Advanced EMG Signal Processing and Perspectives

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Motivation

Motor-unit action potentials (MUAPs) and the corresponding innervation pulse trains have significant diagnostic value and clinical importance. To extract these pieces of information, the recorded electromyograms (EMGs) must be decomposed. This means dealing with superimposed compound signals, which necessitates the application of advanced signal processing methods.

Presentation outline

• Basic idea of EMG decomposition – looking for MUAPs
• Template construction and matching
  – Subtractive wavelet transform
  – Time-scale phase representation
  – Examples
• Higher-order statistics and optimisations
  – Examples
• Why template-based decomposition fails with SEMGs?
  – Demonstration
• Perspectives
EMG – superimposition of several (MUAPs)

Pictorial Outline of Decomposition

Electrode
Muscle

α-Motorneurons

Raw EMG Signal

DECOMPOSITION

Individual Motor Unit Action Potential Trains (MUAPTs)
Basic idea of EMG decomposition: template matching
Templates, clustering and decomposition

• Template extracted adaptively – needle EMG:
  – MUAPs characterised by their features
  – MUAPs searched for and extracted
  – MUAPs classified by clustering, e.g. by nearest neighbour
  – Innervation pulse trains decomposed by template matching

• Fixed template – EMG and MUAP finger-prints:
  – Template modelled, i.e. as the basic SFAP shape
  – Parametric decomposition using multiscale wavelet transform
    • Finger-prints by subtractive wavelet transform (SWT)
    • Decomposition by time-scale phase representation (TSPR)
An example of real MUAP finger-prints by SWT

An example of real EMG finger-prints by SWT

An example of synthetic MUAP finger-prints by TSPR

Decomposition of MUAPs using higher-order statistics combined with non-linear LMS and w-slices

- Models MA(2,3) and MA(3,3), 3 measurements generated
- First MU with 13 fibres 3 mm deep, the second with 14 fibres at 4 mm and the third with 11 fibres at 2 mm
- Spread of the innervation zone 6 mm for the first, 5 mm for the second and 5 mm for the third MU
- Conduction velocity assumed normally distributed with the mean of 4 m/s and standard deviation of 1 m/s
- Thickness of the skin layer set to 2 mm and thickness of the fat layer to 8 mm
- Mean firing rates of the first, second and third MU set to 12 Hz, 14 Hz and 16 Hz, respectively, with standard deviation of 3 Hz
- Rectangular electrodes 5 by 1 mm simulated;
- Interelectrode distance of 10 mm;
- The electrode array placed between the innervation zone and the tendons of fibres of length 70 mm;
- Sampling frequency of 1024 Hz
- Three synthetic SEMG signals generated in duration of 100 s
Application to synthetic EMGs
MIMO(2,3)

Innervation pulse trains – Bernoulli-like random noise

Channel responses – MUAPs
Decomposition of synthetic EMGs

MIMO(2,3): decomposition using non-linear LMS on 3rd-order cumulants

Example of the decomposed MUAPs using w-slices

D. Zazula, A. Holobar: “An approach to surface EMG decomposition based on higher-order cumulants.”,

Slovenian-Italian Workshop on Quantitative Needle and High Resolution Surface EMG,
Ljubljana, Dec. 4, 2006
Decomposition of real SEMG using higher-order statistics with w-slices and non-linear optimisation

Isometric contraction of biceps brachii, 20 % of MVC, signal length of 61,440 samples
Example of the decomposed MUAPs using w-slices (cont.)

Demo

Synthetis needle and surface EMG
Perspective of surface EMG decomposition

Decomposition dilemma:
Direct reconstruction of surface-observed MUAPs unreliable—
Could we reconstruct the innervation pulse trains instead?

\[
P(c_{ij} \mid t) \quad P(t \mid c_{ij})
\]
Benefits and potentials

• The method of convolution kernel compensation (CKC) solves the problem of pulse-train decomposition.
• Benefits:
  – Innervation pulse trains detected very accurately
  – Subsequent MUAP trains constructed by spike-triggered averaging
  – Rather high noise resistance
• Potentials:
  – Clinically-relevant estimates such as triggering frequency, conduction velocity, produced force, and the influence of fatigue obtained reliably
  – Statistically proven about 20 to 30 trains can be decomposed with lower contraction forces using CKC
  – Additional postprocessing may double at least the number of detected pulse trains and make it possible also at higher contraction forces
• Details in the next talk