Segmentation of Surface EMG Signals

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Abstract – This paper compares two different approaches to electromyographic (EMG) segmentation for the purpose of muscle activation pattern identification. A widely known linear EMG envelope technique is compared with a newly designed method based on marker detection in a video. The results are evaluated by comparison of the muscle activity intervals. The experiments show that the video-based technique can achieve similar results to the EMG envelope. The EMG segmentation based on the video processing is more robust for segmentation of various types of EMG signal.

Keywords- electromyography; kinesiology; digital signal processing; EMG segmentation; muscle onset detection

I. INTRODUCTION

Electromyography provides signals that represent the activity of muscles. The investigation of muscle activity is used in many branches of medicine and sports. Based on the scanning method, the EMG signals are divided into two groups: surface and intramuscular. Only the non-invasive surface EMG is used for movement analysis in sport; the invasive intramuscular EMG signal evaluation is predominantly applied in medicine. Here, the signals can be used for diagnosis of neuromuscular diseases, therapy and controlling of prosthetic limbs, while applications in sport include analysis of the biomechanics of human movement.

This paper is focused on the processing of surface EMG for purposes of movement analysis in sports. The surface EMG signals captured during periodic movements are processed in order to detect the onset and cessation of muscle activity, which can reveal information about muscle coordination during periodic movement. Specialists in kinesiology draw conclusions from the muscle activity patterns thus obtained. An example of utilization of the results is the comparison of the muscle coordination of athletes and the general population.

The algorithm applied for the detection of muscle onset and cessation requires the average EMG envelope, which is computed from several movement cycles. To obtain the average envelope, several movement cycles need to be identified, allowing for segmentation of the recording. This work presents a comparison of EMG-based and video-based segmentation techniques.

II. SEGMENTATION TECHNIQUES

Nowadays, the solutions to the task of EMG segmentation can be grouped into three different approaches: video-based, EMG-based, or based on other supplementary signals.

A. Segmentation based on the EMG

Segmentation based on EMG alone is the most commonly used procedure. The EMG signals are recorded in multiple channels from important groups of muscles involved during the sports activity.

However, not all channels of the EMG recording are suitable for detection of movement cycles. The suitability of a certain EMG channel depends on the mode of muscle activity and on the number of onsets and cessations during every movement cycle. The most appropriate EMG signals are generated by muscles working in phasic mode and having only one activity interval within the movement cycle. A detailed description of phasic muscle activity can be found in [1]. Fig. 1 shows examples of differences between suitable and unsuitable EMG signals considered for the segmentation.

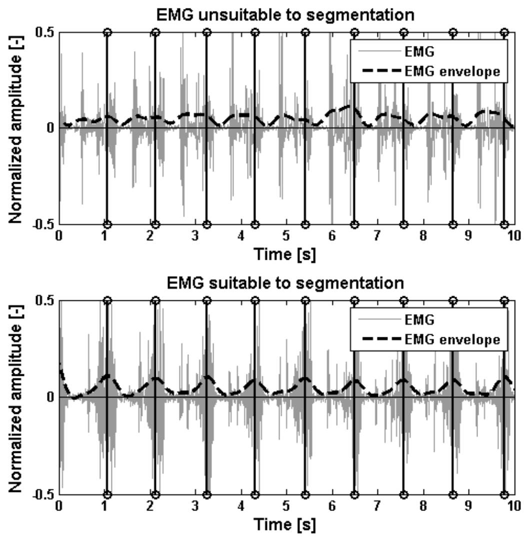

Figure 1. Examples of EMG signals and EMG signal envelopes both unsuitable and suitable for movement cycle detection. The movement cycle boundaries are marked by vertical lines. Note the irregular envelope is in the top plot.

For the suitable EMG channel, the linear EMG envelope is calculated and the signal is low-pass filtered. The boundaries of movement cycles are identified as the maximum or minimum of the signal.

Several other methods usable for detection are described in references [2], [3] and [4].

B. *Segmentation based on the video recording*

Video recording was originally captured in each measurement for the purpose of documentation of the EMG signal. Therefore, the aim was to utilize this previously unused data in order to detect the movement cycles´ boundaries.

In the basic setup, the athlete had to wear colored markers placed on appropriate locations of the body. The detection of human body movement was then realized through the detection of the movement of these markers in the video.

More than one marker was necessary, because the video contained disruptive movements caused by the operator. The interferences in the marker position signals were eliminated by processing the difference of the markers' positions on the x and y axes rather than the positions alone. A satisfactory segmentation results of the EMG signal was already achieved with two-marker tracking.

An example of a signal used for movement cycles´ detection is shown in Fig. 2. A detailed description of the algorithm applied follows in Chap. III.

