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Dynamic muscle fatigue detection using self-organizing maps

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Abstract

Wavelets are used for the processing of signals that are non-stationary and time varying. The electromyogram (EMG) contains transient signals related to muscle activity. Wavelet coefficients are proposed as features for identifying muscle fatigue. By observing the approximation coefficients it is shown that their amplitude follows closely the muscle fatigue development. The proposed method for detecting fatigue is automated by using neural networks. The self-organizing map (SOM) has been used to visualize the variation of the approximation wavelet coefficients and aid the detection of muscle fatigue. The results show that a 2D SOM separates EMG signatures from fresh and fatigued muscles, thus providing a visualization of the onset of fatigue over time. The map is able to detect if muscles have recovered temporarily. The system is adaptable to different subjects and conditions since the techniques used are not subject or workload regime specific.

Keywords: Wavelets; Self-organizing maps; Neural networks; Biomedical signal processing; EMG; Comfort; Muscle fatigue; Transient signal; Visualization

1. Introduction

Electromyograms (EMG) signals have typically many transient components, which can be isolated and classified according to their physiological significance. The EMG signal contains transient signals related to muscle activity. An example of such a signal is shown in Fig. 1. These signals contain information on which muscle groups have been activated.

Another property that can be extracted from analyzing the transient myoelectric signal (MES) is the presence of fatigue. Muscle fatigue can be defined as reduction in the force generating capacity of a muscle. This change in mechanical performance capacity reflects in EMG changes. In the presented work car driving is used as an example of a situation where muscle fatigue can occur. The identification of

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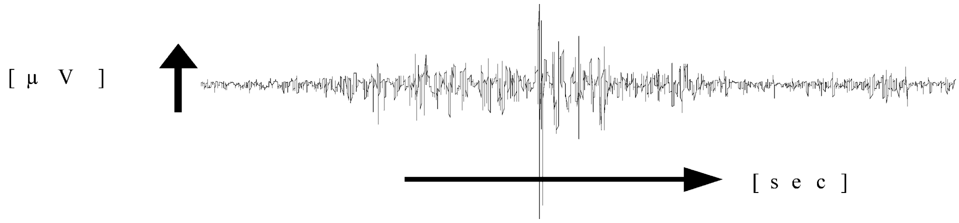

Fig. 1. An example of a surface EMG. The recording shows the contraction of a trapezoid muscle.

specific groups of muscles that show signs of fatigue during the execution of certain driving tasks can be associated with vibration transmission to the body of the driver. In order to be able to assess the effect of the vibrations that are transmitted to the human body the myoelectric signals are recorded and analyzed.

However, a number of problems are associated with the recording and the analysis of the transient myoelectric signal. A main problem is due to the noisy character of the signal. The noisy character is due to the fact that several muscle activations that occur simultaneously are recorded from the electrode(s) that are attached to the skin. What is actually being recorded is the superposition of several muscle activations filtered through different transfer paths of the surrounding tissues and the skin itself.

The most efficient way to use the transient MES is by extracting from the signal a number of useful features. Such features should be closely related with the condition of the muscle and the type of the muscle group that is activated. An example of this is the identification of the type of movement of the arm from recorded triceps and biceps signals. Certain combinations of time-based features that have been extracted from recorded MES can be used as input to a neural network classifier in order to accurately identify movement types in the case of amputees. Such an application has been reported in [1]. However, time domain features are not so robust against signal amplitude variations. A number of more advanced features have been investigated in [2]. These features were based on the use of different types of wavelet transforms and specifically the wavelet packet transform. This transform was used in combination with neural networks to identify the type of movement of the arm. It was shown that in combination with principal components analysis (PCA), a very accurate classifier could be constructed based on wavelet features.

Basmajian and De Luca [3] have shown how the effects of superposition and tissue filtering join to produce a single motor unit action potential (MUAP) detected by electrodes. In additional work both Kupa et al. [4] and Solomonow et al. [5] have reported overall spectral shifts in the surface EMG. These shifts are attributed to the type of muscle fibers activated and may therefore be used for characterization of motor unit recruitment and muscle composition. Investigation of these shifts have been limited to changes in the median frequency of the power spectrum derived using windowed FFT. These methods, however, try to capture time varying spectral shifts that are due to changes in the underlying irregular discrete waveforms, using continuous regular sine waves.

Wavelet analysis allows investigation of these changes using irregular discrete ‘‘little waves’’. These are functions whose shape and duration are much more similar to an actual MUAP. By scaling and translating these ‘‘little waves’’ the resulting decomposition may produce information about the recruitment of the motor units of different type.

Another interesting property that can be extracted from analyzing the surface electromyogram (SEMG) is the presence of fatigue. Successful analysis of transient SEMG signals for fatigue analysis requires suitable spectral estimation techniques. The use of short-time Fourier transform avoids the question of stationary signals by defining the time-interval (local stationary signal) to be used in the computation. There are however restrictions in the use of Fourier transform due to the time frequency resolution. It is found that the minimum allowable window width is approximately 250 ms for a typical SEMG signal [6–8].

A number of studies mention already the good performance of wavelets in transient SEMG processing for fatigue detection, reaction time detection or pattern recognition [9–11].