Adaptive Bio-kinematic Control for Secure Rehabilitation Robotic Devices

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France

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Outlines:

State of the art

- Rehabilitation exoskeleton and interest of research
- Existing control strategies and problems
- Co-contraction

Contributions

- Methods
- Neuro-motor index
- Canonical analysis

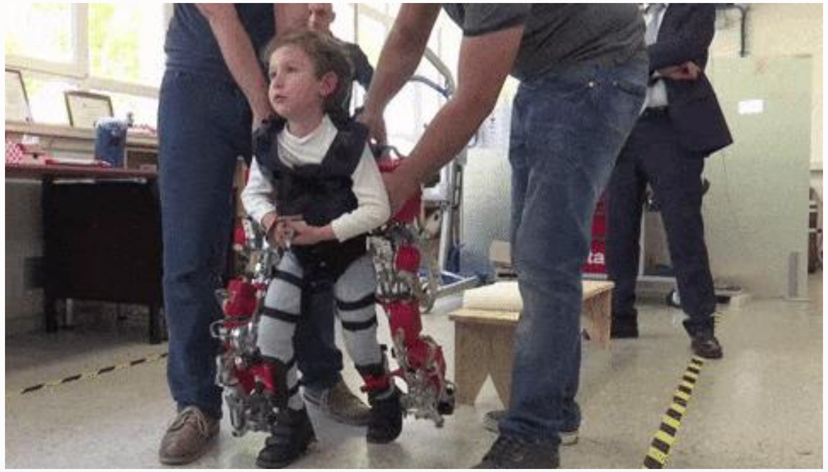
Results

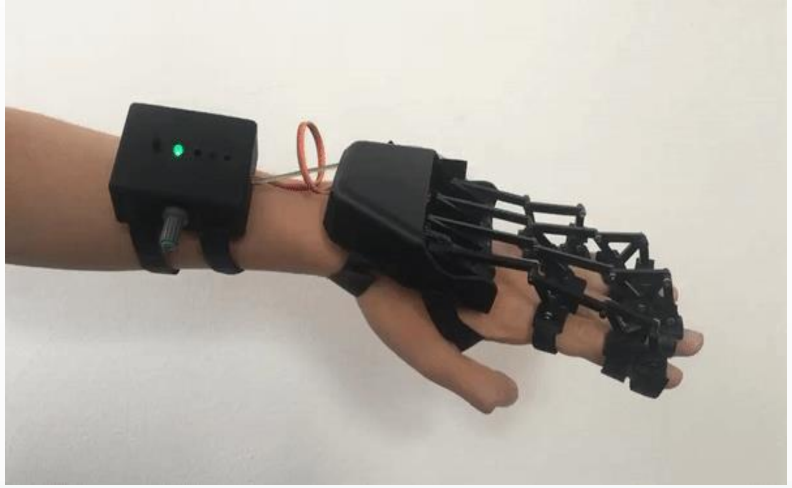
- Online study (High level control loop)

Conclusion

Rehabilitation Exoskeleton- Assisted Therapy

- Mechatronic device help with several types of movement disorders.
- Increase physical performance.
- Fitted to the shape and function of the human body.





Rehabilitation Exoskeleton- Lower Limb Therapy


Spastic gait


Scissor gait


Propulsive gait


Steppage gait


Waddling gait

Gait disorder types


Autonomous


Active orthoses


Overground


Treadmill


Foot-plates

Lower limb rehabilitation exoskeleton models

Control Strategies : Existing Controllers and Problems

Existing controllers

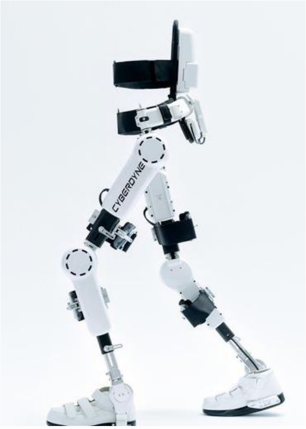
Ekso GT

1

Interaction force controllers using impedance or admittance

2

Musculoskeletal model based on EMG signals



HAL

Problems

- Predetermined trajectories.
- No dynamical adaptation.

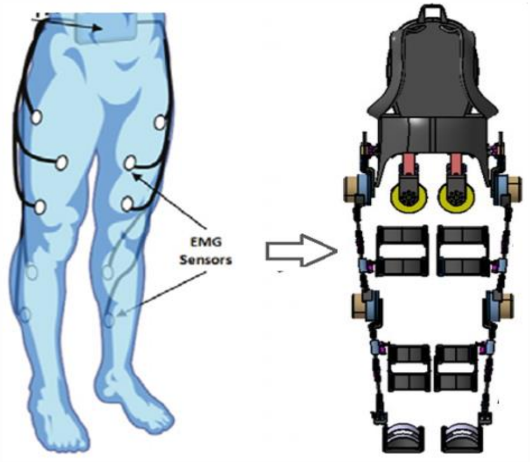
- EMG signals variability
- Walking speed induces non-linear variations
- Inapplicable when muscle disorder.

For both approaches:

- No assessment of patient possibilities
- Inadequate for specific patient's walk.

N. Tabti, M. Kardofaki, S. Alfayad, Y. Chitour, F. B. Ouezdou,and E. Dychus, "A brief review of the electronics, control system architecture, and human interface for commercial lower limb medical exoskeletons stabilized by aid of crutches," Iin 2019 IEEE

Control Strategies : Needs and Goal



Inter-active Controller

SOL exoskeleton - IISV

Needs

- Assistance as needed.
- Patient expertise.
- Intention Detection.

Goal

- Modularity.
- Stability.
- Security.

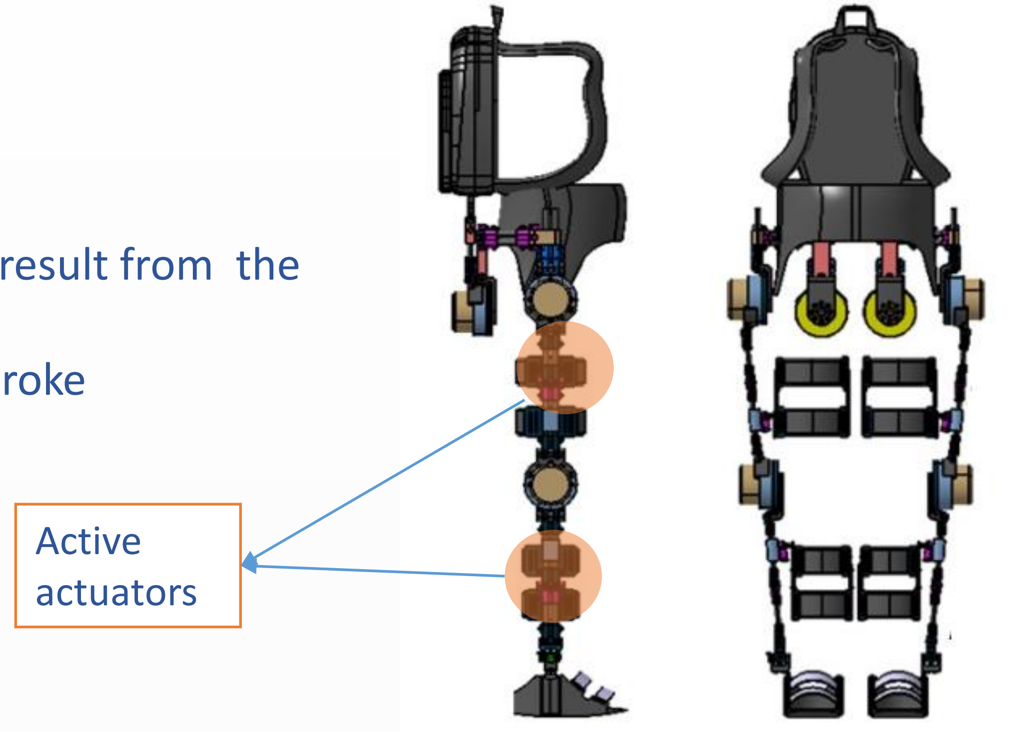
Sol Scalable Exoskeleton Designed by Samer ALFAYD Team’s

