A model for joint angle prediction using EMG signal processing during functional electrical stimulation

Klauer, Christian, Technische Universität Berlin, Control Systems Group, Germany, klauer@control.tu-berlin.de
Irmer, Maximilian, Technische Universität Berlin, Control Systems Group, Germany
Schauer, Thomas, Technische Universität Berlin, Control Systems Group, Germany

Introduction

Neuro-prosthetic systems using functional electrical stimulation (FES) typically introduce artificial muscle forces caused by electrical pulses, e.g., to support residual but limited voluntary activity in functional movements. Control algorithms that incorporate residual muscle activity enable a huge potential in the context of rehabilitation and daily-life support of stroke patients. In the past decade, it became possible to estimate this voluntary action also during active FES by electromyography (EMG) measurements. Up to now, the motion caused by a combination of the patient's voluntary effort and FES can not be predicted by a model. However, to control FES systems, such a model is helpful to enable precise movements. Thus, to allow a better interaction of the FES with the patient, a model for real-time movement prediction based on estimates of the voluntary activity and the applied stimulation intensities is developed in this contribution. A neuro-prosthetic system may then realize a virtual therapist who supports patient-optimized FES interactions. Herein, strategies that instantaneously encourage the patient to maximize his voluntary effort, while maintaining desired motion trajectories, can be realized. In this contribution, the proposed model describes the shoulder joint abduction angle of the arm depending on applied FES to the medial deltoid muscle and simultaneously taken EMG measurements.

Methods

A dynamical muscle model based on a Hammerstein structure is used to describe/predict the joint angle. A static input nonlinearity in form of an Artificial Neural Network (ANN) is used. Inputs to the ANN are the stimulation intensity and the EMG-based estimate of volitional muscular activity. This non-linearity is assumed to describe the combination of both muscle activation types. The output of the ANN is fed to a linear dynamical system of second order, that approximates the biomechanical system. To adapt the parameters of the ANN and the linear dynamics to the individual subject / muscle condition, a least-squares based approach is developed that allows a system identification using previously recorded input / output data. To obtain such data, an experimental procedure is proposed in which the stimulation intensity is increased step-wise such that the resulting joint angles span the desired operational space. During time periods in which the stimulation remains constant in the stepwise signal, the subject is instructed to voluntarily elevate his arm to a constant joint angle in the upper range of the operational space and to release after a short time.

Results

The proposed identification procedure was applied to two healthy subjects. In a next step, the model parameters were identified for each subject, whereby the chosen model structure was able to accurately describe the recorded joint angle. A radial basis function network with 4 basis functions was used as ANN structure. To validate the obtained models, a second data set (validation data) was recorded for each subject and the measured joint angle trajectory was compared to the behavior obtained in a simulation using the identified model. Input data to the model were the stimulation intensity and EMG-based estimate of the volitional muscle activity from the validation data set. The obtained RMS error between the simulated and measured joint angle was 3.75° and 5.14° for both subjects, respectively.

Conclusions

For the prediction of joint angle movements, an ANN-based dynamical model was developed and tested in two healthy subjects. The obtained RMS error shows the feasibility of the proposed joint angle prediction. Herein, the prediction accuracy is sufficiently precise to give beneficial information to model-based neuro-prosthetic control systems. The required identification procedure can be completed within a few minutes and hence it does not hinder the application of the proposed method in clinical environments. Further investigations must consider changing muscle conditions, e.g., muscular fatigue that is progressing comparable fast when using FES. Therefore, the evaluation of the electrically evoked EMG will be considered in future research. This allows the assessment of the stimulation effect that is significantly influenced by muscle fatigue. An extension to multiple muscles and joint angles is also subjected to future work to describe the complete motion of the upper arm. Furthermore, investigations with stroke and incomplete spinal cord injured patients are planned.