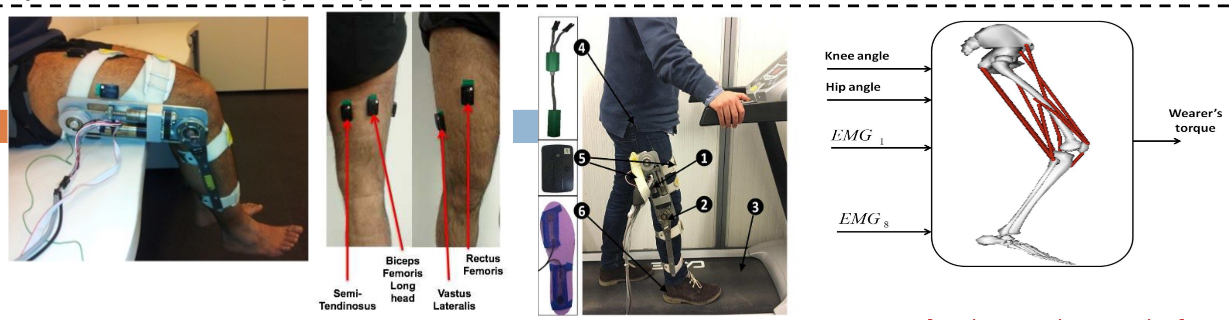
Assistive Robotics at the LISSI-UPEC

LISSI-UPEC

Systèmes robotiques portables - contributions



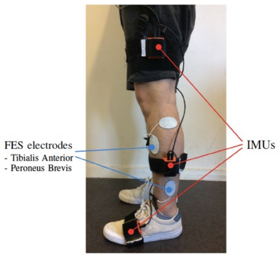
[RSS'13, CEP'14, TRO'19]

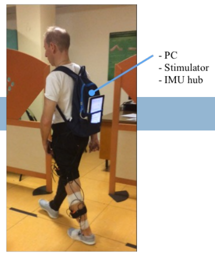
- Détection de l'intention à travers la mesure de bio-signaux
- Estimation du couple articulaire à travers une modélisation musculo-squelettique
- Commande avancée de l'orthèse du genou (impédance, adaptative, saturation, etc.)

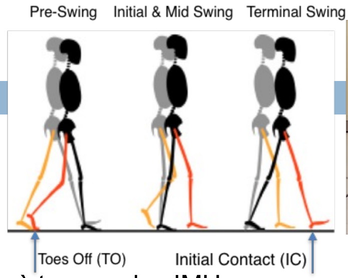
- Estimation en-ligne des activités quotidiennes (marche, etc.) dans un objectif de contextualiser l'assistance
- Commande avancée du robot E-ROWA.

[RAS'15, RAS'16, ICRA'16, TRO'18, TCST'18]

Systèmes robotiques portables - contributions



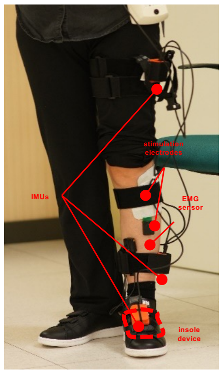




[Brevet WO 2018/0547764 A1, IROS'18]

- Estimation en ligne de la phase oscillante à travers des IMUs
- FES Adaptative du muscle droit antérieur en fonction de la cinématique du membre inférieur des patients parétiques.



[ICORR'17, IFAC'17, IROS'18, TMECH'18, CEP'19]

- Trajectoire désirée dépendante du profil du patient
- Commande adaptative bornée de l'orthèse de la cheville

Outline of the presentation

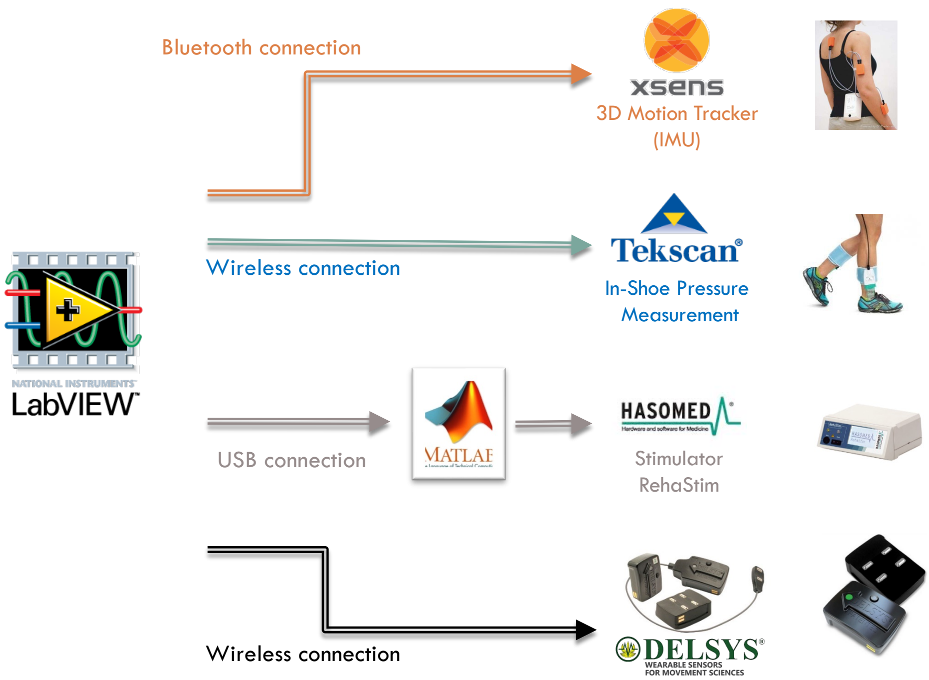
- Objectives
- Stimulation Control System
- Description of the sensors
    - Xsens
    - TekScan
    - RehaStim
    - Delsys

Objectives

- Identify the Acquisition Systems
- Learn to use each device of the system

Sensors

- The system is composed by the use of 4 different devices.
- All of them are controlled by LabVIEW



Xsens

The Xsens is a 3D motion tracker based on a inertial measurement unit, each sensor is connected to the XbusMaster who communicates to a wireless receiver (WR-A) by bluetooth. The WR-A is connected by usb to the computer.

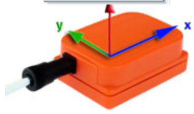
Xsens

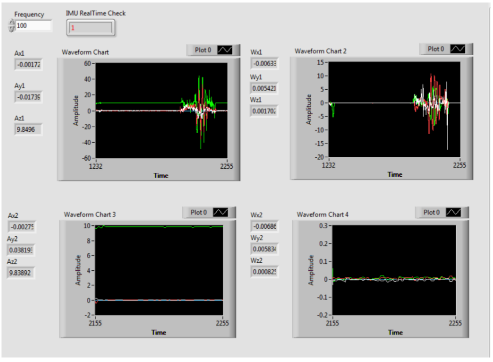
How to use

- Drivers
- Software provided by the company
- Labview

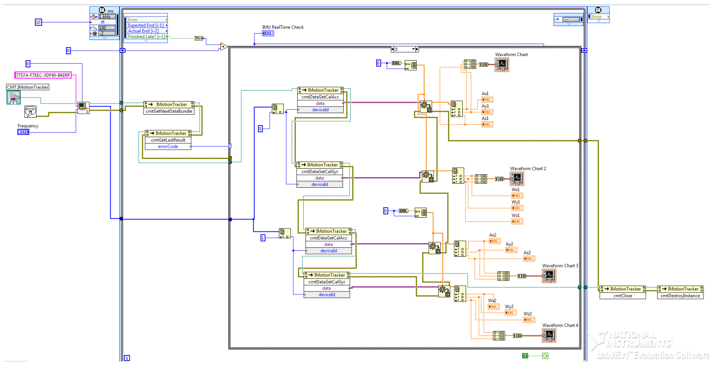
Xsens

Demo Xsens
A demo was developed for the use of the Xsens, the sensor signals are displayed.



