Extraction of Some Relevant Instants from EMG Signal

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Abstract: In this paper, an algorithm to estimate key instants in EMG signal during pre-motrice and motrice phases is developed. It detects automatically *i)* the onset of muscle activity when an explicite recommendation of preparation is dictated (pre-motor onset), *ii)* the onset of effective muscle contraction (motor onset) and *iii)* the instant of muscle contraction desactivation (motor offset).
The algorithm is based on statistical thresholding and counting the number of samples exceeding the threshlold. The counting is ensured by elaborated temporal scanning in forward and backward directions. The threshold calculus is based on statistics of the EMG signal during muscle activity and muscle rest.
The algorithm is illustrated for the superficial flexor muscle during a handgrip exercice and is validated using subjective visual inspection and objective evaluation (error rate). The results revealed that relevant instants in EMG signal are well estimated.

1 INTRODUCTION

Electromyography is the most commonly used tool for investigating muscle function. For example, the ElectroMyoGraph signal (EMG) reveals details of the timing and the magnitude of muscle activation. Regarding timing, an EMG signal is composed of different kind of time intervals. Fig.1 illustrates an example of timing. The preparation duration or pre-motor activity or foreperiod is the time interval between a warning signal motivating mental preparation and a Go signal for motion execution. The pre-motor time is followed by the motor task which is the effective muscle activity (sometimes after a short latency time). The activity generally ends spontaneously or after a termination signal.

Three important instants characterize the time domain evolution. They are: the pre-motor onset which characterizes the onset of pre-motor activity of the muscle during the preparation period (initiation and planification of the motion), the motor onset which characterizes the muscle activity beginning (motor program) and the offset which characterizes the end of the activity (see Fig.1).

Traditionally, the most reliable way to detect onset and offset is the visual inspection and decision of experts like physiological therapists. Although their accuracy, they are very expensive and time consuming.

Signal processing based algorithms has been introduced to overcome these drawbacks. Common methods for detecting muscle activity onset and offset were based on thresholding (Ozgunen et al., 2010), energy operators (Li and Aruin, 2005), signals decomposition and transformation such as empirical mode decomposition (Lee et al., 2009) and many others algorithms.

Although time preparation and its effect on muscle contraction has been investigated since the early 1980 (see for example (Alegria, 1980)), at our knowledge, there is no automatic method to detect the premotor onset. In fact, this task seems difficult since EMG signal during preparation has low level and can be confused to background noise.

In this work, we aim developing a signal processing based algorithm to detect the three most important instants of muscle activity which are the pre-motor onset, the motor onset and the motor offset.The algorithm is inspired from (Abbink, 1999), originally conceived to detect muscle onset which is extended here to estimate the three mentioned instants.

The paper is organized as follows. Section 2 describes some pre-processing tasks useful to prepare the algorithm, such as: *i)* signal smoothing and rectifying, *ii)* muscle activity detection to separate muscle contraction from muscle rest, *iii)* analysis windows choice centered on muscle contraction. Section 3 details the different steps of the proposed algorithm: *i)*

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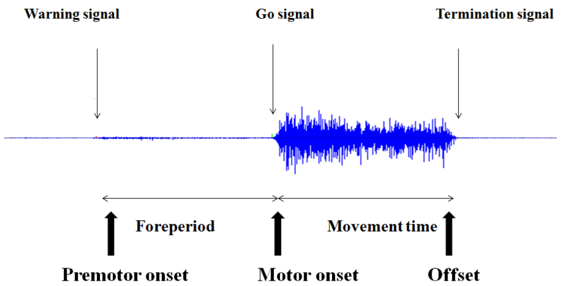

Figure 1: Instants of interest definition.

threshold calculus based on histograms, *ii)* counting of samples exceeding the threshold by adopting a particular manner to scan the analysis window, *iii)* detection of the instants of pre-motor onset, motor onset and offset, *iv)* and finally corrections and adjustments in case of burst or noise. Section 4 presents the results using subjective comparison and quantitative evaluation based on error rates calculus. Finally some conclusions and perspectives are given.

2 PRELIMINARY PROCESSING

After EMG recording, some preliminary tasks are carried in order to prepare data for pre-motor onset, motor onset and motor offset detection.

