Design of a demo experimental setup for human augmentation

Mike Domenik Rinderknecht

Supervisors:

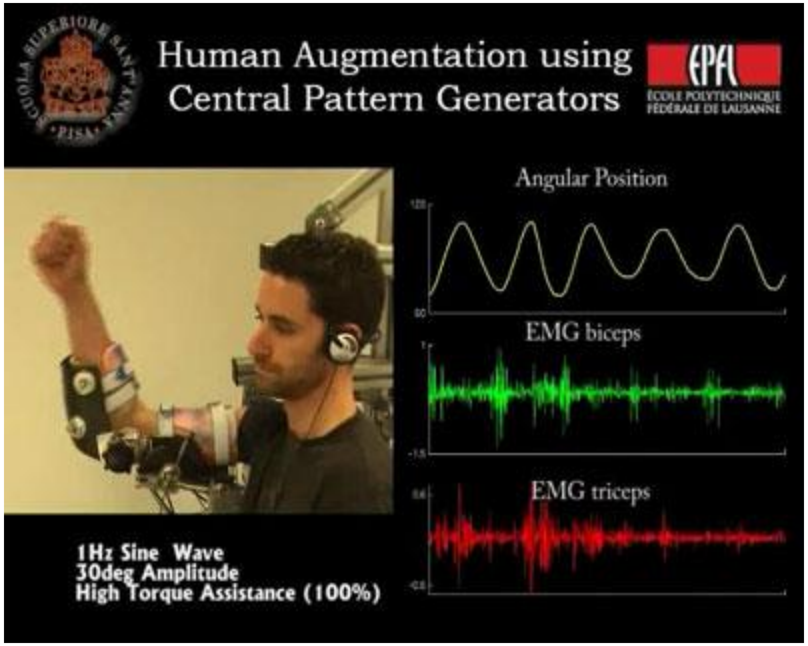
Renaud Ronsse, Alessandro Crespi

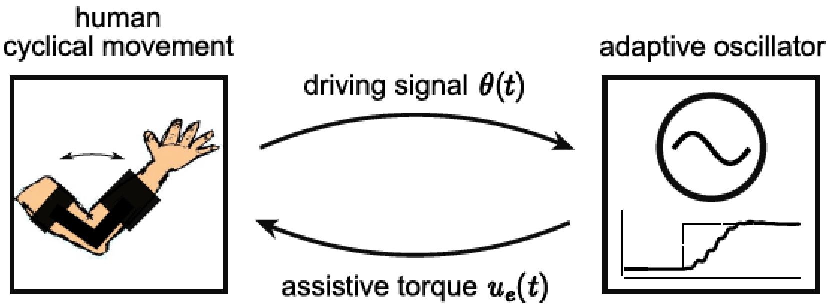
Professor:

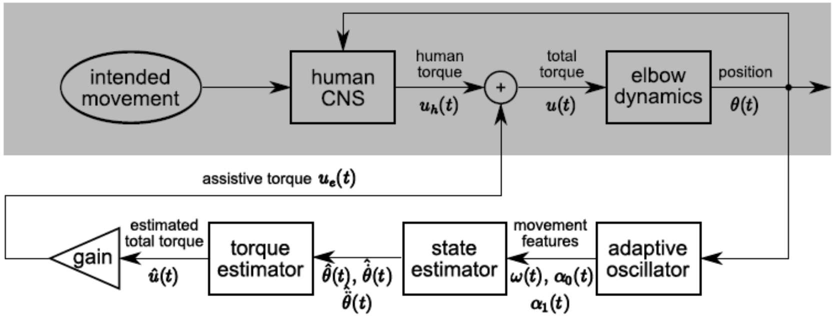
Auke Jan Ijspeert

Microengineering, Semester Project 1 – Final Presentation January 2011

State of the art – Inspiration







R. Ronsse et al., “Human-robot Synchrony: Flexible Assistance using Adaptive Oscillators”, *Biomedical Engineering, IEEE Transactions on*, 2010

Previous Semester Project

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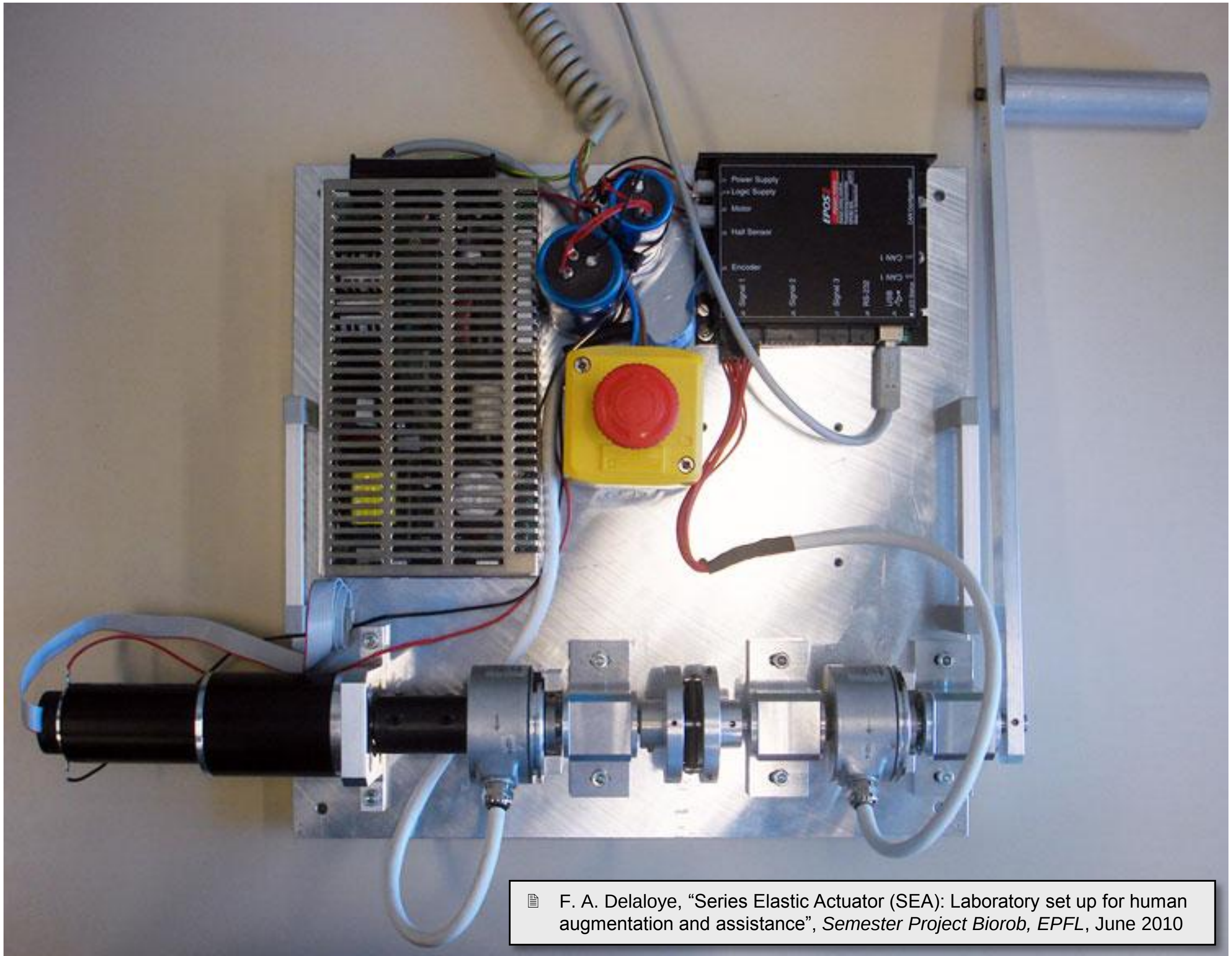

