Rehabilitation robotics using Central Pattern Generators

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ENSIMAG	: Florence MARANINCHI		Final Presentation
			June 25th ,2010

Plan

- ▸ **Project context : BioRob Lab & LSRO**
- ▸ **Goals of the project**
- ▸ **Presentation of the Adaptive oscillators**
- ▸ **Presentation of the Knee-orthosis**
- ▸ **SIMULINK modeling**
- ▸ **Work on the Knee-orthosis**
  - ▸ Transparent mode
  - ▸ Integration of the adaptive oscillators
  - ▸ Results and discussion
- ▸ **Conclusion and future work**

Biorobotics & LSRO Lab

Goal :

To provide a new rehabilitation method to disabled persons

Goal :

Conception of locomotor re-education and walking assistance devices

Rehabilitation robotics

It is an application of engineering to design and develop technological solutions for people suffering from movement disorders
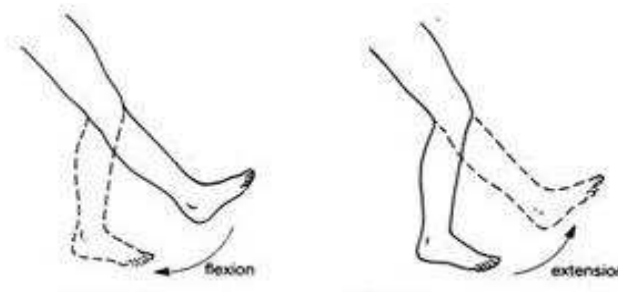
▸ **Issue**

▸ **Solution**
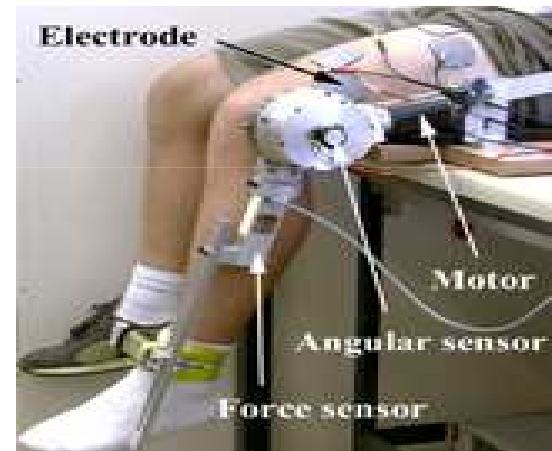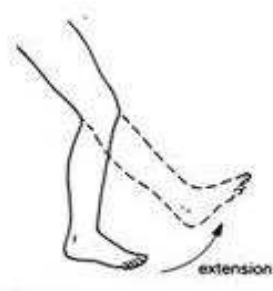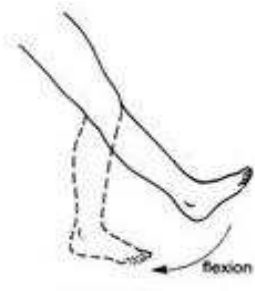
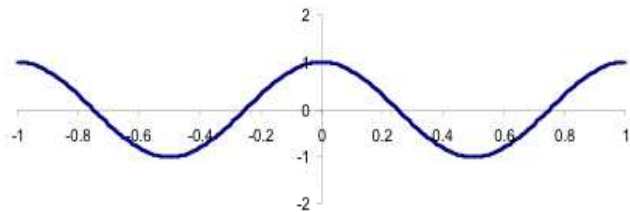# Goals of the project

Autonomy

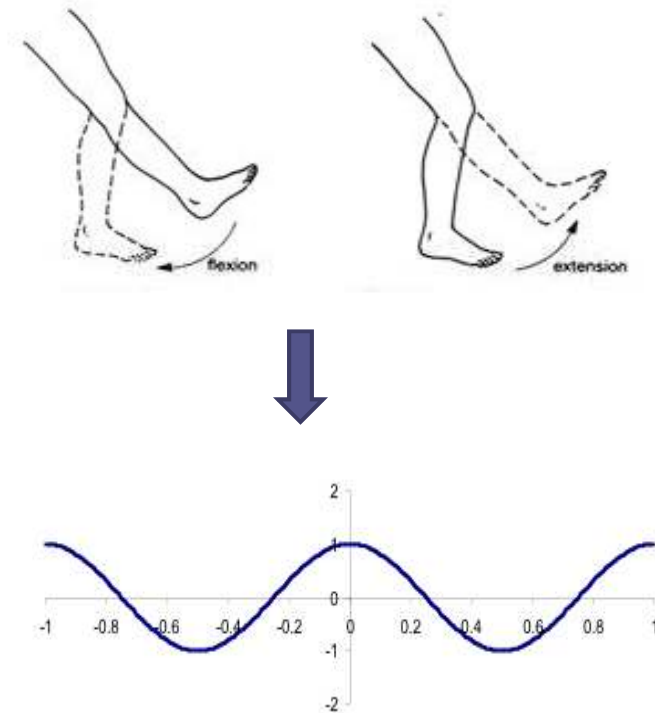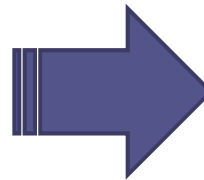
Movement

Goals of the project

Autonomy
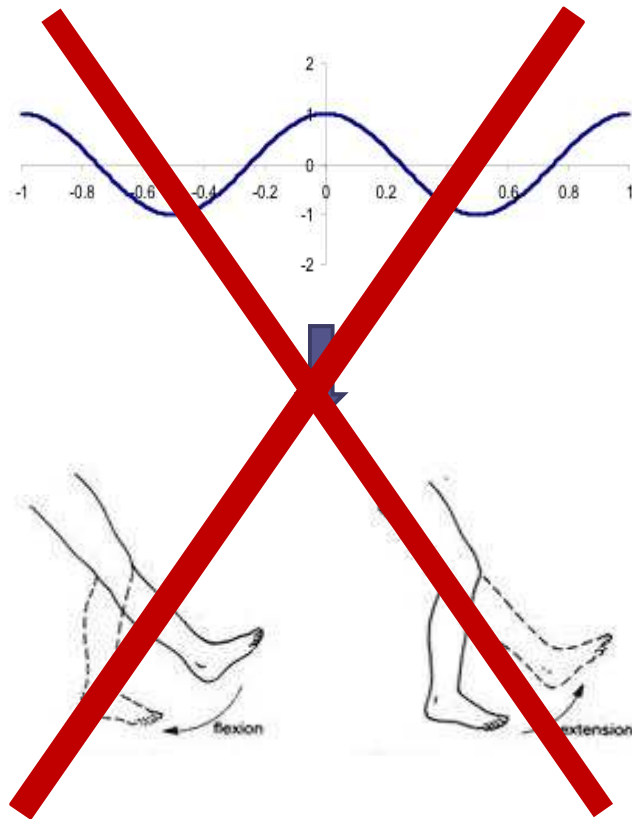
Goals of the project

Movement

Goals of the project

Movement
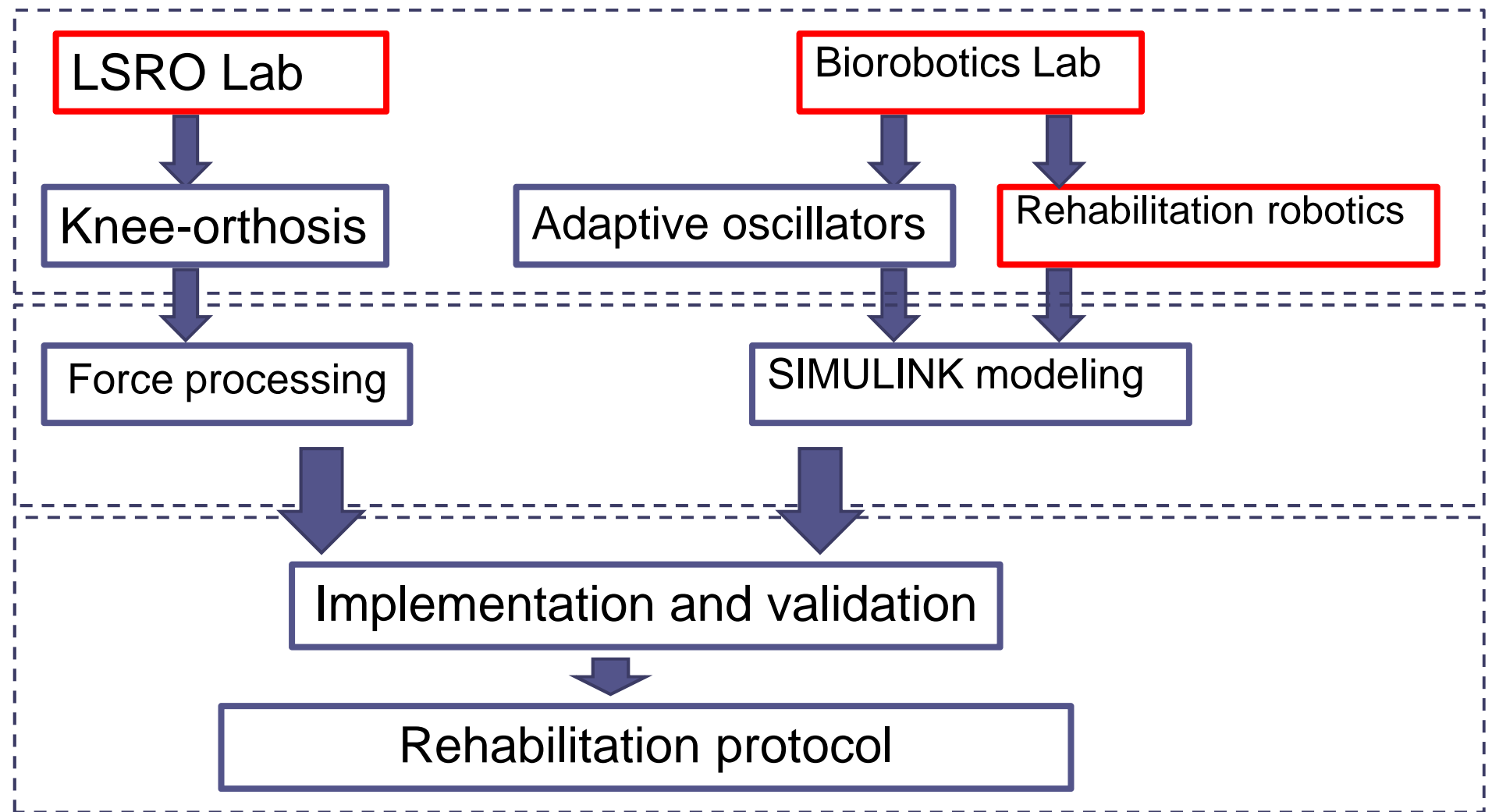
Goals of the project

1) Investigation of a rehabilitation protocol based on the theory of adaptive oscillator.

2) Implementation of the method on the Knee orthosis

3) Test of the method with various movements

4) Validation of the method on healthy people

General Project Schema

General Project Schema
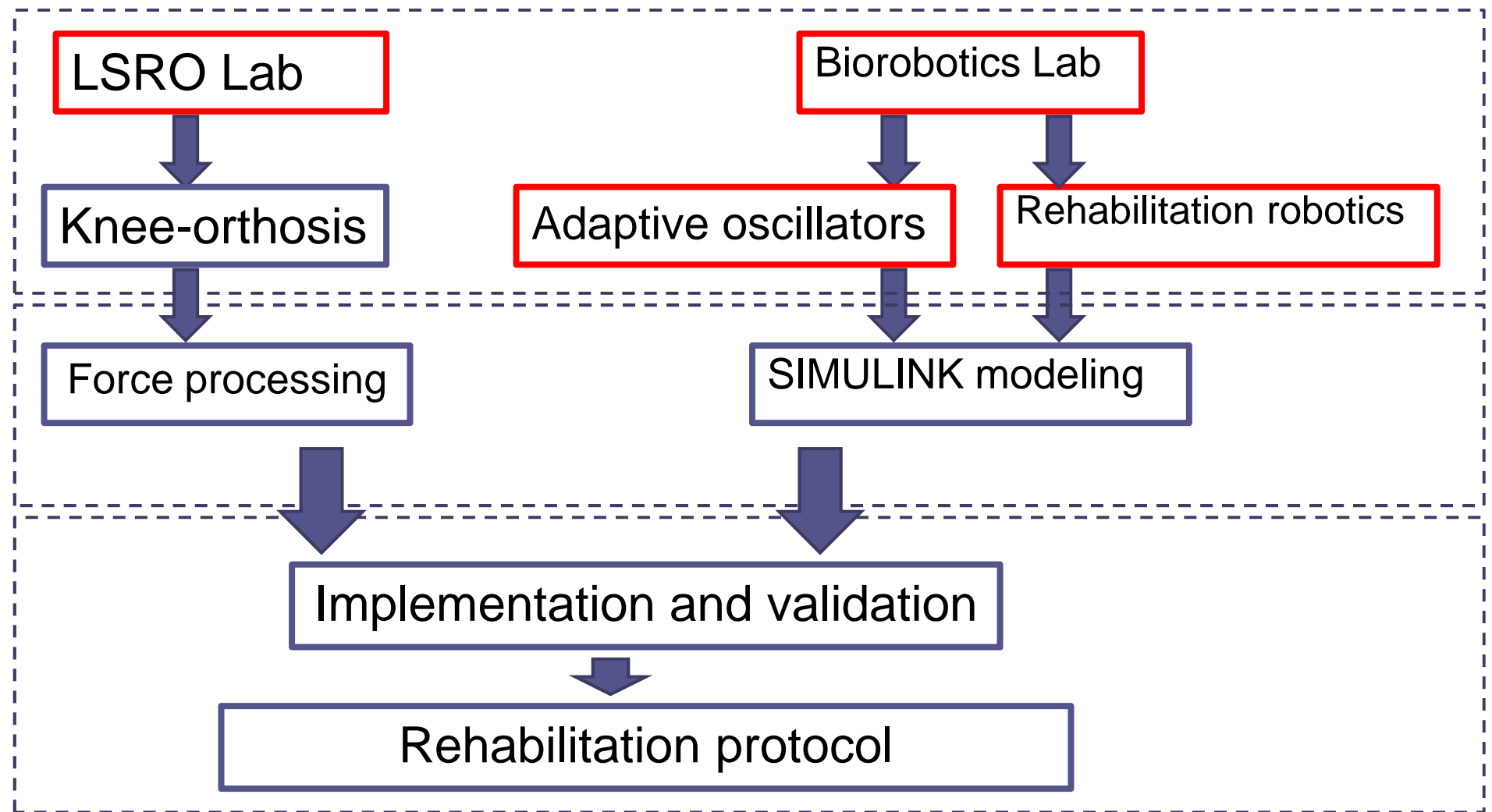
Adaptive oscillators