- The DC component and very low frequency components due to movement and other artifacts are eliminated thanks to a high-pass filtering whose cutoff frequency is 10 Hz. Fig.2.a shows an example of a pre-processed EMG signal composed of 3 contractions of the superficial flexor of the forearm during a handgrip exercice. The contractions last 4.4 s and are alterned with rest intervals of 44s.
- The EMG signal is smoothed so that the steep spikes are cut away and the signal looks like an envelope (see Fig. 2.b). The Root Mean Square (RMS), which reflects the mean power is used:

$$RMS(n) = \sqrt{\frac{1}{N+1}\sum_{k=-N/2}^{N/2} x(n+k)^2}, \quad (1)$$

  where N is the sliding windows size on which each EMG sample $x(n)$ is smoothed. It is chosen equal to 512 samples for a sampling frequency of 1 kHz.
- A preliminary Muscle Activity Detector (MAD) is estimated by comparing each amplitude to a threshold (see Fig.2.c):

$$MAD(n) = \begin{cases} 1 & \text{if} RMS(n) > \tau \\ 0 & \text{otherwise,} \end{cases} \quad (2)$$

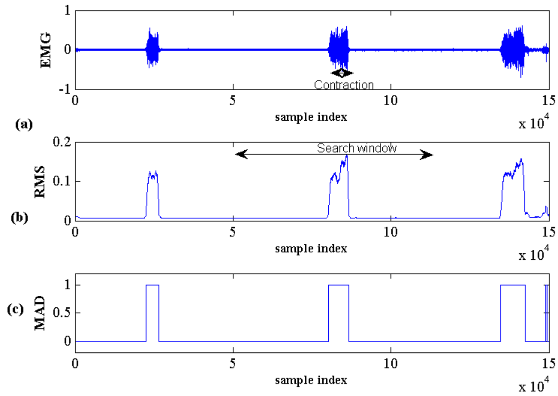

Figure 2: EMG signal, RMS signal and associated MAD flag.

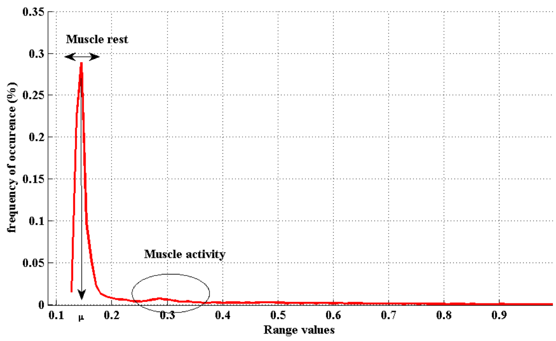

Figure 3: Histogram of the RMS signal.

Where τ is the threshold. It is obtained using the following approach.

- A long RMS signal composed of 15 contractions is used. It is composed of $4.4*15 = 66$ seconds of activity and $44*15 = 660$ seconds of inactivity. The ratio between these two durations is ten. The histogram of this long RMS signal is calculated and illustrated in Fig. 3. It contains one significant peak which represents samples with low values occurring mainly during rest interval. The small peak situated for higher RMS values reflects muscle activity.

From the histogram, the position of the maximum is estimated and is denoted μ and the standard deviation is denoted σ. The threshold τ is estimated as follows:

$$\tau = \mu + \gamma.\sigma, \quad (3)$$

where γ is a regulation parameter adjusted empirically. For muscle activity detection, the experiment showed that it can be chosen equal to 0.5.

3 KEY INSTANTS DETECTION

- According to the *MAD*, each contraction is centered on a window composed of the half of the rest interval preceding it and the half of the rest interval following it. It is called the search interval (see Fig.2.b).
- The work begins in the center of the search interval. Traveling in the direction of the beginning of the interval, a counter index is associated to each position i of the selected window:

$$C(i) = n_h(i) + n_l(i), \qquad (4)$$

where $n_l(i)$ (resp. $n_h(i)$) is the accumulated number of *RMS* values under (resp. above) the threshold τ from position 1 to i (resp. from position i to the end). Experimentally and in this part of the work, the threshold is obtained for $\gamma = 3$ in Eq. 3.

The same process is done by coming back to the center of the search interval and traveling in the direction of the end of the search interval.

- Fig.4 (resp. 5) illustrates the counter index and its first order derivative in the case of a contraction without (resp. with) preparation. One can notice from Fig. 5 that the counter index increases until the contraction preparation begins, it then decreases until the effective contraction begins. It remains constant until the end of the contraction and finally, it increases again.
- The decision to detect the instants of preparation (pre-motor), onset and motor offset are based on the derivative of the counter index (lower parts in the previous figures). The rule is straightforward: if the derivative changes from +1 to -1, the premotor onset is detected. If the derivative changes from -1 to 0, the motor onset is detected and finally, if the derivative changes from +1 to 0, the motor offset is detected.
- Unfortunately, some undesirable short contractions and bursts can arise during EMG acquisition (see for example Fig. 6). They generate, in the counter index, some local deviations from the right way. To avoid them, a smoothing, using for example the median filter, is applied on counter index.
- Moreover, if many onset and offset candidates appear in one analysis window, only one effective onset and only one effective offset must be retained, they are those who correspond to the maximum area in the RMS signal. In fact, the effective contraction lasts more and have more energy than local burst due to noise or undesirable short contractions.

