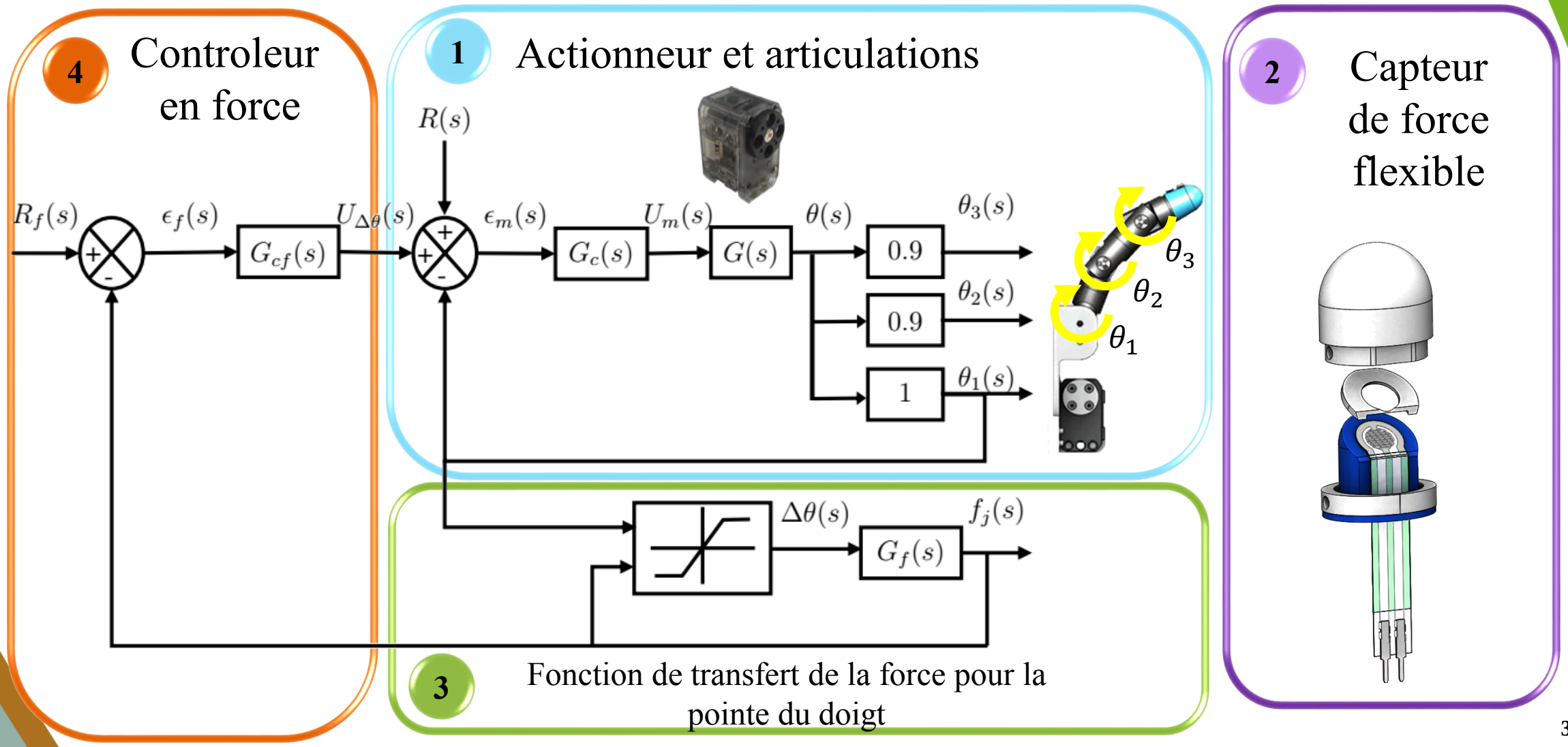
(video)

(video)