F. A. Delaloye, “Series Elastic Actuator (SEA): Laboratory set up for human augmentation and assistance”, *Semester Project Biorob, EPFL*, June 2010

Goals of the project

- **Finalization of mechanical design (proper setting of SEE)**
- **Finalization of electronics (solve voltage and current problems)**
- **Establishment of communication EPOS ⇔ MATLAB**
- **Creation of an easy to use library with functions / blocks**
- **Setting up an experimental protocol (perform experiments with healthy people and analyze results)**

\+ **Publication on the experimental results, depending on timing and results (ICORR 2011 Zürich)**

\+ **Design of a new hardware setup including mechanical torque limitation**

Series Elastic Element (SEE)

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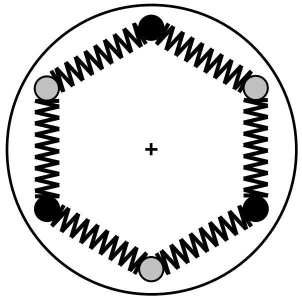
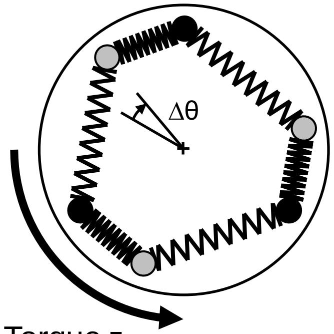
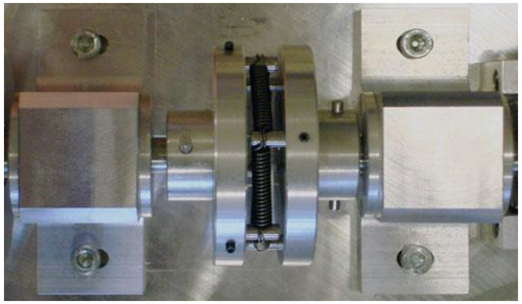
Resting position

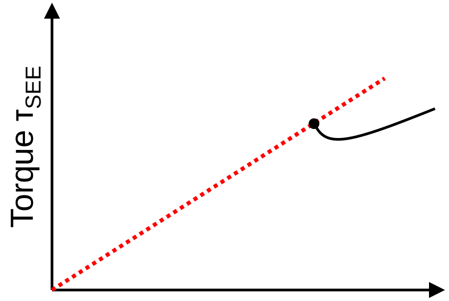


Disk 2 deviated by Δθ





● Pin on disk 1
○ Pin on disk 2



Characterization

Applied ⊥ force at 30 cm	**3 N**
Measured angular deviation	**0.26 rad**
SEE spring rate	**3.8 Nm/rad**

$$k_{SEE} = \frac{F \cdot l}{\Delta\theta} \qquad \tau_{SEE} = \Delta\theta_{max} \cdot k_{SEE}$$

Maximal possible deviation	**0.28 rad**
Maximal SEE torque	**1.1 Nm**

⇨ **Very small maximal torque !**

Safety – Torque limitation

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Problem

Motor stall torque	**2500 mNm**
Gearbox reduction	**126:1**
Gearbox efficiency	**75%**

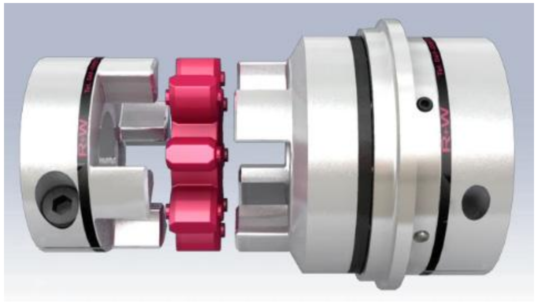
$$M_{elbow,max} = r \cdot M_{stall} \cdot \eta$$

Torque on elbow	**236 Nm**
Equivalent force on forearm at 30 cm	**788 N**
Equivalent mass for horizontal forearm	**80 kg**