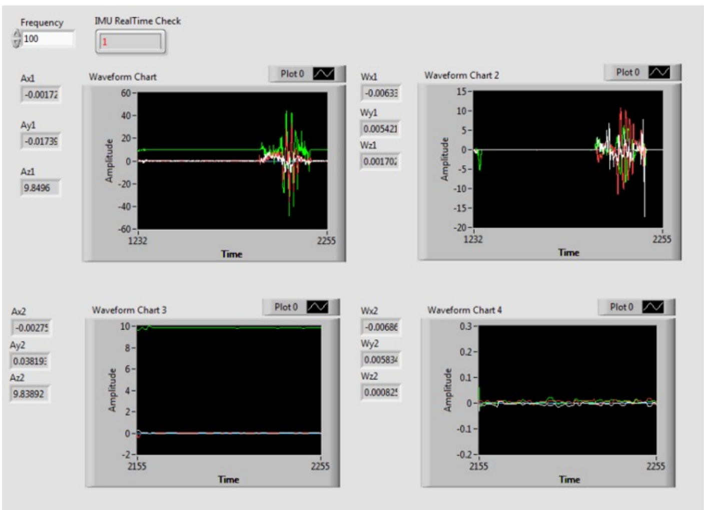


Frontal Panel



Programming Block

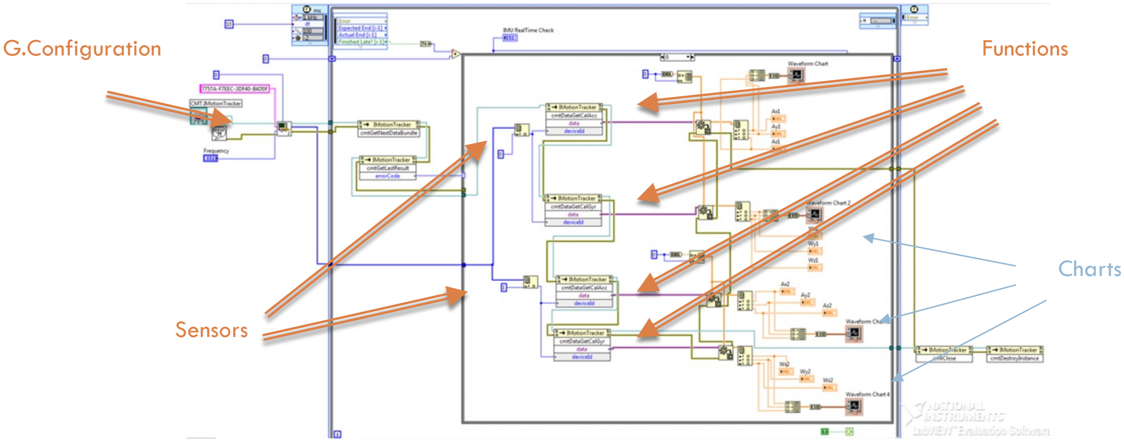
Xsens

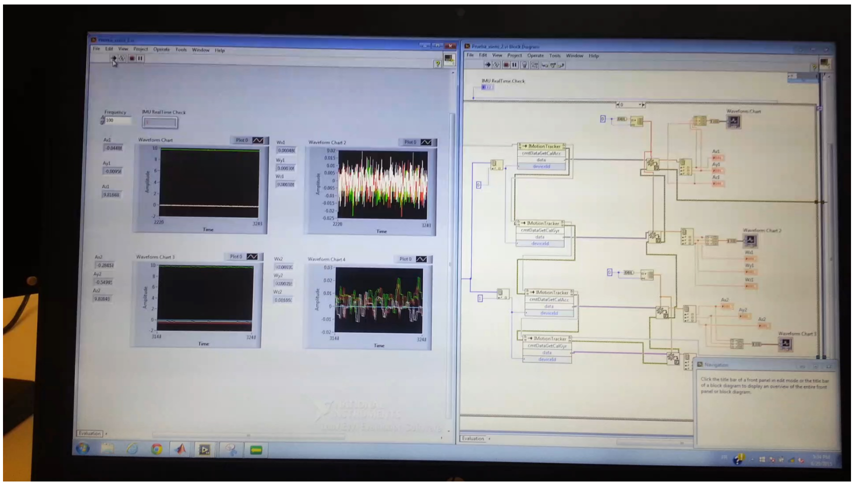


A demo was developed for the use of the Xsens, the sensor signals are displayed in four charts the two on top show the acceleration and velocity of the first sensor, and the two of the bottom show the acceleration and velocity of the second sensor.

Xsens

Calling the functions cmtDataGetCalAcc cmtDataGetCalGyr to obtain the acceleration and velocity of each sensor.





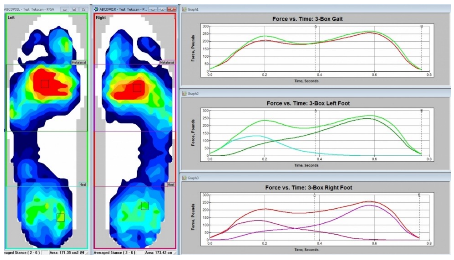
In this example two sensors were used, of which the extracted acceleration and velocity.

The charts on the top show us the velocity and acceleration of the sensor 1

The graphs of the bottom show the velocity and acceleration of the sensor 2

TekScan

Is an “In-shoe systems” that provide detailed information about what is actually occurring inside the shoe. A Tekscan system consists of scanning electronics, software and thin-film sensor. Evaluating plantar pressure through the use of an in-shoe system helps provide a better understanding of foot function.



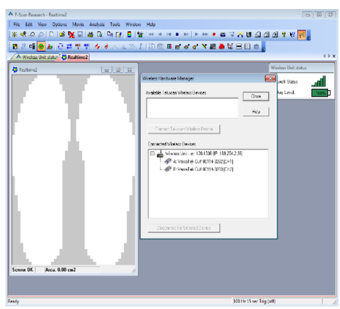
TekScan

How to use

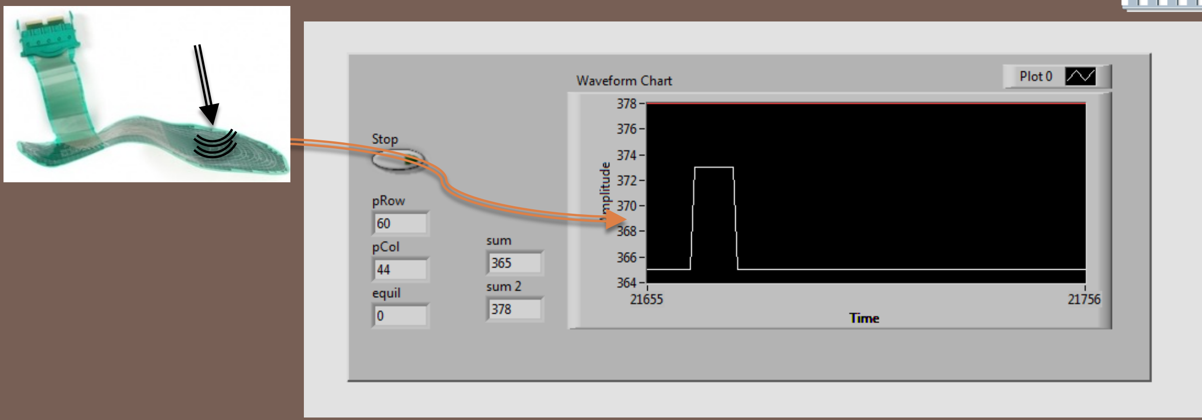
- Drivers
- Software provided by the company

The F-Scan Research-Realtime contains a Wireless Hardware manager who track the nearest device and makes the connection.

- Labview

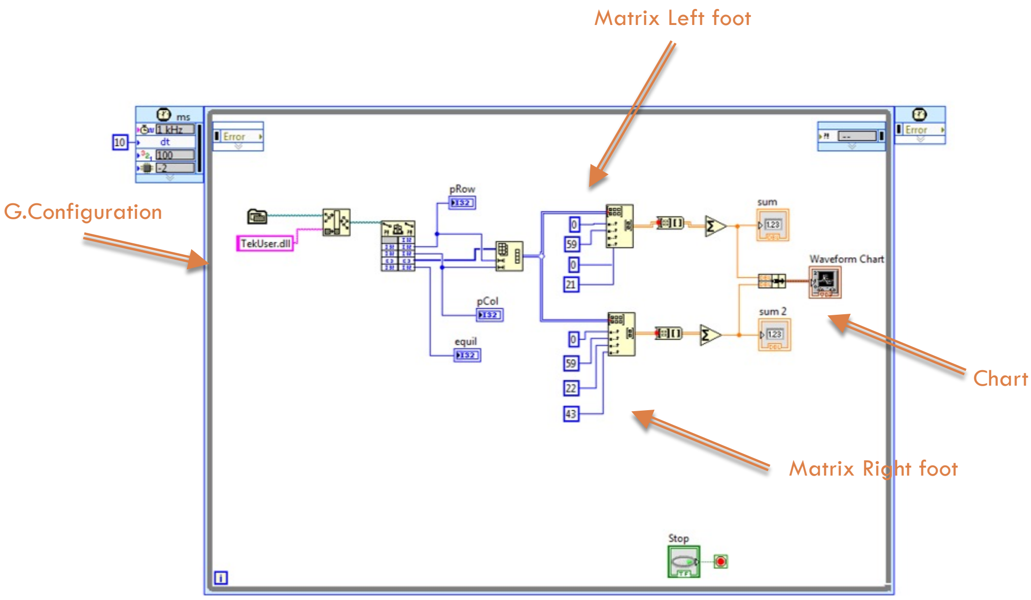


TekScan



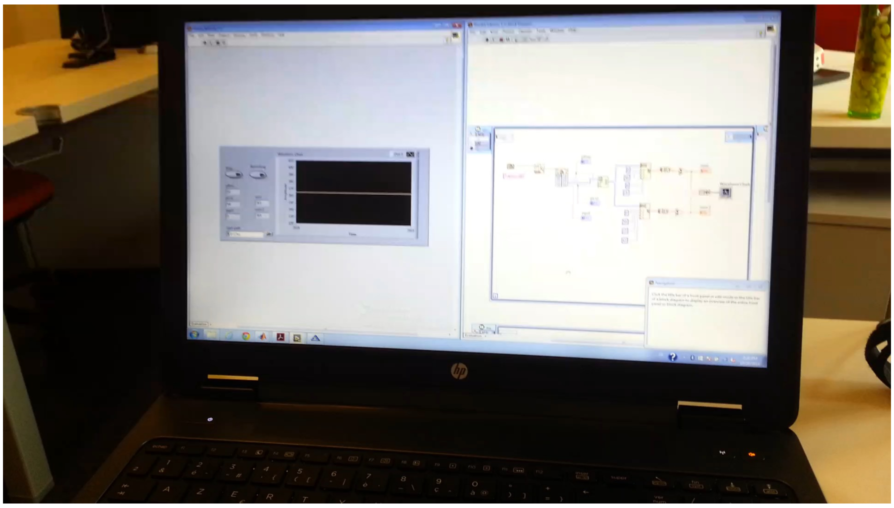
The data of the two insole sensors is displayed in a chart. This data is acquired as a matrix of values of the surface of the sensor, and we displayed as an only value obtained to the sum of each element of the matrix.

