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Seizure Onset Detection based on one sEMG channel

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Abstract— **We present a new method to detect seizure onsets of tonic-clonic epileptic seizures based on surface electromyography (sEMG) data. The proposed method is generic and based on a single channel making it ideal for a small detection or monitoring device. The sEMG signal is high-pass filtered with a Butterworth filter with a cut-off frequency of 150 Hz. The number of zero-crossings with a hysteresis of $\pm 50\mu$V is the only feature extracted. The number of counts in a window of 1 second and the number of windows to make a detection is tested with a leave-one-out method. On 6 patients the method performs with a sensitivity of 100%, a median latency of 7.6 seconds and a median false detection rate of 0.04/h.**

I. INTRODUCTION

Epilepsy is a neurological disorder that causes seizures due to an abnormal excessive or synchronous neural activity in the brain [1]. About 1% of the world's population suffers from this condition. If patients are medicated appropriately most become seizure free, but about 25% do not. Most of these patients experience seizures with predominantly motor symptoms such as tonic-clonic seizures. Their fear of having seizures in public may result in social isolation, and an objective risk of severe and sometimes fatal injuries during seizures increases their perceptions of insecurity. During the seizures the patients are not able to call for help. A simple alarm system, capable of detecting seizures, could help the patients by alerting relatives and caretakers, whenever a seizure sets in. We propose a single channel method, which is reliable and may be implemented in a small monitoring or detection device.

Attempts have been made [2], [3], [4], [5] to develop such a system based on motion data, but none of them is performing well enough to reach clinical use. Earlier we have focused on using several modalities and channels [2], [3], but have now found that a better algorithm may be developed with just one channel from a single modality. We propose a new method capable of capturing the tonic-clonic seizures, with a relatively short latency and without too many false alarms. Our approach is generic and based on a single channel of sEMG from the deltoid muscle and encompasses feature extraction by counting zero-crossings. The method is evaluated on 6 patients with tonic-clonic seizures.

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II. METHODOLOGY

A. Data Collection

The 6 patients were admitted to the Danish Epilepsy Center in Dianalund, Denmark for diagnostic reasons. The recordings included electroencephalography (EEG), video, electrocardiography (ECG) and sEMG electrodes placed on several, clinically relevant muscles. We analysed signals from the left deltoid muscle, as this placement seemed to be the most stable one. The active electrode was placed on the center of the muscle, whereas the reference was placed on the acromyoclavicular joint. The admission lasted 2-4 days depending on the patient. The sEMG was sampled with a frequency of 1024Hz. All patients had tonic-clonic seizures. The number of seizures, sex and age of the patients are listed in Table I together with the lengths of the signals. The times for the beginning and ending of the seizures was annotated by a physician based on video and EEG signals.

TABLE I
THE PATIENTS GENDER, AGE, THE AMOUNT OF SEIZURES AND THE LENGTH OF THE ADMISSION.

Patient	Gender	Age	# seizures	File length [h]
1	M	39	1	93.4
2	M	25	1	46.6
3	F	23	1	25.3
4	F	26	2	95.2
5	M	38	1	96.5
6	M	62	2	95.5

B. Data Processing

The processing of data is split into two parts. The first part is the feature extraction and the last part is the detection approach.

1) Feature Extraction: In a previous study we analyzed the similarities and differences between sEMG signals from real epileptic seizures and sEMG signals from simulated seizures [6]. We showed, that real seizures had a large proportion of data in the frequency band above 100 Hz, in contrast to normal activity. For this study we furthermore made a visual evaluation of all the seizures for the 6 patients and found that the seizures still contained a large proportion of the signal, when preprocessed with a high-pass filter with a cut-off frequency of 150 Hz. This furthermore ensures that a large amount of the artifacts will be removed. We have chosen a Butterworth filter with an order of 20. The group delay of this filter is linear in the frequency band of interest. The seizure of the first patient including prior and posterior normal activity, is shown in Fig. 1 before and after filtering.

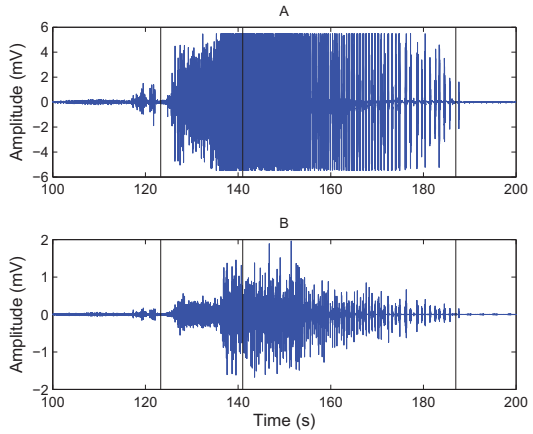

Fig. 1. The upper figure shows the seizure (with surrounding activity) before filtering and the lower shows the signal after filtering. The vertical black dotted lines shows the beginning and ending of the seizure.