▸ Used in the context of <u>rhythmic movement</u> assistance

▸ Predict the state evolution in <u>real-time (without delay)</u>

▸ Modified Hopf oscillator

$$\dot{x} = \gamma(\mu - (x^2 + y^2))x - \omega y + \epsilon F(t)$$
$$\dot{y} = \gamma(\mu - (x^2 + y^2))y + \omega x$$
$$\dot{\omega} = -\epsilon F(t)\frac{y}{\sqrt{x^2 + y^2}}$$

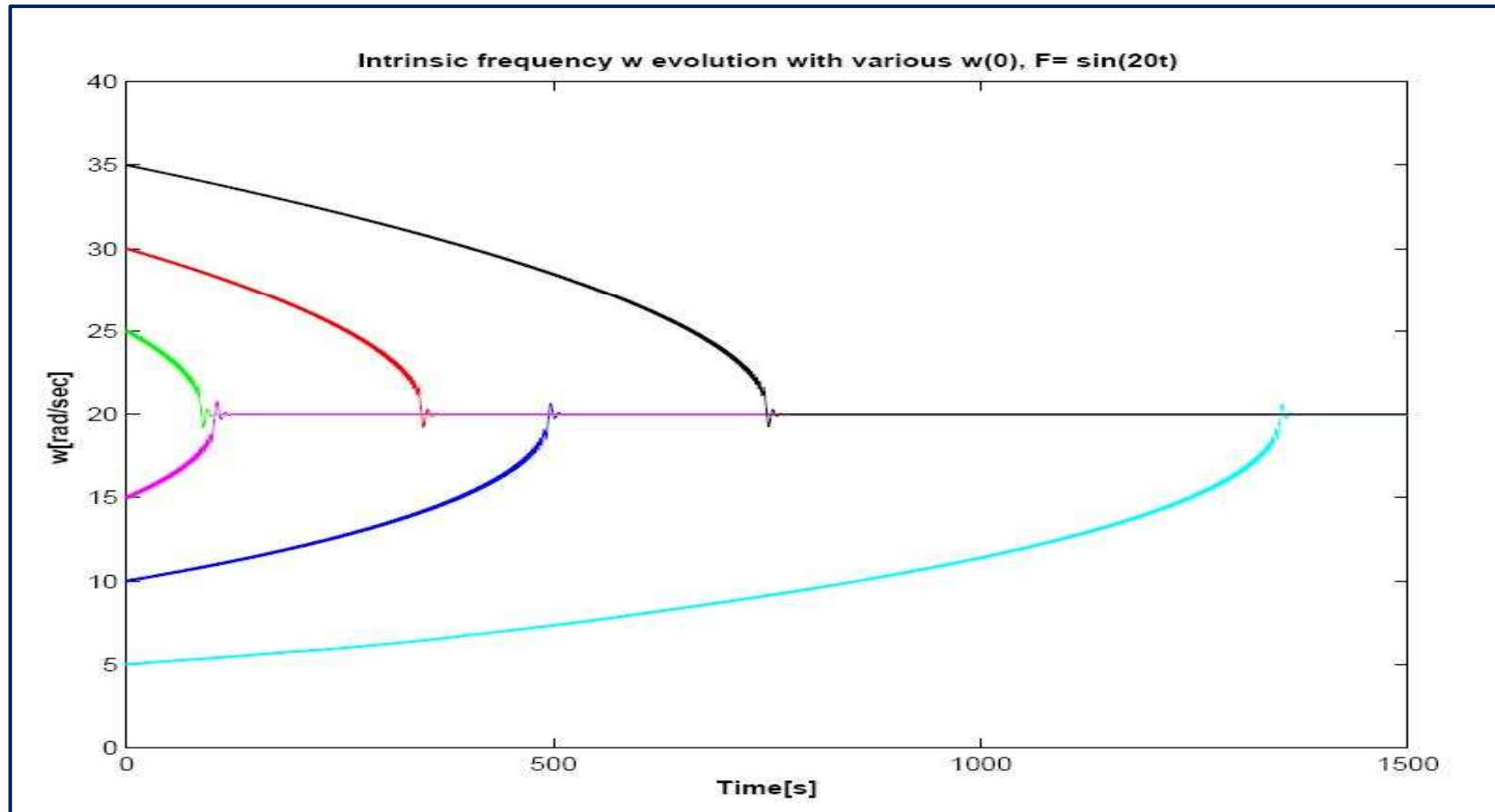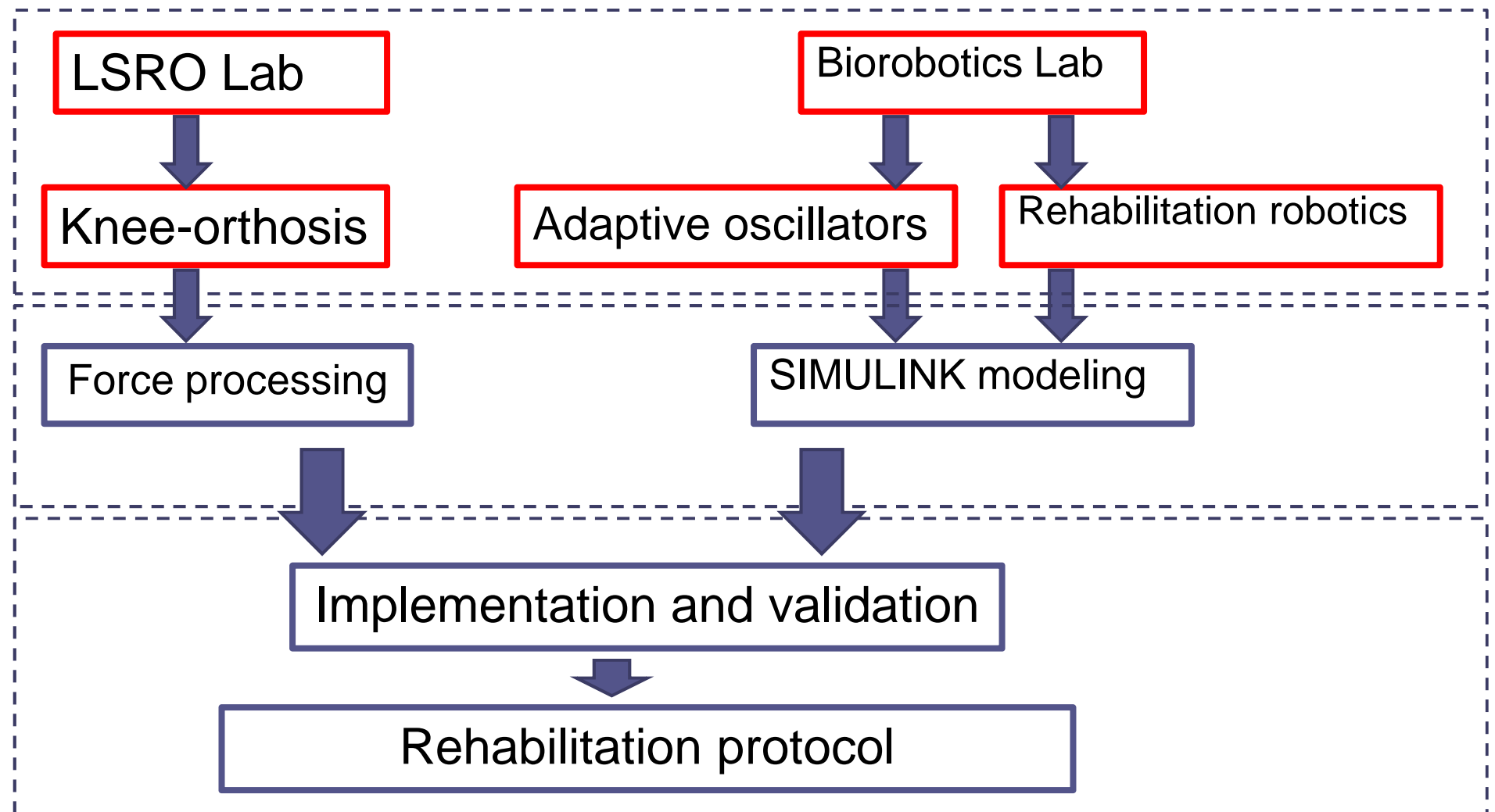# Adaptive oscillators

Signal F(t) = sin (20t)

Intrinsic frequency w evolution with various w(0), F= sin(20t)

General Project Schema

```
LSRO Lab                              Biorobotics Lab

   │                              │              │
   ▼                              ▼              ▼

Knee-orthosis          Adaptive oscillators    Rehabilitation robotics

   │                              │              │
   ▼                              ▼              ▼

Force processing              SIMULINK modeling

   │                              │
   ▼                              ▼

        Implementation and validation

                     │
                     ▼

        Rehabilitation protocol
```
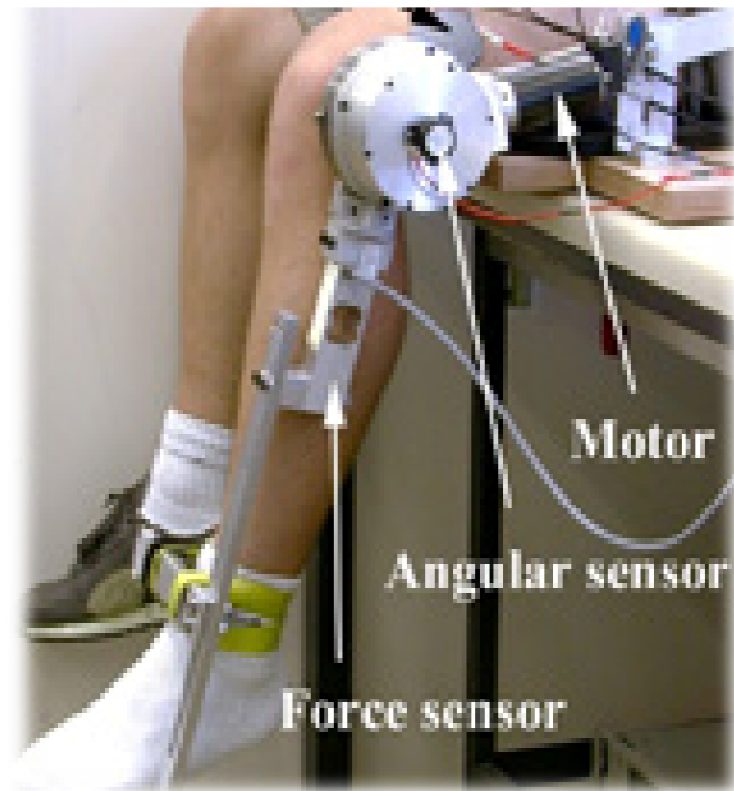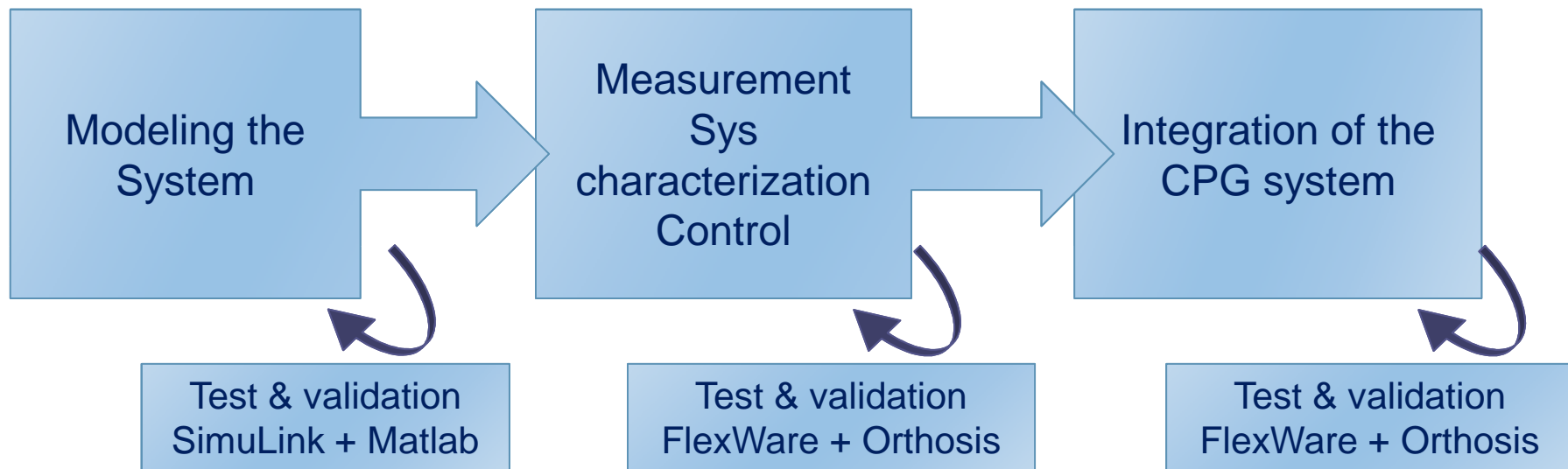
Environment : Knee Orthosis