- Active actuators: in the hip and knee

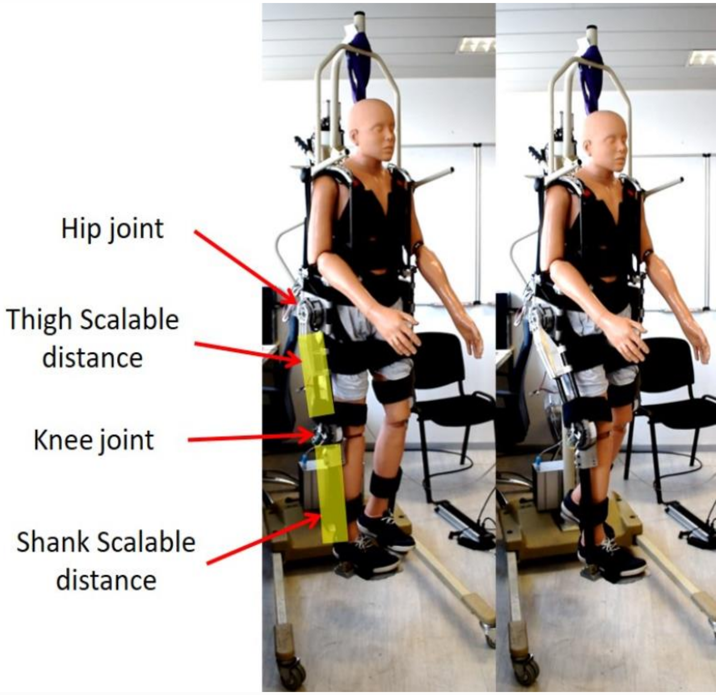
- Scalable with age

- Control strategy tested now :

Compatible with walking problems that result from the central nervous system (CNS)
spinal cord injury, Cerebral palsy, and Stroke

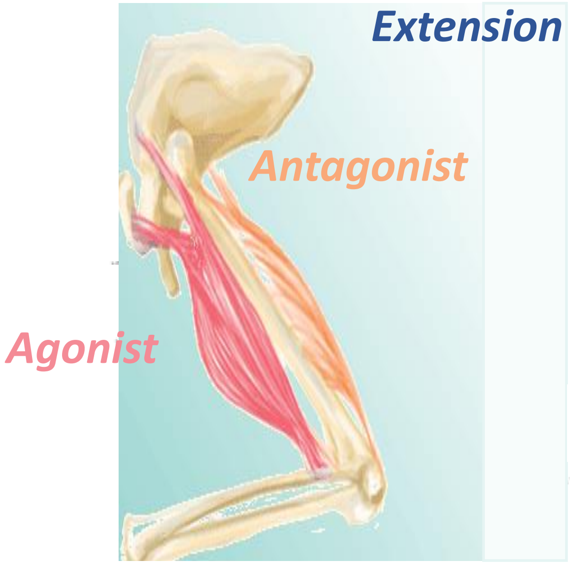


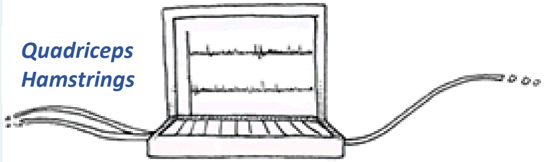
SOL Scalable exoskeleton



M. Kardofaki, N. Tabti, S. Alfayad, , F. B. Ouezdou, Y. Chitour,and E. Dychus, “Mechanical development of a scalable structure foradolescent exoskeletons,” in2019 IEEE, ICRA

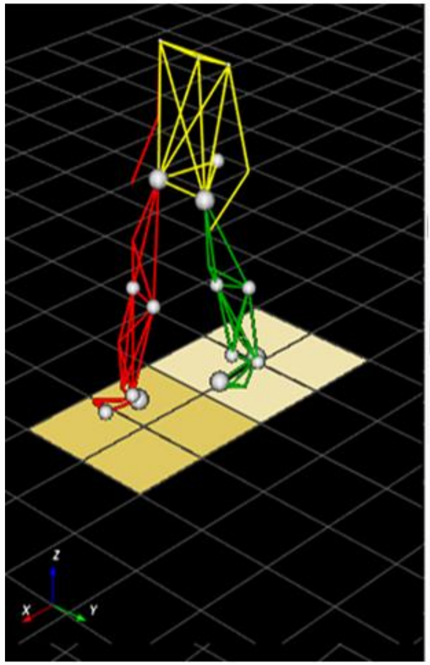
Co-contraction : Co –Contraction Index, Why ?



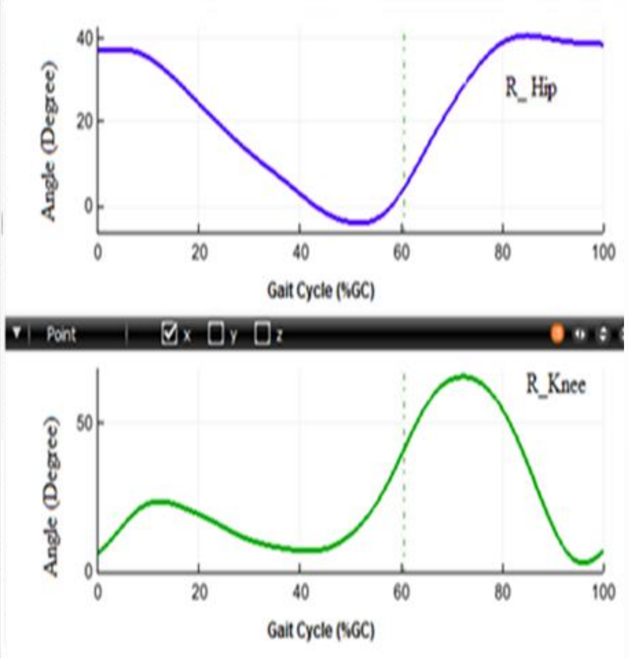


- Related to joint stability *(Basmajian 1977)*
- Indicates the achievement of a motor skill *(Best 2017)*
- Important factor which contributes to the inefficiency of pathological movement *(Winter 1985)*
- Based on EMG , These signals contain information about the intention of the patient *(Lenzi 2012)*

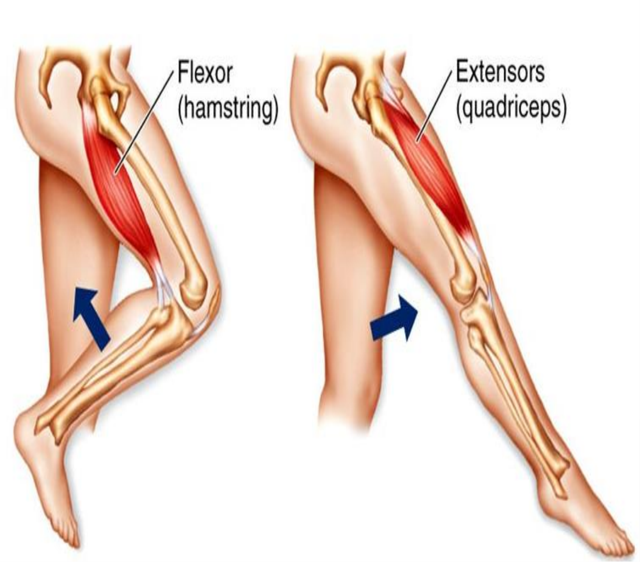
Methods: Bio- kinematic Data



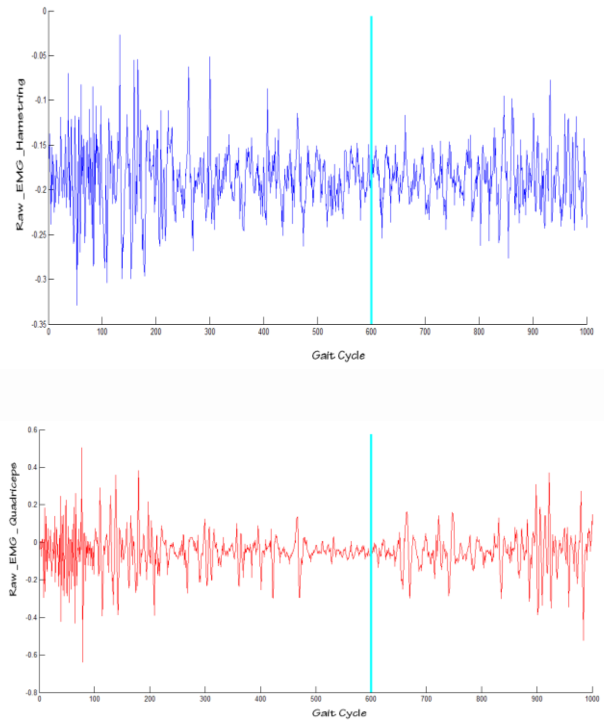
placement of electrodes for kinematic data using MOKKA.