In our previous study on the sEMG signals during real and simulated seizures we showed that simple features are able to distinguish between the two groups [6]. Therefore we chose to focus this study on finding a simple feature, which is able to discriminate tonic-clonic seizures from normal activity. Since the final method is meant to be used in a seizure detection system it is important to capture the seizures at onset. We therefore searched for a feature to discriminate the tonic part of the seizure from normal activities, since the clonic part almost always starts late in these tonic-clonic seizures. We found that with a simple zero-crossing method counting the zero-crossings with a hysteresis of $\pm 50\mu$V, the number of crossings was high throughout the entire tonic phase, see Fig. 2. This hysteresis also ensures that low-amplitude artifacts, remaining even after the filtration, are eliminated from a possible detection as a seizure.

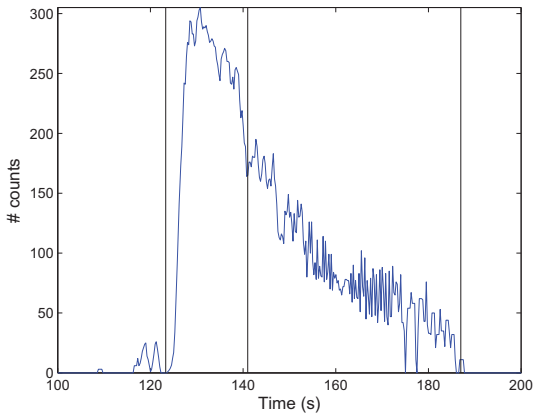

Fig. 2. The number of zero-crossings in windows of 1 second as a function of the time. It is clearly seen that the number of zero-crossings rises fast at seizure beginning, stays high throughout the tonic phase and is then lowered at the start of the clonic phase. The black vertical lines denote the beginning and end of the seizure.

2) Detection Approach: For our method we have chosen to vary two parameters, when searching for the optimal classification of the data into the two options; tonic-clonic seizure and normal activity. The first one is the number of zero-crossings in a given window, called the threshold, and the second one is the number of windows with a count above the threshold needed to classify a seizure. As in one of our previous studies, we have chosen to use a window of 1 second [3]. In this case we have chosen an overlap of 75% for the windows. We chose these values for the two parameters, based on a visual inspection of the feature-plot (see example in Fig. 2 for all seizures. Furthermore this inspection showed that the maximum number of zero-crossings during the tonic phase of the seizures is about 255 counts if all seizures are to be detected. We have though varied the number of counts from 180 to 340. In order to avoid too many false detections while ensuring a sufficiently short latency, the band of well chosen number of windows to make a seizure detection is probably narrow. To ensure that all possible solutions are tested, we have thus varied the number of windows to make a seizure detection from 1 to 40.

We have evaluated the results of the variation of the two parameters by a leave-one-out method, where the values of the parameters are chosen from the best combination based on 5 of the patients, when looking at all combinations in a color-plot. The best combination of parameters is then tested on the last patient. This means that all patients are used five times for training and one time for testing the parameters. An example of the color-plots is shown for the training on patient 1-5 in Fig. 3-5. The green color represents the good choice, yellow is in between and red is a bad choice. The parameters are first of all chosen to ensure that the sensitivity is 100%, which means that only a point in the darker green area of Fig. 3 may be chosen. On Fig. 4 and 5 we then searched for the point that both was closest to a green color within the darker green area from Fig. 3. This will provide the best solution to the combination of a low amount of false positives and at the same time a short latency. A higher threshold and/or a higher number of windows implies a lower number of FP, whereas the latency is lowered by lowering the number of windows and/or lowering the threshold. The green and yellow area for higher number of windows in Fig. 4 is caused by less seizures being detected or even non seizures being detected, see Fig. 3. The choice of parameters for each of the five training sessions are given in Table II.

TABLE II

THE CHOSEN PARAMETERS DURING THE TRAINING PHASE.