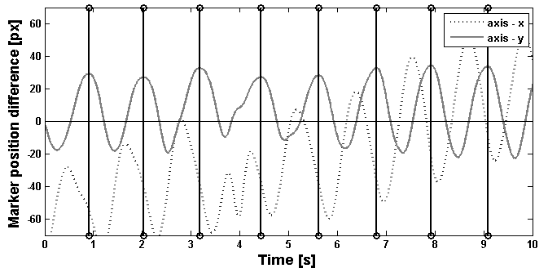

Figure 2. Example of the marker position difference signal. The movement cycles boundaries are marked by vertical lines.

C. *Segmentation based on a supplementary signal*

A suitable type of supplementary signal depends on the sports activity. The supplementary signal can be recorded in standard ways, using an accelerometer, gyroscope or tensometer. The recording of the supplementary signal complicated the measurement process; therefore this approach is used only in necessary cases. The movement cycle detection method is chosen according to the type of supplementary signal.

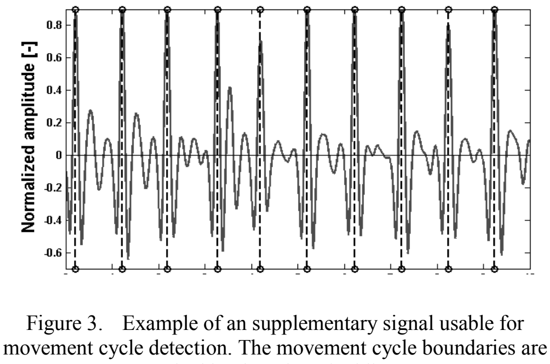

Figure 3. Example of an supplementary signal usable for movement cycle detection. The movement cycle boundaries are marked by dotted vertical lines.

An example of the supplementary signal from accelerometer for movement cycles´ detection is shown in Fig.3.

III. EXPERIMENTS

This chapter describes the recording, the signal database and the algorithms used.

A. *Recording procedure and signal database*

The recordings were obtained during sports activities in natural conditions, namely during cross-country skiing and walking. The length of every recording was approximately 30 seconds. The database of 10 recordings includes both EMG and video signals captured simultaneously.

Color markers were placed on the ankles of athletes. This placement was chosen to be sure that the markers represent the periodicity of motion. The video was recorded with a SONY HDR-SR12 high-definition video camera at a resolution of 576×720 pixels and 25 frames per second. A non-static (freehand) video camera was used, as the recordings were captured in natural conditions.

The surface EMG signals were recorded by the device KaZe05. Synchronization with the video was performed by a trigger (flap): the trigger sends the signal to the KaZe05 and the flap is recorded by the camera. The analog full-wave rectification process and low-pass filtering (cut-off frequency 70 Hz) were used before the analog-to-digital signal conversion. The sampling rate was 200 Hz and resolution 8 bit. We measured 7 muscles: m. gluteus maximus dx., m. gluteus medius dx., m. vastus medialis dx., m. adductor longus dx., m. gastrocnemius caput medialis dx., m. tibialis anterior dx., m. gastrocnemius caput medialis sin. Proper points for placement of electrodes were identified by a physiotherapist.

B. *Signal processing – EMG-based segmentation*

All channels of EMG are segmented using information from one of the channels suitable for segmentation. The EMG signal channel to be used for this purpose is chosen by the operator, although we tested an automatic selection algorithm based on the autocorrelation function.

The suitable channel of the EMG envelope signal is low-pass, filtered by using zero-phase forward and reverse digital filtering. A low-pass FIR filter (order 2000, cut-off frequency 2.6 Hz, stop-band attenuation 55 dB) is applied. The segmentation is based on peak-detection applied to the filtered EMG envelope. Relative maxima having a minimal distance of 0.8 seconds apart are detected.

C. *Signal processing – Video-based segmentation*

The EMG segmentation is derived from the positions of the color markers in the video. The detection of positions is ensured by the designed algorithm. The design of the algorithm is not fully automatic; exceptional cases that are solved by operator interventions. An advanced approach for movement detection is shown in [5].