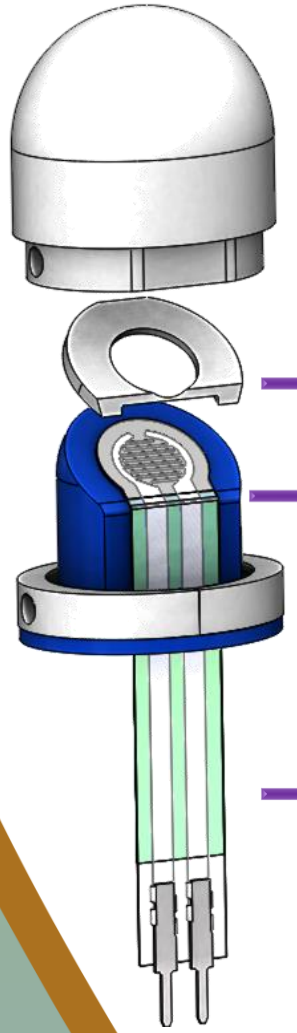
Mean success rate: 97.5%

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

Innovation: ProMain-I contrôle hybride



Innovation: Capteur souple en bout de doigt



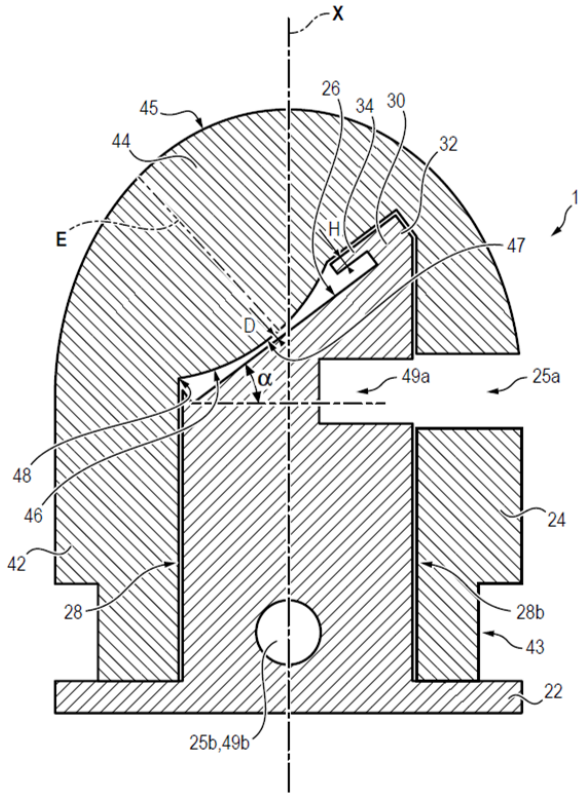
Capuchon flexible

Anneau de fixation

Os

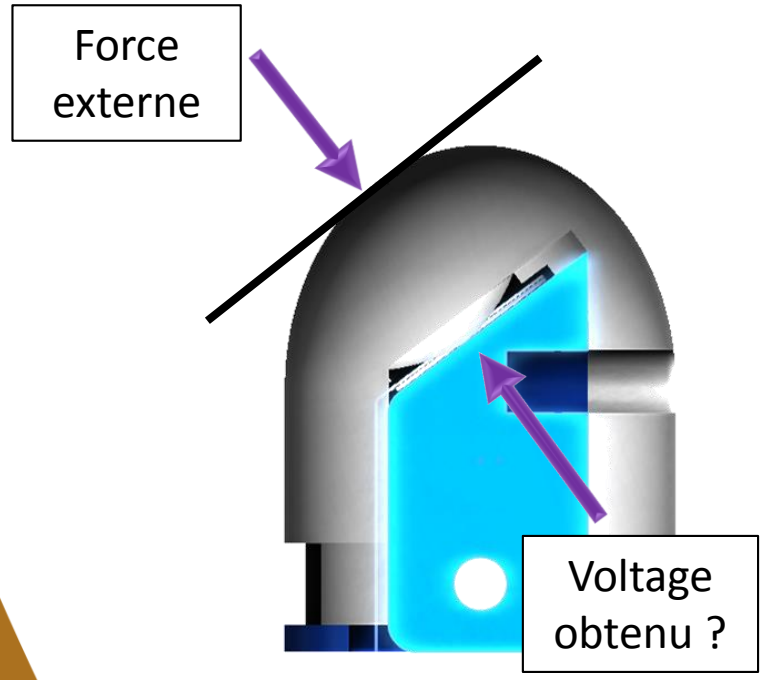
Anneau de support

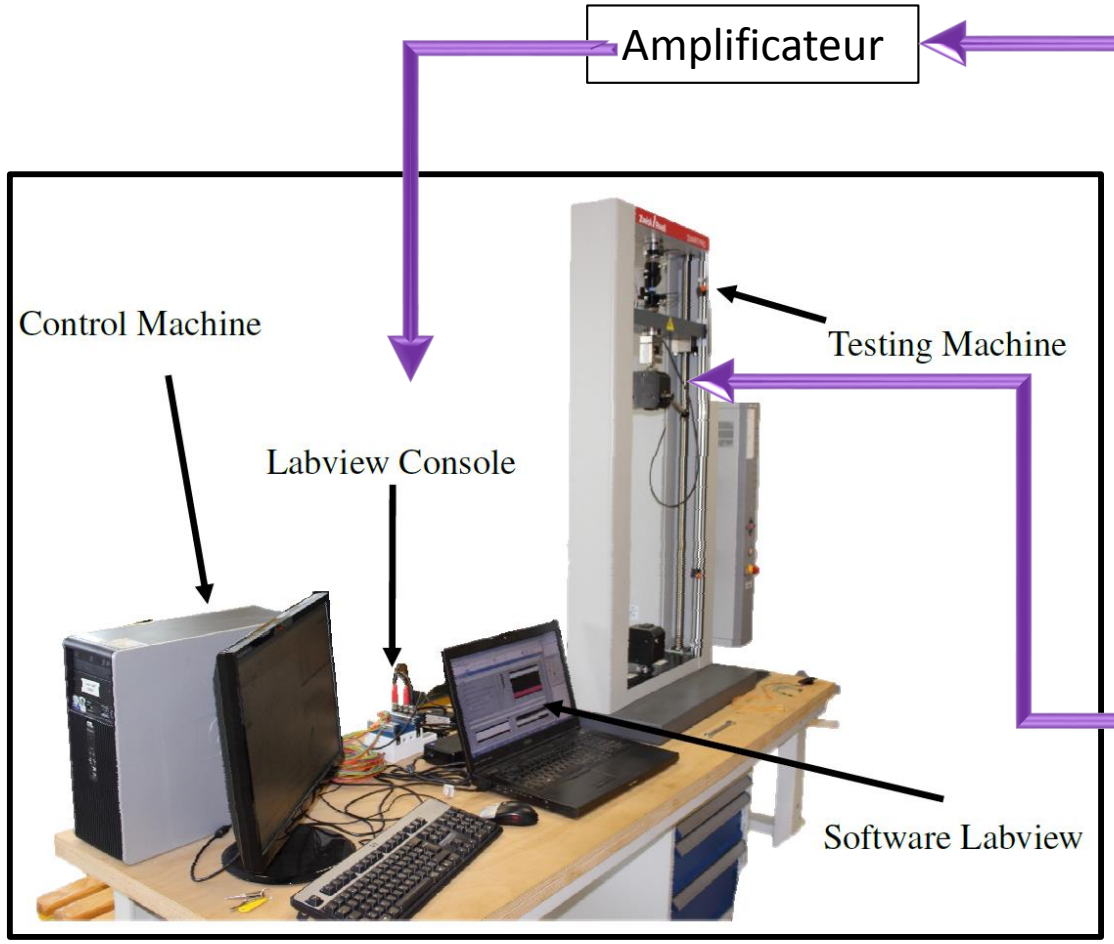
FSR



- Souple
- Mesure la force en bout de doigt

Expérimentation: Caractérisation du capteur souple

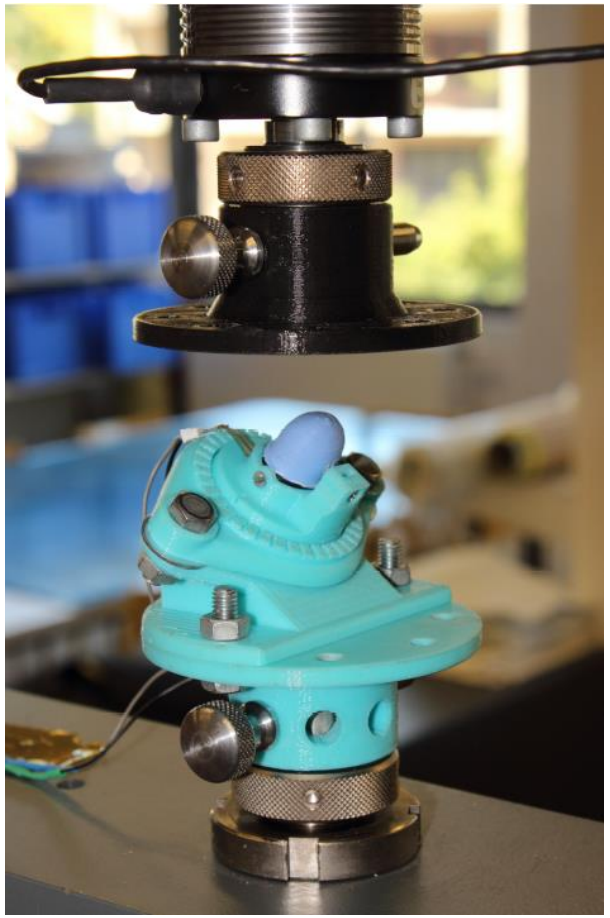


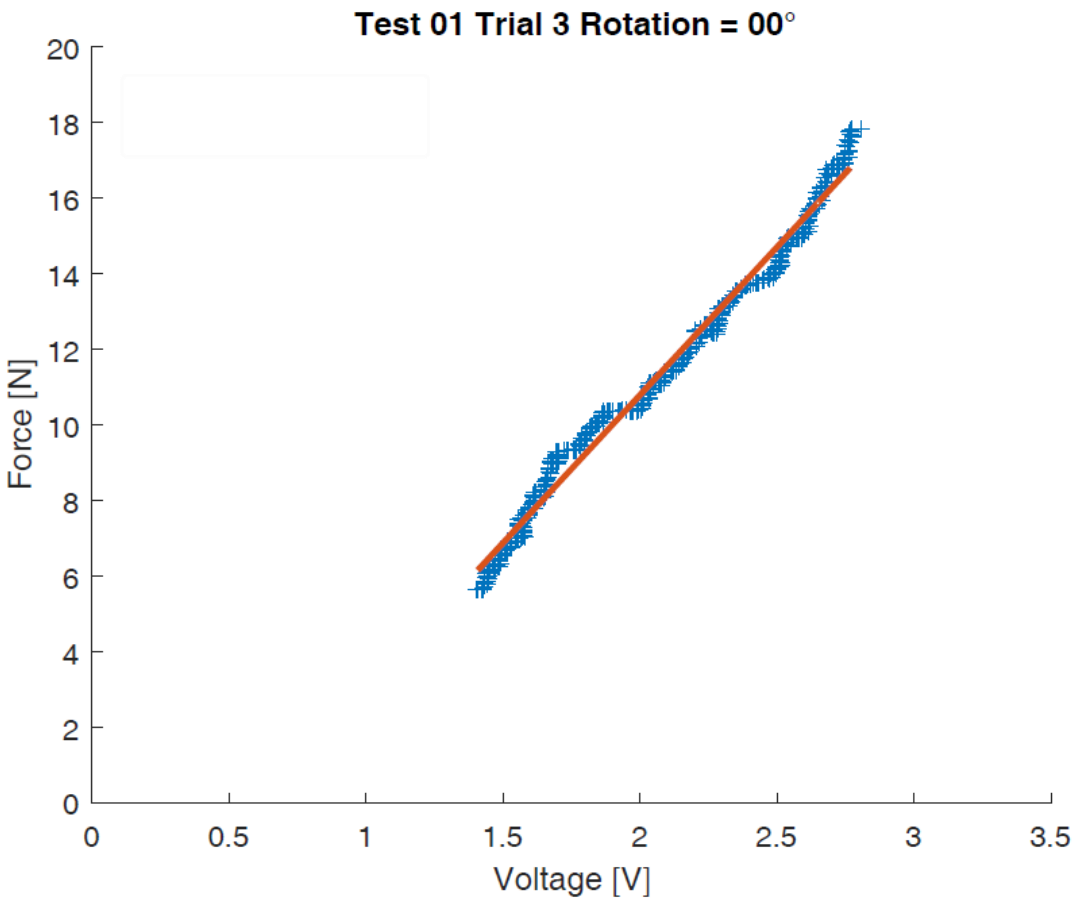


Deux matériaux:

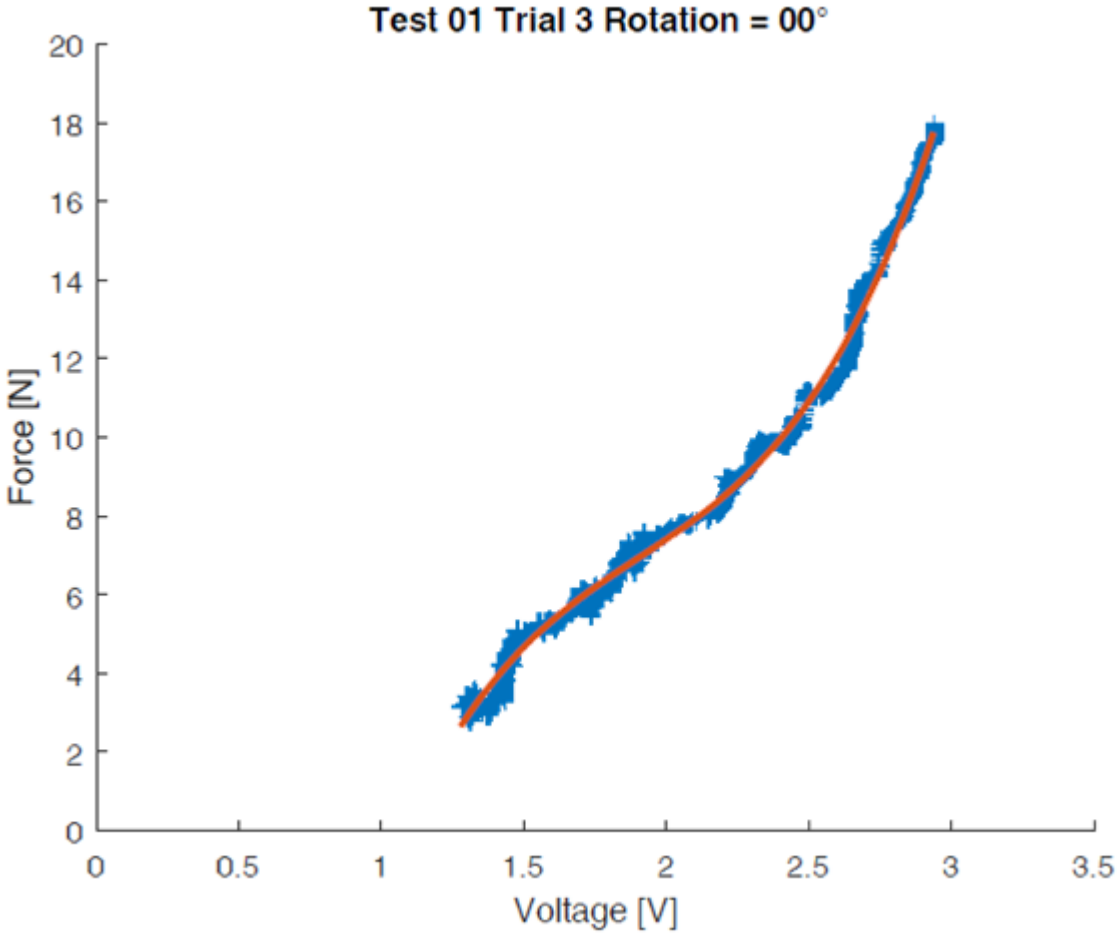
- RTV3535
- RTV127

Résultats expérimentaux: RTV3535





Résultats expérimentaux: RTV127



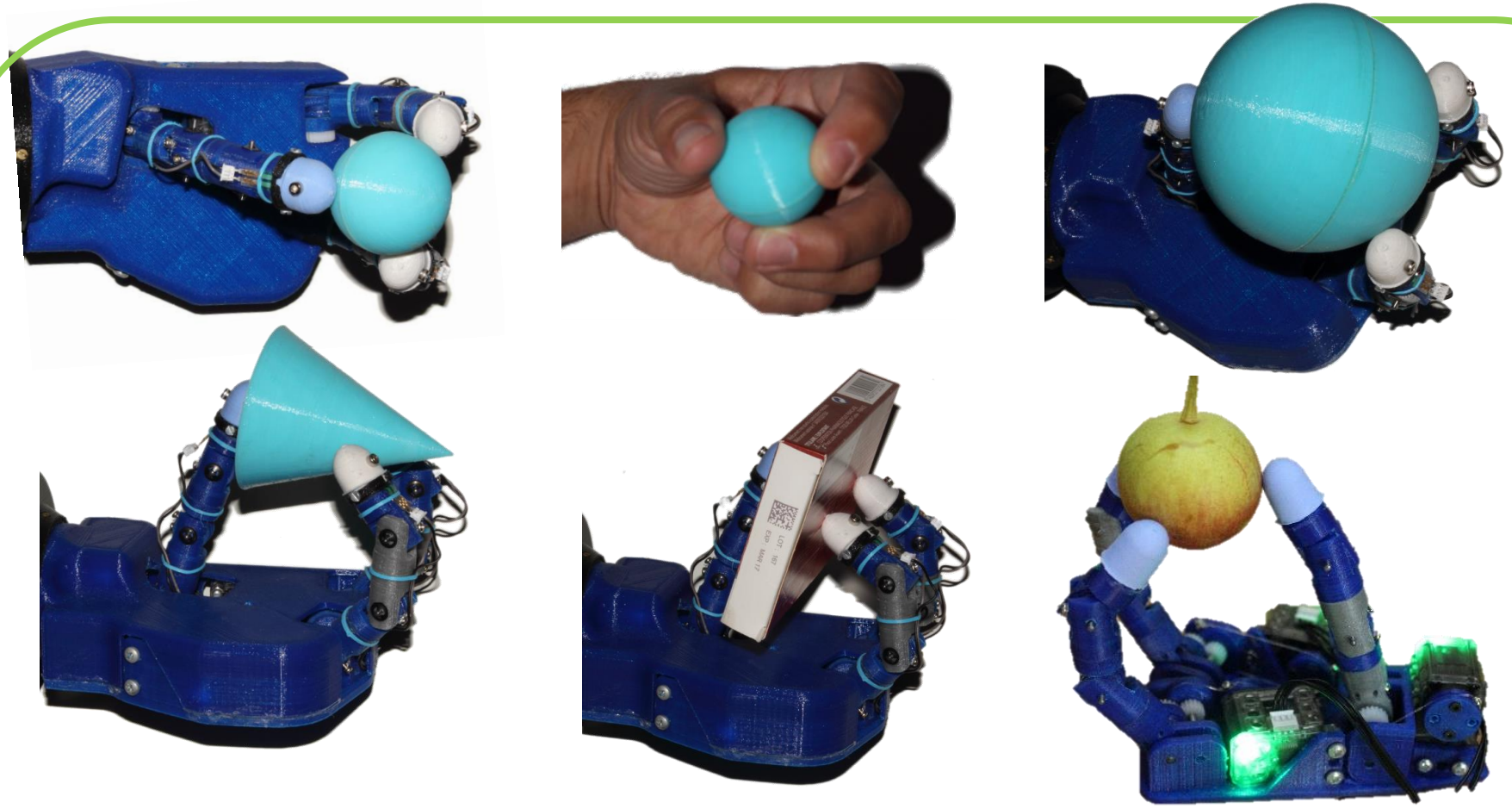
Expérimentation: gestes d’attrapage de précision (1)

Lateral pinch

Precision Disk

Prismatic 3 fingers

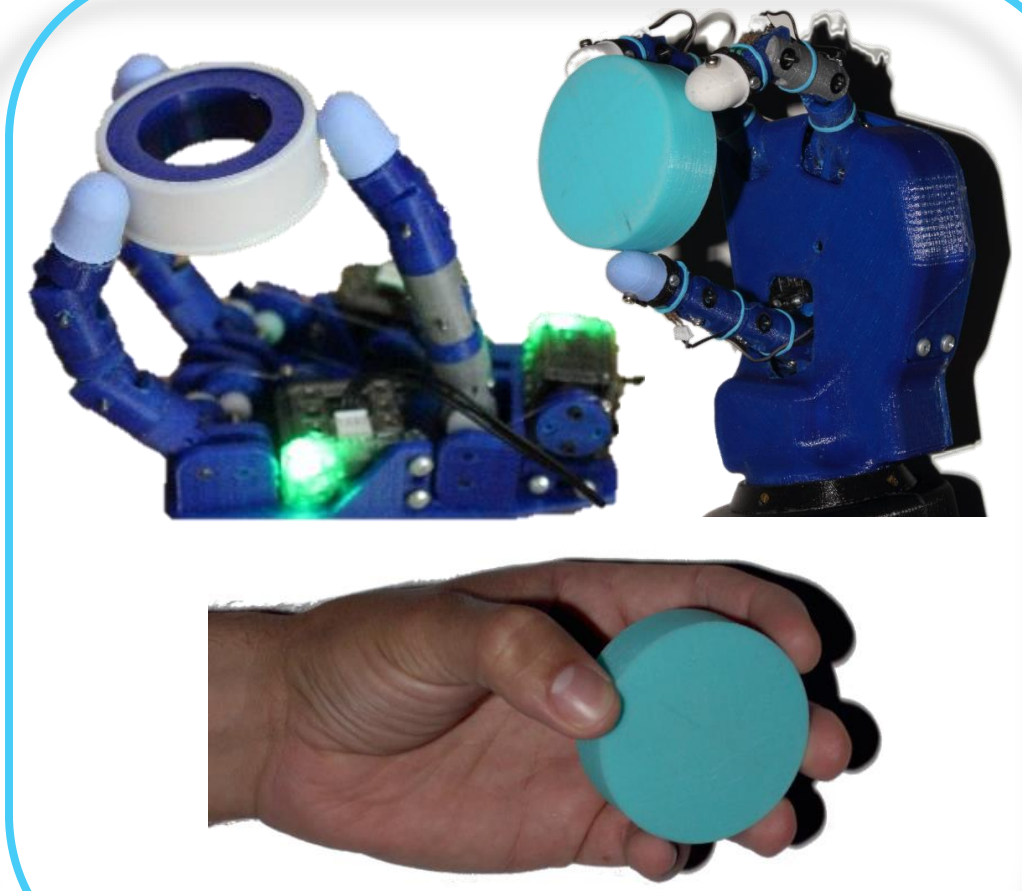
Expérimentation: gestes d’attrapage de précision (2)



Tripod

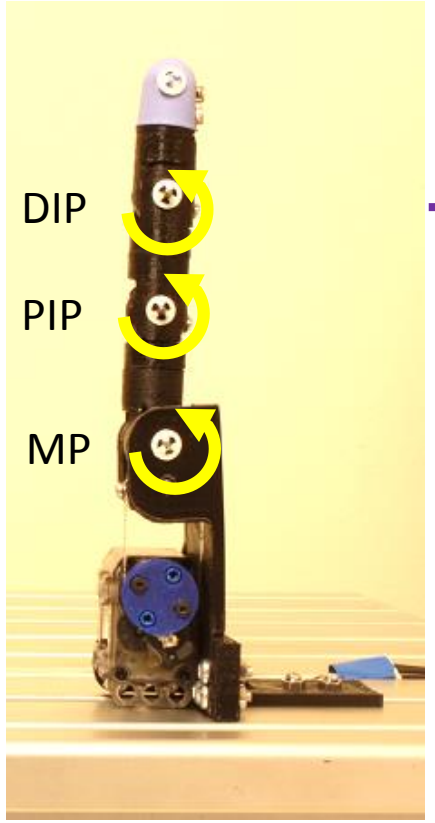
Expérimentation: gestes d’attrapage en force

