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Fuzzy MUAP recognition in HSR-EMG detection basing on morphological features

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ABSTRACT

The idea of 'besides the MU properties and depending on the recording techniques, MUAPs can have unique pattern' was adopted. The aim of this work was to recognise whether a Laplacian-detected MUAP is isolated or overlapped basing on novel morphological features using fuzzy classifier. Training data set was constructed to elaborate and test the 'if-then' fuzzy rules using signals provided by three muscles: the abductor pollicis brevis (APB), the first dorsal interosseous (FDI) and the biceps brachii (BB) muscles of 11 healthy subjects. The proposed fuzzy classier recognized automatically the isolated MUAPs with a performance of 95.03% which was improved to 97.8% by adjusting the certainty grades of rules using genetic algorithms (GA). Synthetic signals were used as reference to further evaluate the performance of the elaborated classifier. The recognition of the isolated MUAPs depends largely on noise level and is acceptable down to the signal to noise ratio of 20 dB with a detection probability of 0.96. The recognition of overlapped MUAPs depends slightly on the noise level with a detection probability of about 0.8. The corresponding misrecognition is caused principally by the synchronisation and the small overlapping degree.

1. Introduction

The surface electromyographic (SEMG) signal reflects the temporal and spatial summation of the electrical activity generated by all active motor units (MUs). The motor unit (MU) is a set of fibres which are activated by the same motoneurone and thus is the smallest functional unit of the contraction activated voluntarily by the nervous system (Basmajian and De Luca, 1985). The action potential of the MU (MUAP) morphology depends principally on intrinsic and extrinsic factors. The intrinsic factors are related to the MU properties like MU size, the fibers type (their diameters and conduction velocities), the fibers density, the fibers dispersion (MU cross section), the innervation zone width and endplates dispersion. The extrinsic factors are related to the volume conductor properties, the relative location of the MU with respect to the electrodes position and to the electrodes configuration (Lateva and McGill, 2001; Merletti et al., 1999; Stalberg et al., 1986). Both the shape and the firing rate of the MUAP are important sources of information for diagnosis of pathologies, either muscular or neuronal disorders (Basmajian and De Luca, 1985; Sonoo and Stalberg, 1993; Iani et al., 1994). This is why the MUAP has been the subject of many researches (Disselhorst-Klug et al., 1998; Farina et al., 2003; Lateva and McGill, 2001; Stalberg et al., 1996).

The investigation of the MUAP morphology in SEMG signals is still a difficult task due to the effect of various factors leading to its misrecognition. This misrecognition is principally caused by the noise and by the disturbance from other MUAPs which overlap the investigated MUAP. Many techniques have been used to detect susceptible MUAPs from the EMG signal which use a specific threshold related to the amplitude and the slope or any kind of occurrence detection techniques (Gazzoni et al., 2004; Lateva and McGill, 2001; McGill et al., 1985; Ren et al., 2006). A candidate MUAP, which can be isolated or overlapped, can be recognized as an isolated one when it occurs many times in the signals. This is usually performed by clustering in the EMG signal decomposition process (Basmajian and De Luca, 1985; Florestal et al., 2009; McGill et al., 1985; Stashuk, 2001). The recognition of the MUAP by clustering depends upon its repetitive versions in time when firing. However, no alternative procedure to recognize directly isolated MUAPs from its morphology is available for SEMG signals.

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In the present work, we investigate the recognition of the isolated MUAP using only its morphology independently to its repetitive versions. With such investigation we try to answer the question: Is it possible to recognize an isolated MUAP from only its morphology using some proper features? This suggests that isolated MUAPs should have specific shape to be recognized. This cannot be true for all isolated MUAPs. However, using the same detection filter in the same position, some MUs would have the same MUAPs waveform; others would have other waveform depending on the MUs architectural properties (Lateva and McGill, 2001). According to many SEMG studies, there are more biphasic waves when the longitudinal single differential (LSD) filter is used (Farina et al., 2003; Merletti et al., 1999). Triphasic waves are commonly detected in longitudinal double difference (LDD) filter and normal double differential (NDD) or Laplacian filter (Farina et al., 2003; Hogrel, 2003; Merletti et al., 1999; Reffad et al., 2007). It appears from this SEMG studies and even from intra-muscular EMG studies (Lateva and McGill, 2001; Petersen and Kugelberg, 1949) that, depending on the MUs architectural properties and on the detection site, the MUAPs shapes can be clustered in particular patterns.

The isolation or the overlapping of a MUAP is a question of degree i.e. a MUAP can be totally or partially overlapped with certain degree. This aspect of vagueness and ambiguity encourages treating the MUAP recognition problem using fuzzy logic (Zadah, 1965). In most cases when using fuzzy systems, rules are generated by a human expert. Whereas in some cases, human expert lacks the proper understanding on the problem itself, therefore the linguistic rules could be erroneous. In such cases as in the present study, numerical data is necessary to derive rules by learning mechanisms (Ishibuchi et al., 1992; Ishibuchi, 2001; Yuan and Zhuang, 1996).