TekScan



Programming block

TekScan



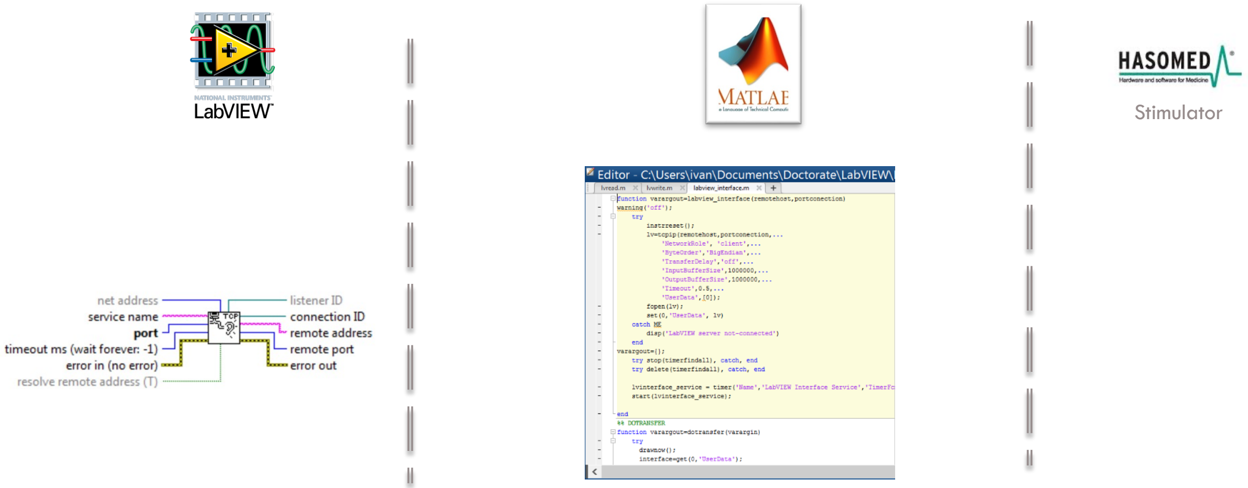
The chart is showing the data acquired as a pulse each time the sensor is pressed.

RehaStim

Is a portable electrical stimulation device that generates impulses, to activate muscles via surface electrodes. Different parameters concerning power and temporal sequence of the impulses can be adjusted individually for each channel.

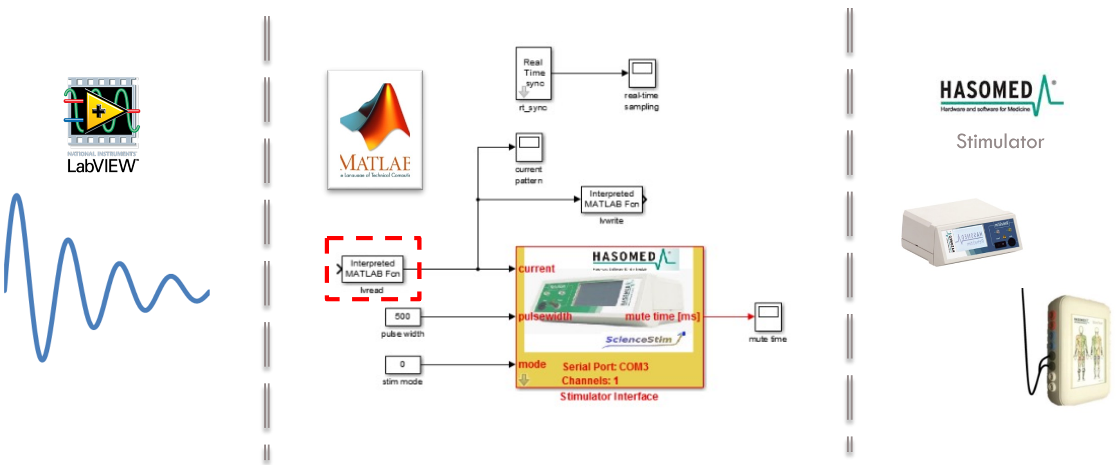
RehaStim

In the Labview interface is opened a tcp ip socket communication, a Matlab Function "Labview_interface" is responsible for performing the configuration of this port with the aim of transmitting data from the graphical interface to the stimulation device.



RehaStim

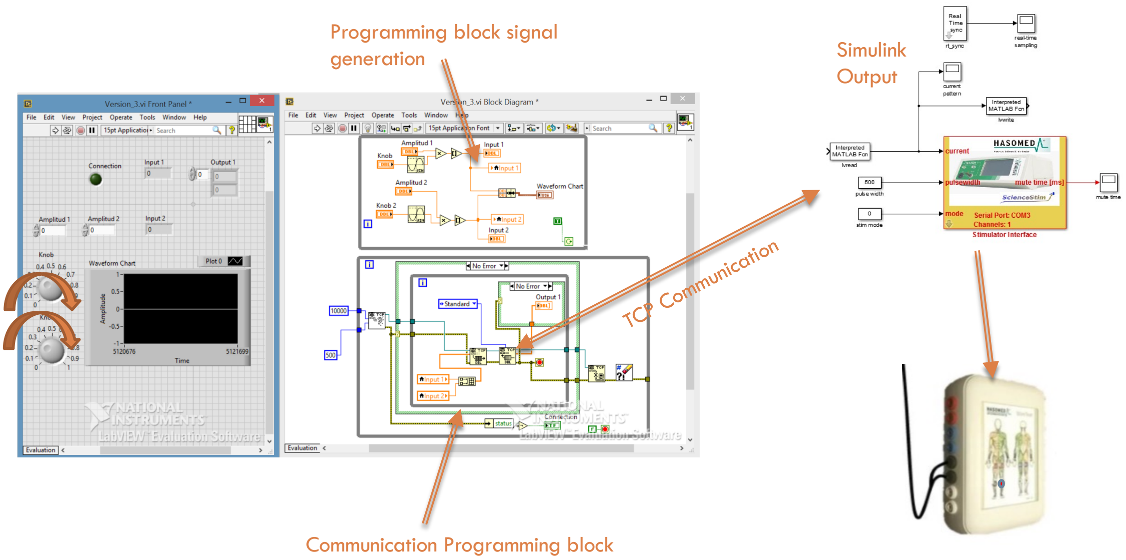
Additional to this communication, the manufacturer has provide a Simulink block to configure and control different parameters of the stimulator: Current, Pulse width, Stimulation Mode, Serial Port and Channels.



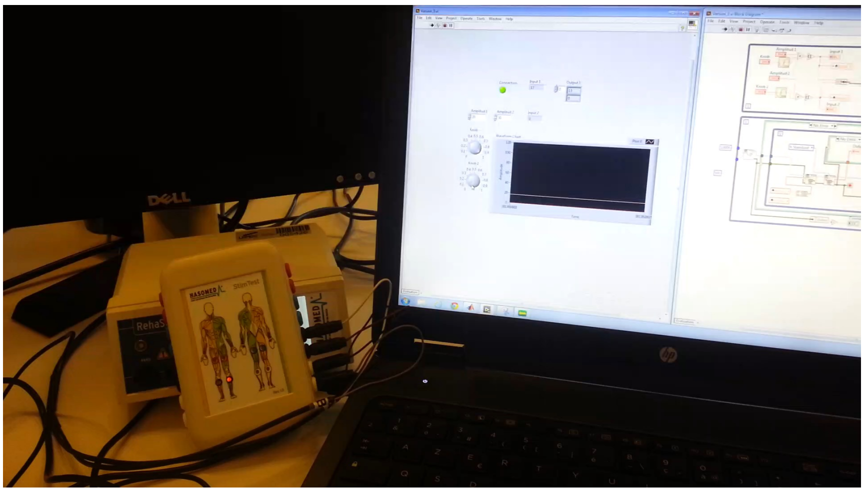
The shape of the required output signal is generated in LabVIEW, this is handled by block Simulink to be physically deployed for the stimulator.

RehaStim

Demo Stimulator. A demo was developed for the use of the stimulator, it was set a single output, to achieve a proportional output current. In the programming block signal generation is generated the current signal that we want as a output.



RehaStim

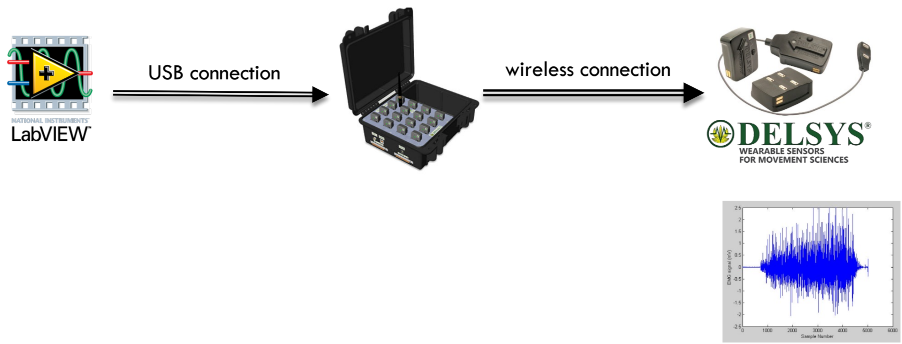


This video shows the operation of the Demo. The outputs of the stimulator are connected to the Stim Test (Dummy), with this device we can visualize the output current as the intensity of brightness of the LED.

In the Programming block signal generation could be programed any desired output signal.