Representation of kinematic data using MOKKA.



Bi-articular muscle group for hip and knee movement.



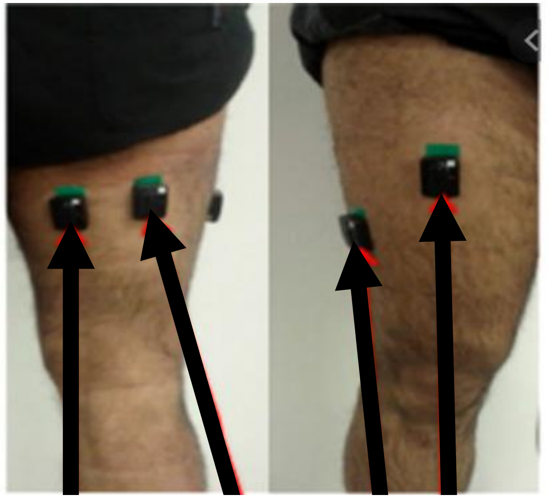
Raw EMG for Hamstrings and Quadriceps using MATLAB.

Methods: Bio- kinematic Processing

EMG Processing

20 Subjects healthy, CP, Stroke

- 11 GC to 1000 points
- Frequency % patient cadence
- Normalisation % MVC and GC



Semi Membranous **Biceps Femoris** **vastus Lateral** **Rectus Femoris**

Shiavi et.al .1998
Hesse et al. 2000

Raw EMG

Elimination of average

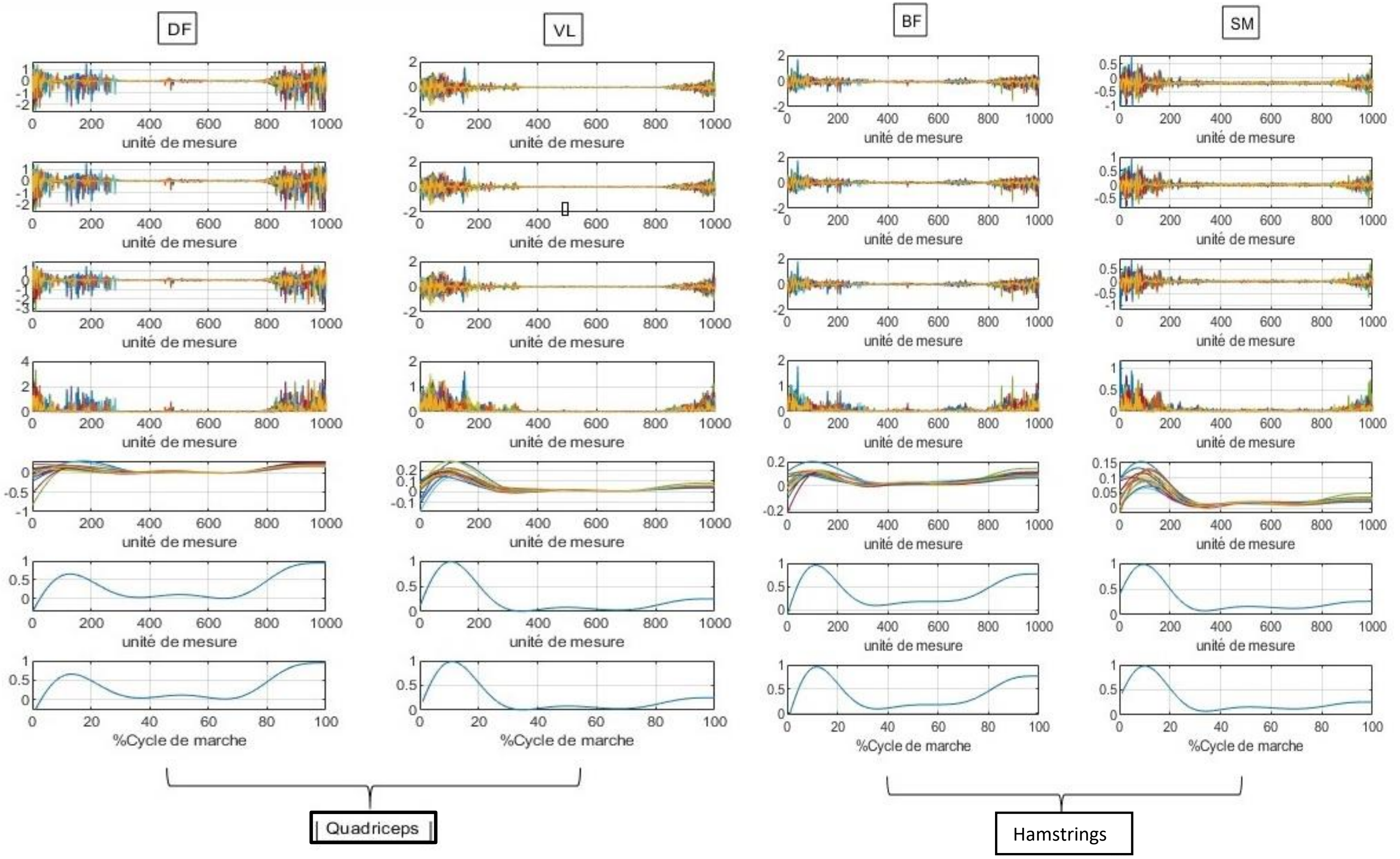
Elimination Of noise

Rectification

Envelop_EMG

Normalisation %MVC

Normalisation %GC

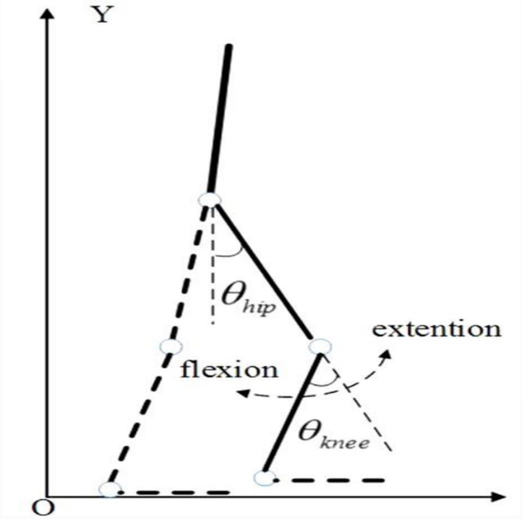


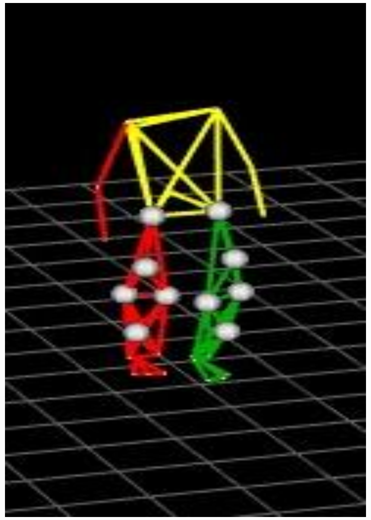
Methods: Bio- kinematic Processing

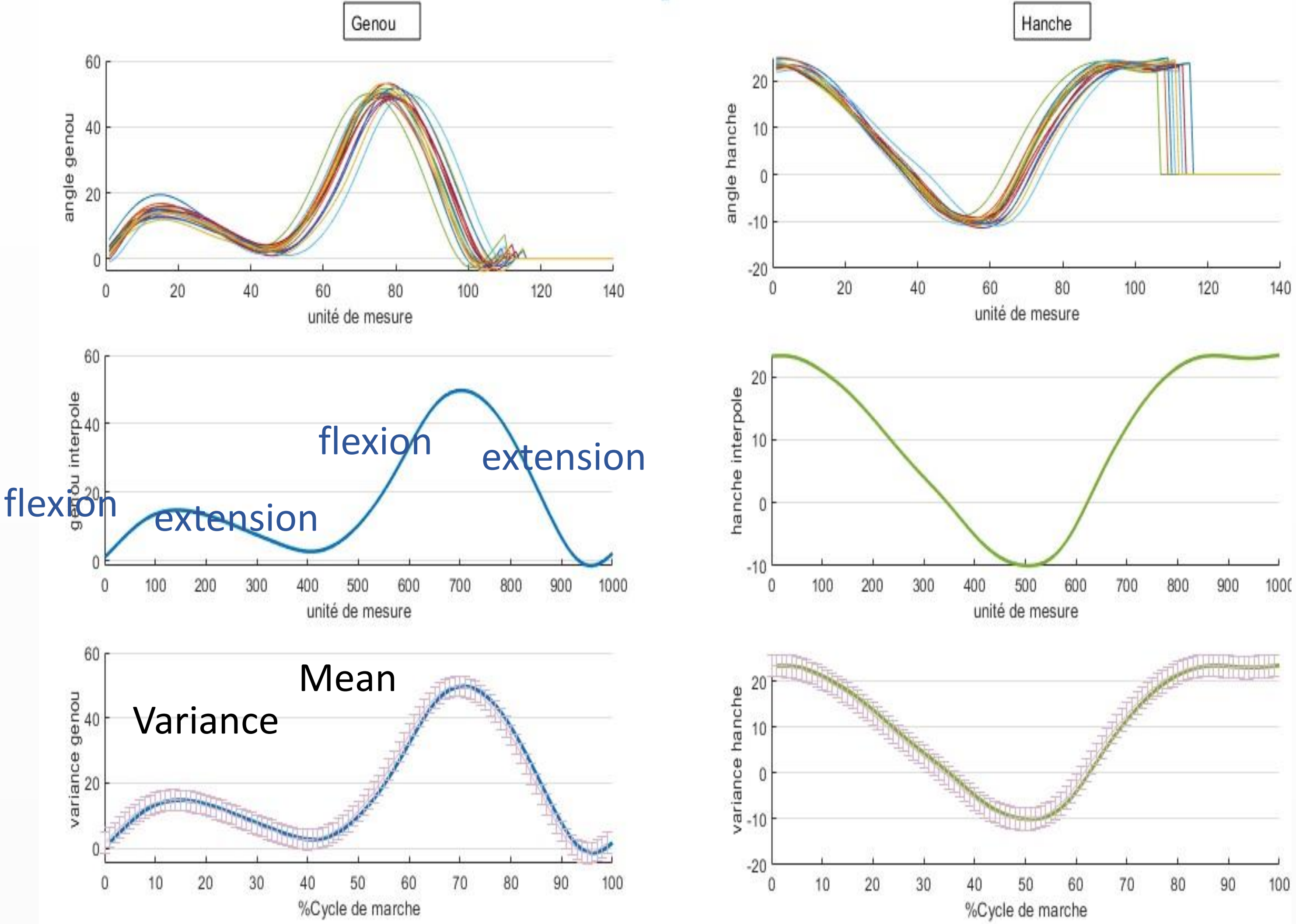
Angular Kinematic :

20 Subjects healthy, CP, Stroke

- 11 gait cycles (GC)
- Interpolation at 1000 points
- Mean and variance
- Indication of disorder (flexion/extension)