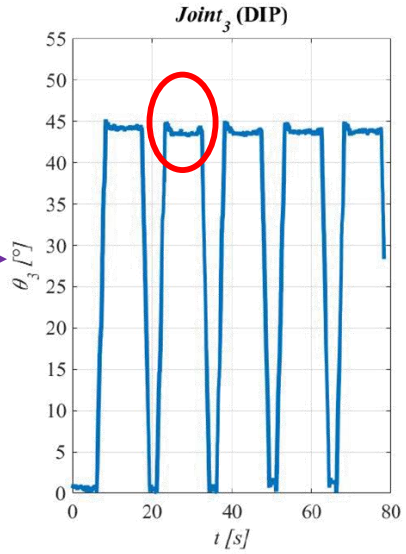
Medium Wrap

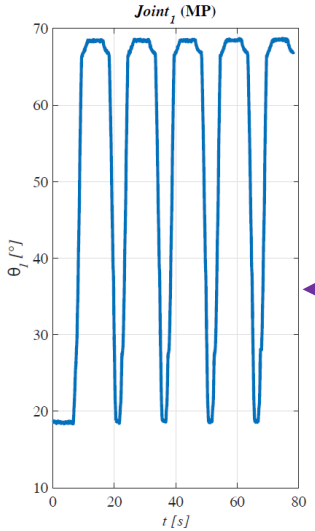


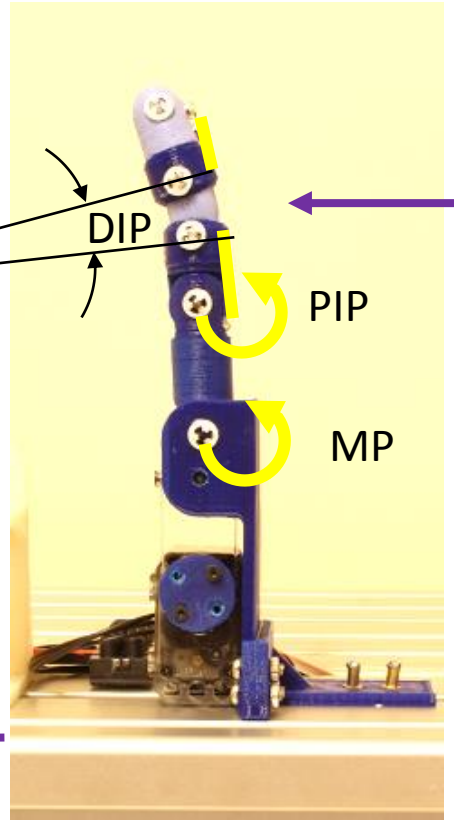
Power Disk

Innovation: développement d'un lien flexible





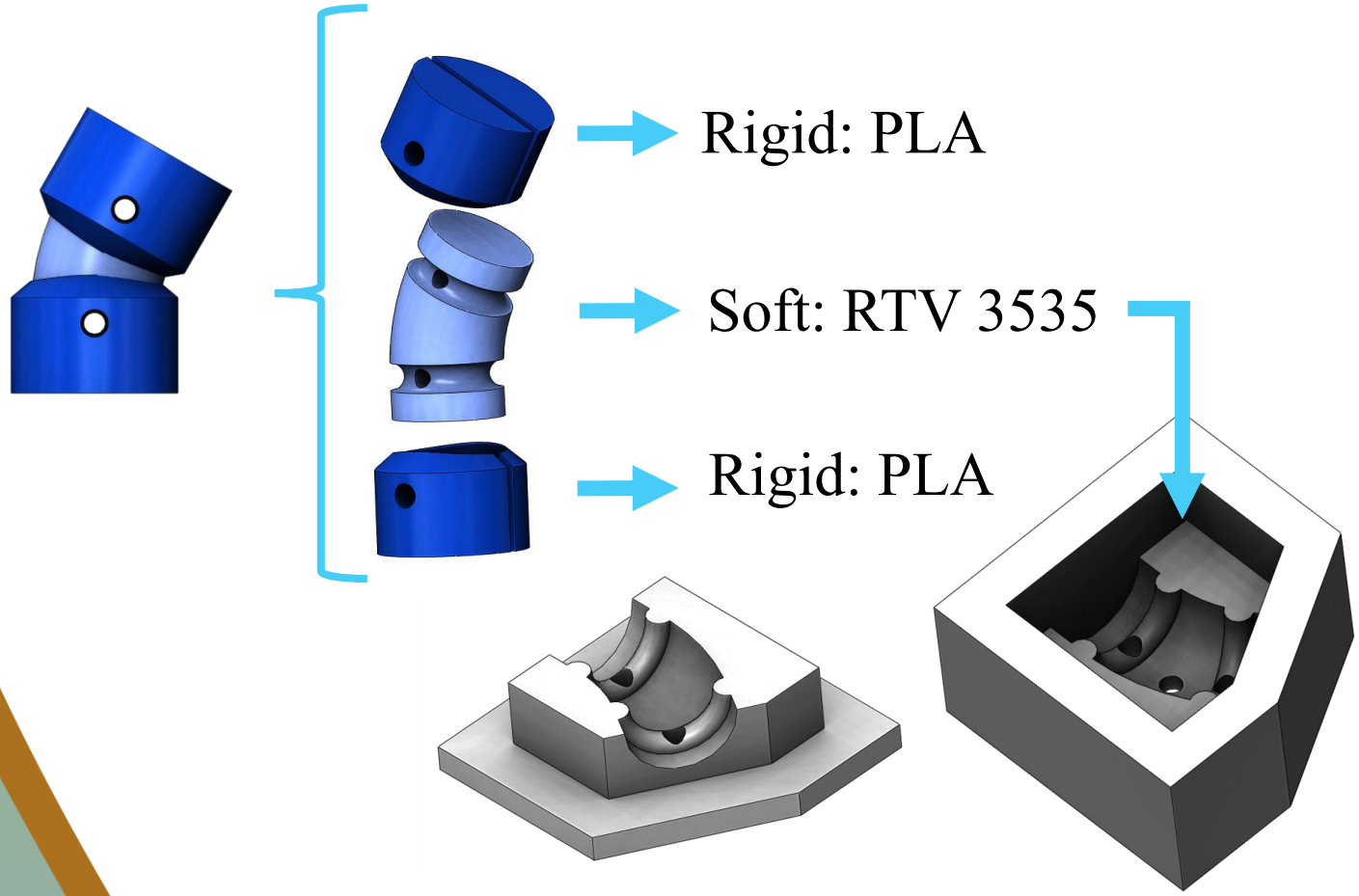


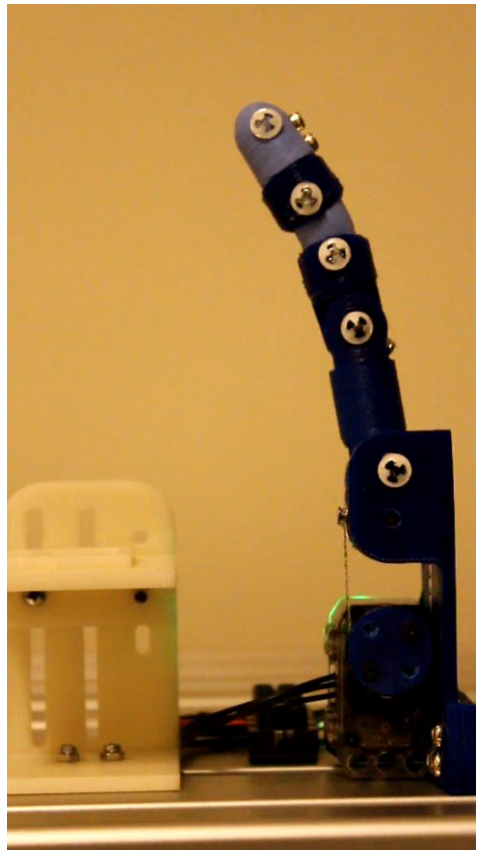


Lien flexible

Adaptable
Fonctionnel
Polyvalent

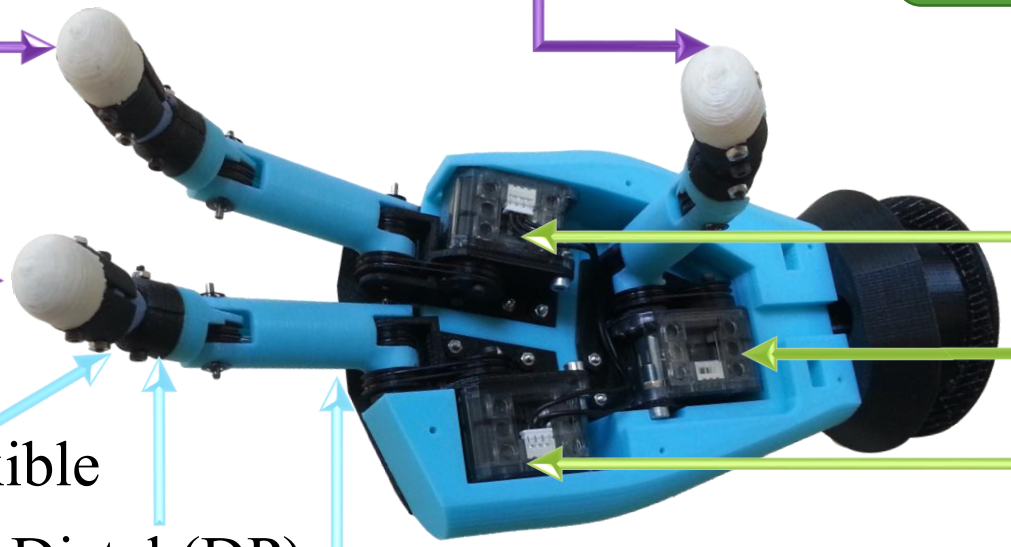
Innovation: conception lien flexible





(video)