⇨ **Admissible torque for the elbow ~ 15 Nm !**

Solutions

- **Mechanical torque limititation**



⇨ **Total disengagement at 15 Nm**

- **Motor current limitation**

$$M = k_M \cdot I \qquad I_{max} = \frac{M_{adm}}{r \cdot \eta \cdot k_M}$$

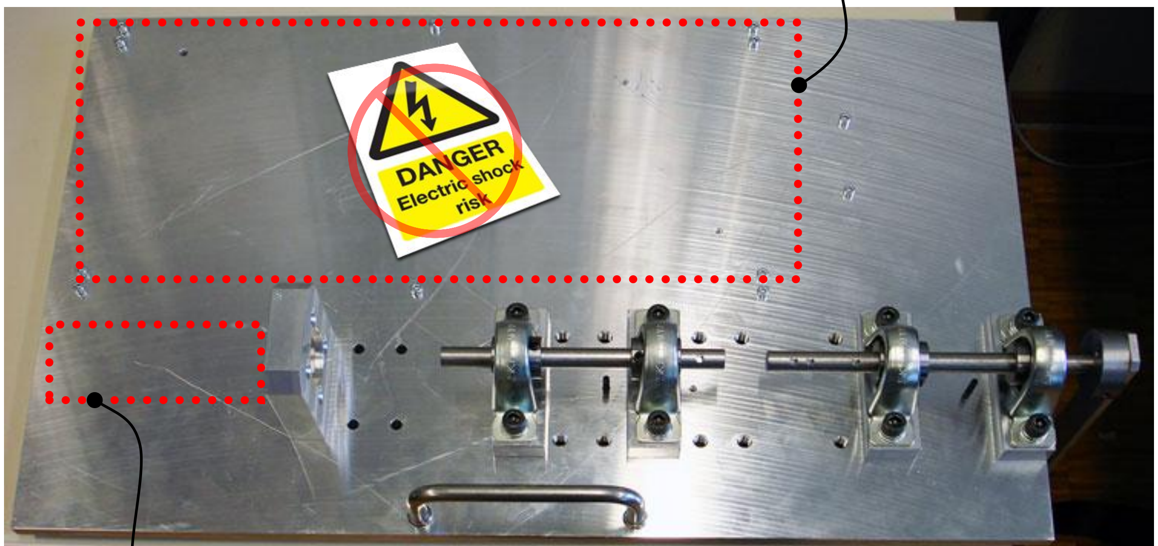
Torque constant	**60.3 mNm**
Maximal motor current	**2.63 A**

⇨ **Torque limitation at 15 Nm**

New device

Goal: safe, flexible and simple design

Housing for electronics



Space for motor + gearbox

Standard Y-bearing plummer block units

New device

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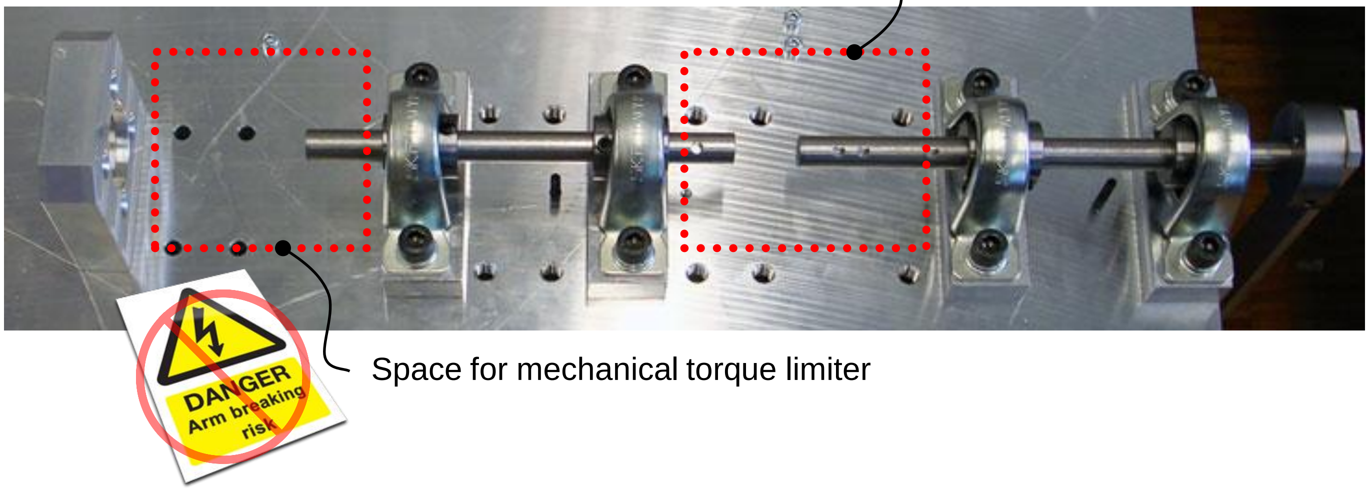
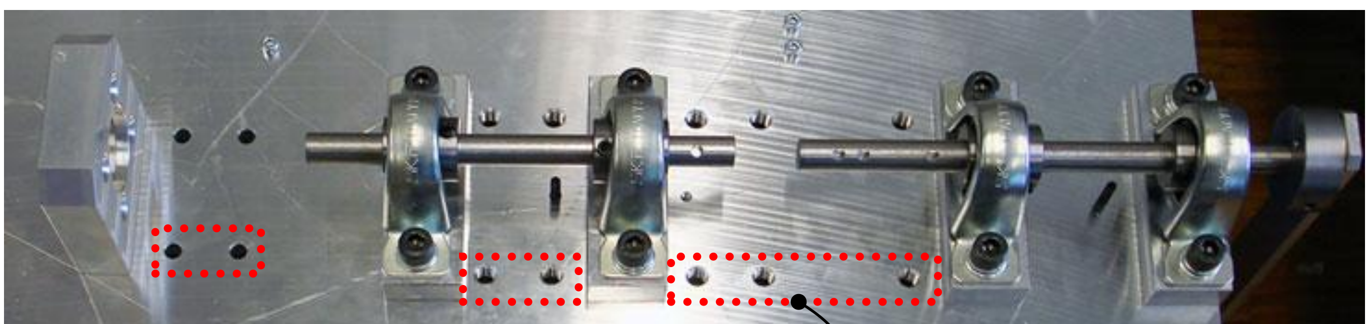
Goal: safe, flexible and simple design