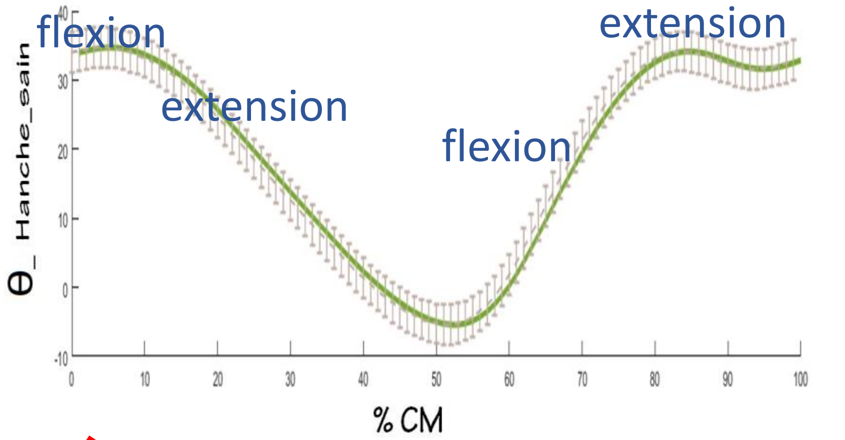


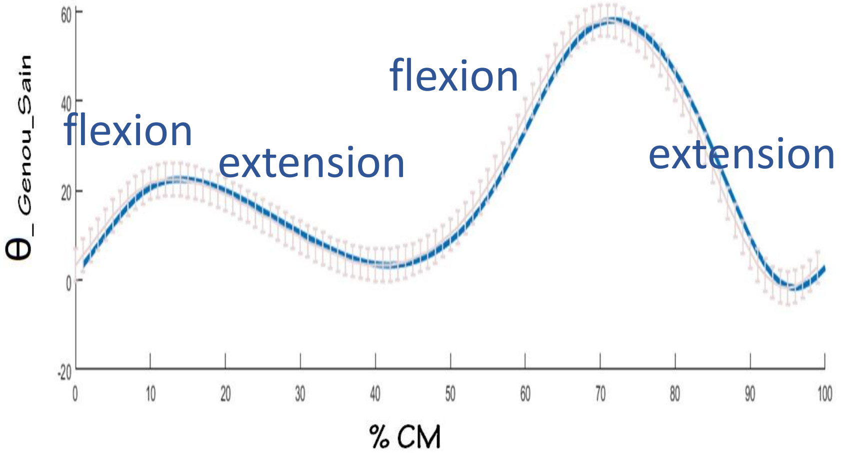




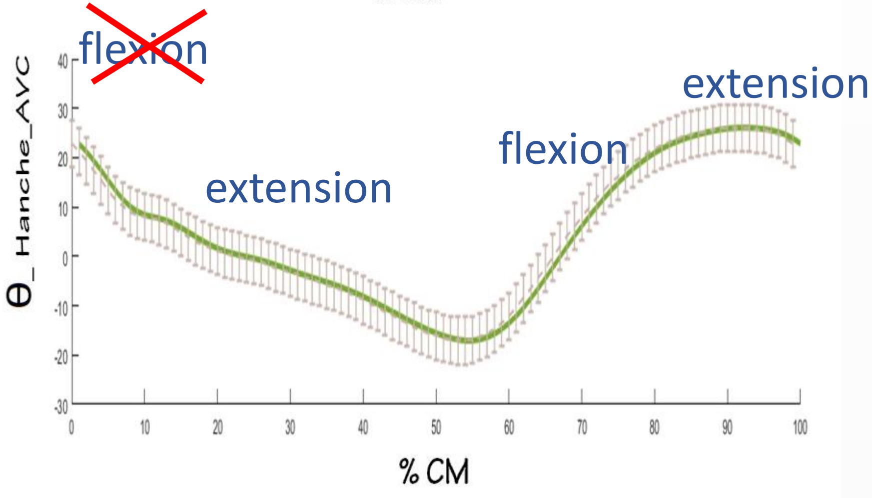
Methods: Bio- kinematic Processing

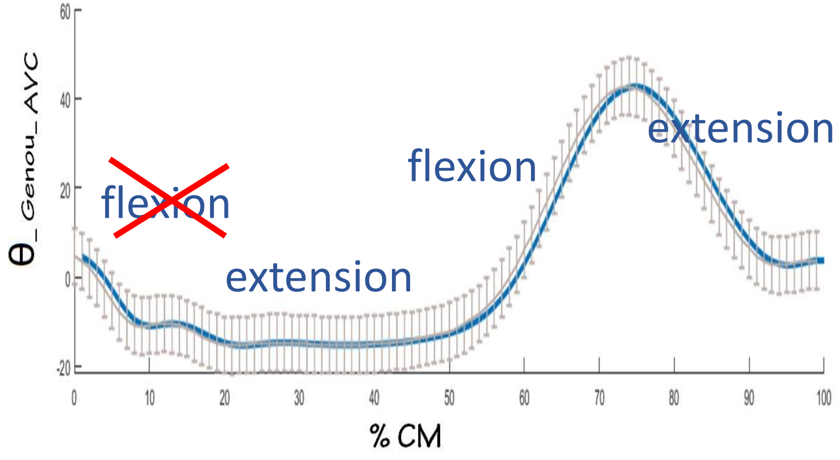
Joint Angles
Healthy subject





Joint Angles
CP subject





Neuro – Motor : Proposed Index

$$f(t) = \mathrm{ENV}\,(emg_{ATNAGO}(t) \cap emg_{AGO}(t))$$

Detection of peaks f(t) : $argmin_t \, | f'(t) |$

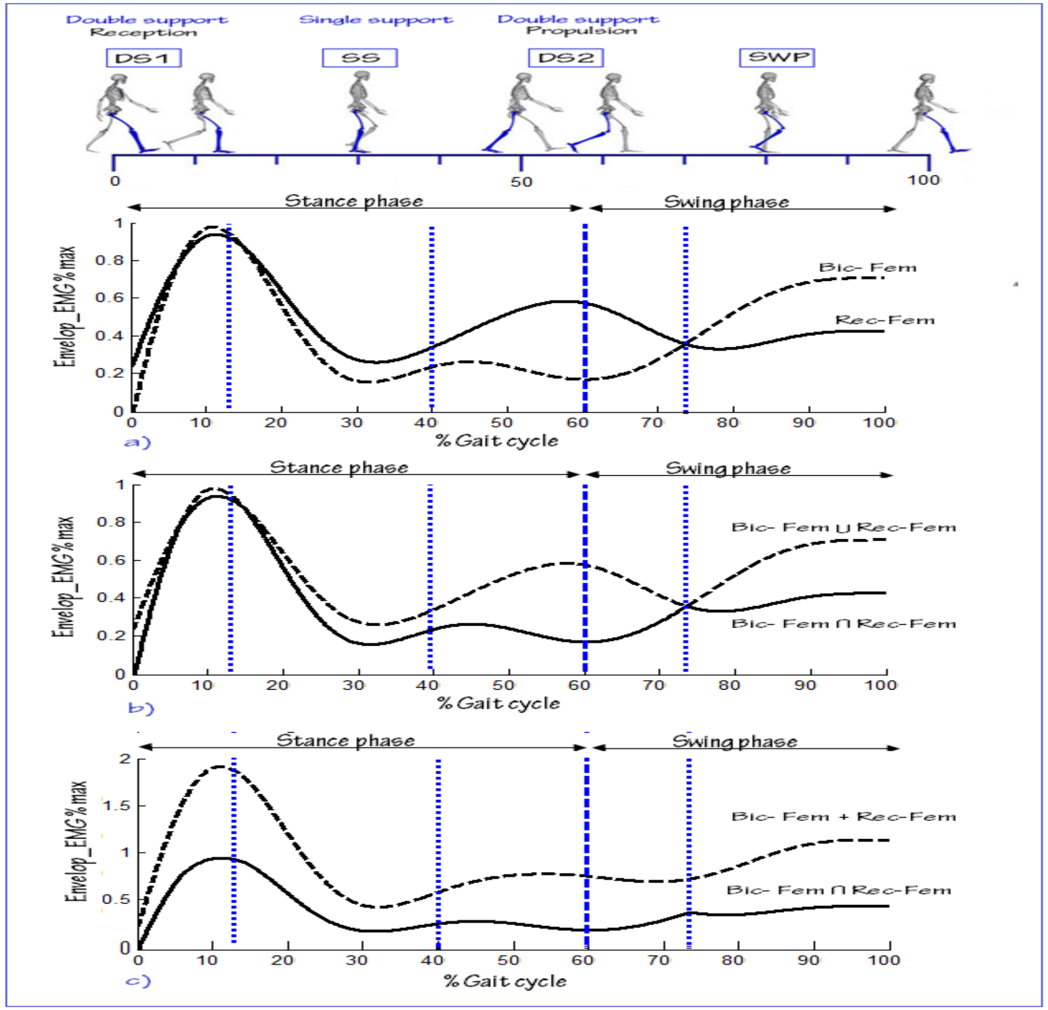
- $R_x(t) = h_1(t) \, . \, f_0 + h_2(t) \, . \, p_0 + h_3(t) \, . \, f_1 + h_4(t) \, . p_1$
- *when* h_1, h_2, h_3 *et* $h_4 \in He;$ p_0 *et* p_1 tangent à f_0 et f_1

$$INM = A(t)\left[\frac{1}{B(t)} + \frac{Rx(t)}{C(t)}\right]$$