▸ Rehabilitation robot

▸ One degree of freedom

▸ Position and force sensors

Torque Γ → | Knee Orthosis | → **Orthosis Position**

→ **Measured force**

Timeline

| Modeling the System | → | Measurement Sys characterization Control | → | Integration of the CPG system |

Test & validation
SimuLink + Matlab

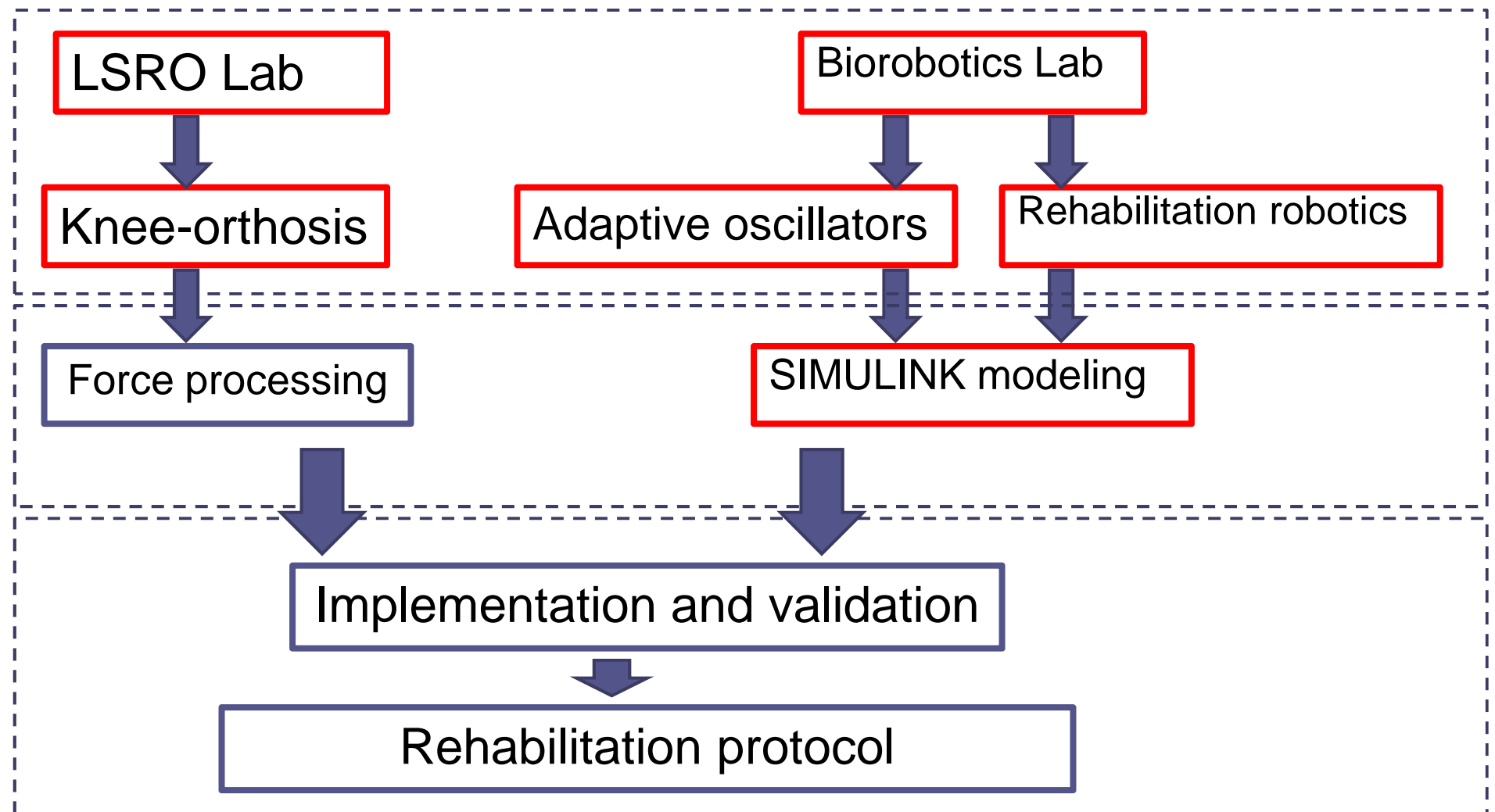Test & validation
FlexWare + Orthosis

Test & validation
FlexWare + Orthosis
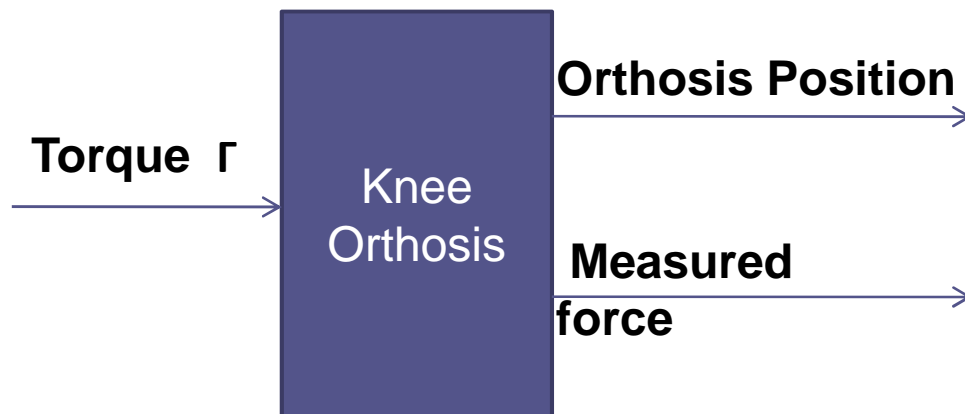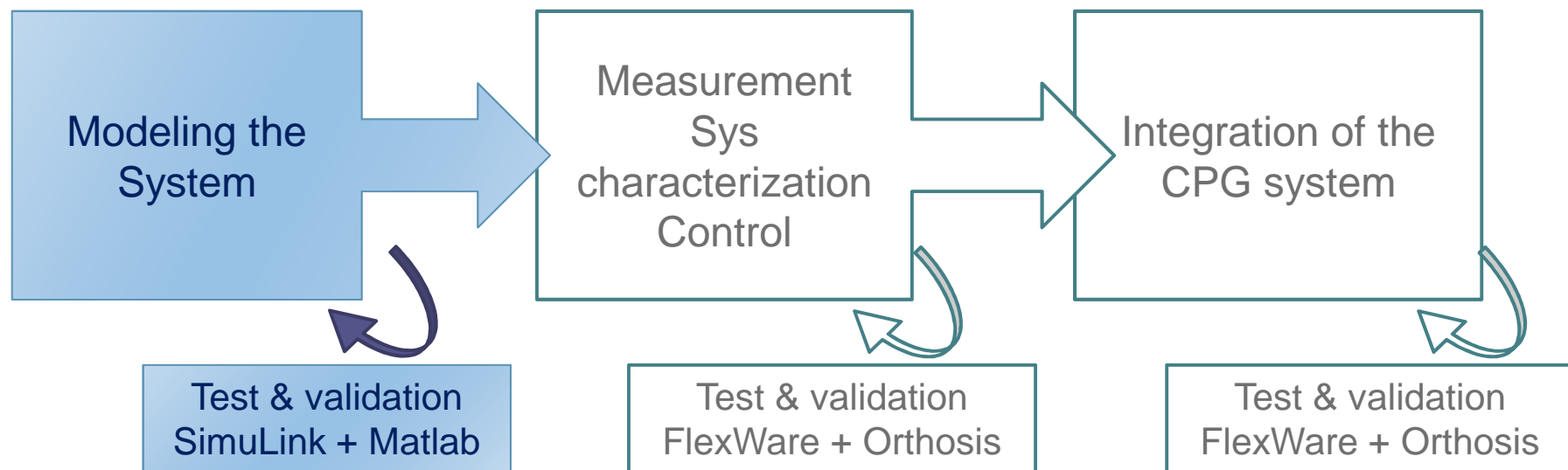
General Project Schema

Timeline : MatLab – Simulink implementation

Modeling the System

Measurement Sys characterization Control

Integration of the CPG system

Test & validation SimuLink + Matlab

Test & validation FlexWare + Orthosis

Test & validation FlexWare + Orthosis

Model and simulation

Measured force

Desired Force

Force controller

Electrode

Motor

Angular sensor

Force sensor

Measured position

Adaptive oscillator

$$\dot{x} = \gamma(\mu - r^2)x - \omega y + \epsilon F(t)$$
$$\dot{y} = \gamma(\mu - r^2)y + \omega x$$
$$\dot{\omega} = -\epsilon F(t)(\frac{y}{r})$$
$$\dot{\alpha}_0 = \frac{\tau}{2}F(t)$$
$$\dot{\alpha}_1 = \tau x F(t)$$

Torque estimator

$$\hat{u} = mgl\sin(\hat{\theta}) + b\dot{\hat{\theta}} + I\ddot{\hat{\theta}}$$

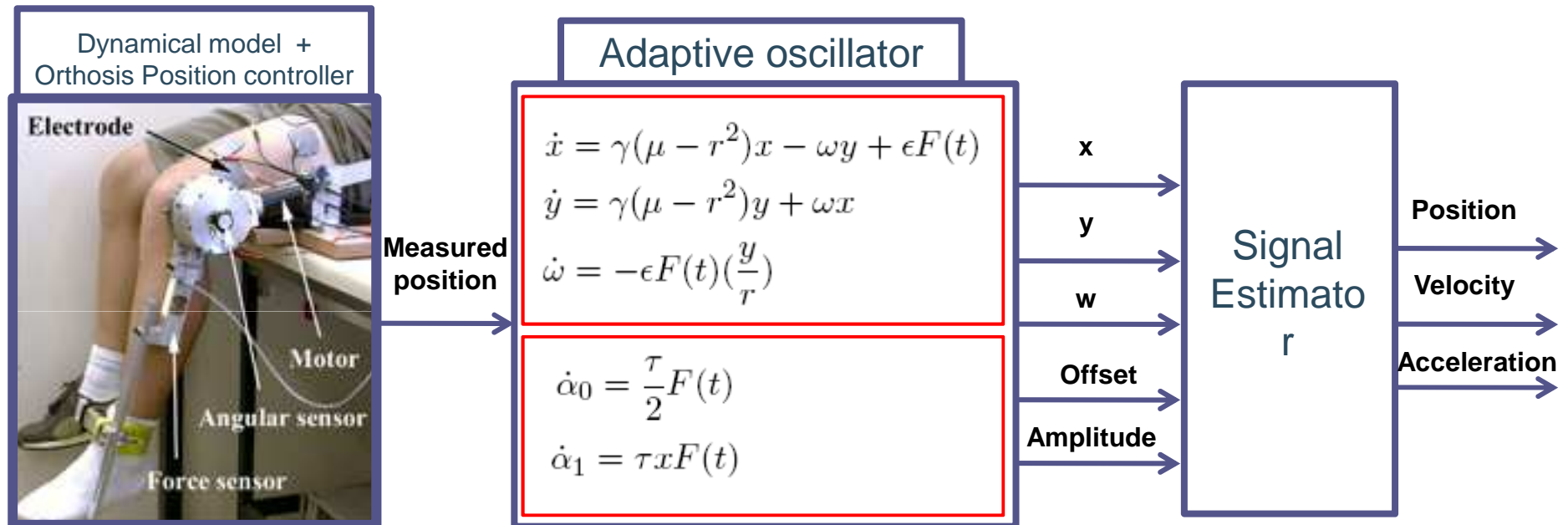**Signal estimation : position, velocity and acceleration**

Model and simulation
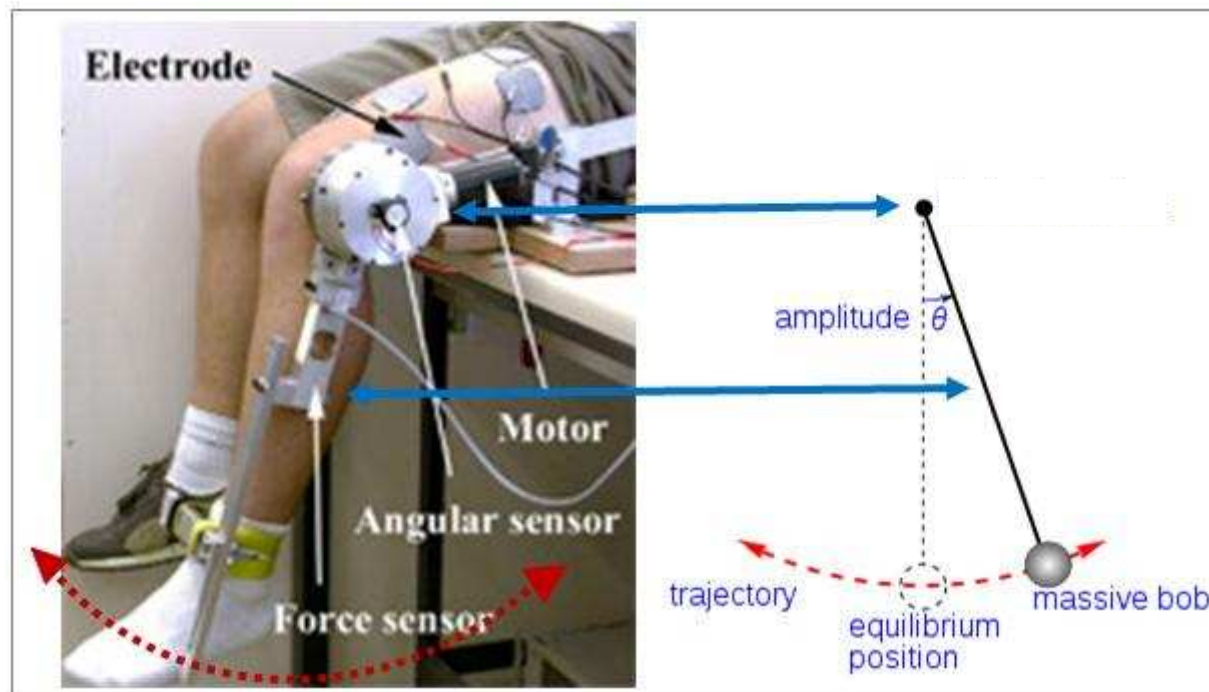
$$I\ddot{\theta} = -mgl\sin\theta - b\dot{\theta} + u$$