Training patients	counts	windows
2,3,4,5,6	254	18
1,3,4,5,6	254	16
1,2,4,5,6	250	18
1,2,3,5,6	250	18
1,2,3,4,6	250	18
1,2,3,4,5	250	18

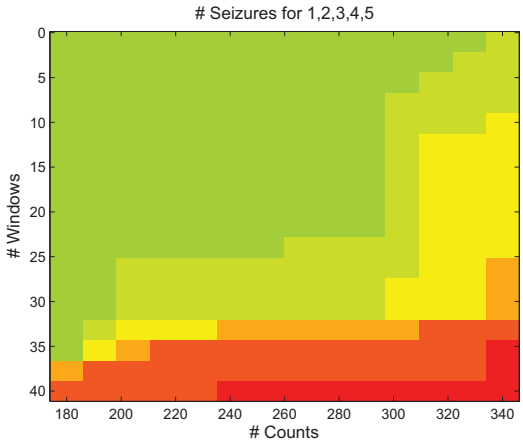

Fig. 3. The sensitivity, where green symbolises 100% and red symbolises 0%.

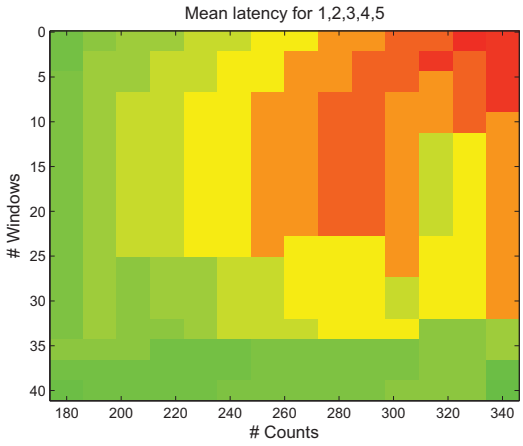

Fig. 4. The mean latency of the seizure detection, where green equals low latency and red equals high latency.

III. Results and Discussion

Based on the leave-one-out method the results for each of the patients obtained with the parameters from Table II is given in Table III. The results for the different patients are very similar; all with a sensitivity of 100%. The false detection rate (FDR) is found to be between 0 and 0.1885, which compared to other studies are very promising values. The latencies are between 7 and 10.5 seconds. This is fine for a monitoring system and would as well be acceptable in a detection device. The latency may be shortened by a change of the parameters, but this will of course induce more false positives as well. To improve the system even more it could be implemented with an adaptive update on the threshold, so every time a seizure is detected the threshold would be fitted to suit the number of counts during the seizures even better. The deltoid muscle was selected for sampling because it is easily accessible, and always involved in generalized tonic-clonic seizures. If a patients seizures have a tonic motor onset in a different location, the method can probably be adapted accordingly whereas different seizure types starting

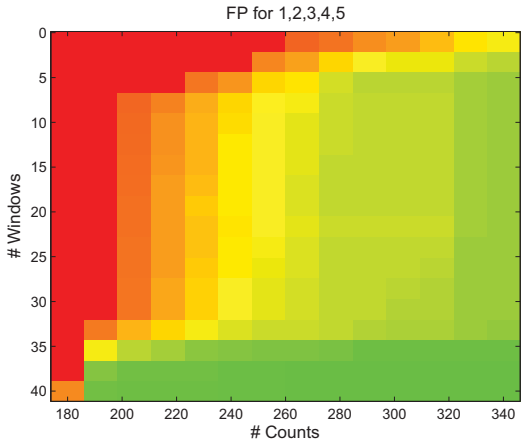

Fig. 5. The number of false positives (FP), where green equals few FP and red equals many FP.

e.g. with myoclonia, automatisms or sensory symptoms will need different approaches. In future studies we will include more patients and seizures to confirm the promising results in this paper.

TABLE III
THE RESULTS FOR EACH OF THE PATIENTS BASED ON THE PARAMETERS FROM TABLE II.

Patient	Sensitivity [%]	Latency [s]	FDR [/h]
1	100	9.5	0.0529
2	100	10.5	0.1075
3	100	8.25	0
4	100	8; 7.25	0.0310
5	100	7	0.0207
6	100	7; 7.25	0.1885

IV. Conclusion

The generic method we present is the first towards detection of tonic-clonic seizures based on a single sEMG channel. The data were classified as tonic-clonic seizure or normal activity based on a leave-one-out method. Our method performed as intended with a sensitivity of 100%, a median latency of 7.6 seconds and a median FDR of 0.04/h. We used no kind of adaption to the individual patients and the method is therefore easy to implement in a simple system for seizure monitoring or detection.

V. Acknowledgements

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