$$A(t) = \int_{t1}^{t2} (ENV_{emg-ago}(t) \cap ENV_{emg-anta}(t) dt)$$

$$B(t) = \int_{t1}^{t2} (ENV_{emg-ago}(t) \cup ENV_{emg-anta}(t) dt).$$

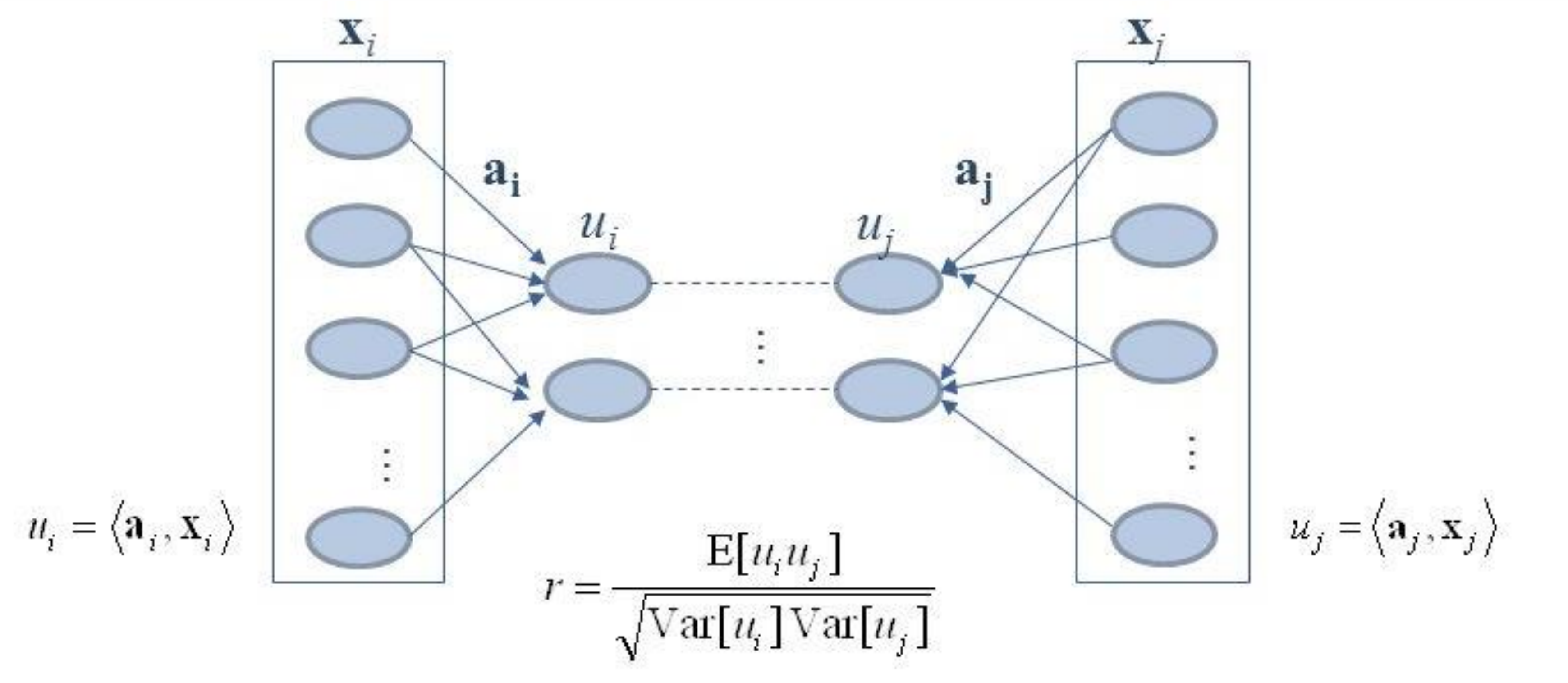
$$C(t) = \int_{t1}^{t2} (ENV_{emg-ago}(t) + ENV_{emg-anta}(t) dt).$$



J. Charafeddine, S. Chevallier, S. Alfayad, M. Khalil, and D. Pradon, “Biokinematic control strategy for rehabilitation exoskeleton based on user intention,” *International Journal of Modeling and Optimization* 2019

J. Charafeddine, S. Chevallier, M. Khalil, D. Pradon, and S. Alfayad, Neuromotor strategy of gait rehabilitation for lower-limb spasticity,” *2019 IEEE, EMBC*

Canonical Correlation Analysis : what is it?