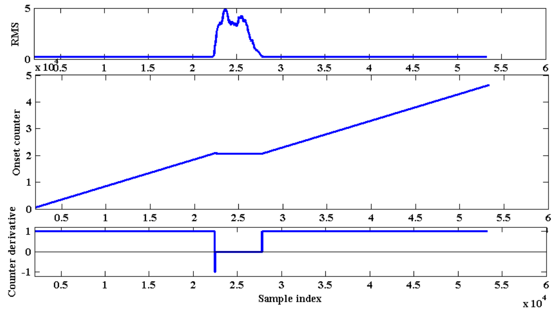

Figure 4: The RMS signal, the counter index and its derivative for a contraction without muscle preparation.

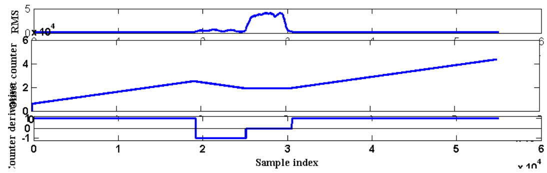

Figure 5: The RMS signal, the counter index and its derivative for a contraction with muscle preparation.

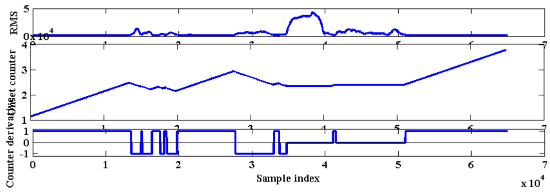

Figure 6: The RMS signal, the counter index and its derivative for a contraction with short contractions and bursts.

4 RESULTS

To conduct the study, a particular experimental protocol was defined. 24 young motivated adults (12 male and 12 female) performed a hand grip motor performance. We chose the superficial flexor to validate the method.

Two separate guidelines were presented to the participants:
• an auto-initiated (self-made) mode: the start and the end of the contraction are managed by the subject itself, without preparation set-point.
• an external triggered mode: a preparation directive is given ("get ready") followed by an execution directive ("Go") after 6.6 seconds.

For each mode, 5 consecutive hand-grip contractions are carried. Each one lasts 4.4 seconds and is followed by a long period of rest (44 seconds).

Table 1: Error rate of instants estimation.

Instant	pre-motor onset	motor onset	offset
Total error rate (%)	17	3.3	2

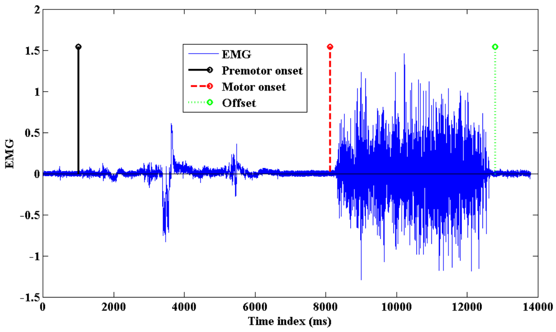

Figure 7: Illustration of relevant instants detection.

The EMG signals are recorded using EL508 system which is produced by the BioPac company. Signals are sampled at 1 kHz.

Fig. 7 shows an example of muscle contraction and the detected instants. From visual inspection, one can see that pre-motor onset, motor onset and offset are well detected.

From the database of the 240 contractions, we calculate the relative error as the difference, in absolute sense, between the estimated instant and the one determined by visual inspection. The error rate is resumed in Tab. 1. One can see that error rate is very low for motor onset and offset (3.3 % and 2 % respectively). It is however, slightly higher for pre-motor onset (17 %). This last result is predictable since pre-motor phase is characterized by low level signal and can be confused to acquisition noise and muscle rest. When they are non null,the values of errors, in milliseconds, are:
• motor onset: 36, 260, 344, 383, 1002, 1633 and 1708,
•: offset: 112, 114, 115, 119 and 167,
• pre-motor onset: the number of errors is higher, thats why their histogram is used for illustration (Fig. 8). One can see that the error range value is quite large (from 0 to 6500 ms). It means that when an error occurs, the estimation can be either quite precise or quiet wrong.

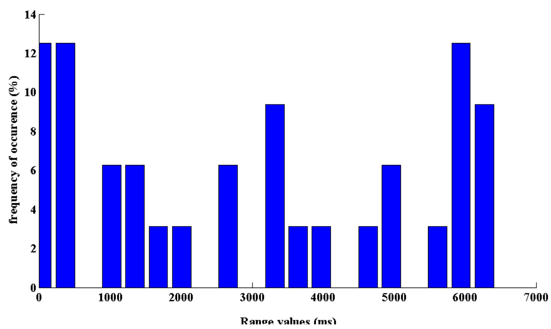

Figure 8: Histogram of pre-motor onset estimation error.

5 CONCLUSION

In this paper, an automatic algorithm to detect some important instants in EMG signal has been developed. It is based on the entire EMG signal (including rest interval) to estimate a threshold and to count, in a particular manner, the number of samples exceeding it. The results are very satisfactory in terms of motor onset and offset and present slight errors for pre-motor onset detection.

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