Advanced Control Strategies for Neuro-Prosthetic Systems

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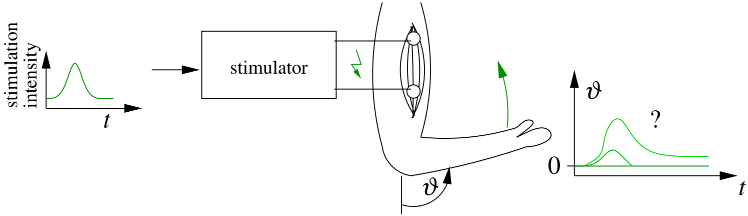
TAR 2013, Berlin, Germany

Functional Electrical Stimulation (FES)

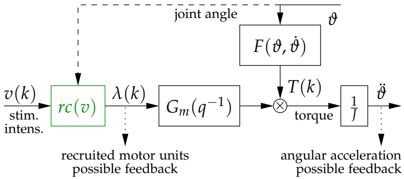
- Application of electrical current pulses to a muscle for inducing force.
- The pulses (20 to 60 Hz) are modulated through pulsewidth and current amplitude.

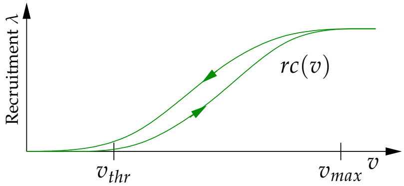


Common difficulties of feedback control for FES

- 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 λ

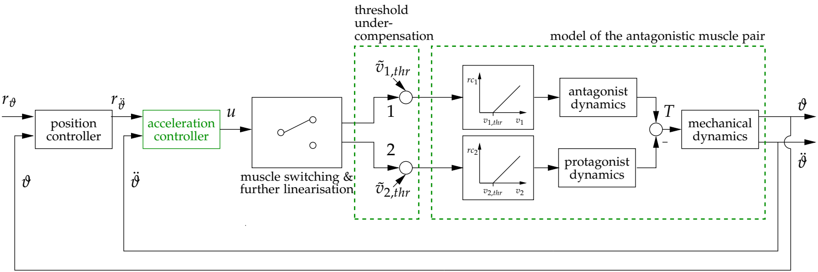


Figure: Acceleration control system & model.

- 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.

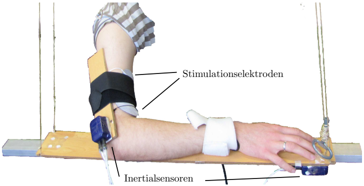


Figure: Experimental Set-up.

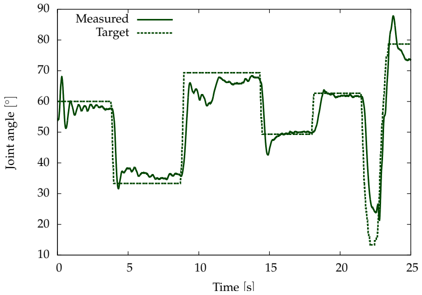
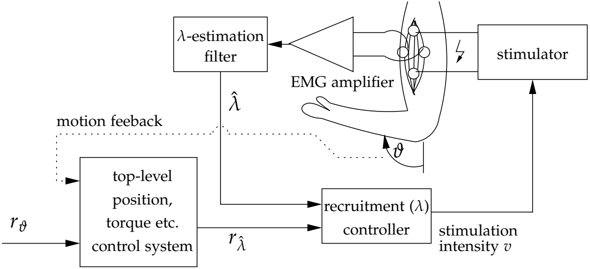
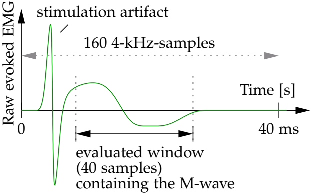


Figure: Results for a joint angle control experiment.

- 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.

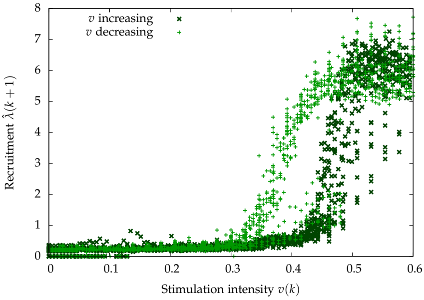
Proposed solution: Feedback control of the muscular recruitment index λ. The stimulation intensity v is adjusted such that a reference is tracked.

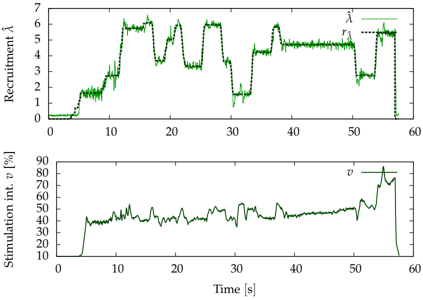




- Measurement and signal processing of the FES-evoked EMG gives $\hat{\lambda}$.
- At an higher level, the joint-angle ϑ is controlled by giving a desired recruitment level $r_{\hat{\lambda}}$.

λ-Control: Results





- 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 then needed.
- Now, a recruitment profile is applied instead of direct stimulation.

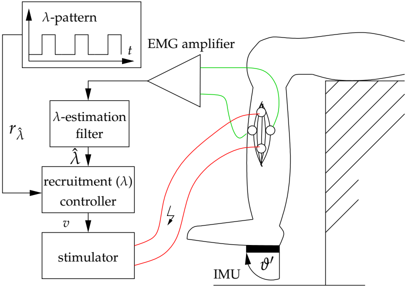
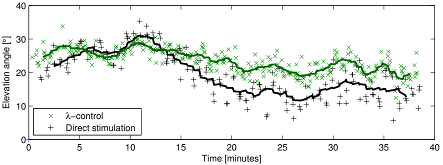


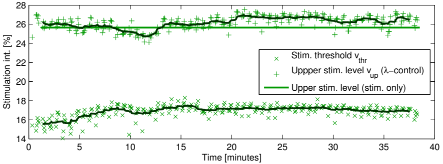
Figure: Experimental set-up.

Application of λ-control to the drop foot compensation problem – Results

Comparison of λ-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 λ-controlled steps.
- Using λ-control, the adaptation to time variances is possible. Required stimulation increased by up to 12.6 % wrt. the minimum.





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, λ-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!