Large space for new SEE design

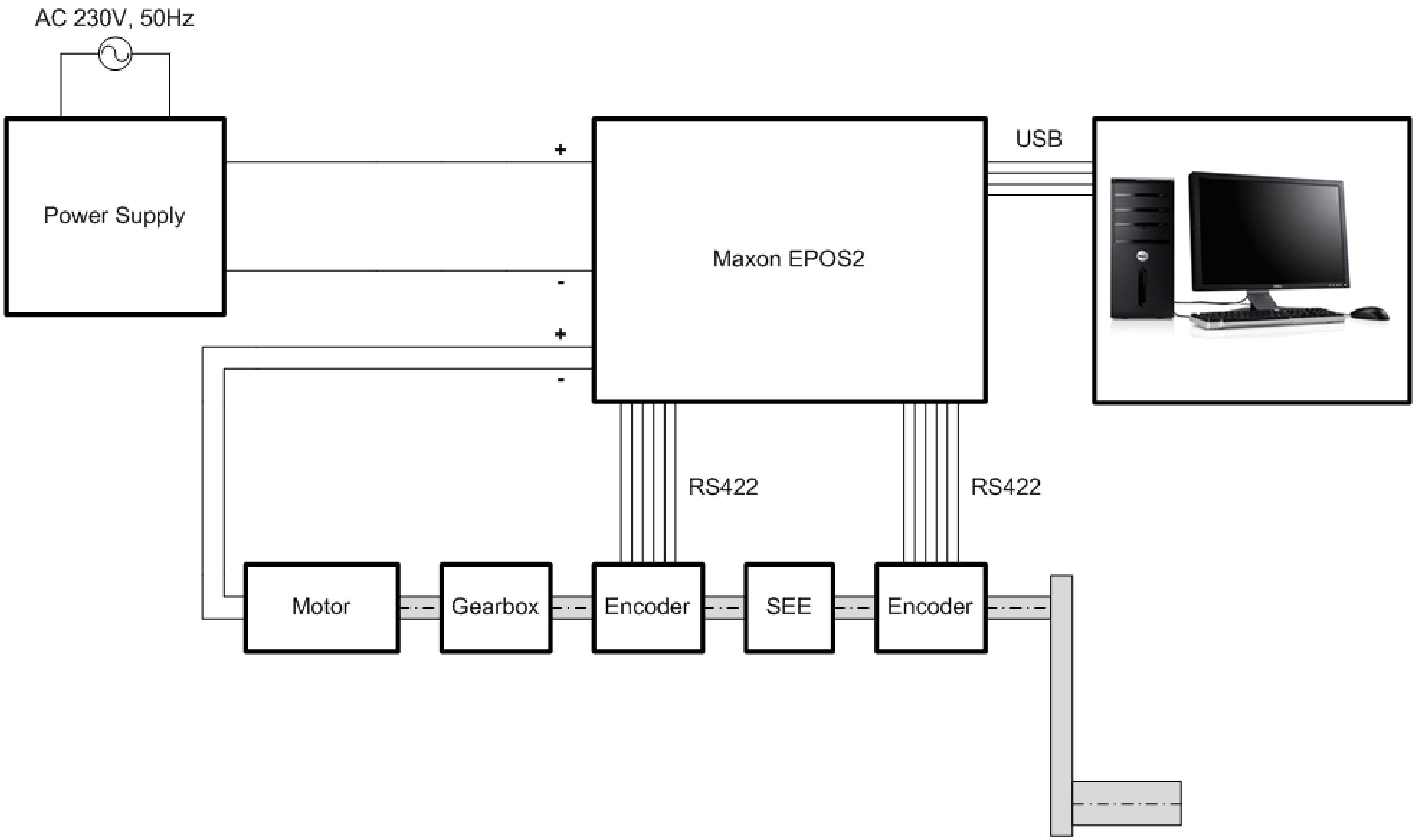


Space for mechanical torque limiter

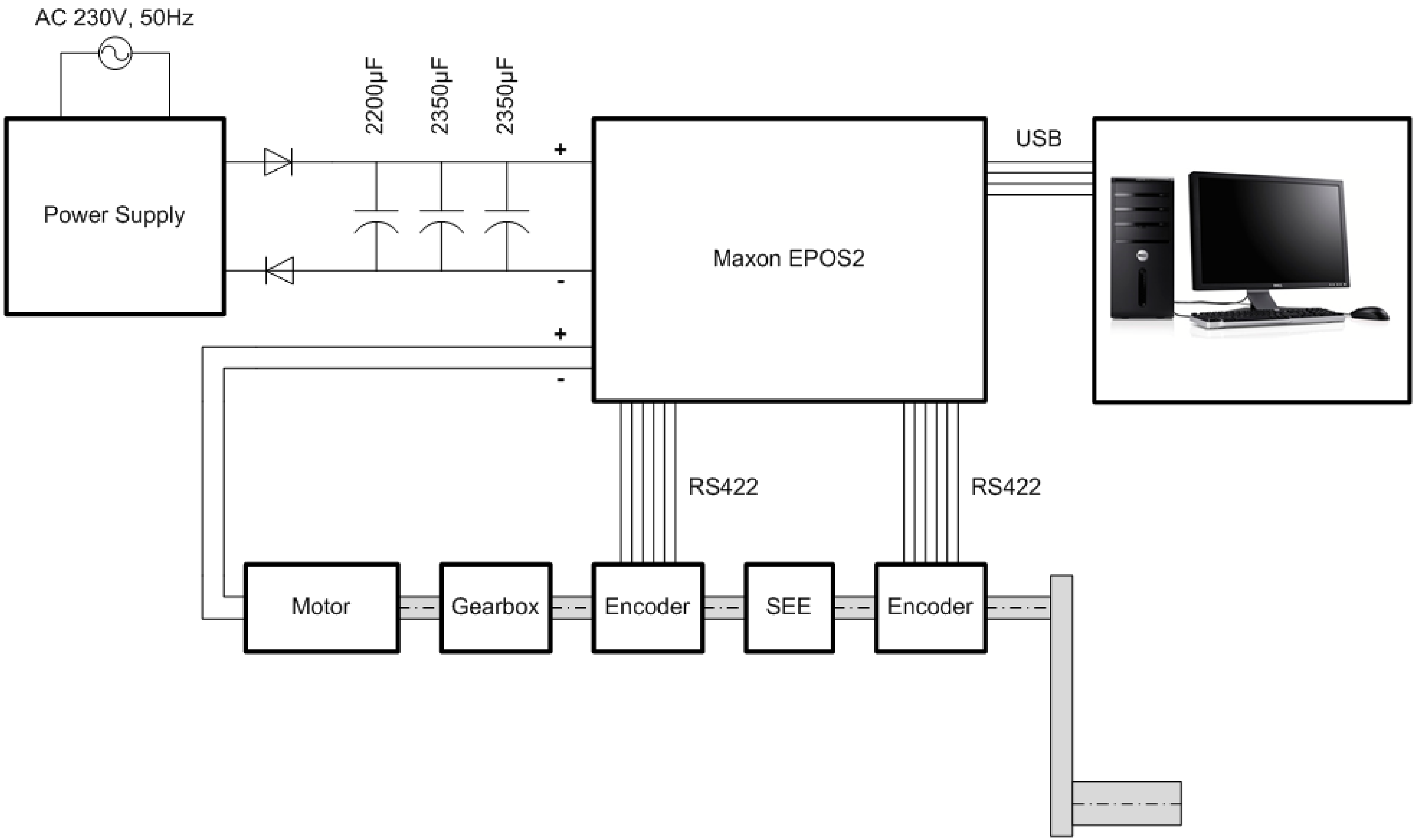


Various configurations possible

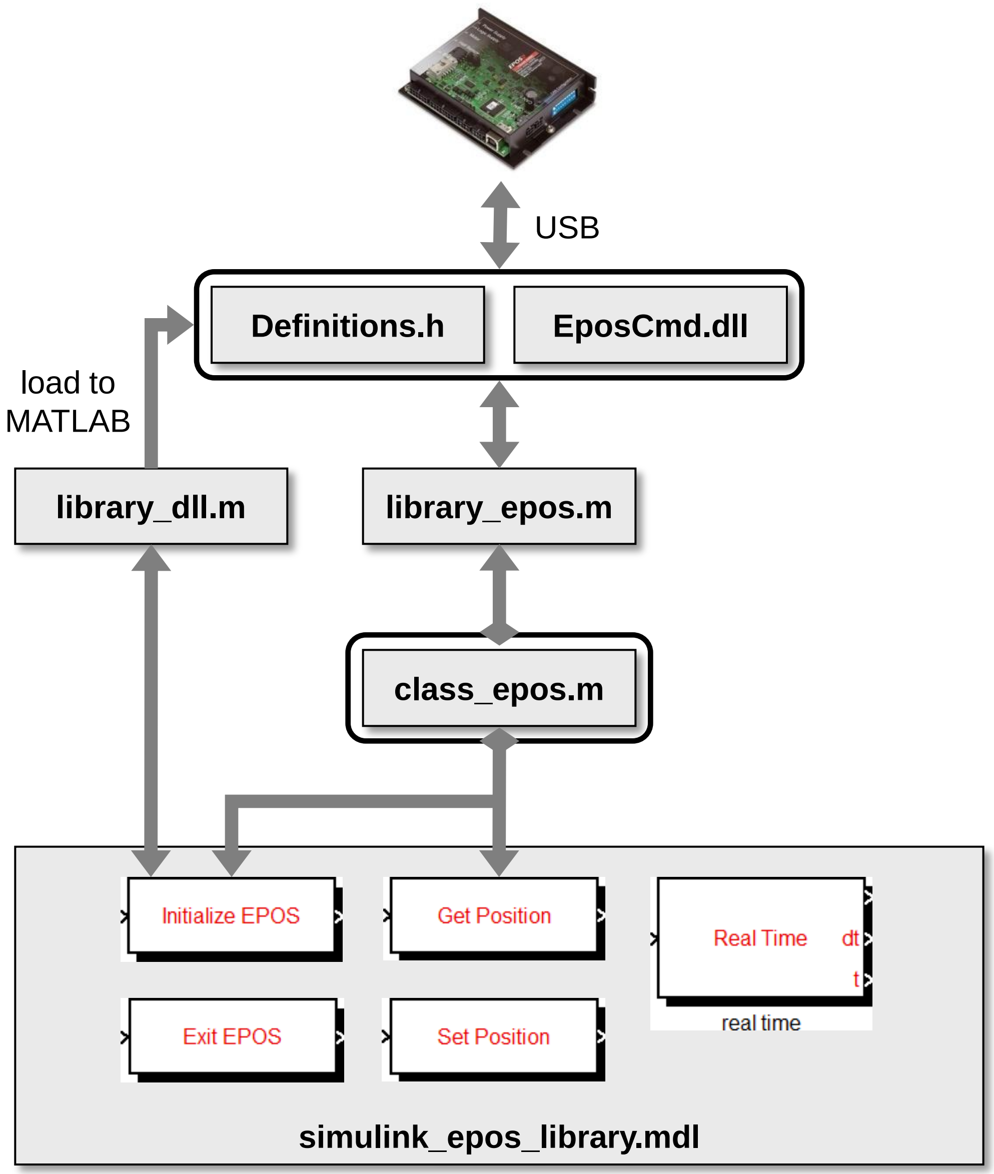
Electronics