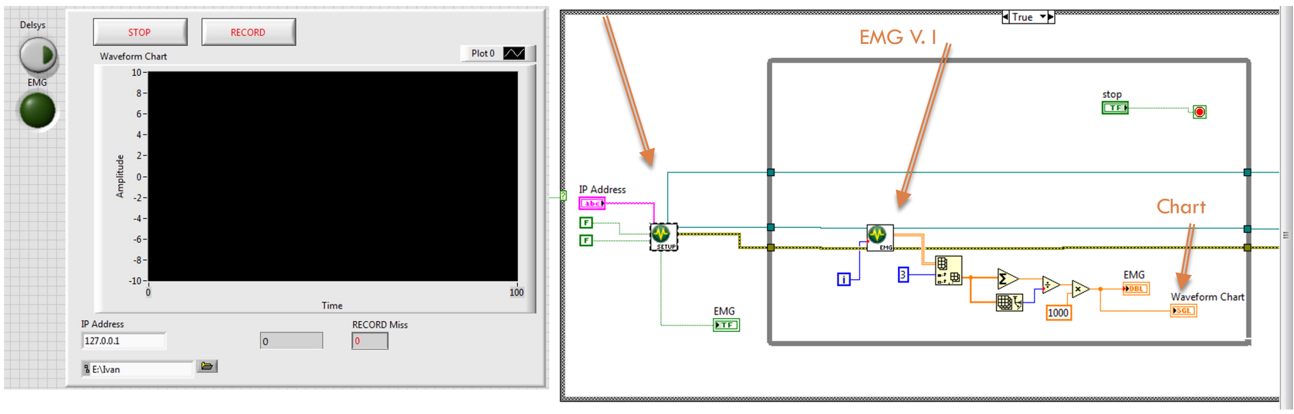
Delsys Wearable Sensors

The Trigno Wireless EMG System is a high-performing device designed to make EMG signal detection reliable and easy. Each sensor is wirelessly connected to a central processing unit and this at the same time connected by USB to the PC.



Delsys Wearable Sensors

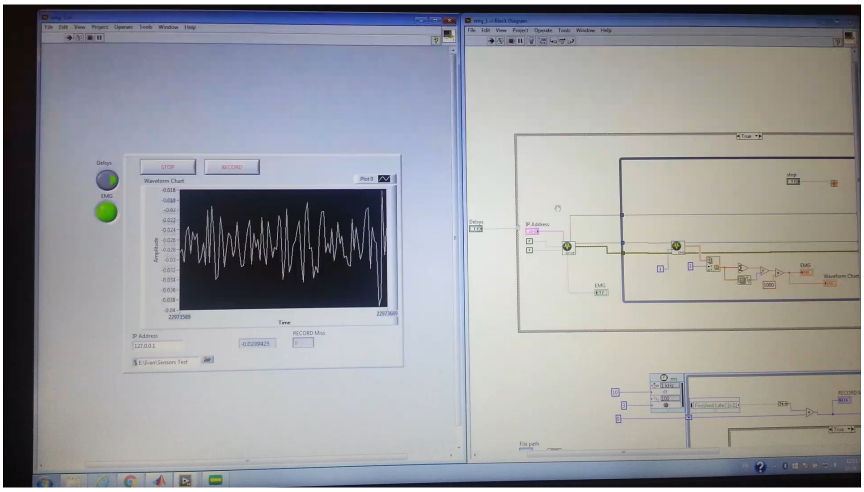
G. Configuration



Frontal Panel

Programming Block

Delsys Wearable Sensors



This video shows the operation of the Demo. The EMG sensor is attached a the tibialis muscle, in the frontal panel is displayed the EMG signal acquired of the activity of this muscle.

1. Sensors – different application

- Tekscan
  - **In-shoe plantar pressure analysis**
  - Paper-thin sensors placed inside footwear capture dynamic in-shoe pressure information.

Tekscan system and associated sensors

Record pressure data in real-time via Wi-Fi network

1. Sensors

Xsens

- Human motion tracker
- The Xsens Kit includes 6 small and accurate 3DOF Orientation Trackers. Each tracker provides drift-free 3D orientation as well as kinematic data: 3D acceleration, 3D rate of turn and 3D earth-magnetic field.

Xsens Kit

Full-body measurement system

1. Sensors

Delsys

- The Trigno™ Wireless EMG System includes 6 EMG sensors and 2 wireless 4-Channel FSR (Force Sensitive Resistor) Sensors . Each EMG sensor also has a built-in triaxial accelerometer.

Trigno™ Wireless EMG System and EMG sensors

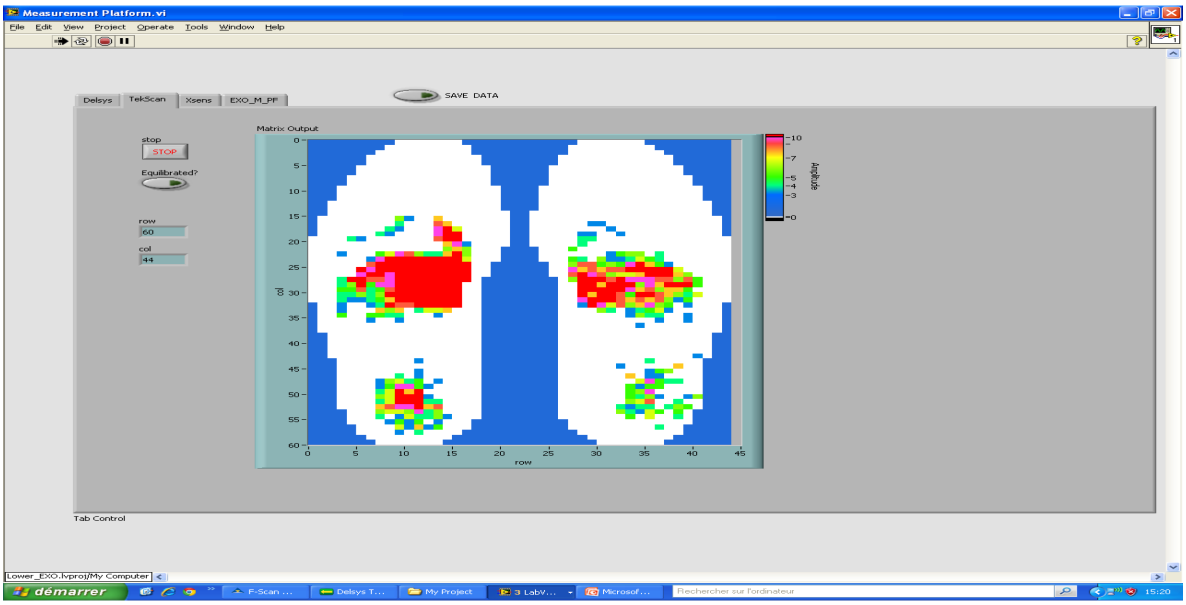
2. Measurement Platform

- The measurement platform integrates these three types of sensors (Tekscan, Xsens and Delsys) by a third party driver supported by Labview.