The aim of this work was to recognize whether the triphasic MUAPs detected from single-channel NDD-filtered EMG signals (Disselhorst-Klug et al., 1998, 2000; Farina et al., 2003) are isolated or overlapped basing on novel MUAPs features using a fuzzy classifier. For this purpose, signals were recorded from three different muscles having different MUs size and properties, the abductor pollicis brevis (APB), the first dorsal interroseus (FDI), and the biceps brachii (BB) muscles of the right hand. The recognition problem of the isolated/overlapped MUAPs was seen as a classification problem in which training data were prepared and labelled by an expert from recorded signals to constitute learning and test examples for the fuzzy classifier. While labelling the MUAPs, the expert might be erroneous in some MUAPs classes therefore; synthetic signals in which MUAPs classes are known correctly were used as reference to evaluate the elaborated classifier.

2. Methods

To recognize automatically MUAPs (isolated or overlapped) from high spatial resolution EMG (HSR-EMG) signals, different processing steps had to be conducted. Fig. 1 shows an overview of the steps by which this task of recognition was achieved.

2.1. Subjects

Eleven healthy subjects voluntarily participated to record signals for this study. Six women (age: 27.4 ± 3.64 years, height: 1.65 ± 0.08 m, body mass: 74.16 ± 22.85 kg) and five men (age: 29.6 ± 4.5 years, height: 1.83 ± 0.07 m, body mass: 85 ± 15.8 kg). No subject is known to have symptoms of neuromuscular diseases.

2.2. Data acquisition and preprocessing

To prepare training data containing candidate MUAPs having triphasic form with one peak, signals had to be recorded at low contraction level in such way isolated MUAPs can be presented in the signals. Templates with more than one peak have been discarded using preliminary rules and are not considered as candidate MUAPs. Prior to the measurements, for each considered muscle the electrodes position has been determined to show no effects of the innervation zone. Each subject was asked to perform three times isometric voluntary contraction at low force level separated by a 3-min rest in between. Signals of 10 s duration were recorded from the three muscles using a two-dimensional 16 electrodes configuration in each trial (Fig. 2). The best trial and the best NDD-filtered channel in term of having less noise and clear MUAPs were chosen. The use of the NDD filter was motivated by its selectivity to get more isolated MUAPs and less overlapped ones (Disselhorst-Klug et al., 2000; Rau and Disselhorst-Klug, 1997). The inter-electrode distance (IED) used for small muscles (APB and FDI) was 2.5 mm and 5 mm for the biceps. The conditions of measurement obey the SENIAM recommendations (Hermens et al., 2000). Signals were amplified by a factor 1 K (20- to 400-Hz bandwidth amplifier) and sampled at 4 KHz using a 12-bit A/D converter. If necessary, residual power-line interference embedded in the chosen signals was removed with spectral interpolation method.

2.3. Candidate MUAPs detection

The candidate MUAPs which can be isolated or overlapped constitute a database to serve as learning examples for the fuzzy classifier as well as to test its performance. The detection of these candidate MUAPs was performed by an algorithm based on preliminary rules which investigates the triphasic template in the signal. As the isolated MUAP has a triphasic form with main principal peak (Fig. 2), any triphasic wave template can be an isolated MUAP. When the algorithm starts to scan a signal searching for the candidate MUAPs, it stops at each peak to investigate the template related to that peak. The search function traverses from the peak forward and backward to achieve the minimum point after having found the positive peak in both directions. During the searching phase of the minima, if an inflection point is found, it would be the minimum point instead. The triphasic templates which do not fulfil the preliminary rules are not isolated MUAPs and those must be directly rejected from the set of candidate MUAPs. Templates with more than one peak will be discarded and will not be a subject of recognition: these templates are already overlapped MUAPs. The examination of all templates in the studied signals provided a set of 1406 candidate MUAPs.

The preliminary rules are function of some morphological parameters of the candidate MUAP. These parameters are described in the 'visible morphological parameters' section. Preliminary rules are defined in the following.

- The principal peak must be negative ($P < 0$).
- The two peaks beside the principal peak must be positive ($P1 > 0$ & $P2 > 0$).
- The principal peak must be higher than the two positive peaks ($-P > \max(P1, P2)$).
- The two minimums of the extremities (point m1 ($f1$) and m2 ($f2$)) must be at least a quarter smaller than the two positive peaks.
- The absolute difference between the two positive peaks must be less than 3/5 of the maximum of the two peaks.
- The degree of curvature at the peak must be bigger than the degree of curvature of the positive peaks.
- Point $p1$ and $p2$ must be reached directly from point p (i.e. one inflection point must exist between p and $p1$ and between p and $p2$).