Torque

CPG & torque estimator

Dynamical model +
Orthosis Position controller

Electrode

Motor

Angular sensor

Force sensor

Measured position

Adaptive oscillator

$$\dot{x} = \gamma(\mu - r^2)x - \omega y + \epsilon F(t)$$
$$\dot{y} = \gamma(\mu - r^2)y + \omega x$$
$$\dot{\omega} = -\epsilon F(t)\left(\frac{y}{r}\right)$$

$$\dot{\alpha}_0 = \frac{\tau}{2}F(t)$$
$$\dot{\alpha}_1 = \tau x F(t)$$

x

y

w

Offset

Amplitude

Signal Estimator

Position

Velocity

Acceleration

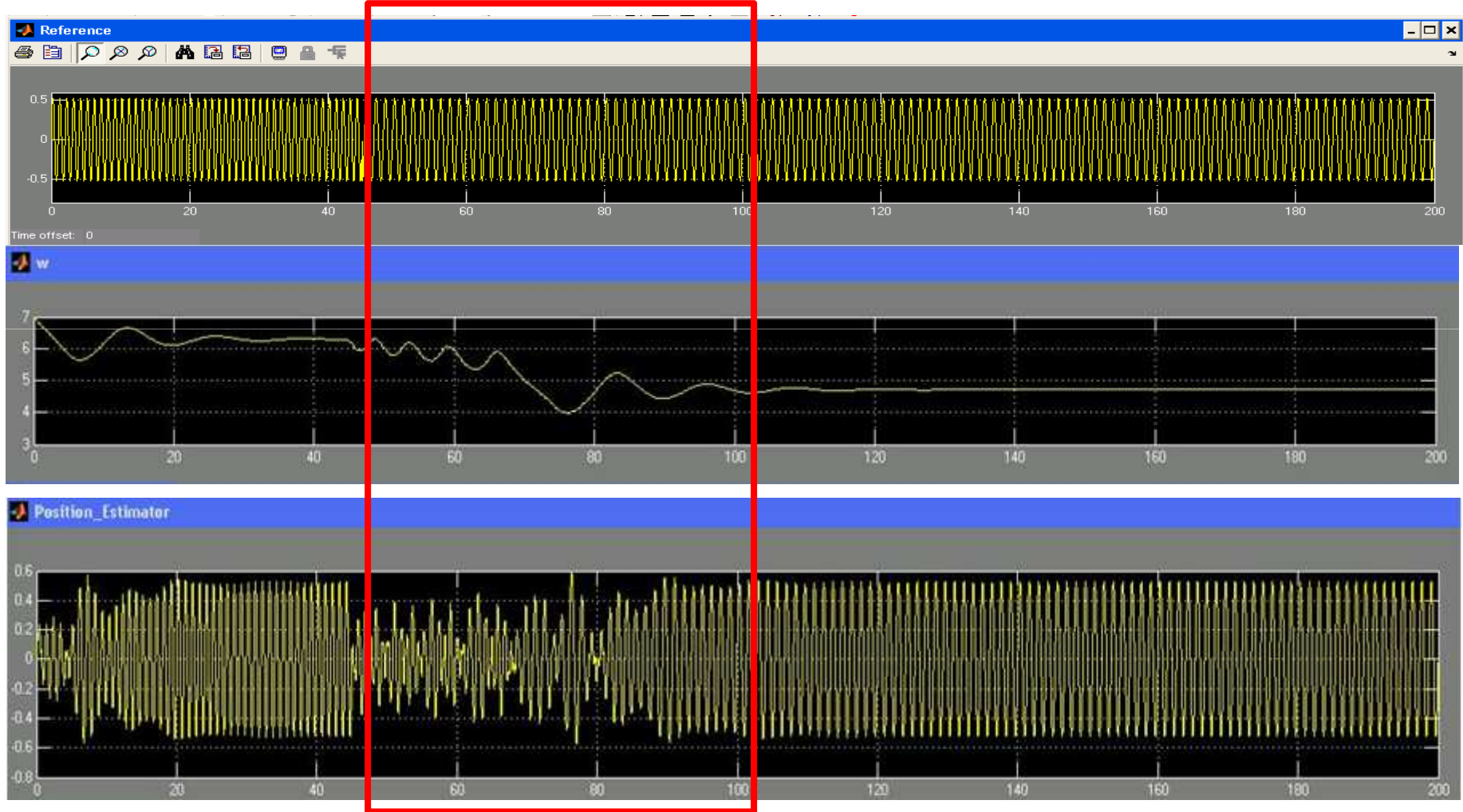# Simulation & results

$$\omega = 2\pi \quad \rightarrow \quad \omega = 1.5\pi$$

Simulation & results

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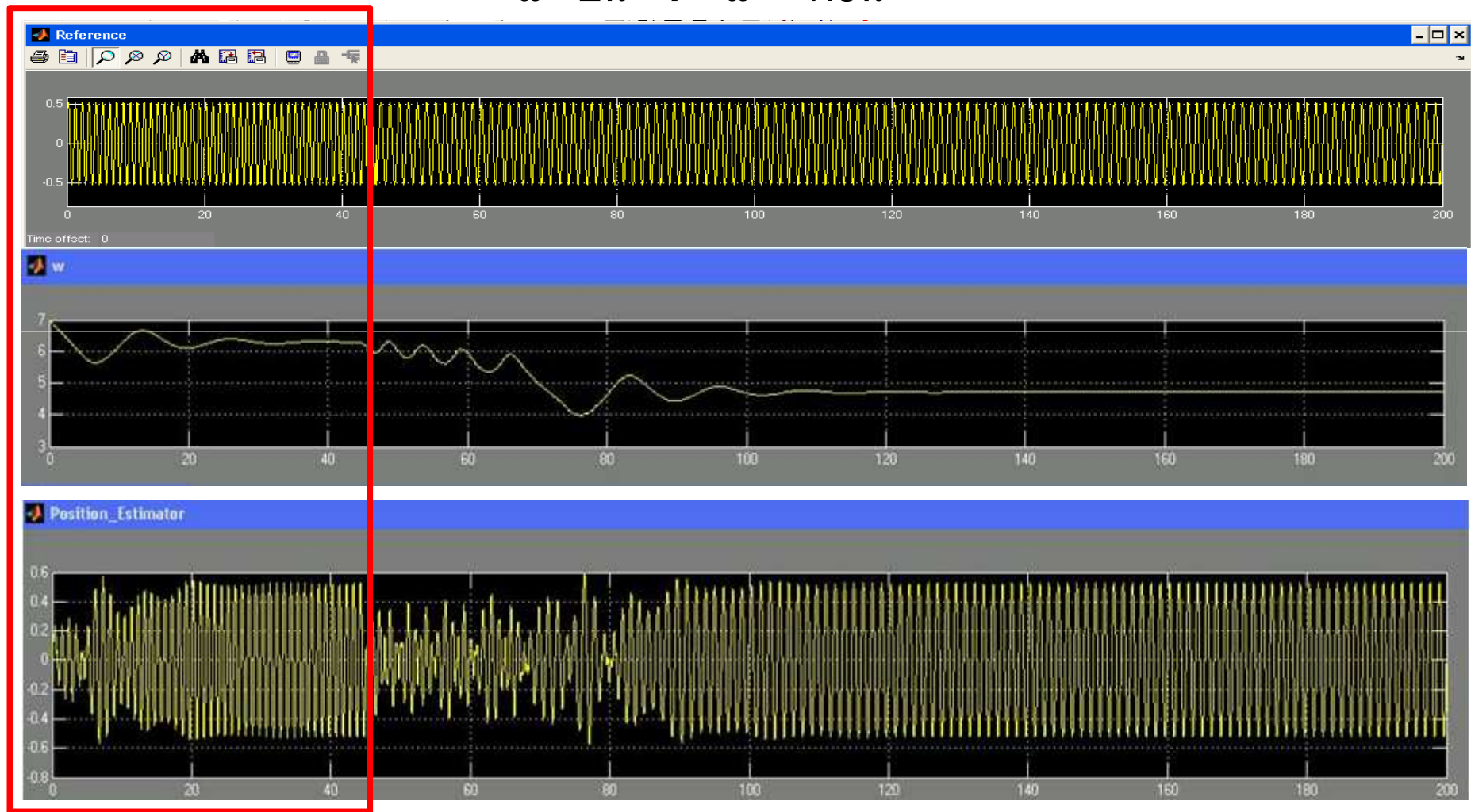
Simulation & results

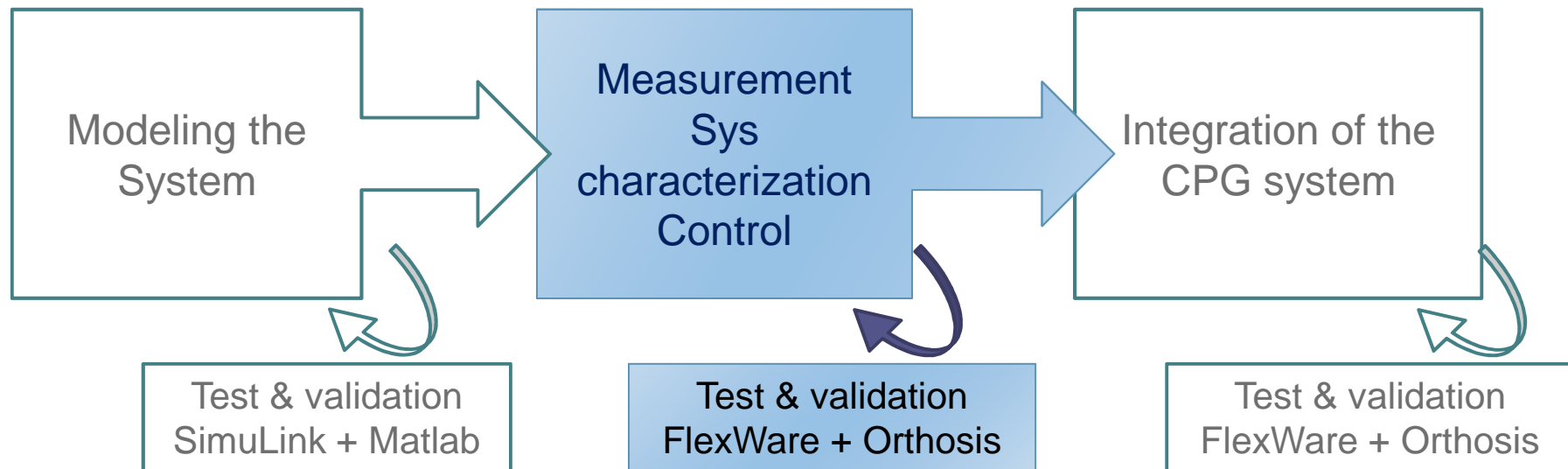$$\omega = 2\pi \quad \rightarrow \quad \omega = 1.5\pi$$
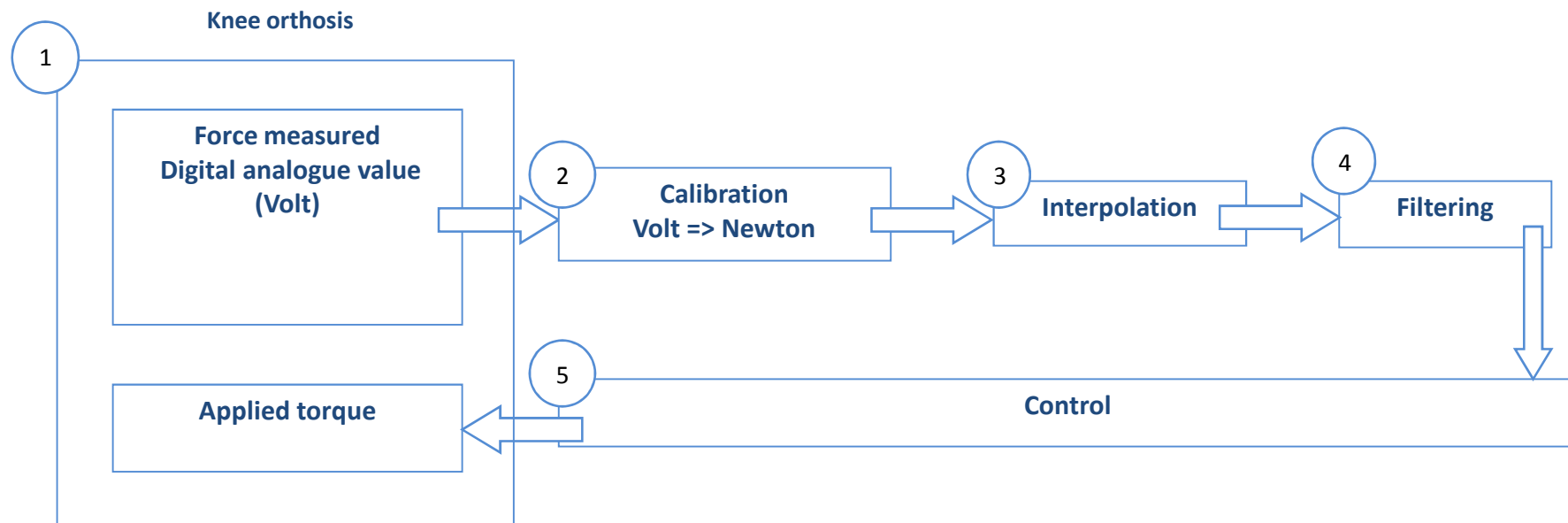
General Project Schema

Timeline: Force

Modeling the System	→	Measurement Sys characterization Control	→	Integration of the CPG system