The Sensors of Measurement Platform

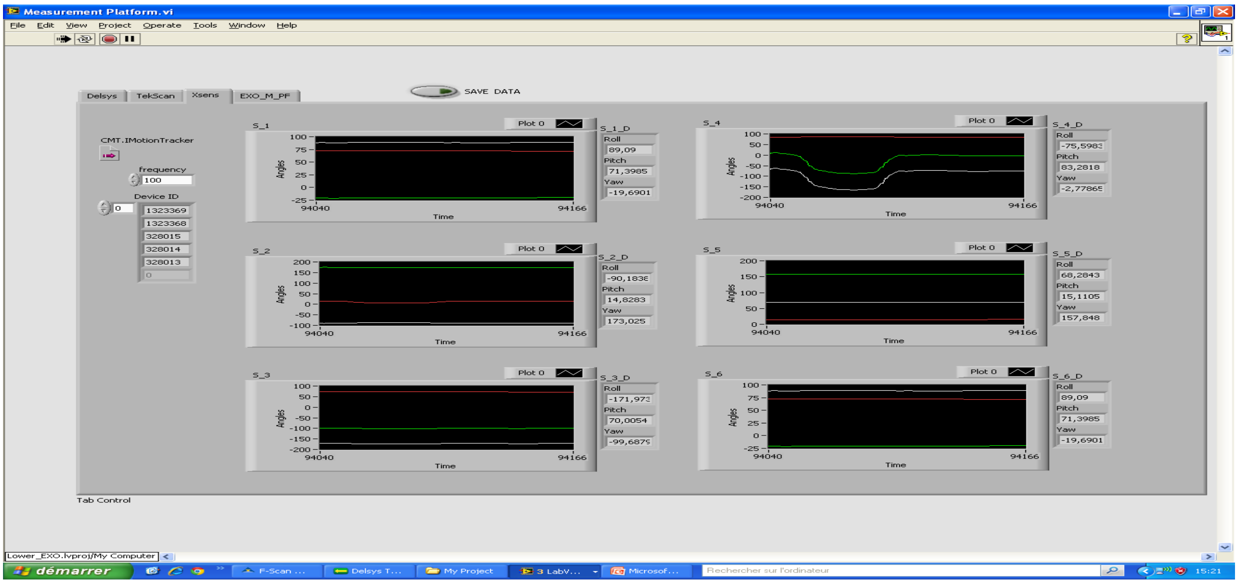
3. LabVIEW Interface

- **Tekscan**
  - Acquiring the pressure data from two foot sensors



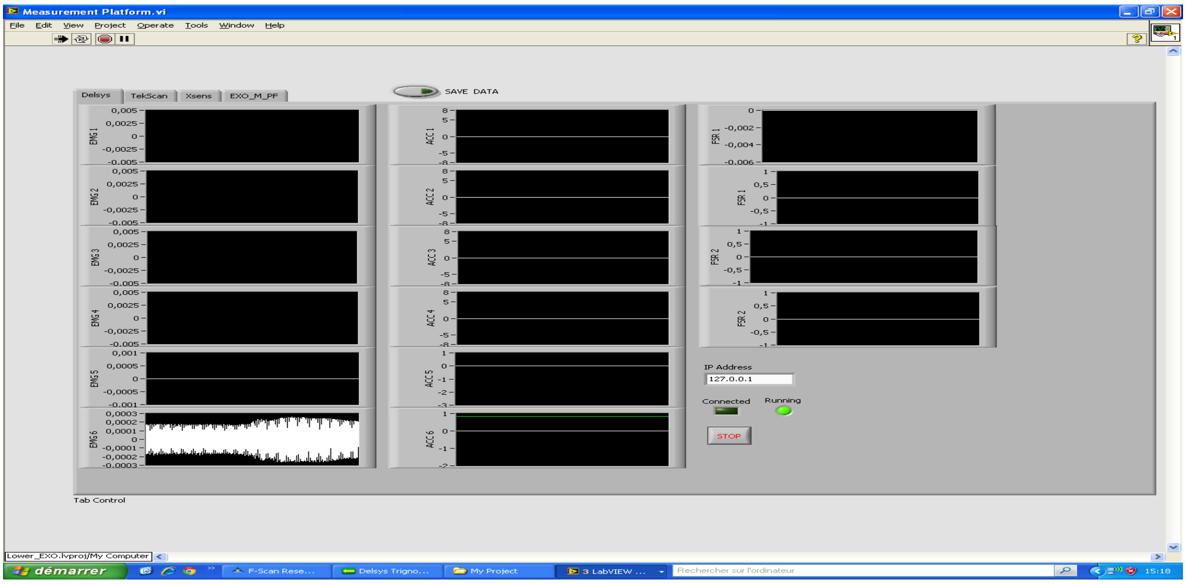
3. LabVIEW Interface

- Xsens
  - Measuring the Euler angles, angular velocities and accelerations of each lower-limb joint (ankle, knee and hip joint).



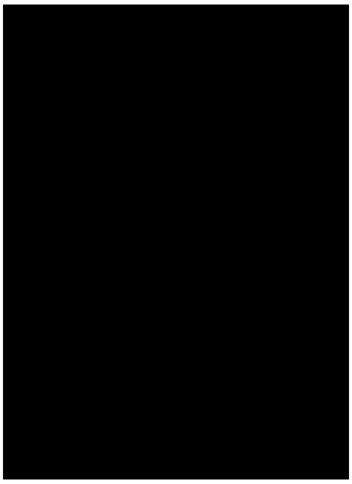
3. LabVIEW Interface

- Delsys
  - Acquiring the EMG signals from 6 muscles, 3-axis accelerations from associated limbs, and FSR forces from two hands.



4. Sit-to-Stand Experiments

- The participant was asked to stand from sit position without hands' assistance at three different speeds (lower, normal and faster) respectively.
- Acquiring the angle, angular velocity and acceleration of each lower-limb joint during the sit-to-stand process.



Demo video

5. Other Demos

Measuring the EMG and ACC signals by Delsys system

5. Other Demos

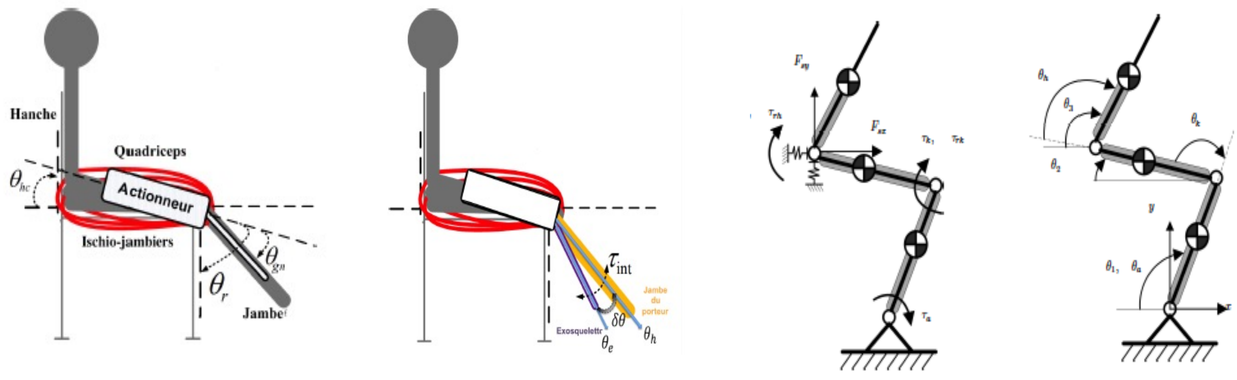
Plantar Pressure

5. Other Demos

Motion Tracking

Human/robot model

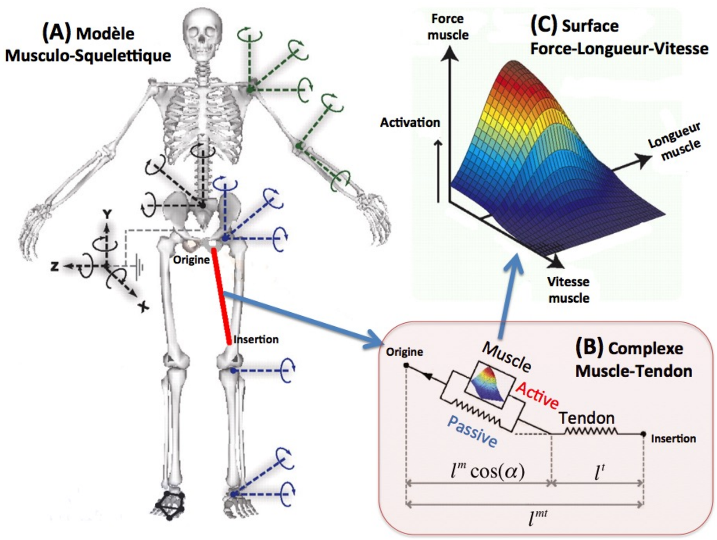
- Dynamic modeling of the human/robot system
- Intention detection through the use of bio-signals – EMG
- Estimation of the joint torque using Hill-based musculo-skeletal model

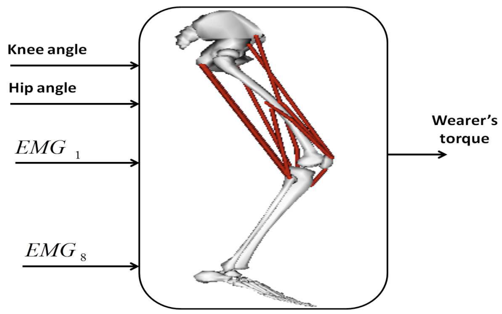


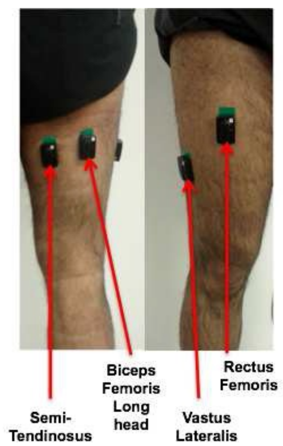
Movement equation of the knee/shank system

$$J\ddot{\theta} + B\dot{\theta} + \frac{\partial E_p}{\partial \theta} = \tau_e + \tau_h$$
$$\theta_h = \theta_e + \delta\theta$$
$$M(q)\ddot{q} + C(q,\dot{q}) + G(q) = Ru + J^T F$$

Hill-based musculo-skeletal model (knee joint)



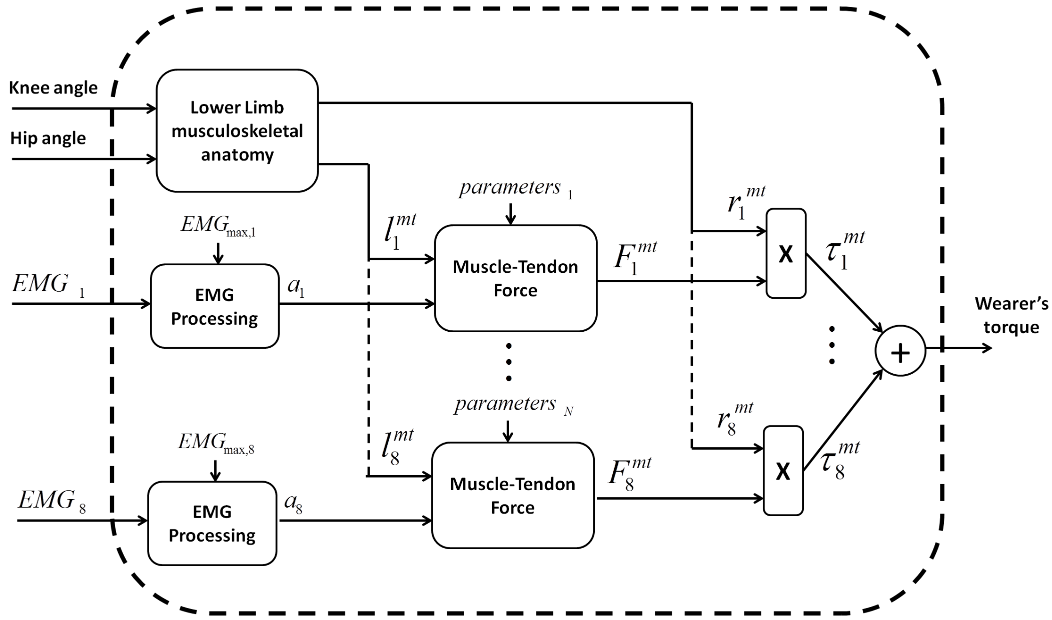




RF: Rectus Femoris
VL: Vastus Lateralis
VM: Vastus Medialis
VI: Vastus Intermedius
ST: Semi-Tendinosus
SM: Semi-Membranous
BL, BS Biceps Femoris Long/Short head