Electronics



Communication EPOS – MATLAB – Simulink



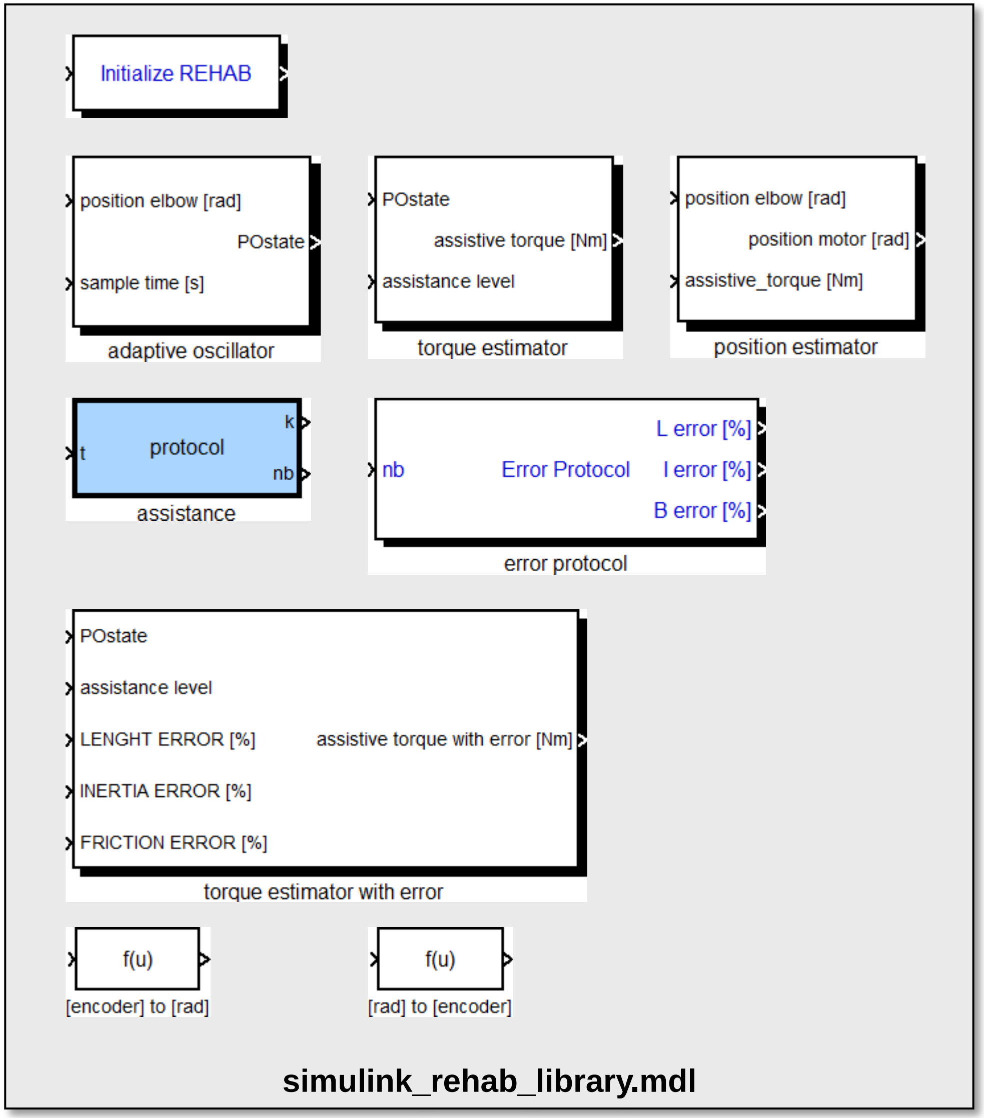
DLL, Header file

MATLAB m-files

MATLAB class

Library of Simulink Blocks with MATLAB Level-2 S-Functions

Simulink rehab library



MATLAB Level-2 S-Function