ProMain-II



- Lien flexible

- Matériaux intelligents
  Pour le muscle
  et/ou le tendon

Méthodologie de conception du muscle artificiel

Attendus biomécaniques

Mécanisme du robot

Attendus de l'actionnement

Muscle artificiel

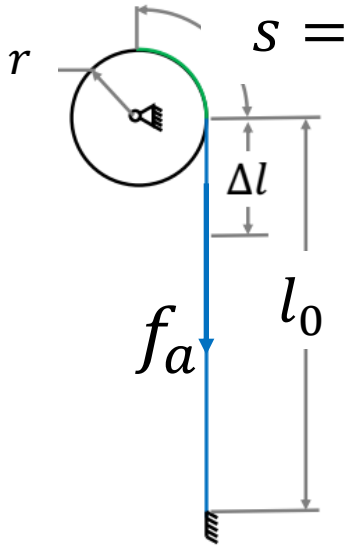
Matériaux activés électriquement

Ionic Polymer Metal Composite (IPMC)
Electrolyte gels (E. gels)
Conductive Polymers (CPs)
Piezoelectric Ceramics (PCs)

Rheological Fluids (R. Fluids)
Electronic ElectroActive Polymers (E. EAP)
Shape Memory Alloys (SMAs)

Principe d'actionnement des matériaux intelligents

Allongement (E)



$$s = r\theta_{j1}$$

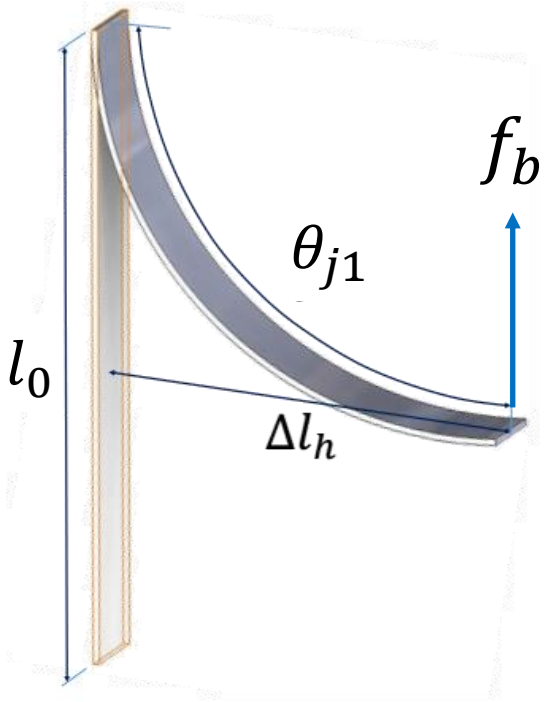
$$\varepsilon_a = \frac{\Delta l}{l_0}$$

$$r = 7mm$$

124.7Nmm $\leq C_{j1} \leq$ 175.8Nmm

$\varepsilon_a \geq 0.045$ 17.8N $\leq f_a \leq$ 25.1N

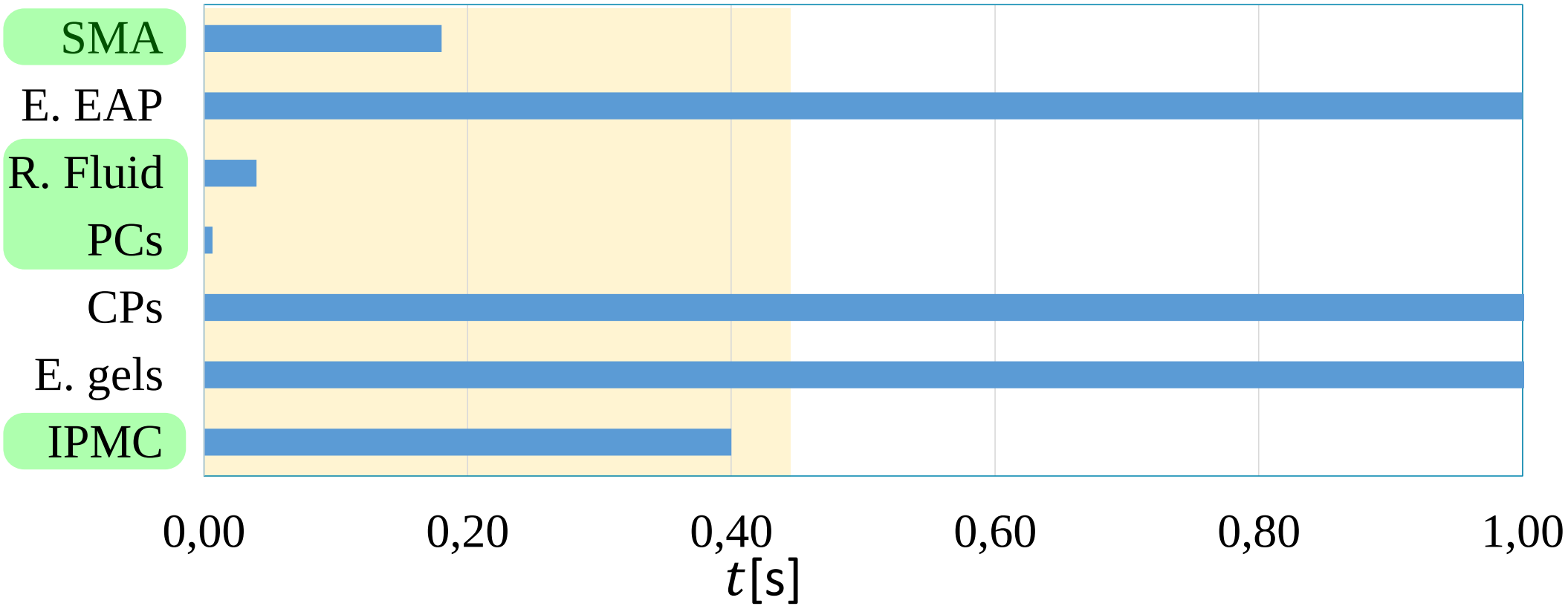
Flexion (B)



$$\varepsilon_b = \frac{\Delta l_h}{l_0}$$

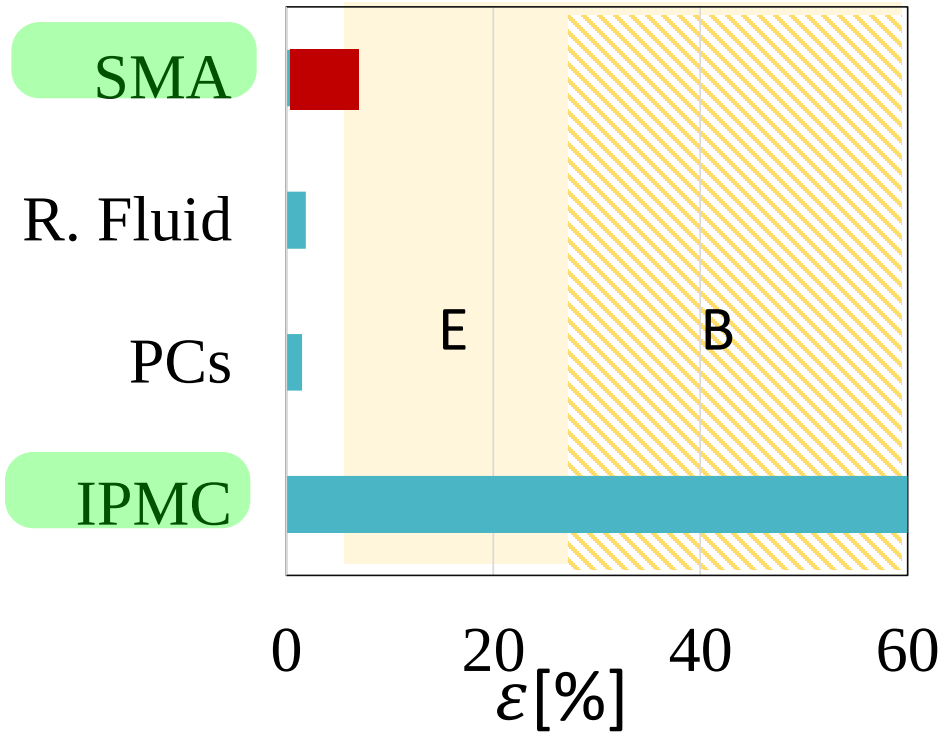
$\varepsilon_b \geq 0.5$ 4.8N $\leq f_b \leq$ 6.7N

Temps de réponse des matériaux intelligents



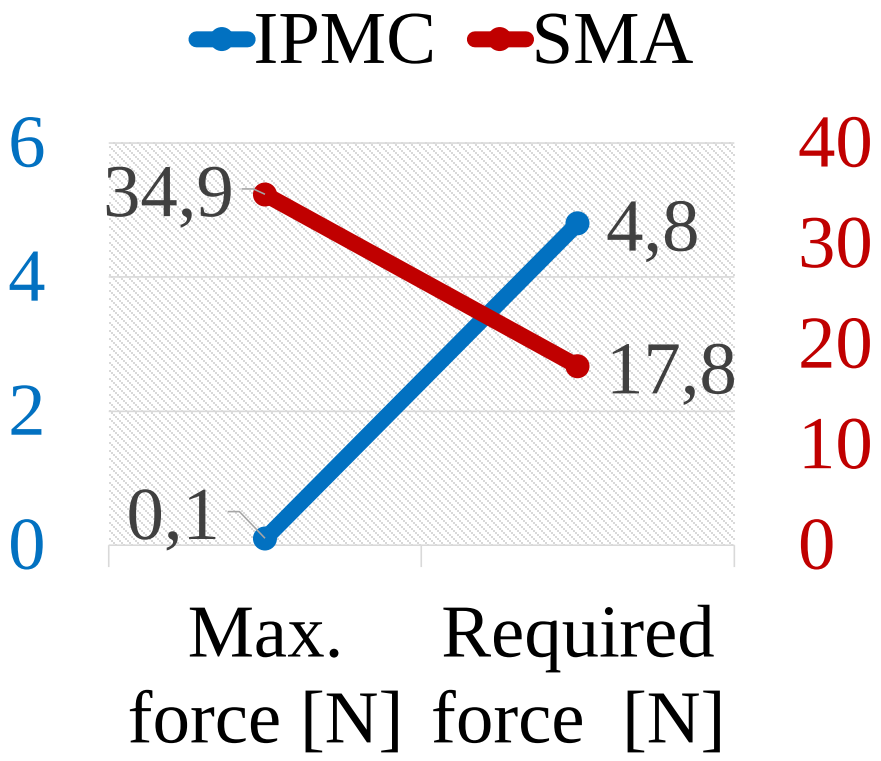
[0.18s, 0.45s]