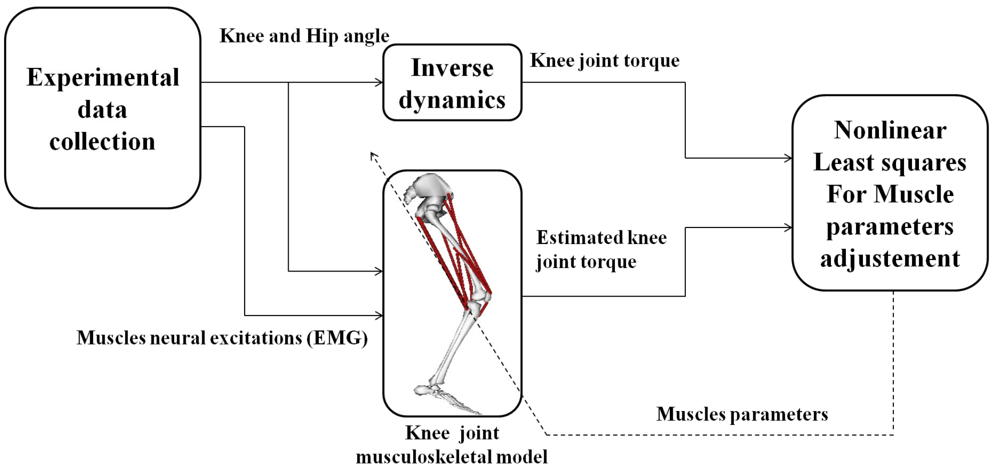
Hill-based musculo-skeletal model (knee joint)

Estimation of the joint torque



Parametric identification

- Parameter identification of the equivalent system (lower-limb/exoskeleton)
- Parameter identification of the muscle-tendon model

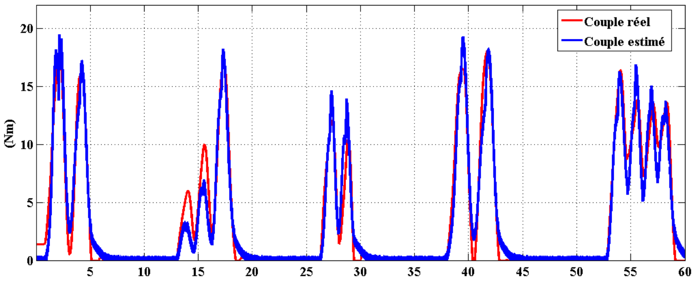


Identification process

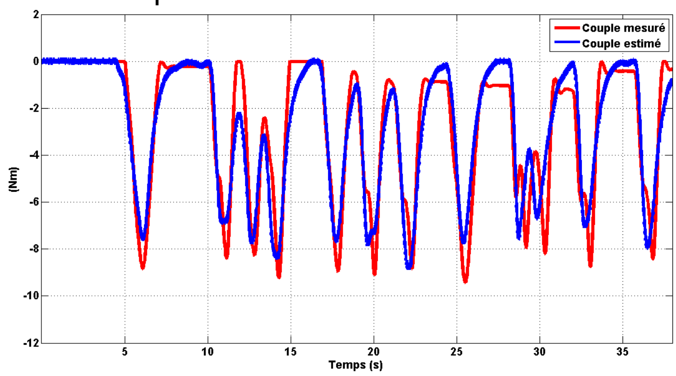
$$Minimize_{\chi} \frac{1}{N} \sum_{i=1}^{N} \left(\tau(i) - \sum_{j=1}^{4} \tau_j(\chi_i) \right)^2$$

$$\chi = [l_s^t, l_0^m, F_{max}, Sc]$$

Parametric identification of the muscle model



Example of cross-validation for extensor muscle



Example of cross-validation for flexor muscle

Muscle		$l_m^o(cm)$	$l_s^t(cm)$	$F_{max}(N)$	Sc
RF	-	8.6	34.2	748	0.95
	*	8.4	34.6	780	1
VL	-	8.3	16.2	1620	0.83
	*	8.2	15.7	1870	1
VM	-	8.2	11.8	1188	1.05
	*	8.9	12.6	1295	1
VI	-	7.8	12.7	1163	1.1
	*	8.7	13.6	1235	1
SM	-	7.93	40.5	992	0.84
	*	8	35.9	1030	1
ST	-	18.8	24.7	315	1.06
	*	20.1	26.2	330	1
BL	-	10.3	36	641	0.85
	*	10.9	34.1	720	1
BS	-	18.1	10.6	379	0.82
	*	17.3	10	413	1

Lower Limb Musculoskeletal Parameters (-:identified, *:[ref])

[ref] E.M. Arnold, S.R. Ward, R. L. Lieber, and S.L. Delp, A model of the lower limb for analysis of human movement, Annals Biomedical Engineering, 38(2), pp.269-79, 2010

Robust control law strategies

- Human-centered based approaches for assistance-as-needed paradigms
- Contextualized control laws with respect to the progress of the rehabilitation process
- Security of the wearer (Stability proofs using Lyapunov theory)
- Do not alter the natural movement of the wearer within assistance context

Assisted based control-laws

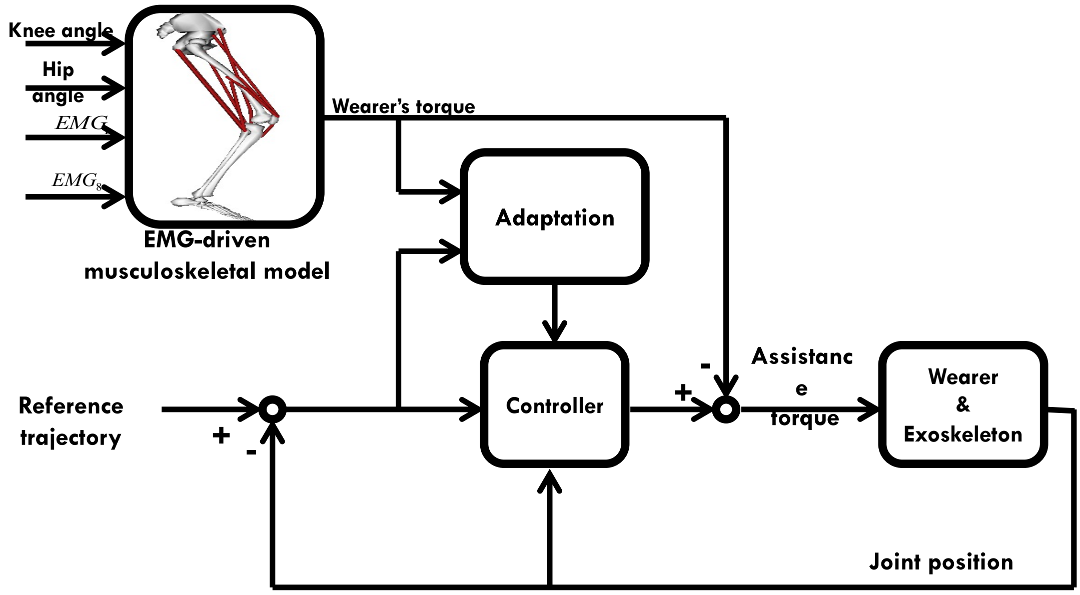
Assistive-modes:

- **Passive** (assisted): Exoskeleton guided movements for repetitive motions to increase the range of motion and reduce the stiffness. Population: SCI patients
- **Active-assisted**: Wearer guided movements assisted by the exoskeletons to increase motion range of affected joints, muscle strengthening to improve motor coordination and force/torque amplification. Population: SCI patients and elderly
- **Resistive**: Exoskeleton driven in the opposite direction of the wearer motion for muscle strengthening. Population: SCI patients and elderly