Test & validation
SimuLink + Matlab

Test & validation
FlexWare + Orthosis

Test & validation
FlexWare + Orthosis
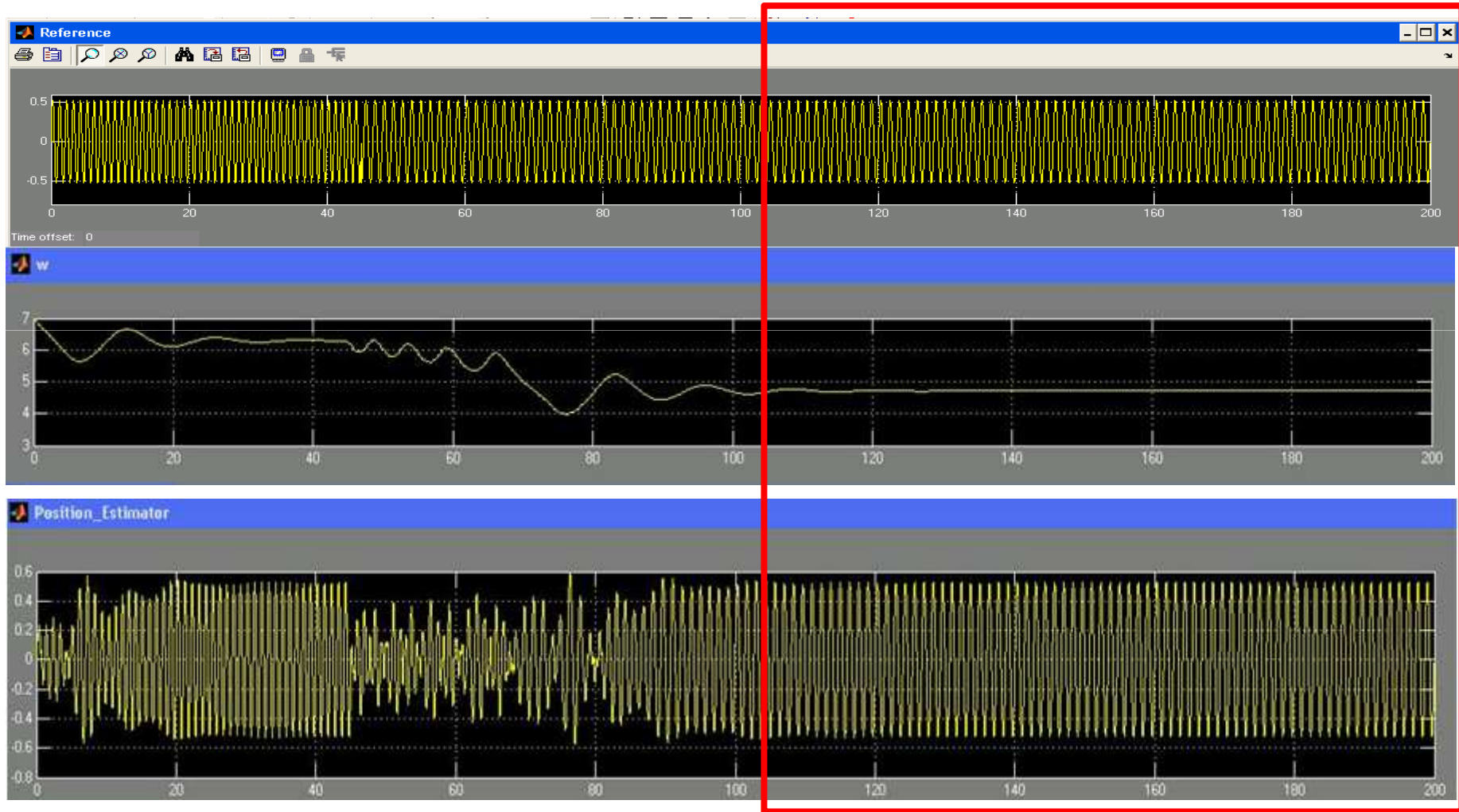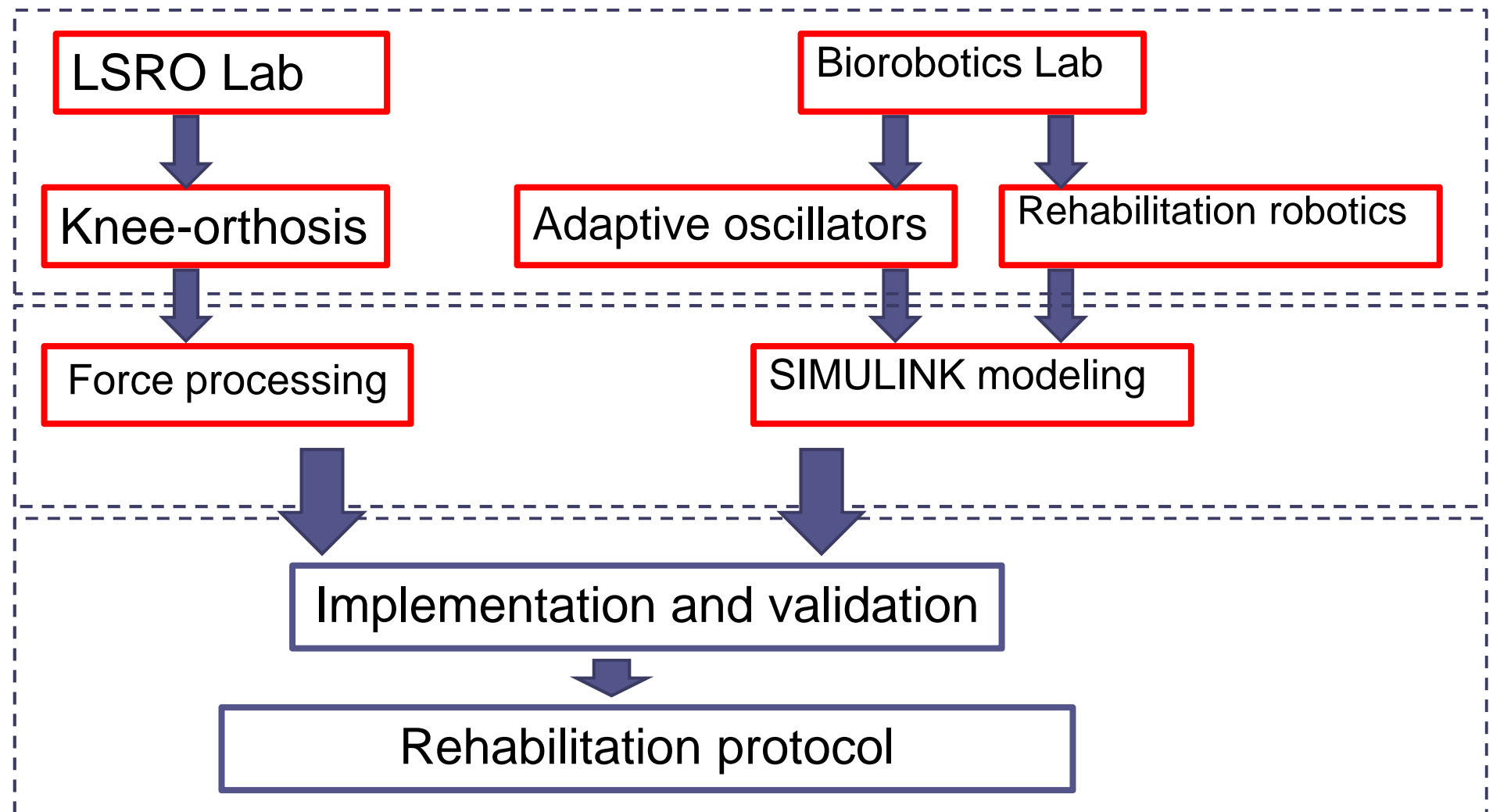
Implementation: Transparent mode

▶ 1st Objective:

      Make the orthosis transparent for the user

▶ 5 Steps :

Knee orthosis

① → **Force measured Digital analogue value (Volt)** → ② **Calibration Volt => Newton** → ③ **Interpolation** → ④ **Filtering**

⑤ → **Applied torque** ← **Control**
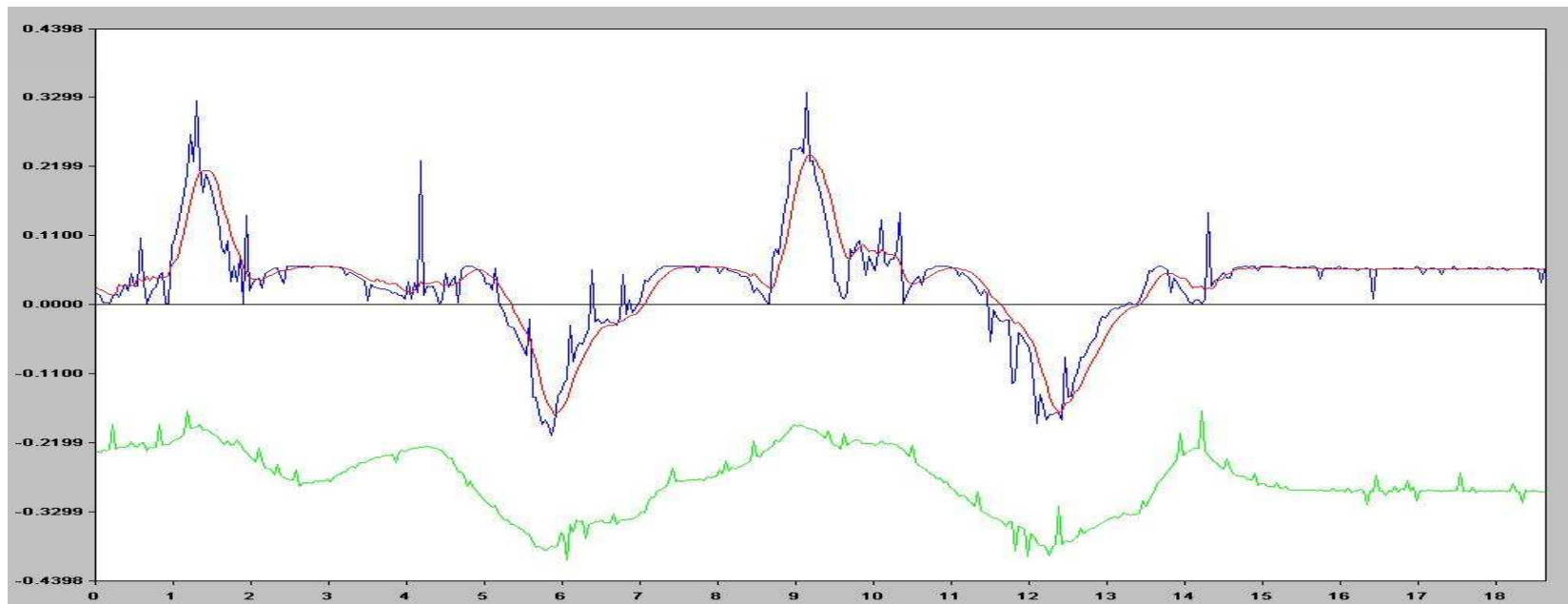
Calibration, Interpolation and filter
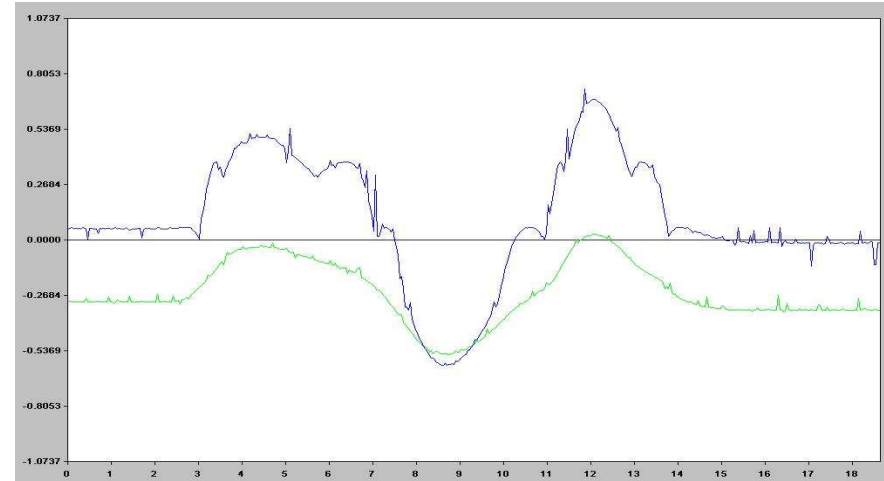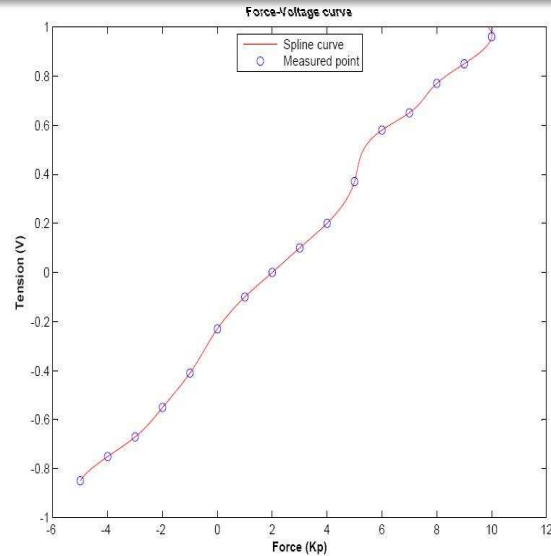
Using the following filter : $\tau = \dfrac{1}{B_p}$ ➡ $B_p = 20\ \text{Hz}$

$$\frac{y_f}{y} = \frac{1}{1 + \tau s} \quad \Longrightarrow \quad y_f = \frac{\tau}{T_e + \tau}\, y_f^- + \frac{T_e}{T_e + \tau}\, y$$
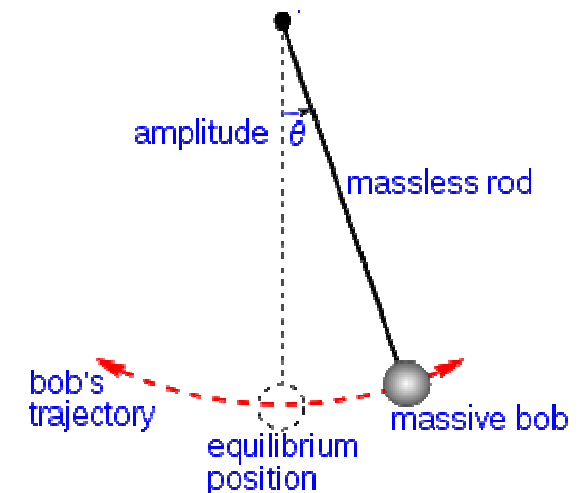
Implementation: Filtering

