Rehabilitation robotics using Central Pattern Generators

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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
Introduction | Plan | Environment | Model & simulation | Implementation | Conclusion

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

- Flexion
- Extension
Goals of the project

Autonomy
Goals of the project

Movement

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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

LSRO Lab
- Knee-orthosis
- Force processing
- Implementation and validation
- Rehabilitation protocol

Biorobotics Lab
- Adaptive oscillators
- SIMULINK modeling
- Rehabilitation robotics

Introduction | Plan | Environment | Model & simulation | Implementation | Conclusion
Adaptive oscillators

- Used in the context of **rhythmic movement** assistance
- Predict the state evolution in **real-time (without delay)**

- Modified Hopf oscillator

\[
\begin{align*}
\dot{x} &= \gamma(\mu - (x^2 + y^2))x - \omega y + \epsilon F(t) \\
\dot{y} &= \gamma(\mu - (x^2 + y^2))y + \omega x \\
\dot{\omega} &= -\epsilon F(t) \frac{y}{\sqrt{x^2 + y^2}}
\end{align*}
\]
Adaptive oscillators

Signal $F(t) = \sin(20t)$
Environment : Knee Orthosis

- Rehabilitation robot
- One degree of freedom
- Position and force sensors
Timeline

- Modeling the System
  - Test & validation SimuLink + Matlab

- Measurement Sys characterization Control
  - Test & validation FlexWare + Orthosis

- Integration of the CPG system
  - Test & validation FlexWare + Orthosis
General Project Schema

LSRO Lab
- Knee-orthosis
  - Force processing

Biorobotics Lab
- Adaptive oscillators
  - SIMULINK modeling
- Rehabilitation robotics

Implementation and validation
Rehabilitation protocol
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

Model and simulation using Central Pattern Generators (CPGs) for rehabilitation robotics.

**Equation 1:**
\[ \ddot{u} = mg \sin(\theta) + b\dot{\theta} + I\dot{\theta} \]

**Equation 2:**
\[ \begin{align*}
\dot{x} &= \gamma(\mu - r^2)x - \omega y + eF(t) \\
\dot{y} &= \gamma(\mu - r^2)y + \omega x \\
\dot{\omega} &= -eF(t)\left(\frac{y}{\tau}\right) \\
\dot{\alpha}_0 &= \frac{\tau}{2}F(t) \\
\dot{\alpha}_1 &= \tau x F(t)
\end{align*} \]
Model and simulation

\[ I \ddot{\theta} = -mglsin\theta - b\dot{\theta} + u \]

Torque
CPG & torque estimator

Adaptive oscillator

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

Dynamical model + Orthosis Position controller

Electrode
Motor
Angular sensor
Force sensor

Measured position

Signal Estimator

Position
Velocity
Acceleration

\begin{align*}
\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{r}_0 &= \frac{\tau}{2} F(t) \\
\dot{r}_1 &= \tau x F(t)
\end{align*}
Simulation & results

\[ \omega = 2\pi \rightarrow \omega = 1.5\pi \]
Simulation & results

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\[ \omega = 2\pi \rightarrow \omega = 1.5\pi \]
General Project Schema

- **LSRO Lab**
  - Knee-orthosis
  - Force processing
  - Implementation and validation
  - Rehabilitation protocol

- **Biorobotics Lab**
  - Adaptive oscillators
  - SIMULINK modeling
  - Rehabilitation robotics

**Introduction | Plan | Environment | Model & simulation | Implementation | Conclusion**

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Timeline: Force

- **Modeling the System**
- **Measurement System characterization Control**
- **Integration of the CPG system**

**Test & validation**
- Simulink + Matlab
- FlexWare + Orthosis

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Implementation: Transparent mode

- 1st Objective:
  Make the orthosis transparent for the user

- 5 Steps:

1. Knee orthosis
2. Force measured
   Digital analogue value (Volt)
3. Calibration
   Volt => Newton
4. Interpolation
5. Filtering
   Control

Applied torque
Calibration, Interpolation and filter

Using the following filter:

\[ \tau = \frac{1}{B_p} \quad \Rightarrow \quad B_p = 20 \text{ Hz} \]

\[ \frac{y_f}{y} = \frac{1}{1 + \tau s} \quad \Rightarrow \quad y_f = \frac{\tau}{T e + \tau} y_f + \frac{T e}{T e + \tau} y \]
Implementation: Filtering

Using the following filter:

\[ \tau = \frac{1}{B_p} \quad \Rightarrow \quad B_p = 20 \text{ Hz} \]

\[ \frac{y_f}{y} = \frac{1}{1 + \tau s} \quad \Rightarrow \quad y_f = \frac{\tau}{T_e + \tau} y_f - \frac{T_e}{T_e + \tau} y \]

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Implementation: Transparent mode

Measuring the stabilization tension for a set of position

![Position-Voltage curve](image)
Implementation: Transparent mode

Desired force \( = 0 \)

\[ + \quad \text{PID Controller} \quad + \]

Measure d position

Measure d force

Electrode

Motor

Angular sensor

Force sensor
Validation of the transparent mode

**Measured force (Newton)**

- **Neg**
  - Without any implementation: 62.95 Newton
  - With transparent mode: 38.29 Newton

- **Pos**
  - Without any implementation: 47.17 Newton
  - With transparent mode: 25.82 Newton
General Project Schema

LSRO Lab
- Knee-orthosis
- Force processing

Biorobotics Lab
- Adaptive oscillators
- SIMULINK modeling

Implementation and validation

Rehabilitation protocol
Timeline: Integrating CPG

- Modeling the System
- Processing the force sensors measurement
- Integration of the CPG system

Test & validation:
- SimuLink + Matlab
- FlexWare + Orthosis
Validation of the oscillator block
Validation of the system

**Measured force (Newton)**

- **Extension**
  - Without any implementation: 62.95
  - With transparent mode: 38.29
  - With force controller and assistance $K = 0.5$: 18.29

- **Flexion**
  - Without any implementation: 47.17
  - With transparent mode: 25.82
  - With force controller and assistance $K = 0.5$: 10.61

**Human effort**

- **Extension**
  - Without any implementation: 24.66
  - With transparent mode: 21.35
  - With force controller and assistance $K = 0.5$: 0

- **Flexion**
  - Without any implementation: 0
  - With transparent mode: -15.21
  - With force controller and assistance $K = 0.5$: -20
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

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Additional slide [3] : Part of the Simulink model
Additional slide [4]: E.g. of the measurement procedure
**Additional slide [5] : General schema**

- **Desired Force**
  - **Force controller**
    - \( \hat{u} = m g l \sin(\hat{\theta}) + b \hat{\theta} + I \ddot{\theta} \)

- **Torque estimator**

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

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