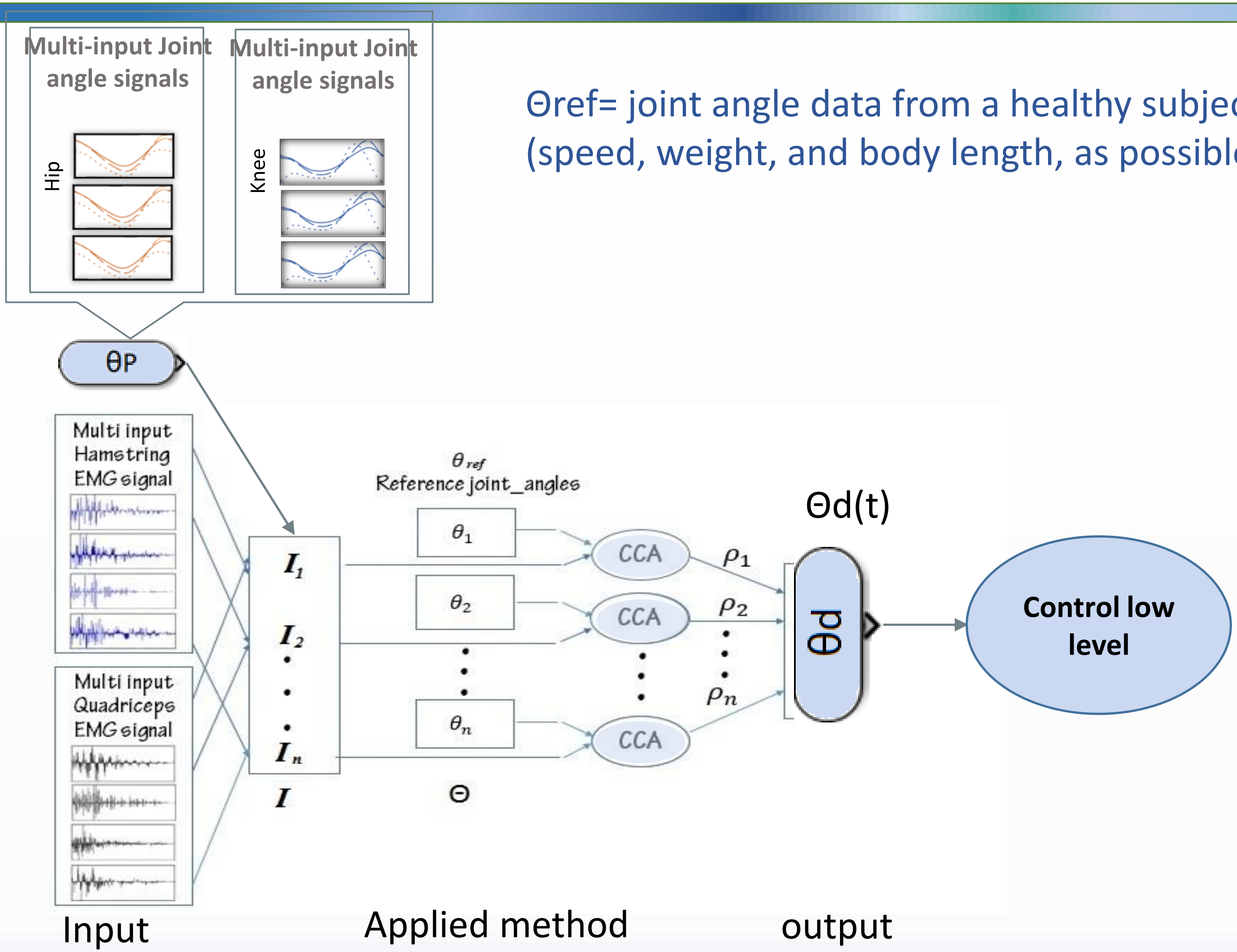


$$u_i = \langle \mathbf{a}_i, \mathbf{x}_i \rangle$$

$$u_j = \langle \mathbf{a}_j, \mathbf{x}_j \rangle$$

$$r = \frac{\mathrm{E}[u_i u_j]}{\sqrt{\mathrm{Var}[u_i]\mathrm{Var}[u_j]}}$$

Online Study : Precision of Command Angle



Θref= joint angle data from a healthy subject (compatible with the patient (speed, weight, and body length, as possible)

$$\max_{(W_I, W_\Theta)} \rho(I,\Theta) = \frac{E\,(I^T\,\Theta)}{\sqrt{E(I^T\,I)E(\Theta^T\,\Theta)}}$$

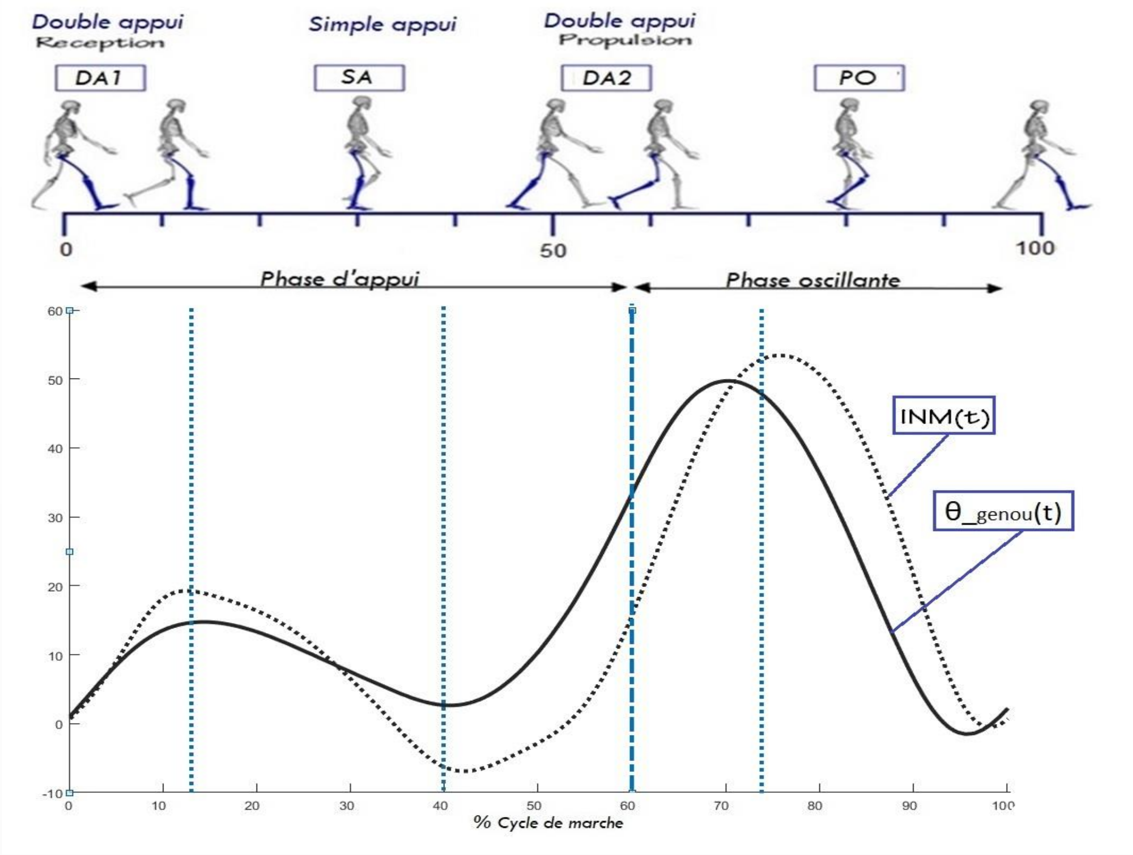
$$= \frac{E(\,W_I^T I\; I^T\,W_\Theta\,)}{\sqrt{E\,(W_I^T\;I\;I^T W_I\,)\;E\,(W_\Theta^T\Theta\Theta^T\,W_\Theta)}}$$