Déformation active et force d'actionnement



$\varepsilon_e \geq 4.5\%$

$\varepsilon_b \geq 50\%$



$17.8\text{N} \leq f_e \leq 25.1\text{N}$

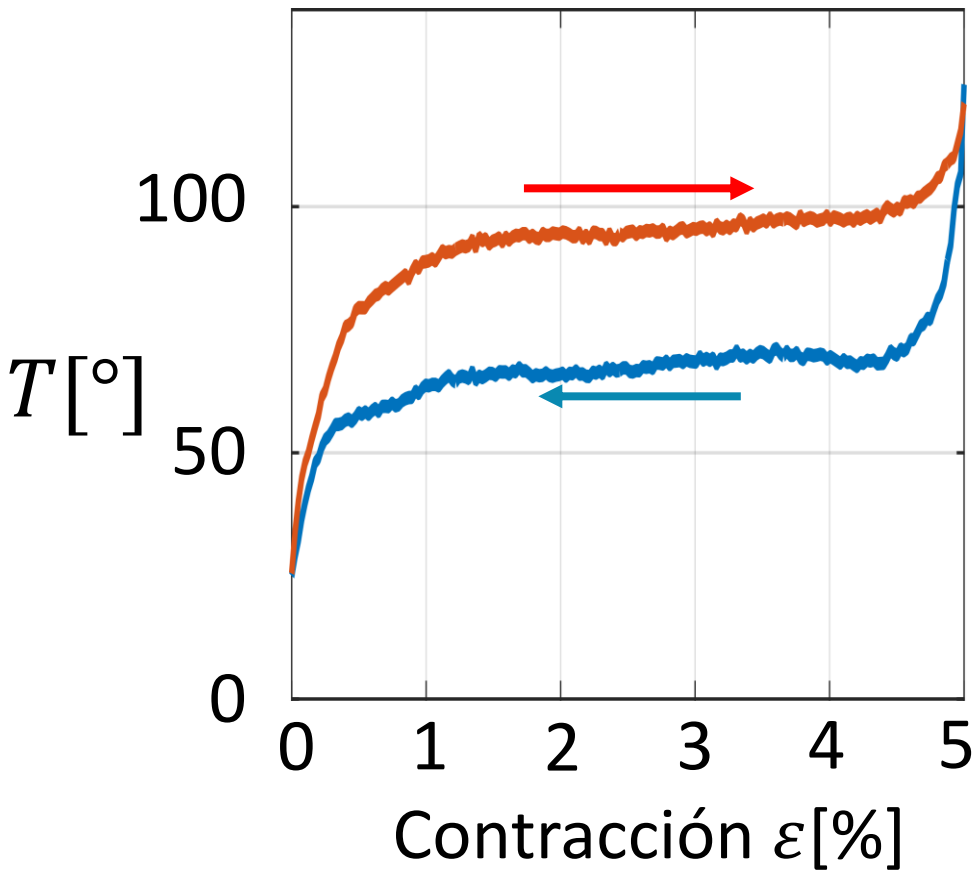
$4.8\text{N} \leq f_b \leq 6.7\text{N}$

Principe de fonctionnement du SMA

Application d'un courant électrique

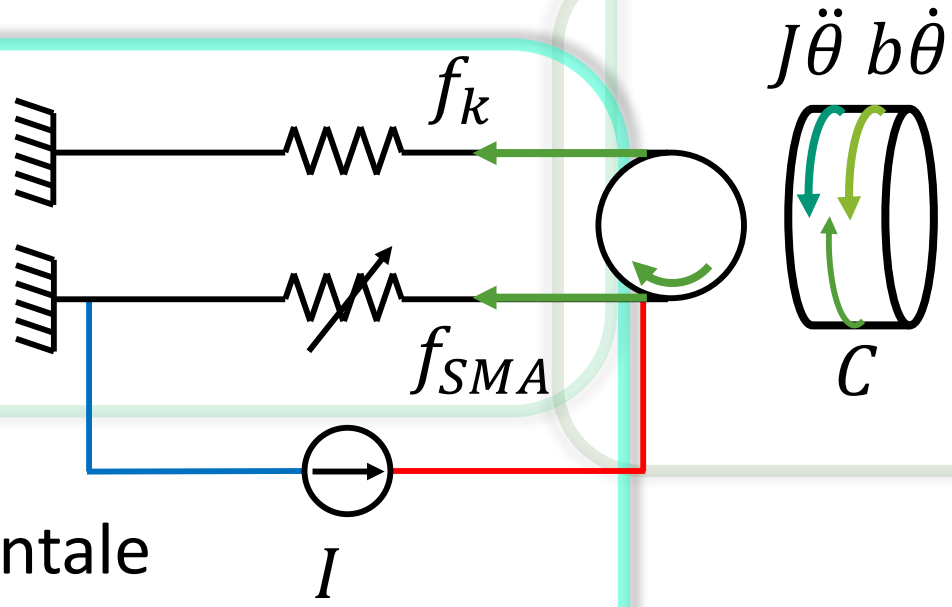
Augmentation de la température

Le matériau se contracte



Modélisation d'un actionneur en SMA

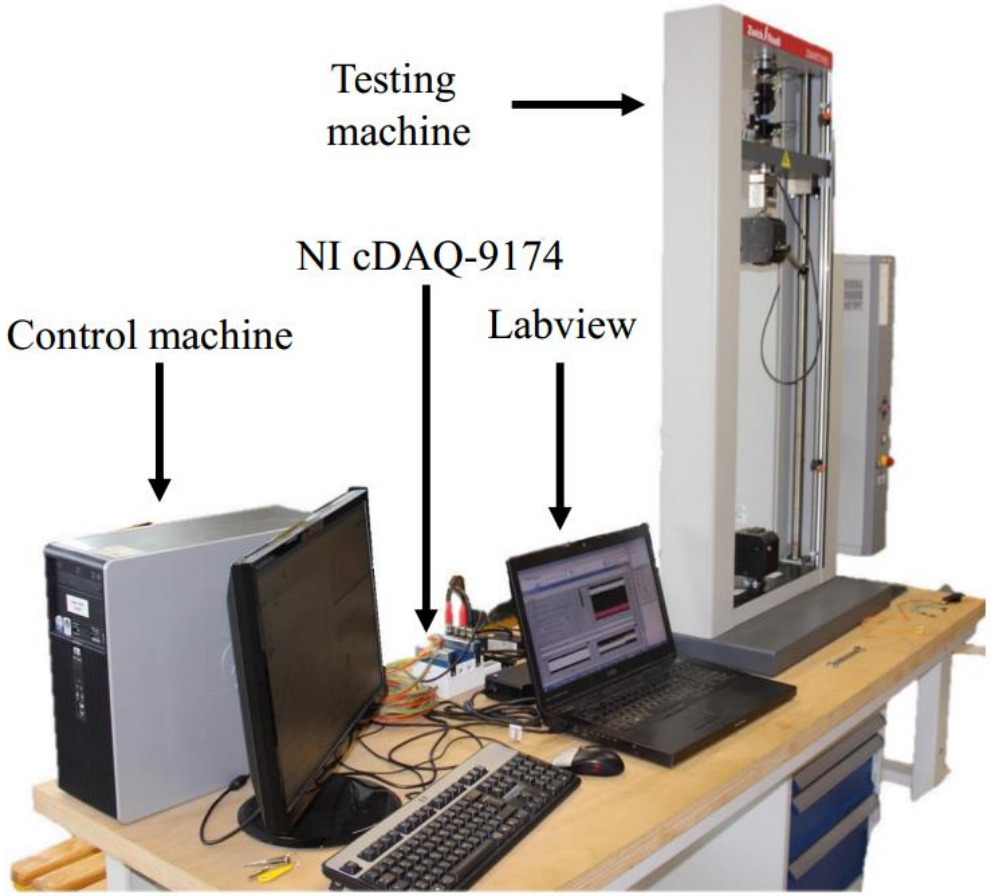
Loi constitutive du SMA

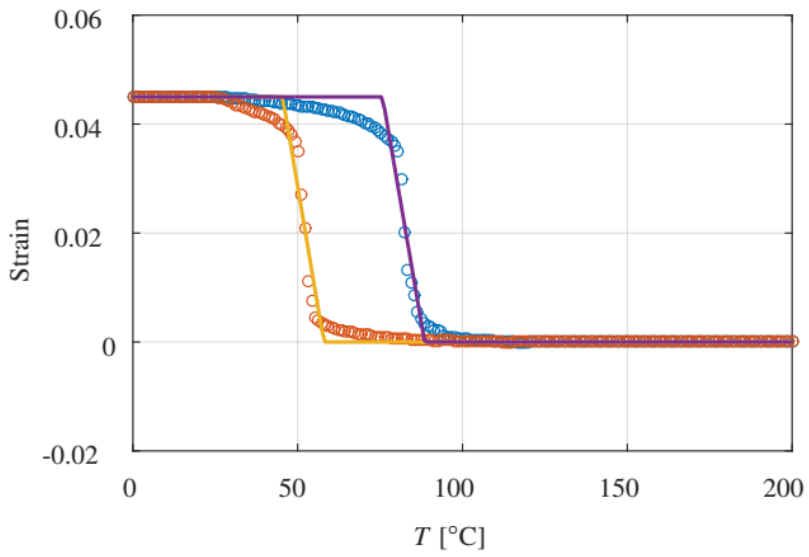


Equation fondamentale cinématique

