Advanced Control Strategies for Neuro-Prosthetic Systems

Christian Klauer\textsuperscript{1}, Jörg Raisch\textsuperscript{1,2}, Thomas Schauer\textsuperscript{1}
\textsuperscript{1}Control Systems Group, Technische Universität Berlin
\textsuperscript{2}Max-Planck-Institut für Dynamik komplexer technischer Systeme, Fachgruppe System- und Regelungstheorie, Magdeburg

contact: klauer@control.tu-berlin.de

TAR 2013, Berlin, Germany
Functional Electrical Stimulation (FES)

- Application of electrical current pulses to a muscle for inducing force.
- The pulses (20 to 60 Hz) are modulated through pulsewidth and current amplitude.

Common difficulties of feedback control for FES

- The outcome of a stimulation pattern is difficult to predict.
- Complex models require long lasting identification experiments. Parameters are not valid in the long term.
**Problem:** Linear recruitment function $rc(v)$ which is time varying and difficult to model.

**Solution:** Measurement and feedback control of representatives for the muscle state.

- Angular acceleration $\ddot{\vartheta}$
- Amount of recruited motor units $\lambda$
The under-compensation of the muscular thresholds leads in combination with a switching strategy to a dead-zone.

An underlying feedback of the angular acceleration compensates the dead-zone effects.

In an outer level cascade, a joint angle controller is applied.
The method was applied to control the elbow-joint angle of a healthy subject via the antagonistic muscle pair (biceps – triceps).

The arm was placed in a way that movements were not affected by gravity.

A fast positioning with a low rise time of 100 ms was observed.
Proposed solution: Feedback control of the muscular recruitment index $\lambda$. The stimulation intensity $v$ is adjusted such that a reference is tracked.

- Measurement and signal processing of the FES-evoked EMG gives $\hat{\lambda}$.
- At an higher level, the joint-angle $\vartheta$ is controlled by giving a desired recruitment level $r_{\hat{\lambda}}$. 

Christian Klauer\textsuperscript{1}, Thomas Schauer\textsuperscript{1}, Jörg Raisch\textsuperscript{1,2}
An exemplary estimate of the non-linear recruitment is illustrated.

The muscular recruitment is difficult to model.

However, the feedback controller is able to precisely control the recruitment.

The behaviour between target- and actual recruitment is approx. linear.
**Problem:** Foot elevation in SCI-patients.

- Commercial stimulation systems typically apply a pre-defined stimulation profile. (Muscular fatigue is neglected)
- To ensure a sufficient foot elevation, the stimulation intensity is higher than needed.
- Now, a recruitment profile is applied instead of direct stimulation.

**Figure:** Experimental set-up.
Application of $\lambda$-control to the drop foot compensation problem – Results

**Comparison of $\lambda$-controlled foot elevation to direct stimulation**

- Alternation of steps induced by both methods for ca. 40 minutes.
- Profile for direct stimulation is gathered from five initial $\lambda$-controlled steps.
- Using $\lambda$-control, the adaptation to time variances is possible. Required stimulation increased by up to 12.6% wrt. the minimum.
Conclusions

**Acceleration control**
- Counteracts badly compensated recruitment functions & rejects mechanical input disturbances.
- Not applicable under isometric conditions

**λ-control**
- Compensation of non-linear & time-varying effects in the muscular recruitment function.
- Potential for fatigue-compensation has been demonstrated.
- The effort for modelling & control of FES-activated muscles is significantly reduced.
Co-contractions in antagonistic muscle pairs

- For antagonistic muscle pairs, $\lambda$-control enables to keep both muscles co-contracted even in the long term.
- Modulation of mechanical impedances (e.g. friction) becomes possible.
- It is expected to allow neuro-prosthetic systems to mimic the natural motor control behaviour.
Thank You for your attention!