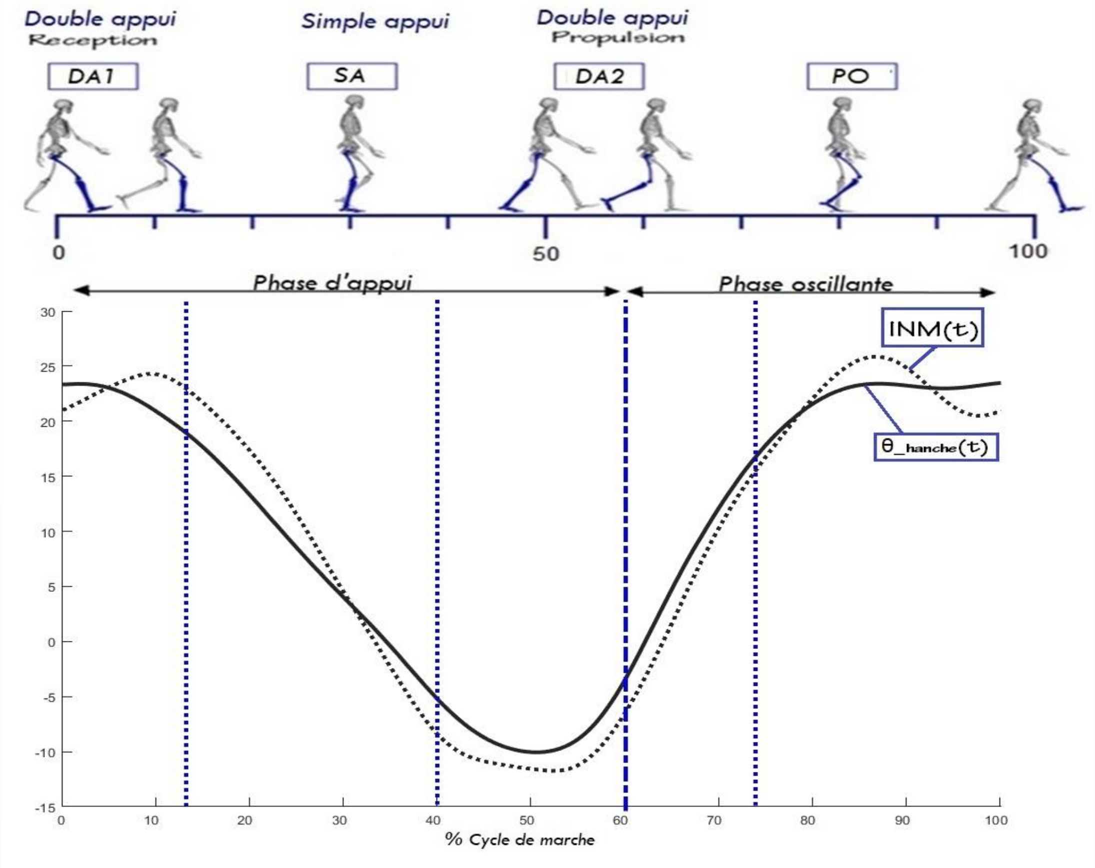
1- Input signals (+ Processing)

2- Determine θ= f (INM)

3- Select θ_d = CCA (θ, θ_{ref})