Using the following filter : $\quad \tau = \dfrac{1}{B_p} \quad \Longrightarrow \quad B_p = 20 \text{ Hz}$

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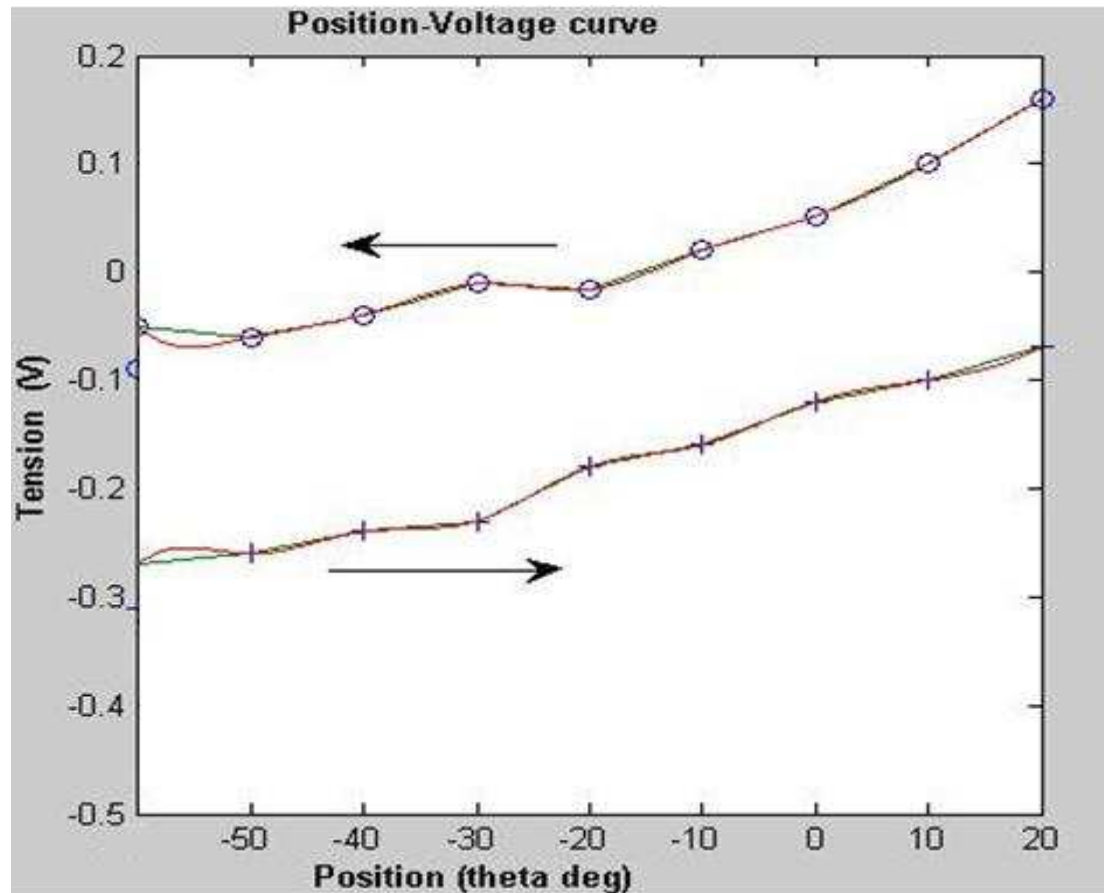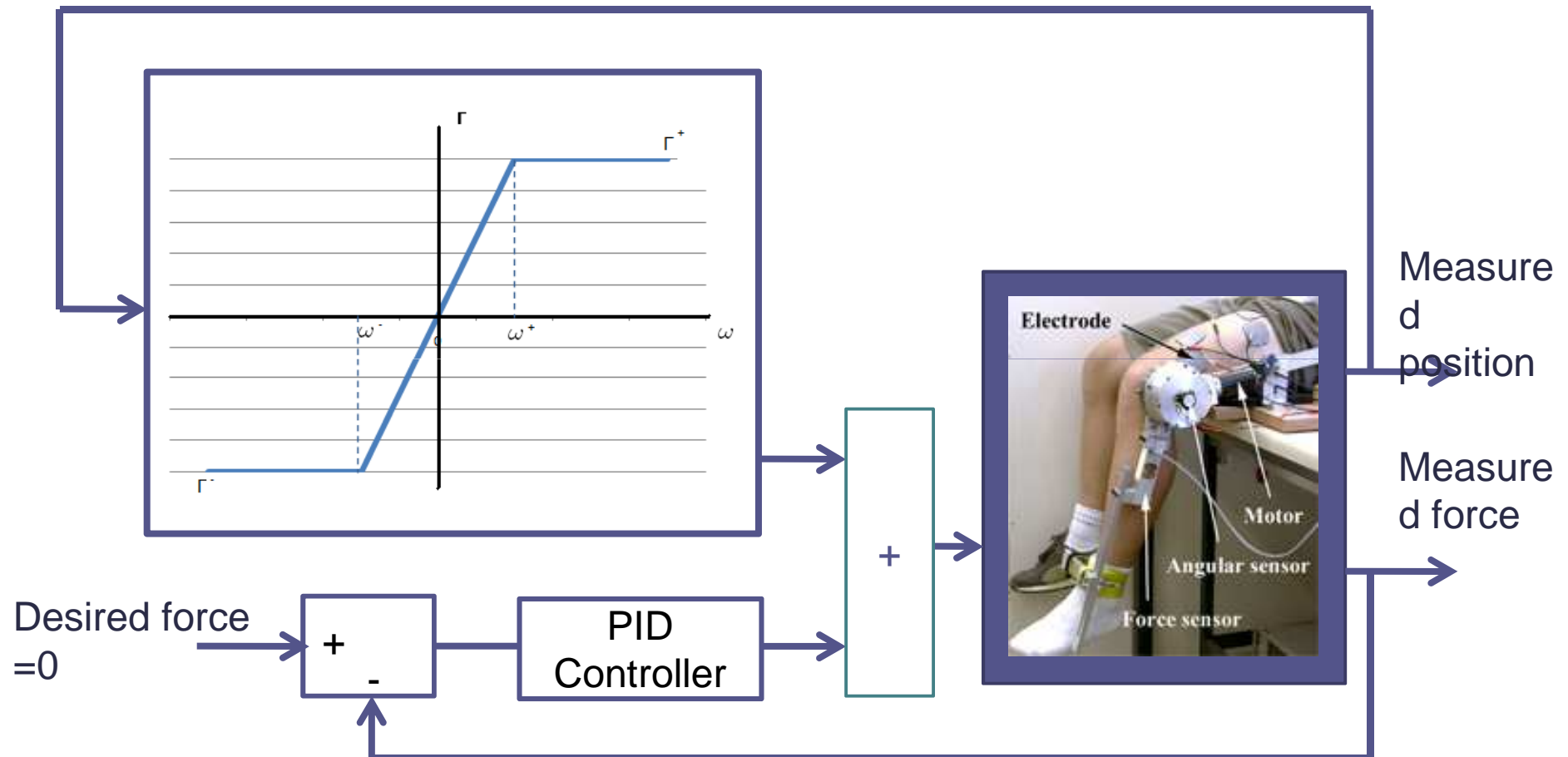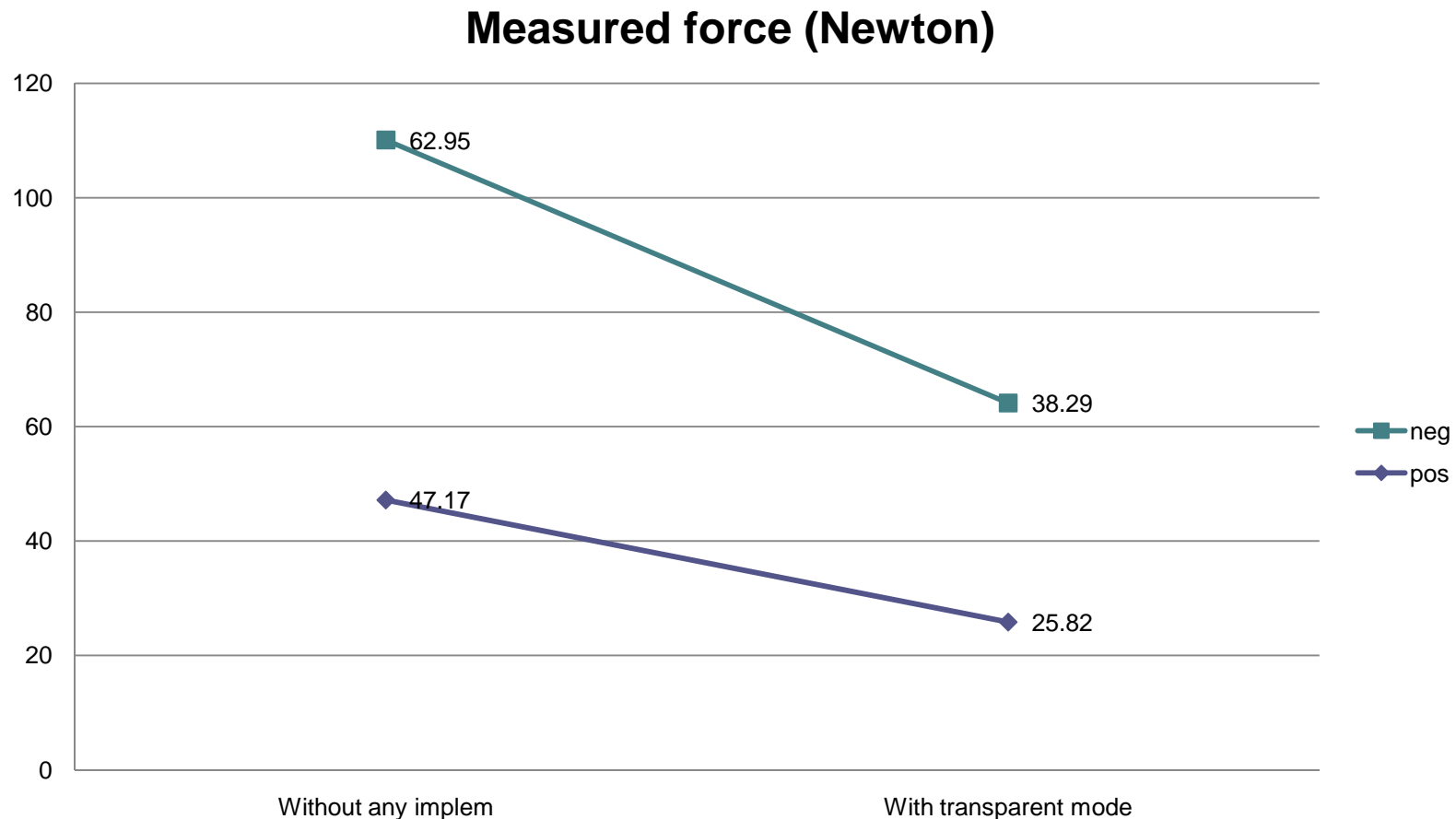
Implementation: Transparent mode