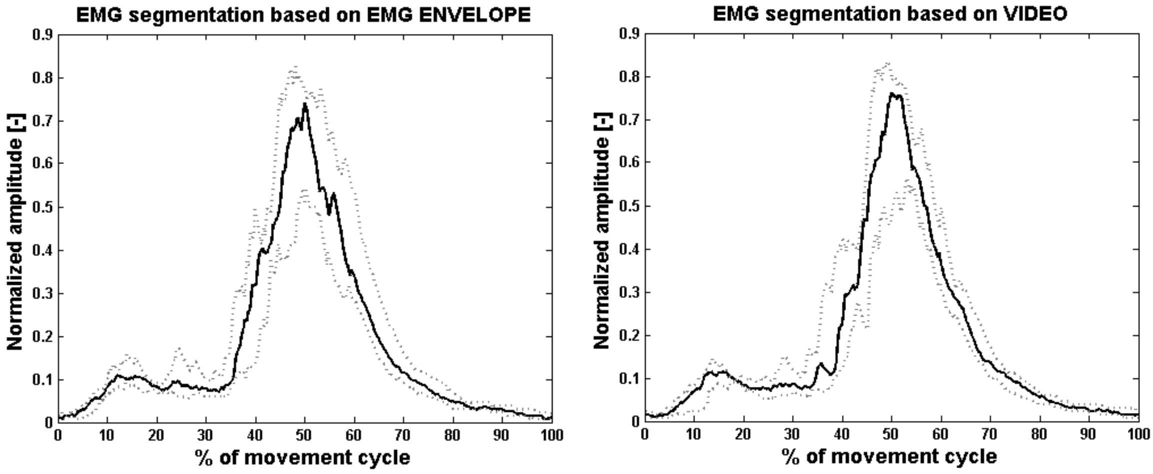

Figure 4. The median EMG envelope signal in the movement cycle for the muscle gastrocnemius caput medialis sin. during cross-country skiing. Dotted lines show the lower and upper whisker defined as the 25th and 75 percentile of data distribution.

Initialization of marker pixels in the first frame of the video recording is required at the beginning of the algorithm used for video processing. A sample frame of the recording and selection of the pixels is presented in Fig. 5. The pixels' values are then converted from the RGB to the HSV color model., which better represents the hue of color. The histograms for selected pixels are processed and thresholds for HSV components are set.

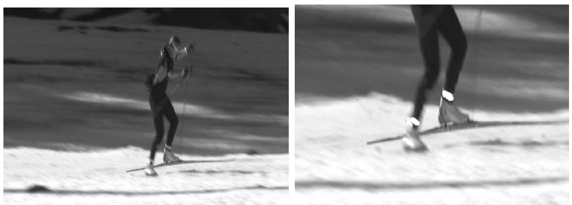

Figure 5. The initialization of marker pixels: left whole frame without any marking, right detail of the frame with selected markers.

The process gradually searches for the positions of markers in the video. The first step in each frame is to segment the markers by using HSV component thresholding. The markers not selected in initialization are undesirable in segmentation, because it is necessary to eliminate the pixels, hence the markers are detected only in the cutout regions. The suspicious region of interest for each track marker is determined by using information about the center position in the previous frame. When a given cutout does not contain pixels, the exception is solved by the intervention of the operator.

The centers of segmented clusters are searched by the K-means algorithm. The final step of the process is the correct assignment of the class marker in successive frames. The score is calculated for all combination assignments of classes, this being the sum of the distances of the markers. One marker is from the processed frame and the second is in the previous frame. If a unique class assignment is impossible using the score, the operator is prompted to provide the class assignment. The signal used for segmentation is calculated by the difference of positions of two markers on the x and y axes.

D. *Signal processing – Segmentation comparision*

The first process step is calculation of the normalized EMG envelope signal. The entire EMG envelope is normalized by the maximum value of each channel separately. The further step is the segmentation of EMG envelopes in accordance with cycles of movement. The processing differs only in the technique used for movement cycles detection.

After segmentation of the signal, the envelopes from several movement cycles are interpolated to a uniform length (0 % to 100 % of movement cycle) and averaged. Moreover, the median is calculated for every position within the movement cycle as can be seen in the Fig. 4. These operations follow separately in every channel.

The muscle activity is detected by using envelope thresholding: parts exceeding 25 % of the maximum are marked as activity.

IV. RESULTS

The presented results were acquired by processing the selected database record with representative characteristics. Similar results were obtained during the processing of all database records. The EMG-based segmentation used the 5th EMG channel. Fig. 6 shows lengths of movement cycles detected by both EMG- and video-based techniques. Average values and standard deviations are presented in Tab. 1.

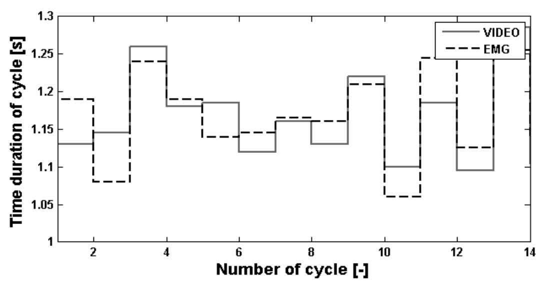

Figure 6. Length of movement cycles detected by both EMG- and video-based segmentations.