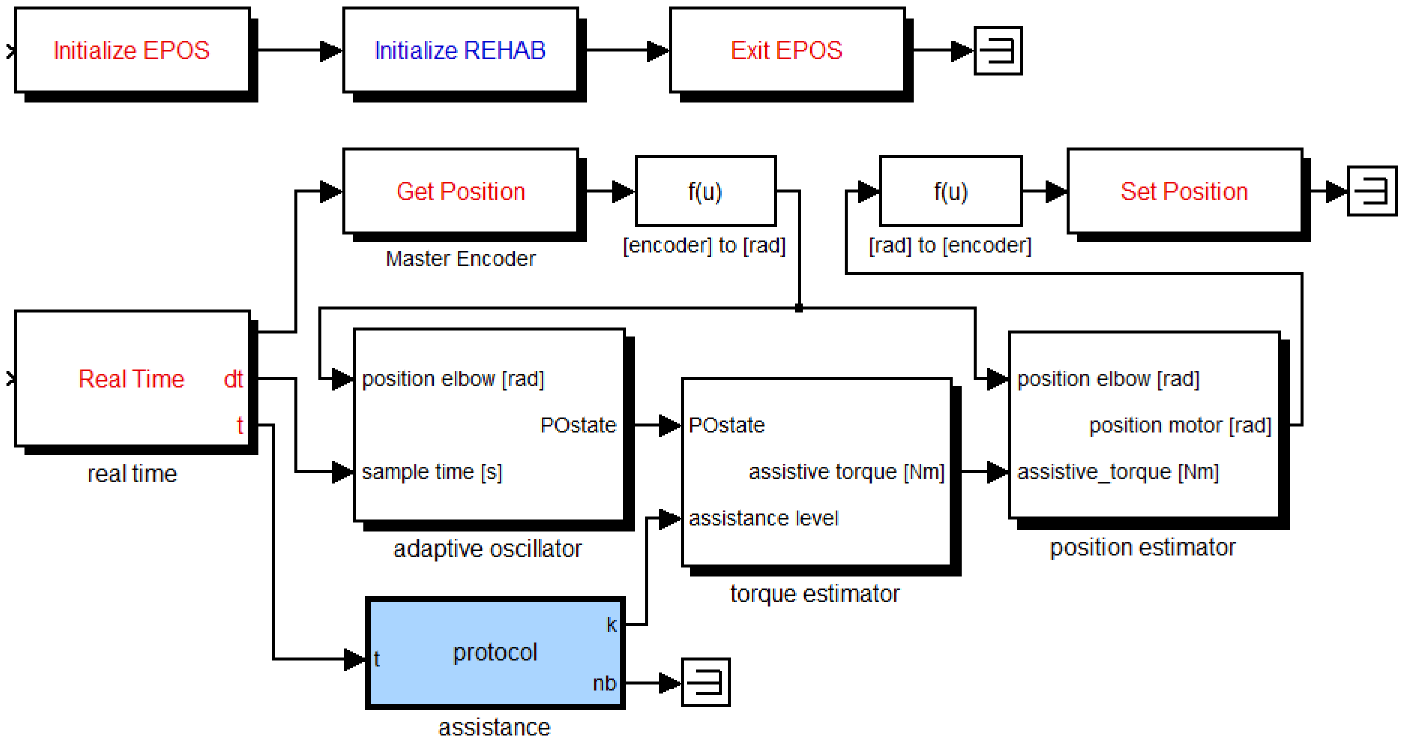
Embedded MATLAB Functions

Embedded MATLAB Functions

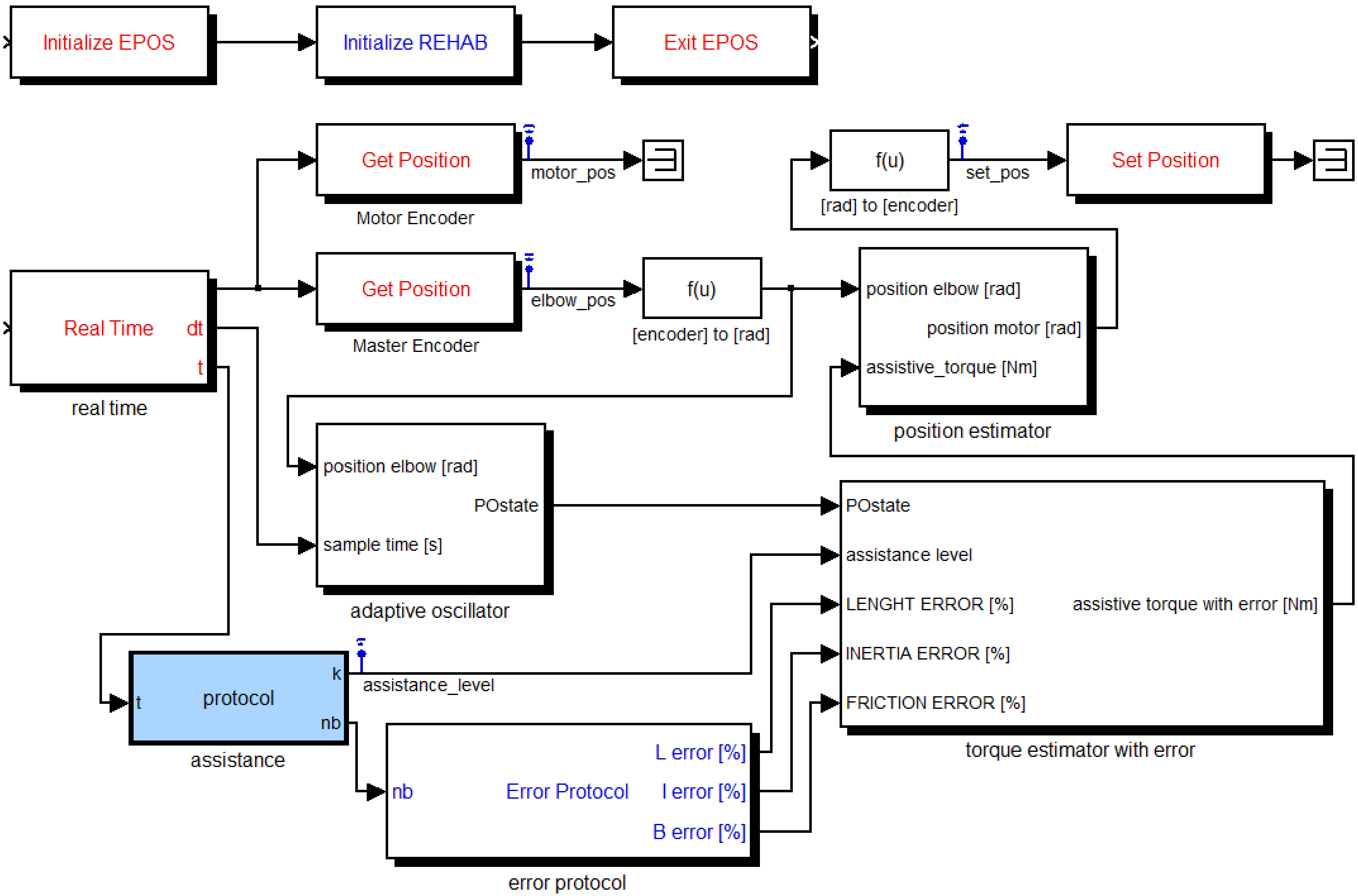
Embedded MATLAB Functions

Function Blocks

Simulink example



Experiments – Simulink model



