Detection and Filtering of EMG for Assessing Voluntary Muscle Activity during FES

Schauer T, Salbert RC, Negård N-O, Raisch J

Max Planck Institute for Dynamics of Complex Technical Systems, Systems and Control Theory Group, Magdeburg, Germany

Email: schauer@mpi-magdeburg.mpg.de

Abstract

The aim of this work was to develop a laboratory set-up to assess voluntary activity of up to 4 different muscles which undergo simultaneously an artificial electrical stimulation. Voluntary muscle activity is detected from surface EMG. To eliminate stimulation artefacts, the EMG amplifier is automatically muted during stimulation pulses. The measured EMG between stimulation pulses is then considered as superposition of a lower frequency component (m-wave, muscle artefact) caused by electrical stimulation and a higher frequency component caused by voluntary muscle contractions. The latter part is extracted using a digital high pass filter. The entire set-up was realised by using commercially available hardware, which is controlled in soft real-time from a PC running Matlab/Simulink™ under standard Linux.

1 Introduction

The determination of voluntary muscle activity on electrically stimulated muscles from surface EMG has been of great interest recently [1-4]. By detecting the residual activity of partially paralysed muscles this signal can be used to control the stimulation of the muscle itself. A real application of EMG controlled FES has been recently reported [4].

The detection of EMG during electrical stimulation (ES) is problematical as large signal artefacts occur. The electrical stimulation pulses cause a stimulation artefact which may drive the EMG amplifier into saturation or even damage the amplifier inputs. To deal with this problem, the EMG amplifier can be either shut down (muted) at the onset of the stimulation pulses or must provide a fast recovery from input overloads. Different devices with EMG and ES units have been designed to fulfil one of these requirements [1-4]. However, most of these systems are not commercially available.

The second problem in detecting voluntary muscle activity represents the muscle artefact (m-wave) resulting from the electrical stimulation. The amplitude of this EMG artefact is generally in the range of some mV whereas the intensities of the voluntary EMG component are usually in the range of µV.

Fortunately, the frequency spectra of voluntary EMG and m-wave do not overlap completely. Voluntary EMG possesses frequency components in the range from 30 to 500 Hz. However, frequencies above 200 Hz do not contribute significantly to the muscle artefacts. By applying a high pass filter to the EMG sequence between the stimulation pulses one can extract the high frequency contents of the voluntary EMG.

An often used approach to high pass filter the EMG signal is the following: The m-wave is assumed to be slowly varying from one to another stimulation period, so that the difference between the actual muscle artefact and predicted muscle artefact can be interpreted as the voluntary EMG signal [1,2]. The predicted m-wave represents either the last m-wave [1] or the output of some adaptive filter algorithm [2]. In reality, muscle artefact amplitudes depend strongly on stimulation intensity. For this reason, this simple high pass filtering approach will fail for strongly varying stimulation intensities.

Alternatively, the EMG signal between stimulation pulses can be directly high pass filtered [4] using a conventional analogue or digital filter. However, the amount of available filter data is limited due to the stimulation frequency. This imposes some problems on the selection of suitable filter algorithms.

In the following, a possible set-up for detecting voluntary EMG based on commercially available hardware (EMG amplifier and stimulators) is described. All components are controlled from a PC using Matlab/Simulink™.
2 Methods

The used set-up for EMG detection is depicted in Figure 1. The NeuroLog™ System\(^1\) has been used to build a 4-channel EMG amplifier consisting of the following modules: AC preamplifier (NL824) with analogue high pass filter and selectable gain, isolation amplifier (NL820A) and filter module (NL135) with analogue low pass filter and 50 Hz notch filter.

The pre-amplifier offers a mute input for suppression or reduction of overload artefact signals. This can be operated from the isolation amplifier without bridging the isolation barrier, triggered from an electrical signal to provide an automatic mute feature.

Main part of the set-up is a Linux-PC running Matlab/Simulink™. The electrical stimulation and the EMG measurements are synchronised. Two commercially available 8-channel current stimulators\(^2\) have been successfully embedded into the setup. Communication with the stimulators is established via the serial port. Protocols are open and a C++ communication library\(^3\) is made accessible under GPL. At onset of the stimulation pulses a mute signal for the EMG amplifier is generated either by the PC (for MicroStim8™ stimulator) or directly by the stimulator (for MotionStim8™ stimulator).

The analogue output (EMG) of the isolation amplifier is sampled at 4 kHz using a PCI data acquisition card\(^4\). A device driver\(^5\) for Linux is provided under GPL. The data acquisition runs continuously in the background. New samples are first stored on the card’s buffer and at half full buffer interrupt events transferred to the device driver buffer. Simulink™ reads out data from the device buffer at stimulation frequency.

As the data acquisition card transfers measurements only at half full buffer events to the device buffer, in general there are not all EMG measurements from the last stimulation period at the begin of a new stimulation period available. For this reason, analysis of EMG is carried out for the second last stimulation period for which all EMG measurements are available. To synchronise electrical stimulation and EMG measurements the DAQ device driver delivers a PC-clock based time stamp for the buffer half full events, so that a drift in stimulation events and measurements can be detected and compensated. Such a drift can easily result from uncertainties in the quartz frequencies of PC-clock and DAQ-clock.

As the EMG sequence to filter is very short, care is taken to minimise start-up and ending transients by matching initial conditions. Zero-phase forward and reverse digital filtering was achieved by using the Matlab routine \texttt{filtfilt}. The lower graph of Figure 2 shows the output of the filter algorithm. The final measurement for the voluntary muscle activity EMG, is calculated by rectifying the filtered signal and building the mean value over one or more stimulation periods. Taking more stimulation periods into account smoothes the signal but introduces a time delay as well.

3 Results

The described set-up and methods have been evaluated with one subject suffering from a head injury. Stimulation was applied to the wrist extensor (M. extensor carpi radialis).
longus/brevis) while EMG was recorded on the same muscle. The subject was not able to extend his wrist more than 30 degree voluntarily.

The lower graph of Figure 3 shows the determined voluntary muscle activity EMGv (calculated over one stimulation period) during a trapezoidal stimulation envelope (upper graph). The subject was requested to extend the wrist for 3 periods of 3 s as much as possible. Stimulation frequency and current amplitude have been fixed to 20 Hz and 30mA respectively.

In a next test, the determined voluntary muscle activity was used to control the electrical stimulation of the same muscle. For this purpose, the signal EMGv was smoothed even more by taking the mean value over 10 stimulation periods. A linear relation between EMGv and the stimulation pulsewidth was used. The stimulation was not raised before EMGv exceeded 5 µV. Pulsed width also saturated at 500µs for EMGv, levels above 20µV.

Figure 4 shows the results of such a EMG controlled stimulation trial. The subject was repeatedly extending his wrist, whereas his voluntary muscle activity induced the supporting electrical stimulation.

4 Discussion and Conclusions

Voluntary muscle activity can be successfully detected by the described set-up and filter algorithm. The baseline of the determined voluntary muscle activity EMGv rises only slightly when the stimulation is active. Voluntary actions can be clearly detected as seen in Figures 3 and 4.

The development of filter algorithms for EMG processing as well as the design of EMG based control strategies are simplified by the use of Matlab/Simulink™. Simple proportional control of the stimulation intensity depending on voluntary muscle activity could be realised.

References


Acknowledgements

We would like to express our sincere thanks to the subject who volunteered to take part in the study and to the Median Klinik NRZ Magdeburg, Germany, for their support. We are grateful to the Ministry of Education and Cultural Affairs (Saxony-Anhalt, Germany) for the financial support which they awarded to the project.