Equation Fondamentale temperature

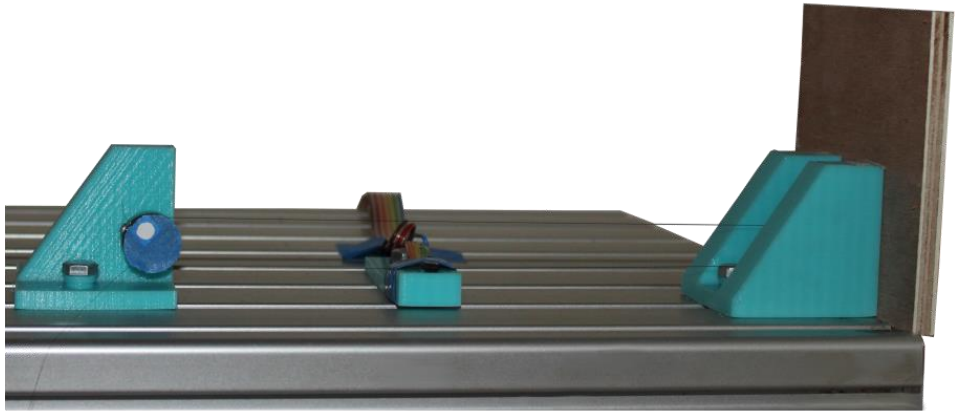
Expérimentation: identification des paramêtres

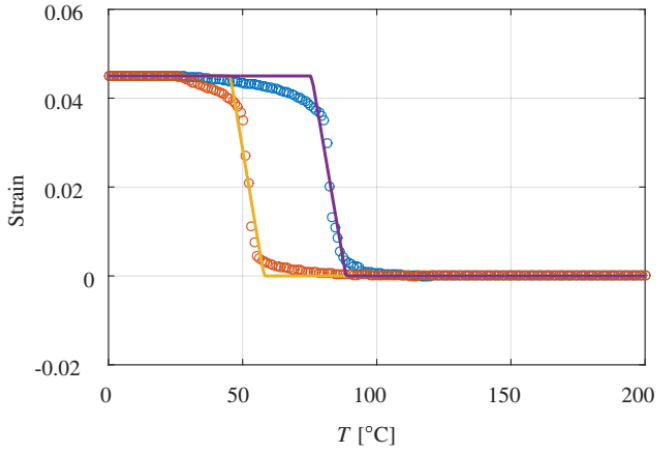


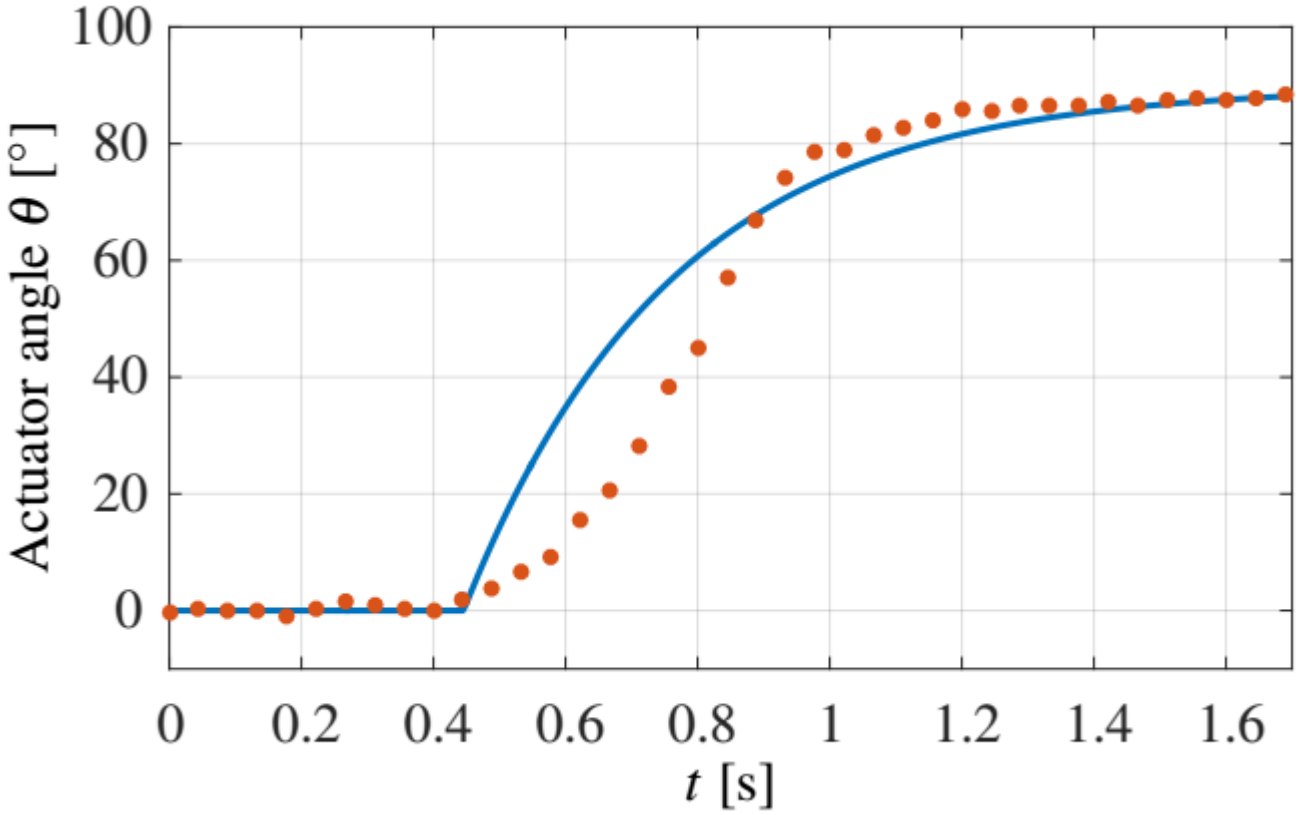


Fabricant	$\rho,\ \alpha^A,\ \alpha^M$
Mesurés	$E^A,\ E^M$
Identifiés	$\Delta s_0,\ M_s,\ M_f,\ A_s,\ A_f$

Simulation vs résultats expérimentaux

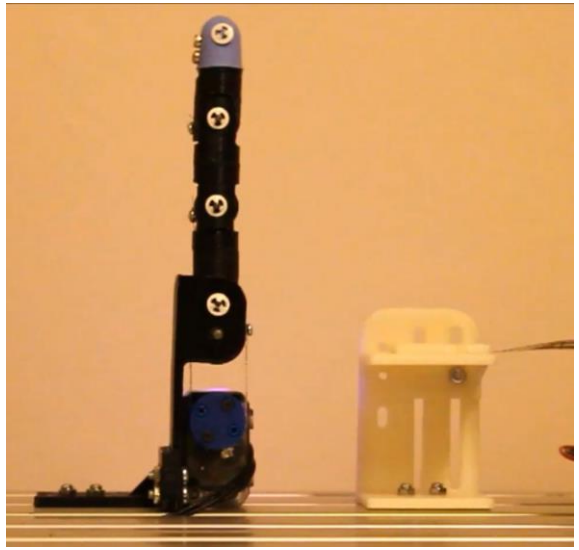


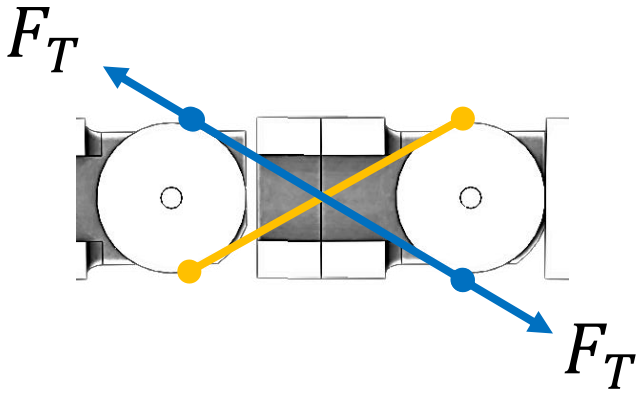




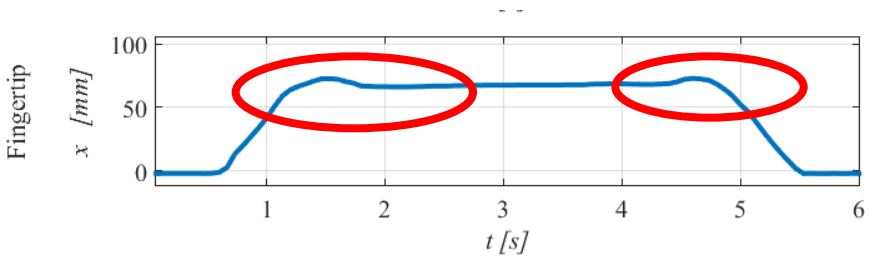
Contrôle de rigidité du tendon avec SMA (stabilité de l'attrapage)