Experiments – Predictions

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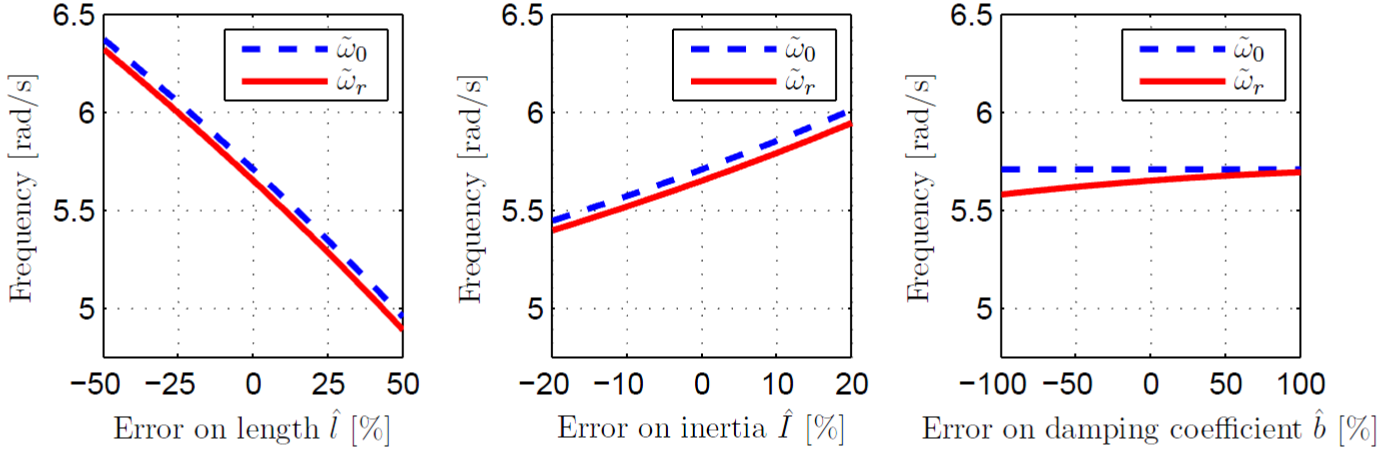
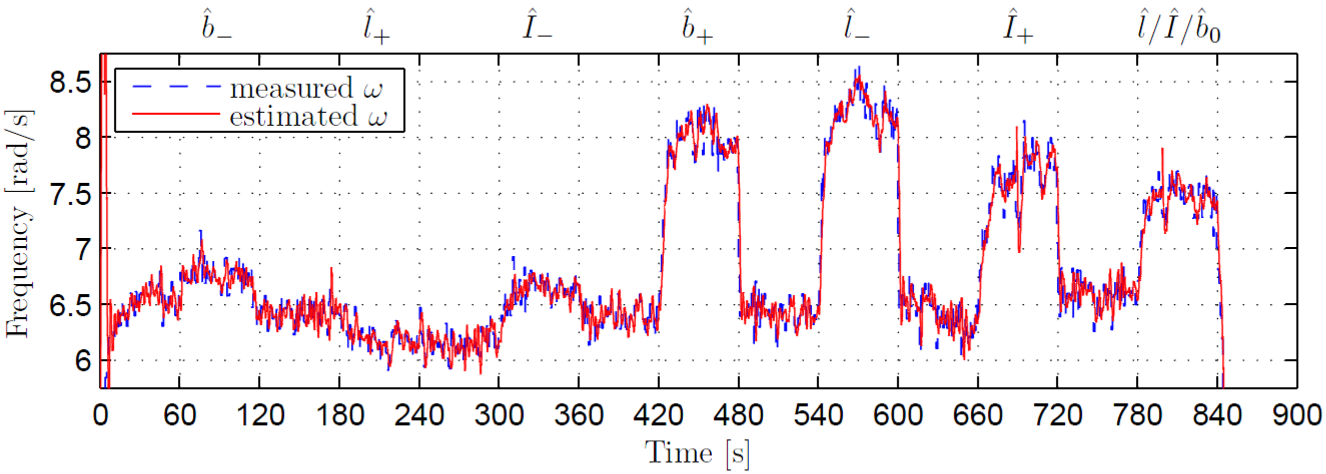
Frequency variations of a representative participant as a function of estimation errors