Measuring the stabilization tension for a set of position

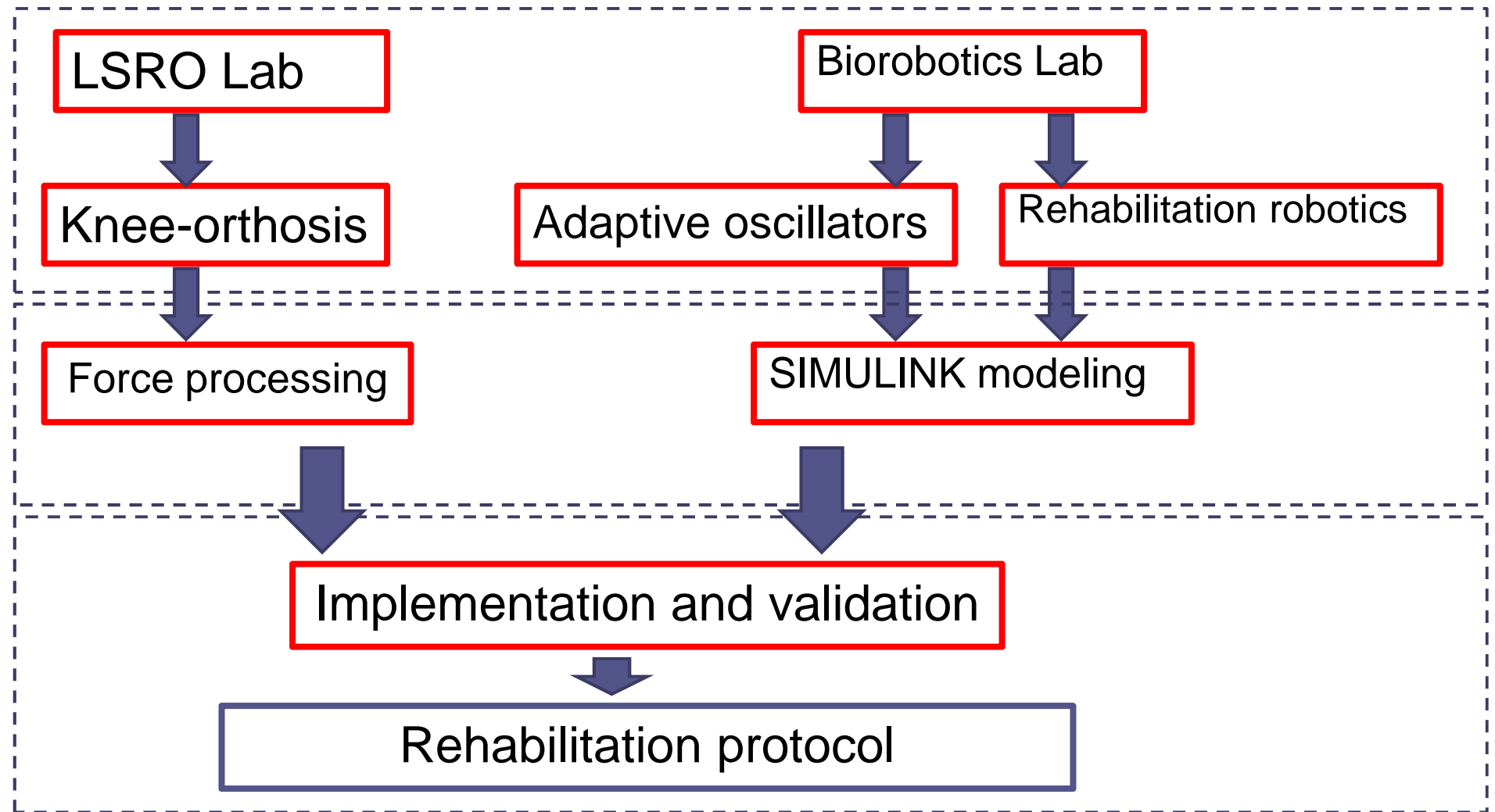# Implementation: Transparent mode
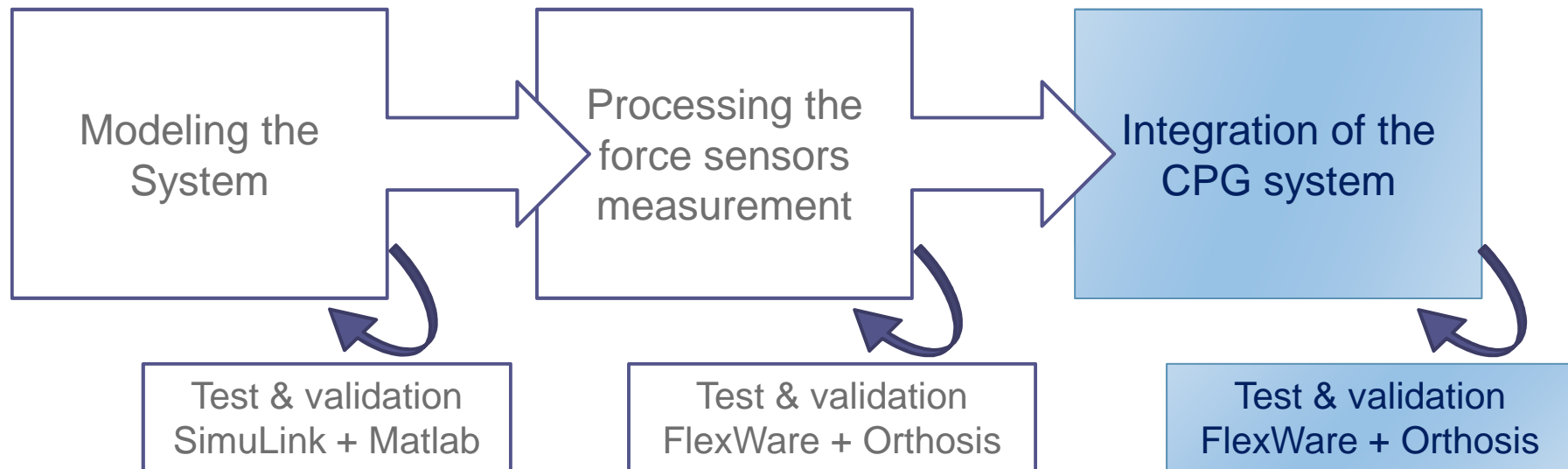
Validation of the transparent mode

Measured force (Newton)

General Project Schema

Timeline : Integrating CPG

Modeling the System

Processing the force sensors measurement

Integration of the CPG system

Test & validation
SimuLink + Matlab

Test & validation
FlexWare + Orthosis

Test & validation
FlexWare + Orthosis

Validation of the oscillator block
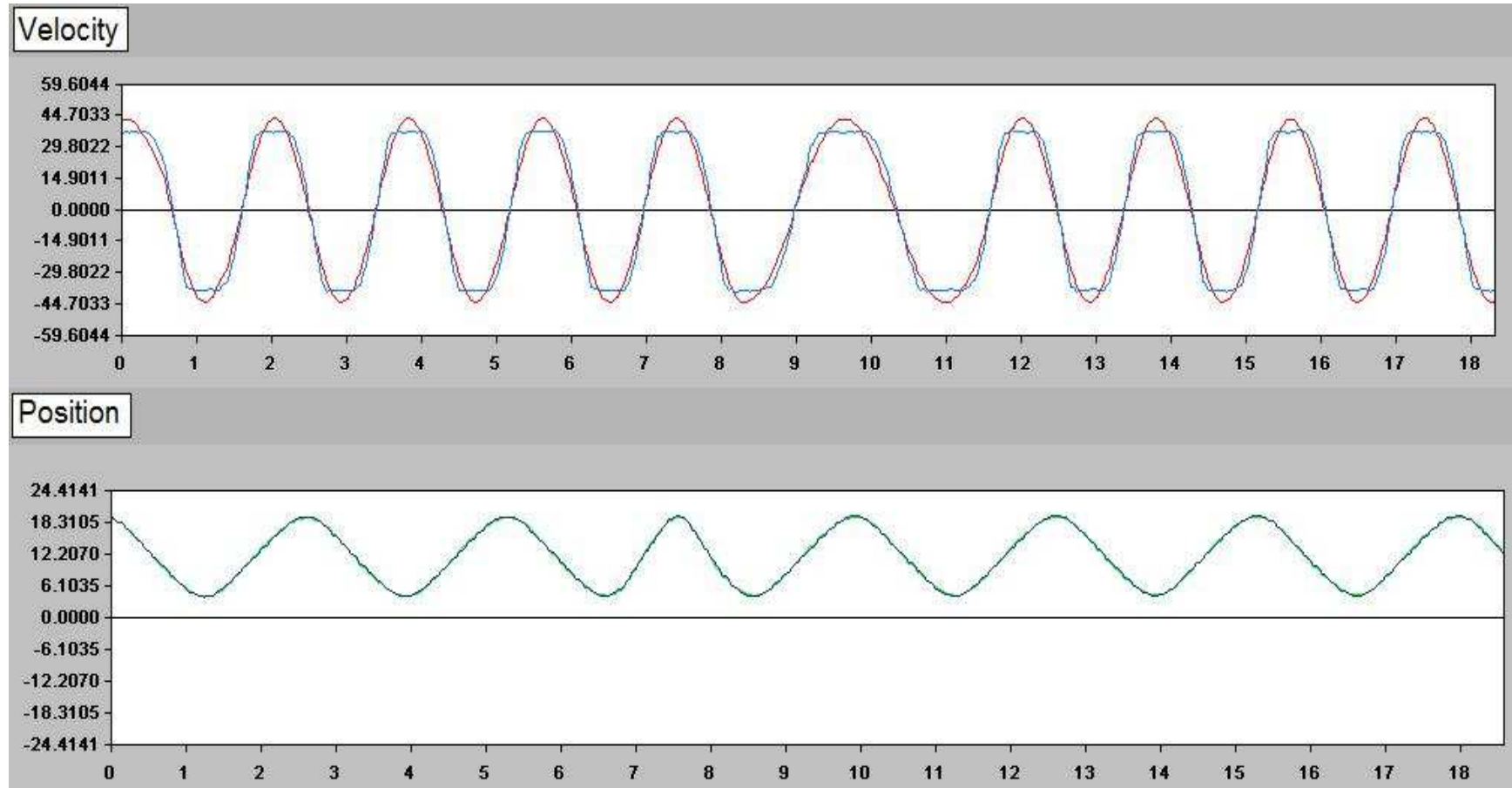
Validation of the system

Measured force (Newton)

62.95

38.29

47.17

25.82

18.29

10.61

Without any implem

With transparent mode

With force controller and assistance K= 0.5

- Extension
- Flexion

Human effort

24.66

21.35

0

-15.25

-20

Without any implem

With transparent mode

With force controller and assistance K= 0.5

- Extension
- Flexion
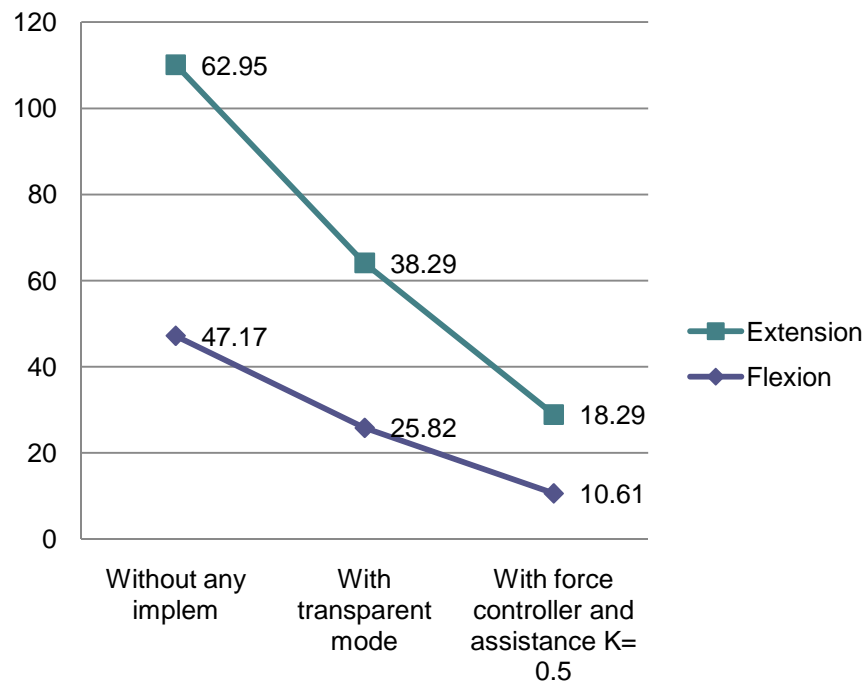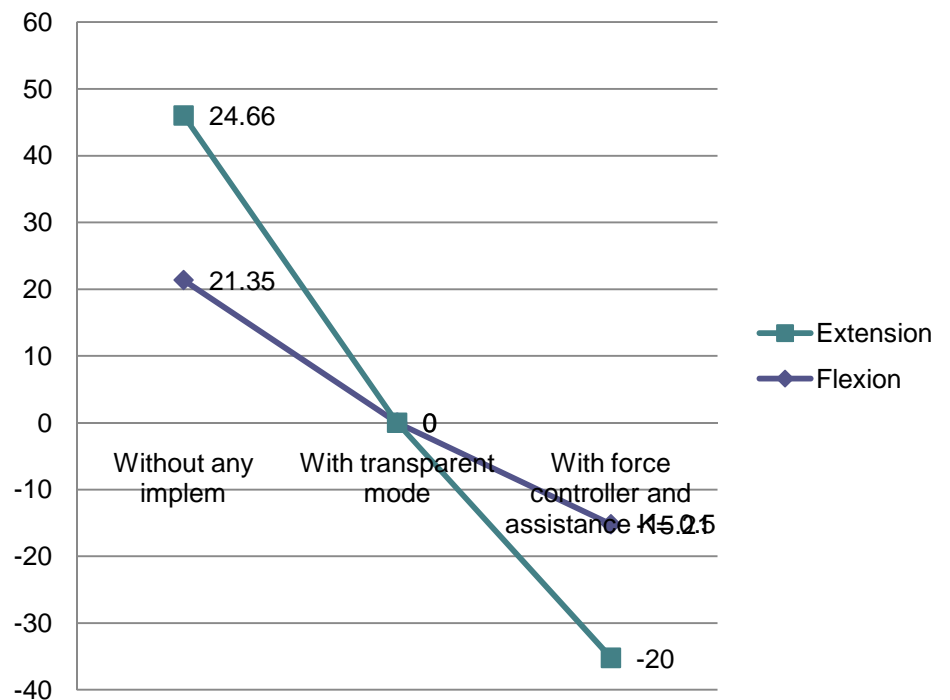
DEMO