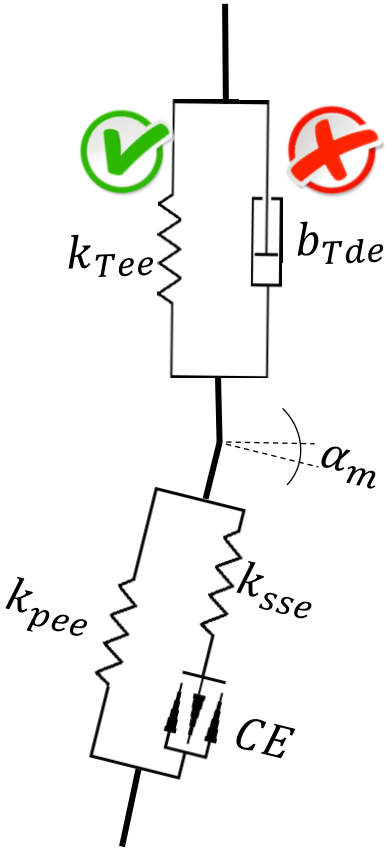
(video)





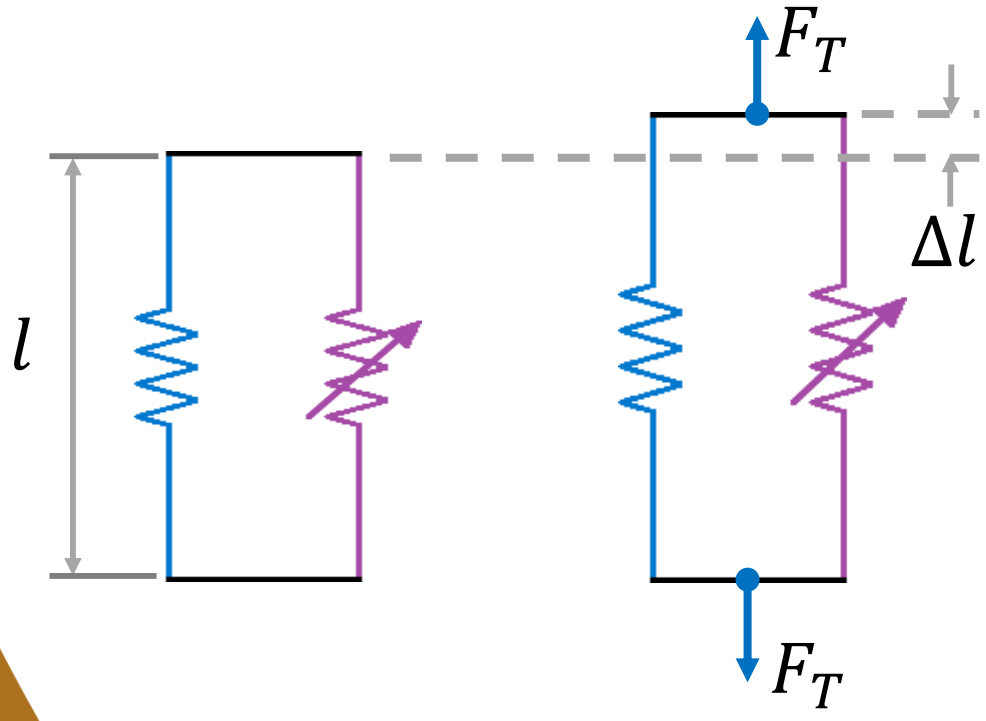
Glissement durant le contact

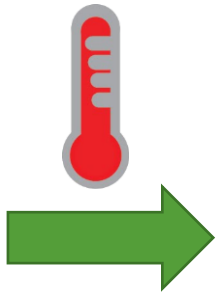




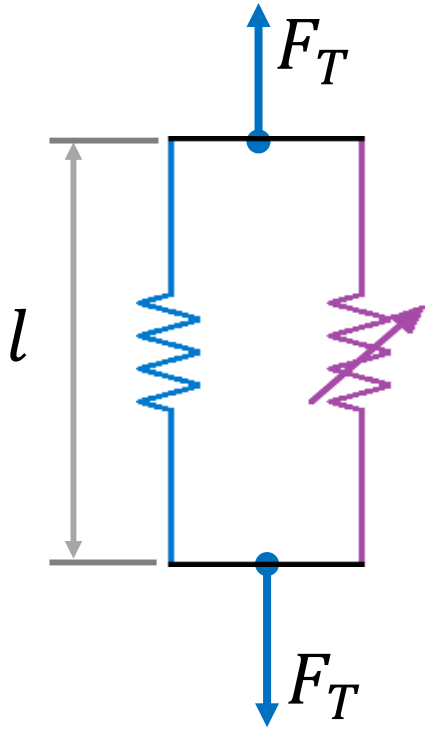
Principe de fonctionnement du tendon

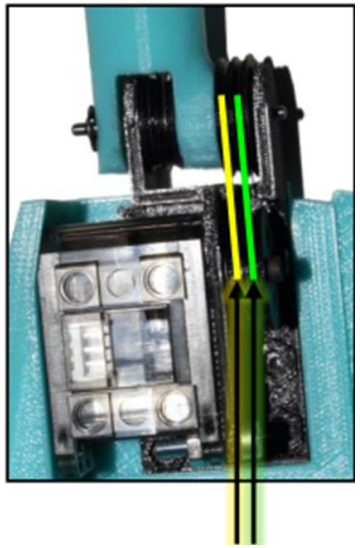
Déformation du tendon
Produit par le glissement





$$T = f(u, i, t)$$





- SMA
- Tendon élastique

Conclusions

Exigences de la main

- Flexion 90°
- F=[4.78N, 6.70N]
- [0.18s, 0.45s]

ProMain-I

- Mécanisme épicyclique
- capteur de force en bout de doigt
- Contrôle en force-position

ProMain-II

- Actionneur en SMA
- Lien flexible
- Mécanisme épicyclique avec tendon SMA

Exigences de l'actionnement

- [124.7Nmm,175.8Nmm]
- Conception du muscle

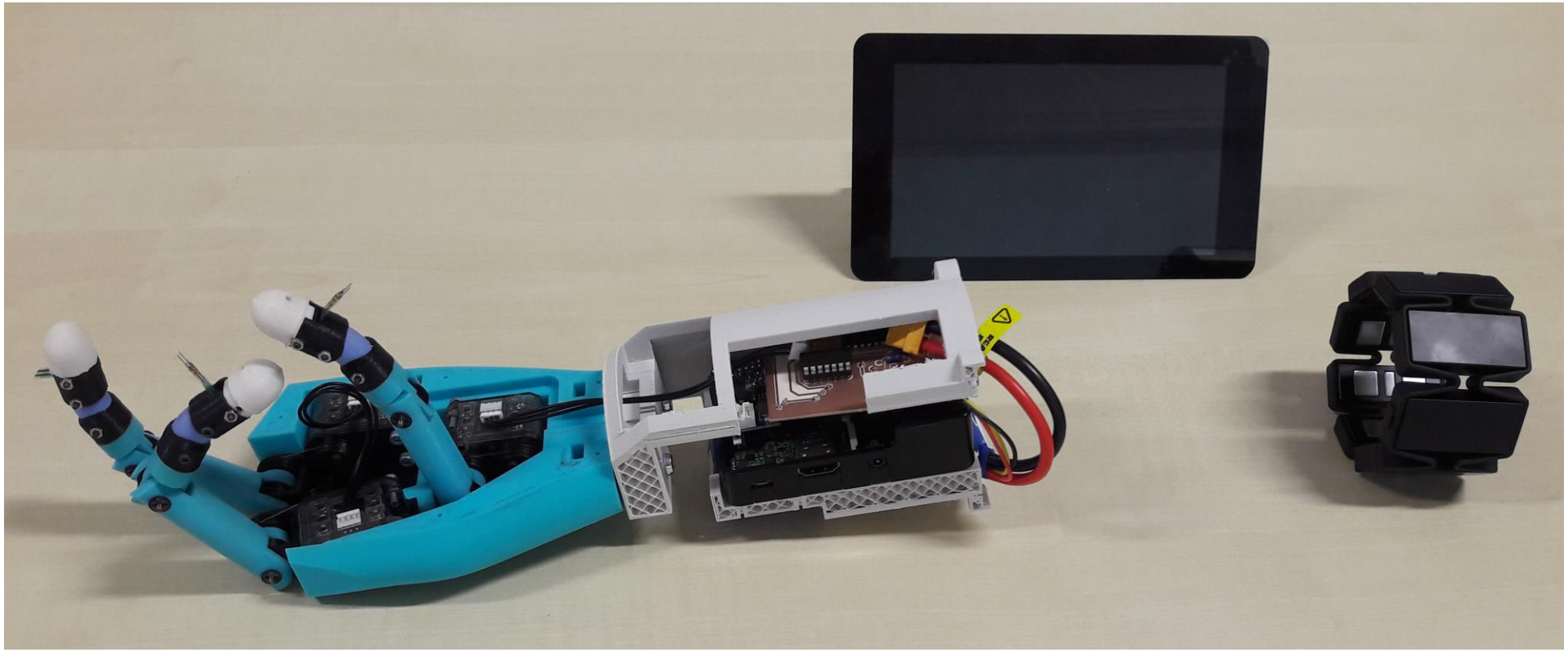
Soft kinematic link, FR 1656673, Jun 2016

Hand mechanism, FR 1656914, Jul 2016

Soft fingertip force sensor, FR 1655991, Jun 2016

Perspectives

Modèle cinématique	• Validation et tests en 3D • Expérimentation ProMain II en laboratoire Motion Capture
Mécanisme épicyclique avec SMA	• Evaluer les avantages d'un contrôle de rigidité
Matériaux intelligents	• Modélisation et tests avec IPMC pour améliorer le mécanisme d'actionnement • Développement d'un système d'actionnement hybride IPMC+SMA
ProMain II	• Tests sur le contrôle et l'attrapage d'objets • Tests avec patients amputés

Activités 2017-2018

- Démonstrateur
- Portage des programmes sur Rasberry Pi
- Interfaçage: myo – moteurs – capteurs bout de doigt