Saturation based control

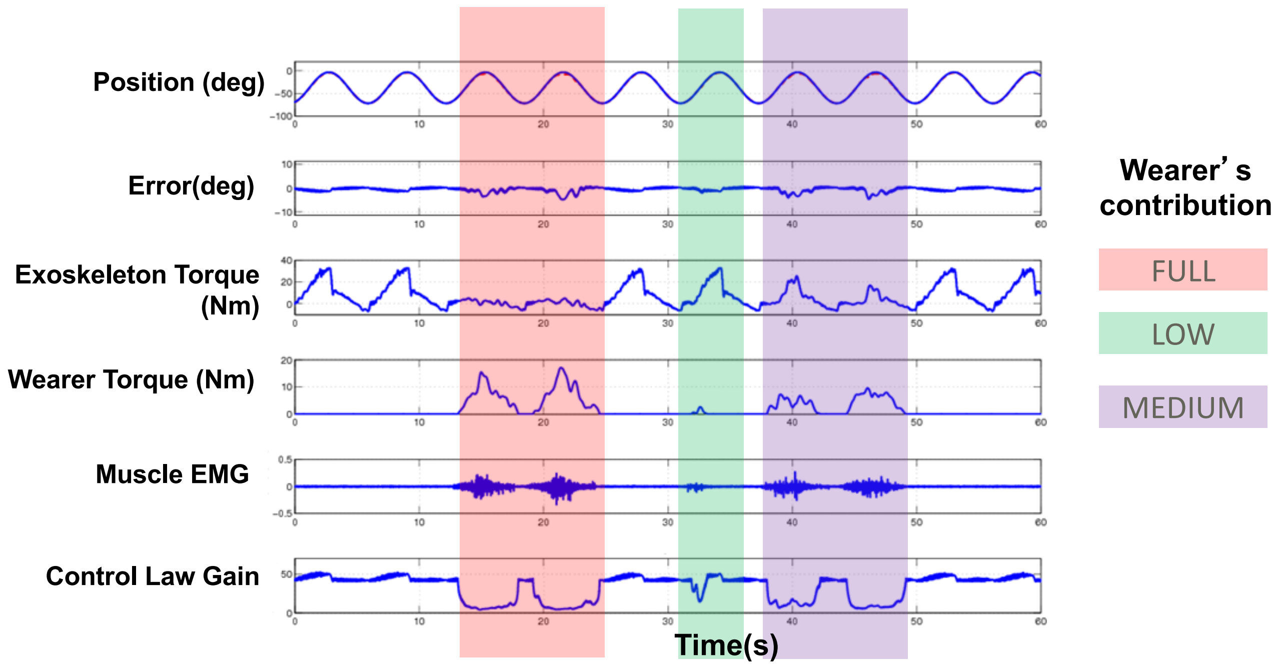
Passive mode and Active-assisted mode:
Intention detection through EMG measurements
- **Assistance Increases** IF deviation from the reference trajectory is important
- **Assistance Decreases** IF the wearer can handle the tasks

$$\lambda = \lambda_0 \frac{1 + K_1 \|e\|}{1 + K_{12} \|\tau_h - \tau_{hd}\|}$$



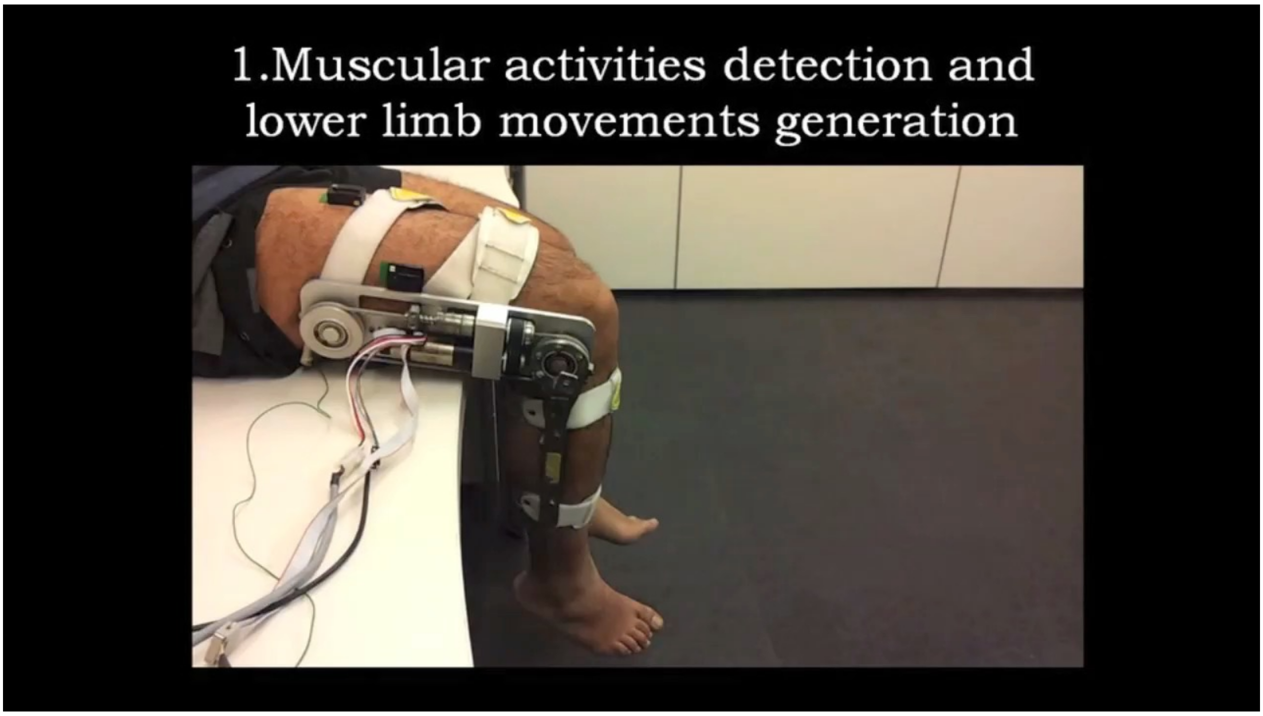
Saturation based control

Passive mode and Active-assisted mode [RSS 2013] [Control Engineering Practice 2014]



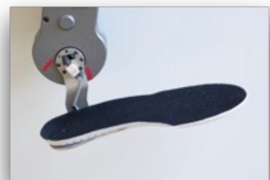
Saturation based control

Passive mode and Active-assisted mode



Towards hybrid solutions - Actuated Ankle Foot Orthosis (AAFO) and Functional Electrical Stimulation

NI myRIO



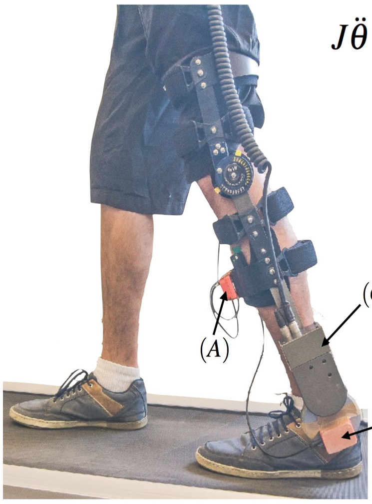
AAFO insole

IMU

FSR sensors

EMG sensors

Adaptive control of an Ankle Foot Orthosis



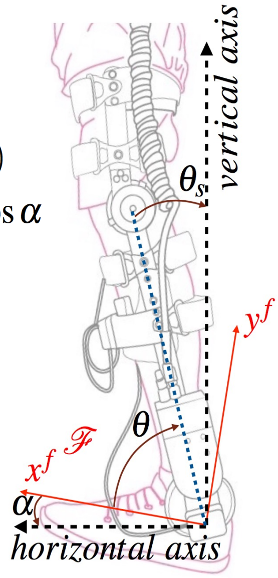
Dynamics of the foot-AAFO system

$$
\begin{aligned}
J\ddot{\theta} &= \tau_f + \tau_a + \tau_s + \tau_r + \tau_{gravity} + \tau_h + \tau \\
&= -A\mathrm{sign}\dot{\theta} - B\dot{\theta} - C(a_y \cos\alpha - a_x \sin\alpha) \\
&\quad - K(\theta - \theta_r) - (R_1 x_1 - R_2 x_2 - R_3 x_3)\cos\alpha \\
&\quad - \tau_g \cos\alpha + \tau_h + \tau
\end{aligned}
$$

Foot angle from horizontal

$$\alpha = \theta + \theta_s - \frac{\pi}{2}$$

(A) IMU used to estimate the angle between the shank and the vertical axis
(B) IMU measuring the translational accelerations
(C) Active-ankle-foot-orthosis.



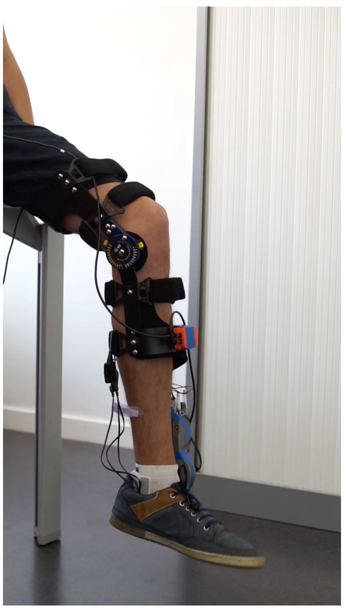
Control torque

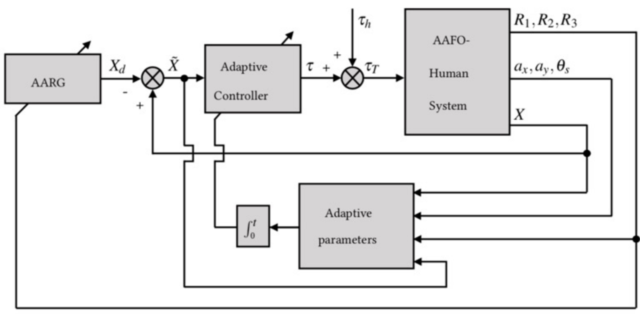
$$
\begin{aligned}
\tau =& \hat{J}(\ddot{\theta}_d - \lambda\dot{\tilde{\theta}}) + \hat{A}\mathrm{sign}\dot{\theta} + \hat{B}\dot{\theta} + \hat{K}(\theta - \theta_r) \\
&+ \hat{C}(a_y \cos\alpha - a_x \sin\alpha) + \hat{\tau}_g \cos\alpha - \kappa s \\
&+ \hat{\gamma}(R_1 x_1 - R_2 x_2 - R_3 x_3)\cos\alpha
\end{aligned}
$$

$$\hat{W} = [\hat{A},\ \hat{B},\ \hat{C},\ \hat{K},\ \hat{J},\ \hat{\gamma}, \hat{\tau}_g]^T$$