Healthy subject : Estimation of joint angle from NMI

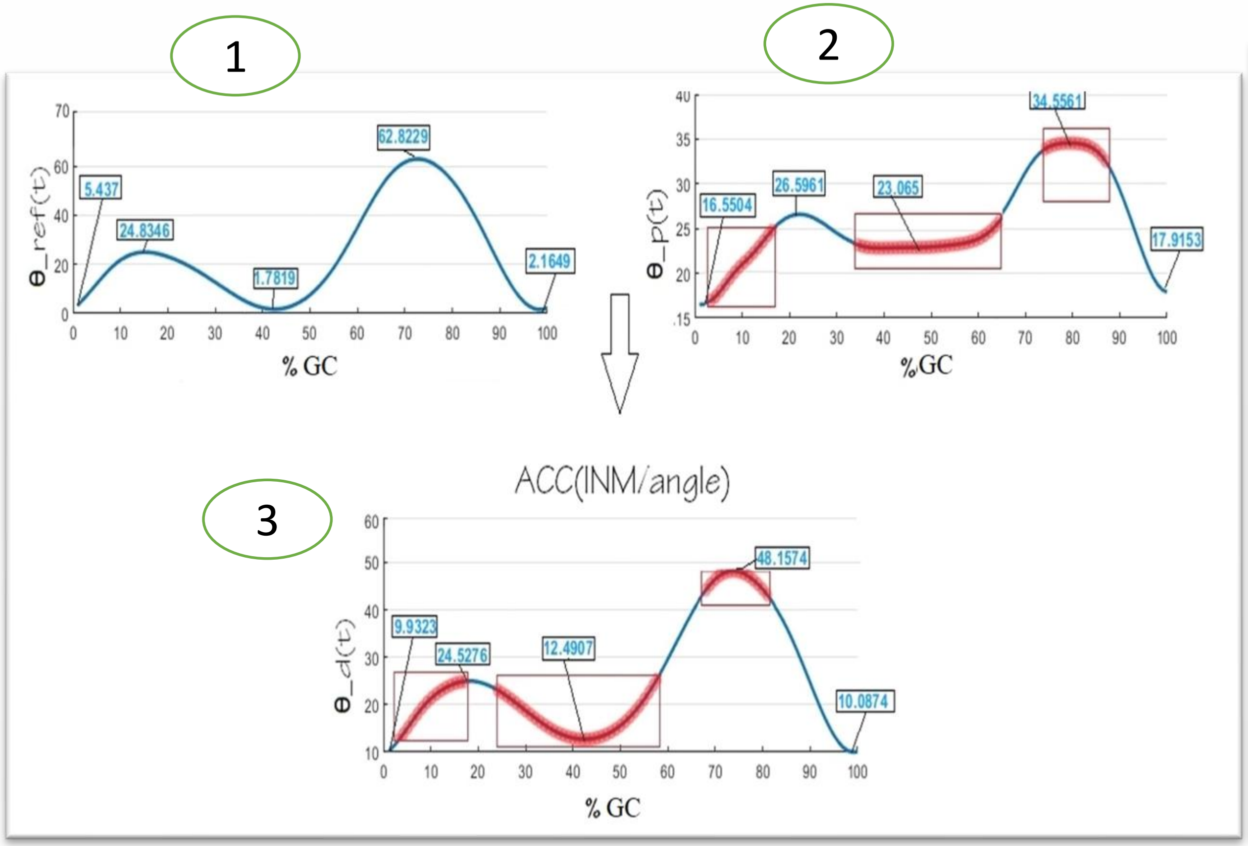




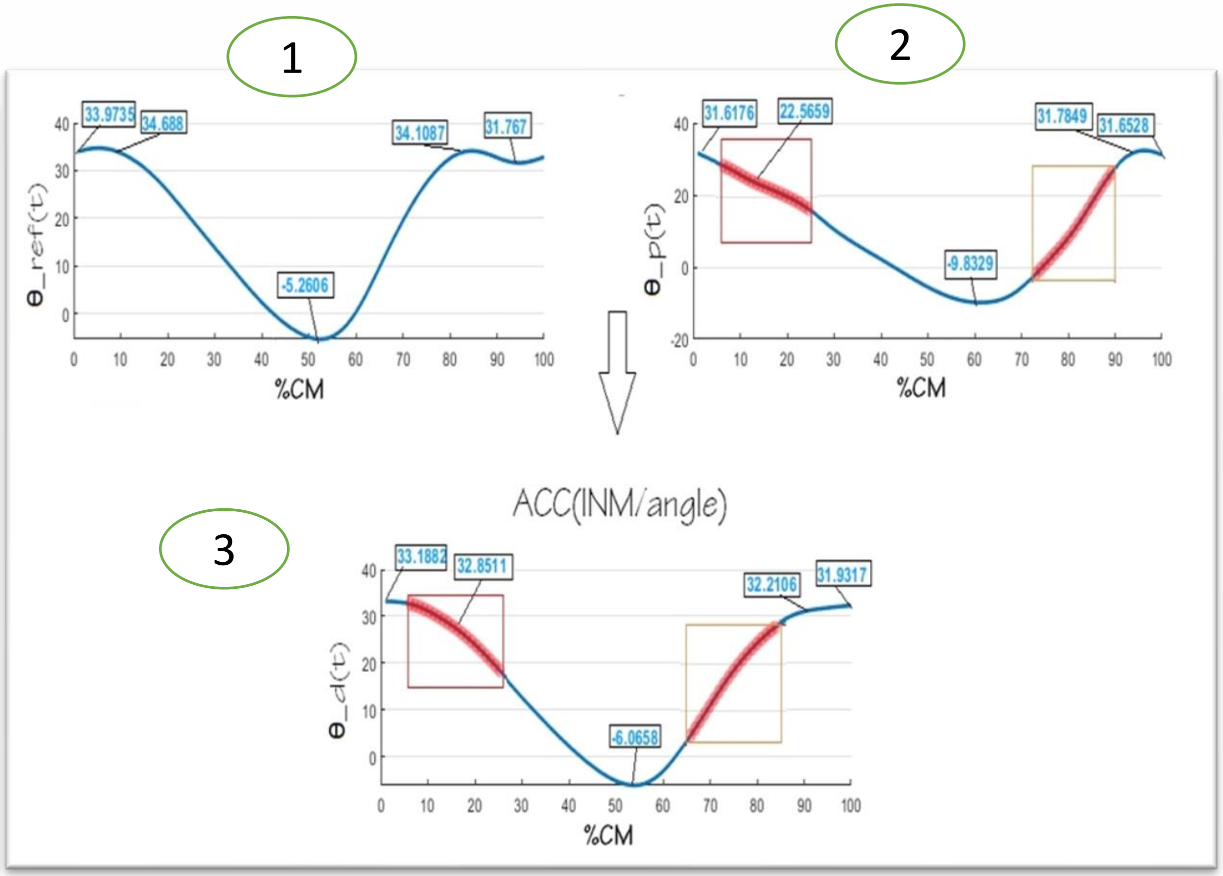
Results

Finally, the correction of the kinematic curves for 11 neurological patients (with CP and Stroke) is testing:

The rate was achieved reaches 45% to 82%



Knee



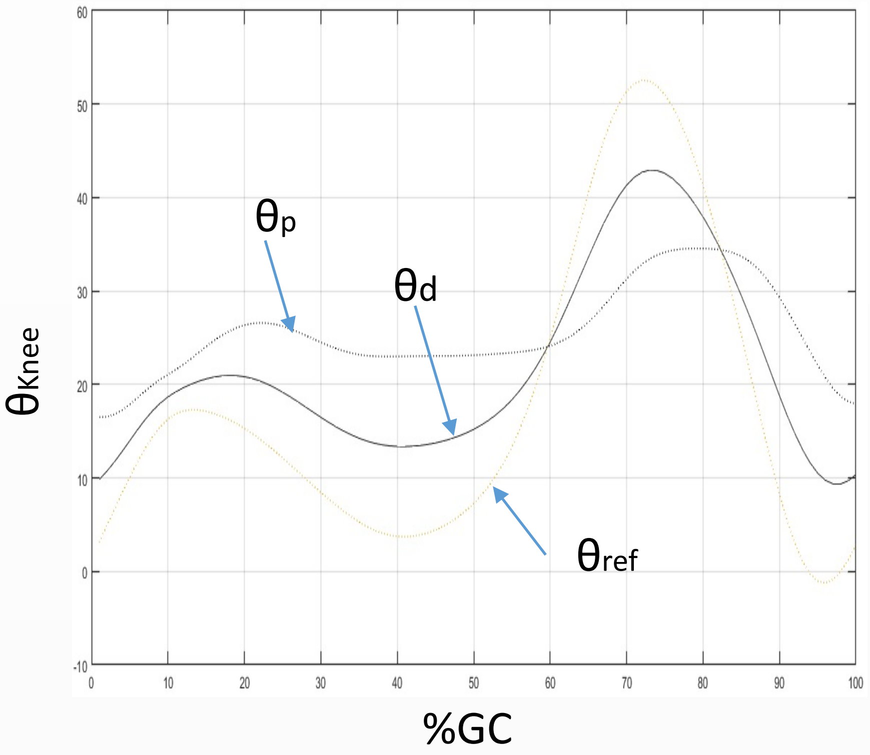
Hip

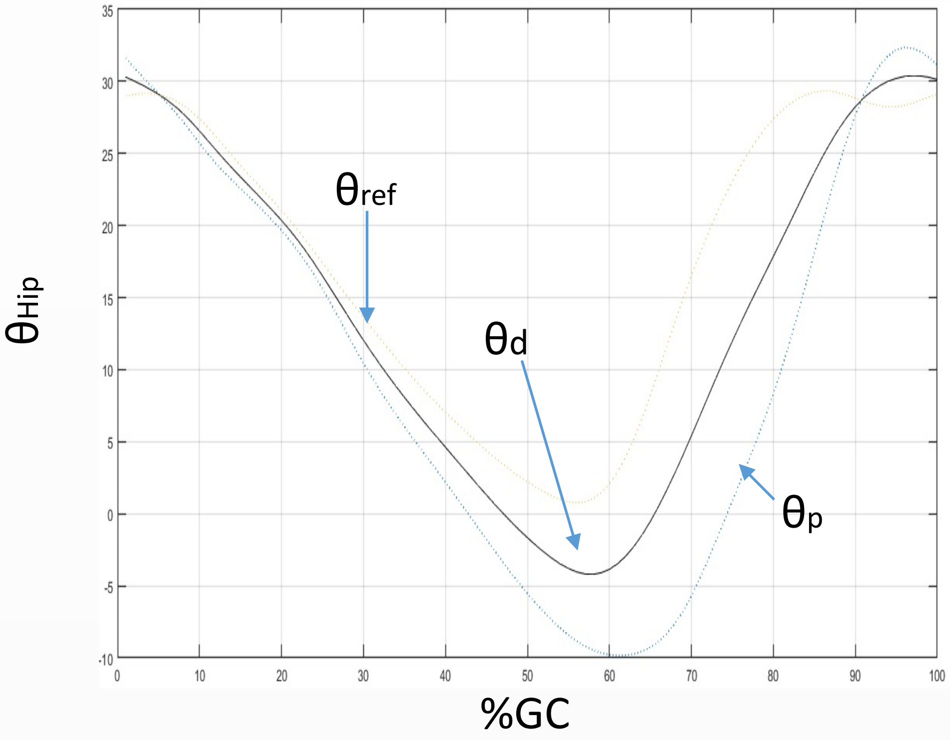
Results

Characteristics of Θd :

- Have values between θp and θref

- Respect the expertise of the patient and his muscle capacity





Conclusion and Perspective

- **Control an exoskeleton is important but it should done with collaboration.**
- **The effectiveness of using (NMI) for bio kinematic-based control strategy for user-lead rehabilitation exoskeleton was investigated to achieve the needed collaboration in respect the capacity of muscle patient.**
- **The CCA method is used for extracting the better angle information (θd) from the multi EMG signals .**
- **Θd is the output of our high-level loop and will be the input for the low-level loop using PID controller for SOL Exoskeleton**

Thank you