TABLE I. LENGTH OF MOVEMENT CYCLES

Segmentation	*Detected period*	
	Mean ± std [s]	*Median [s]*
EMG envelope	1.168 ± 0.059	1.163
Video	1.165 ± 0.031	1.158

The results achieved by different techniques are compared using the muscle activity detection. The results are aligned according to the average EMG in the 7th channel using the correlation function. Fig. 7 presents an example of muscle activity detection performed on curves obtained by both segmentation methods. The correlation of average EMG signals after EMG- and video-based segmentations was greater than 0.98 in all channels.

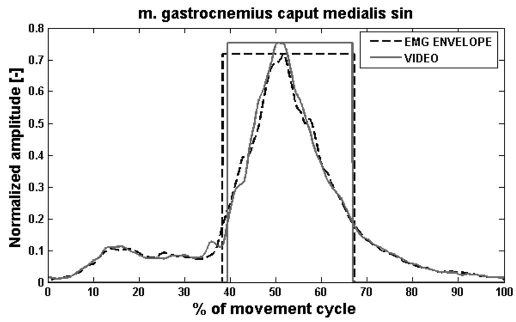

Figure 7. Example of muscle activity detection in the 7th channel (vertical lines) performed on average EMG envelopes obtained by both EMG- and video-based segmentations.

Fig. 8 summarizes activity detected on all muscles, allowing evaluation of the muscle de/activation sequence. This form of results is suitable for comparison of obtained muscle coordination.

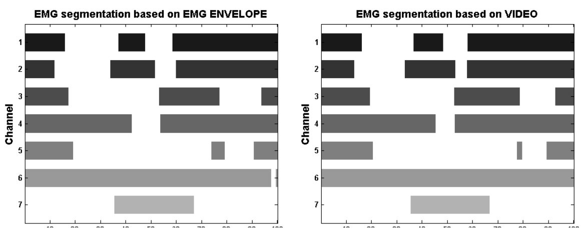

Figure 8. Muscle activity intervals detected on average EMG envelopes. The presence of a horizontal line indicates activation of the corresponding muscle in the respective part of the movement cycle.

V. DISCUSSION & CONCLUSIONS

The results presented in Fig.4 show that the video-based segmentation has smaller variance of data. The results of other channels were similar for both segmentation techniques. The comparison of movement cycle lengths detected by both methods presented in Fig. 6 shows similar results.

As can be seen in Fig. 8, the results obtained using both segmentation approaches are comparable. The results of the 6th channel were probably affected by irregular operation of the corresponding muscle resulting in problematic detection on the averaged envelope, which does not correlate well with several realizations, regardless of the precision of the segmentation.

It should be noted that the activation pattern detected during the EMG-based segmentation also depends on the channel used. These variations are usually rather low, unable to affect the conclusion regarding the muscle de/activation sequence.

We recommend using video-based segmentation if the video recording is available and if the markers are properly placed and visible. In this case, the segmentation is expected to be precise and independent of muscle activity. The EMG-based segmentation can provide comparable results; however, the channel used for segmentation has to be chosen carefully not to cause distortion of the results due to erroneous detection.

Video processing has greater requirements for signal preparation and computing performance. As a benefit, it provides results independent of the EMG signal. If the EMG signal does not contain a suitable channel to detect motion cycles and the supplementary segmentation signal is not available, the video-based segmentation provides the desired results.

VI. ACKNOWLEDGMENT

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REFERENCES

[1] LATASH, Mark L. *Neurophysiological basis of movement*. Champaign, IL: Human Kinetics, c1998, x, 269 p. ISBN 08-801-1756-7.

[2] VIEIRAA, Taian M.M., R. MERLETTIA, L. MESINA. Automatic segmentation of surface EMG images: Improving the estimation of neuromuscular activity. *Journal of Biomechanics*. 2010, vol. 43, pp. 2149–2158.

[3] EL FALOU, W, J DUCHÊNE, M KHALIL, M GRABISCH, F LINO. A segmentation approach to long duration surface EMG recordings. *Journal of Electromyography and Kinesiology*. 2005, vol. 15.

[4] KAUR, Gurmanik, A. S. ARORA a V. K. JAIN. Comparison of the techniques used for segmentation of EMG signals. *MACMESE'09 Proceedings of the 11th WSEAS international conference on Mathematical and computational methods in science and engineering*. 2009, vol. 11, pp. 124-129.

[5] REMONDINO, F. Tracking of Human Movements in Image Space. In: International technical report at IGP – ETH Zurich, 2001