Adaptive control of an Ankle Foot Orthosis

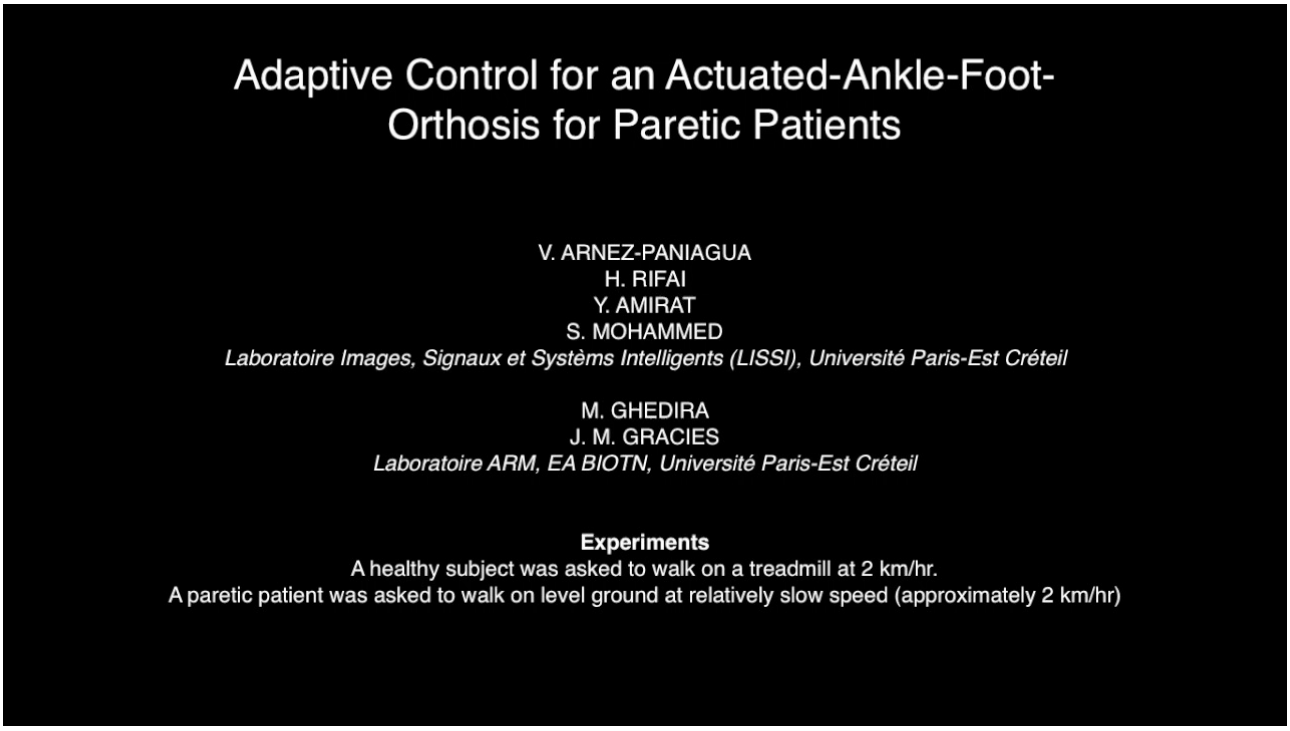
Model reference adaptive control - MRAC





Adaptive control of an Ankle Foot Orthosis

Model reference adaptive control - Whole gait cycle assistive sessions (*Paretic patients)*



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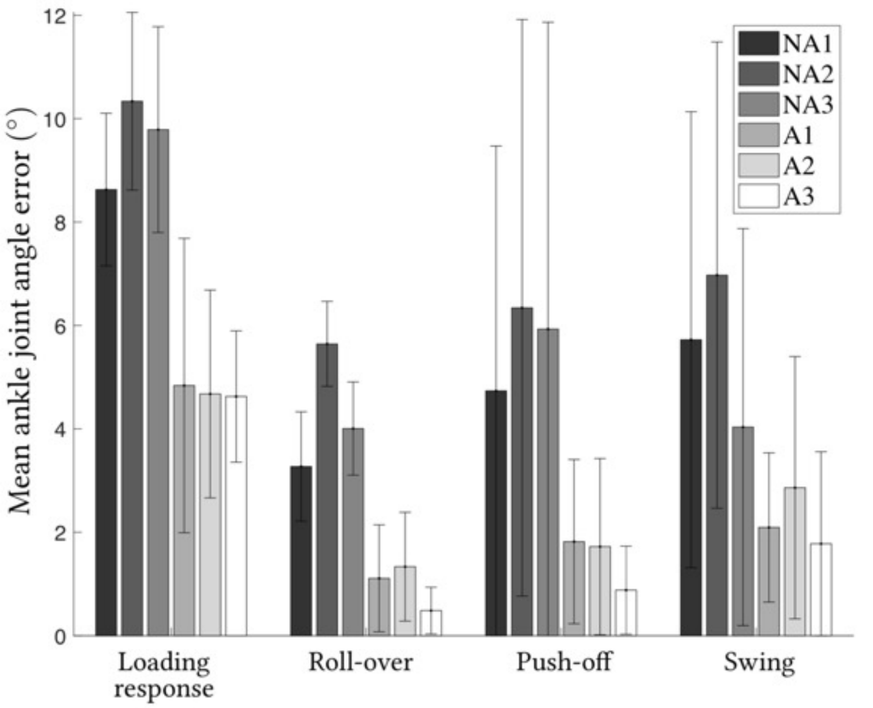


51% 77% 74% 60%

Lower Limb Assistive Robot – LISSI - UPEC

Embedded computer system
- Data acquisition system based on **FPGA**
- Long-life battery
- **Wireless communication** with a host computer

High precision sensor system
- Joint angle measurement by **high resolution absolute encoder**
- Precise torque control

Active assistive components
- **Series elastic actuation** modules
- Mechanical clutches for convenient don/doff

Adjustable mechanical frames
- Aluminum frame with several bolt holes
- Frame length adjustment in discrete manner

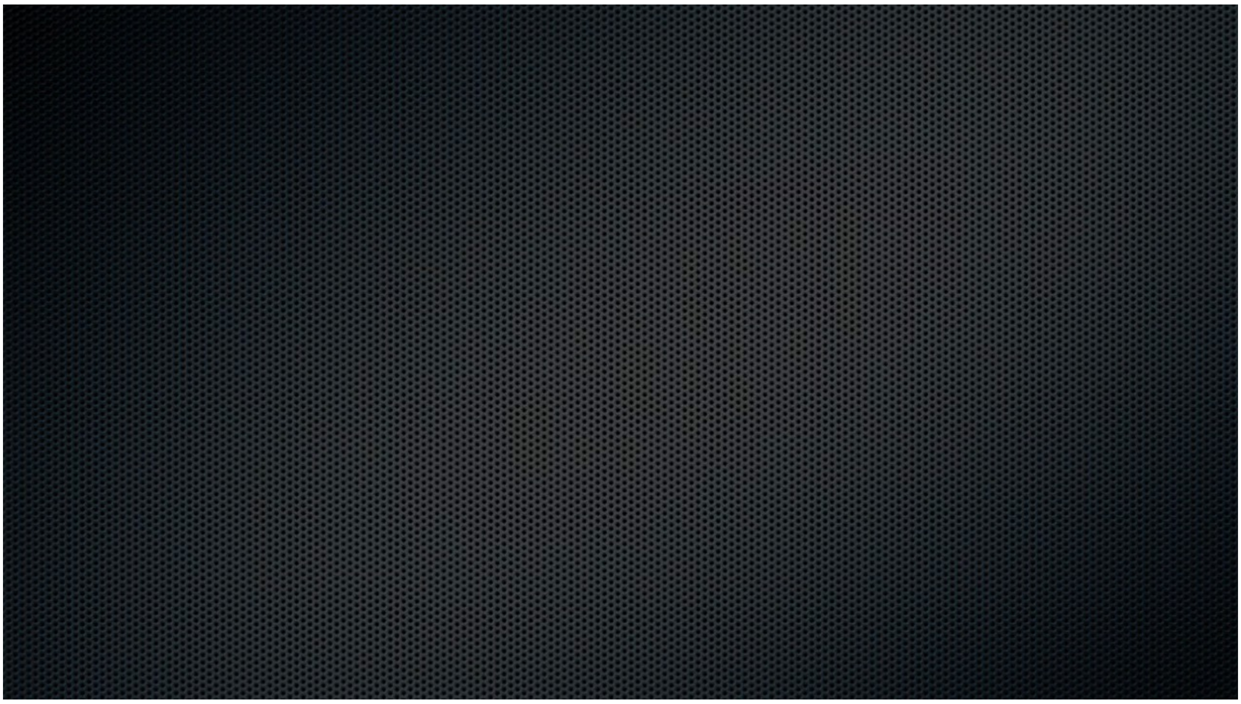
Smart shoes system
- Ground reaction force measurement
- Gait phase detection
- Ankle joint with one degree of freedom

Lower Limb Assistive Robot - LISSI - UPEC

Height	100~150 cm
Weight	10.7 kg
Maximum joint torque	25 Nm
Actuation module	Series Elastic Actuator
No. of sensors	8(FSR)+4(abs. enc.) + 6(inc. enc.) = 18
DAQ & control board	MyRIO-1900
Control	Position

Lower Limb Assistive Robot - LISSI - UPEC

Lower Limb Assistive Robot - LISSI - UPEC



L’acquisition de l’exosquelette Atalante par Henri-Mondor - l’action du collectif #ProtegeTonSoignant

- L’exosquelette permet aux soignants de faire remarcher des patients très tôt après leur sortie des soins intensifs et à tous les stades de la rééducation (Société Wandercraft)
- Budget: 175 K€