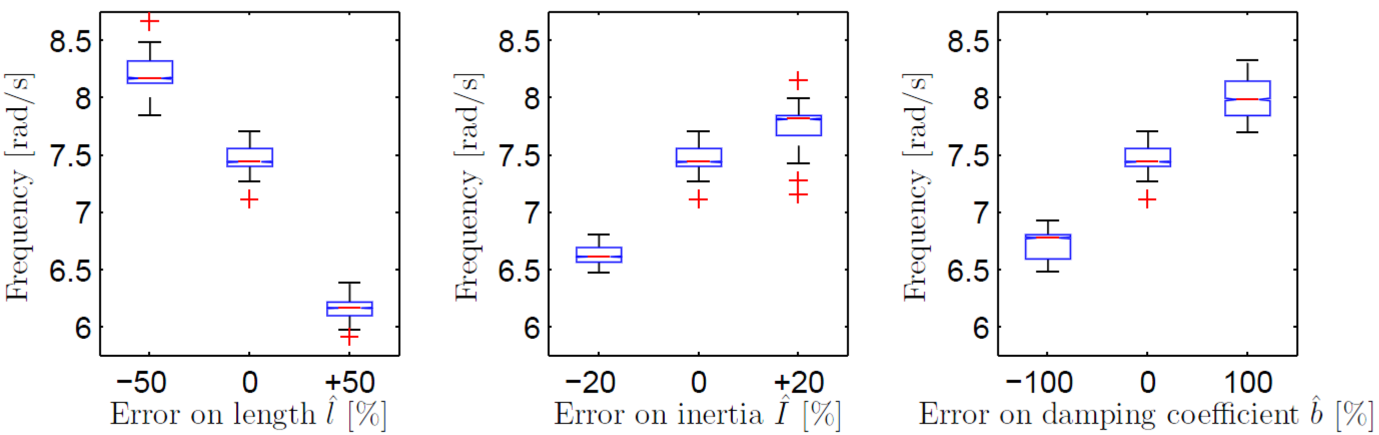
- **Overestimating equivalent length** ⇨ **Smaller movement frequency, and vice-versa**
- **Overestimating inertia** ⇨ **Larger movement frequency, and vice-versa**
- **Overestimating damping coefficient** ⇨ **Slightly larger movement frequency, and vice-versa**

Experiments – Results

Frequency evolution of a representative participant during the different configurations



Steady state frequencies of a representative participant



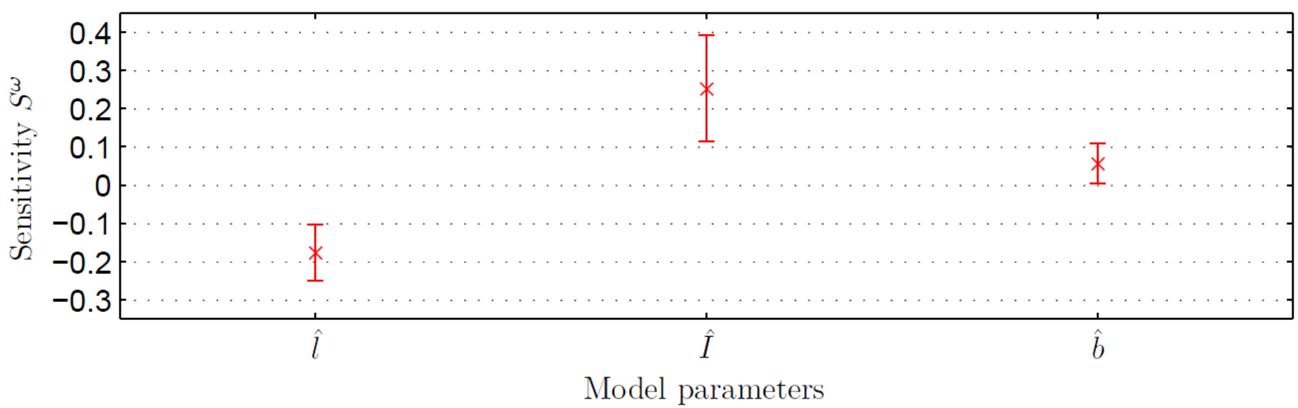
Experiments – Results

Wilcoxon rank-sum test on the frequencies

	$L_- > L_0$	$L_0 > L_+$	$L_- > L_+$	$I_- < I_0$	$I_0 < I_+$	$I_- < I_+$	$B_- < B_0$	$B_0 < B_+$	$B_- < B_+$
Participant 1	✓ $p < 0.001$	✓ $p < 0.001$	✓ $p < 0.001$	✓ $p < 0.001$	✓ $p < 0.001$	✓ $p < 0.001$	✓ $p < 0.001$	✓ $p < 0.001$	✓ $p < 0.001$
Participant 2	✓ $p < 0.001$	✓ $p < 0.001$	✓ $p < 0.001$	× $p < 0.001$	✓ $p < 0.001$	✓ $p < 0.001$	✓ $p < 0.001$	✓ $p < 0.001$	✓ $p < 0.001$
Participant 3	✓ $p < 0.001$	✓ $p < 0.001$	✓ $p < 0.001$	✓ $p < 0.001$	× $p < 0.001$	✓ $p < 0.001$	× $p < 0.001$	✓ $p < 0.001$	✓ $p < 0.001$
Participant 4	✓ $p < 0.001$	✓ $p < 0.001$	✓ $p < 0.001$	✓ $p < 0.001$	✓ $p < 0.001$	✓ $p < 0.001$	× $p < 0.001$	× $p < 0.001$	× $p < 0.001$
Participant 5	✓ $p < 0.001$	✓ $p < 0.001$	✓ $p < 0.001$	✓ $p < 0.001$	✓ $p < 0.001$	✓ $p < 0.001$	✓ $p < 0.001$	✓ $p < 0.001$	✓ $p < 0.001$

⇨ 39 of 45 tests (87%) correspond to the predictions, confidence levels > 99.9%

Sensitivity



e.g. for the length:

$$S^{\omega}_{\hat{l}} = \frac{\Delta\bar{\omega}_{\hat{l}}}{\bar{\omega}_{\hat{l}_0}} \cdot \frac{\hat{l}_0}{\Delta\hat{l}}$$

Experiments – Publication

M. D. Rinderknecht, F. A. Delaloye, A. Crespi, R. Ronsse and A. J. Ijspeert,

"*Assistance using adaptive oscillators: Sensitivity analysis on the resonance frequency*"


Assistance using adaptive oscillators: Sensitivity analysis on the resonance frequency

Future work

- **Iteration on SEE design, develop a new solution**
- **Accurate system identification of the new device to integrate a correct dynamical model into the control**
- **Further experiments with people**

Questions

Thank you for your attention.