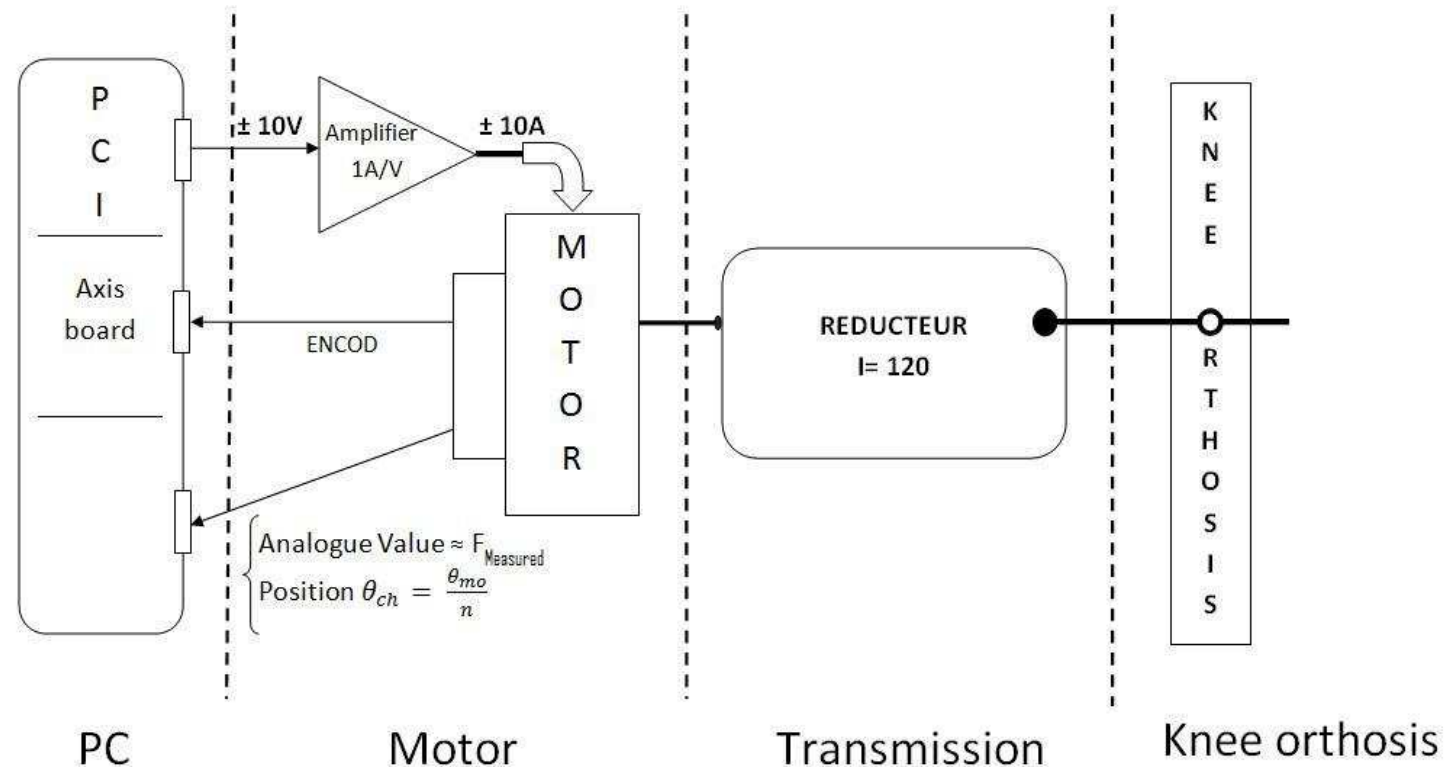# Future work

- ▸ Test of the method with various movements

- ▸ Validation of the method on healthy people

- ▸ Work on the LAMBDA robot offering 3 DOF

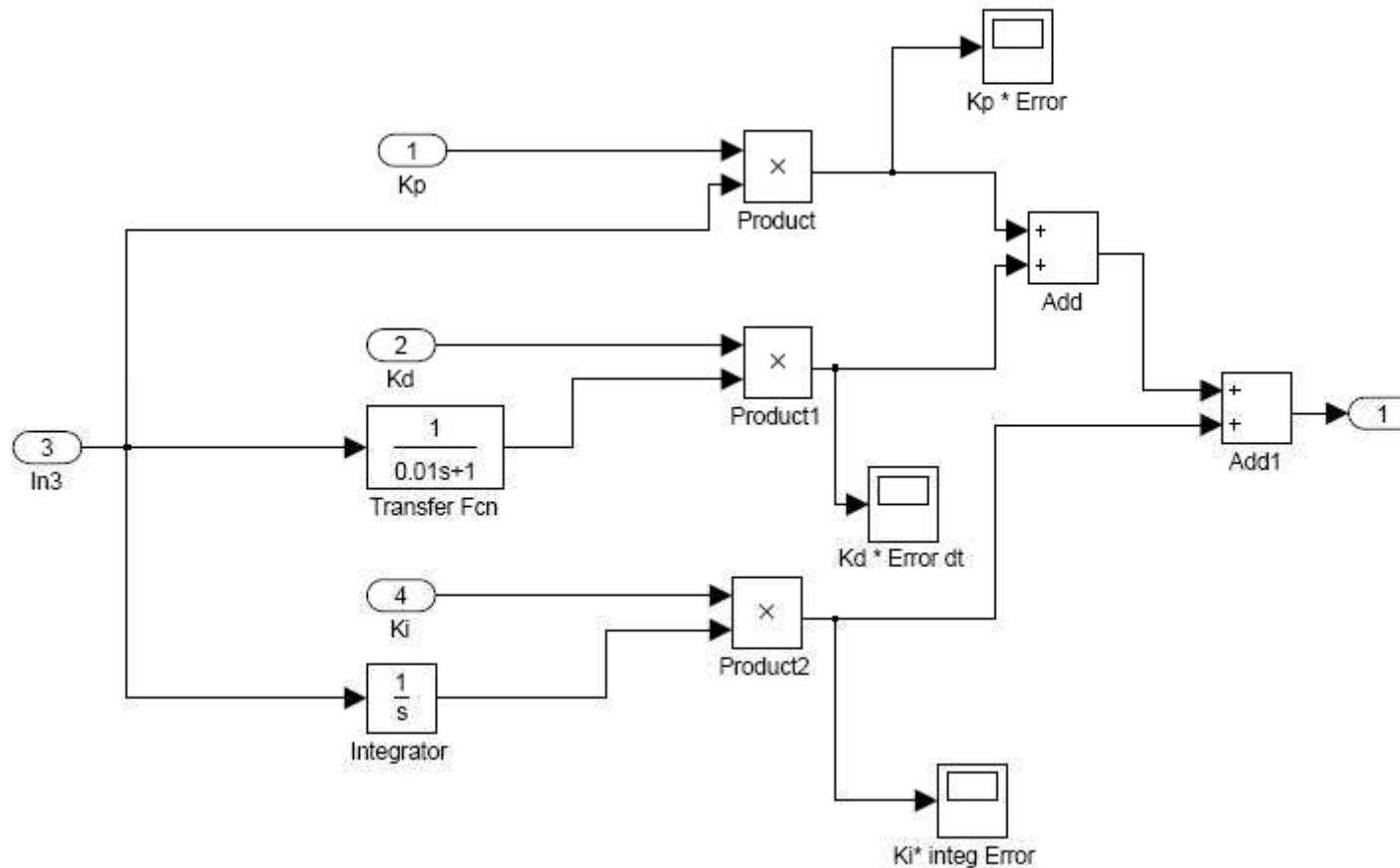- ▸ Design of a preliminary rehabilitation protocol.

Questions ?

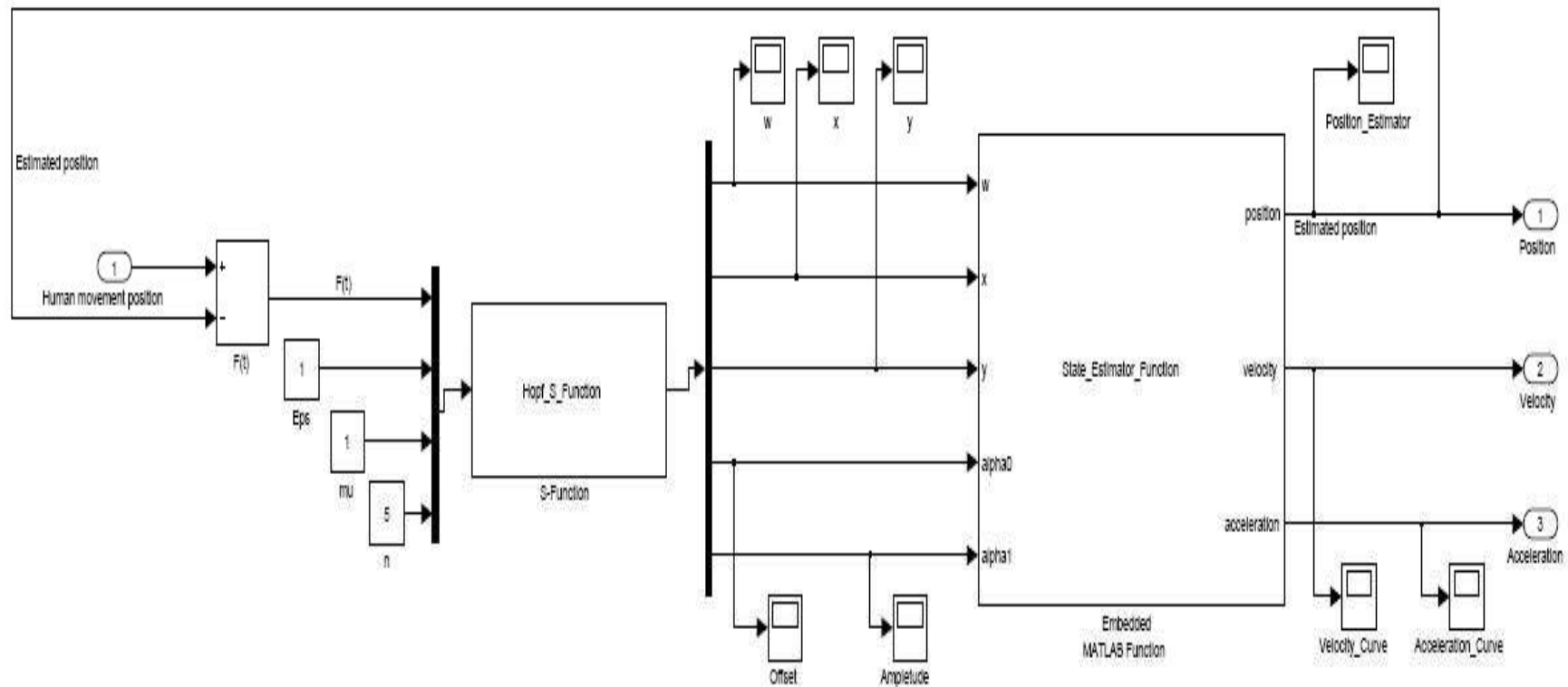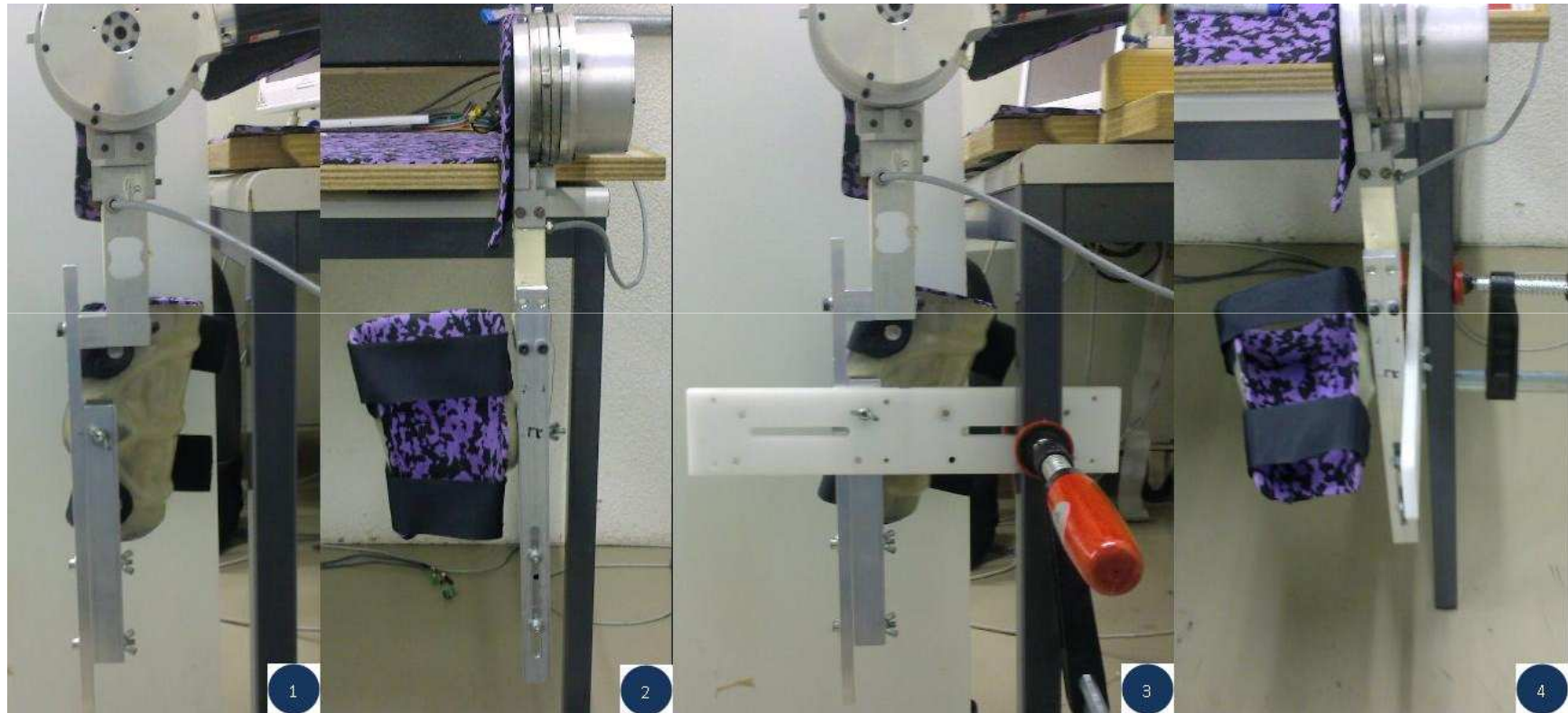## Additional slide [1] : Schema of the Knee orthosis system

Additional slide [2] : Controller

Additional slide [3] : Part of the Simulink model

Additional slide [4] : E.g. of the measurement procedure

Additional slide [5] : General schema

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Desired Force

Force controller

Electrode

Motor

Angular sensor

Force sensor

Measured position

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Torque estimator

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Signal estimation : position, velocity and acceleration