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Automatic multi-modal intelligent seizure acquisition (MISA) system for detection of motor seizures from electromyographic data and motion data

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ABSTRACT

The objective is to develop a non-invasive automatic method for detection of epileptic seizures with motor manifestations. Ten healthy subjects who simulated seizures and one patient participated in the study. Surface electromyography (sEMG) and motion sensor features were extracted as energy measures of reconstructed sub-bands from the discrete wavelet transformation (DWT) and the wavelet packet transformation (WPT). Based on the extracted features all data segments were classified using a support vector machine (SVM) algorithm as simulated seizure or normal activity. A case study of the seizure from the patient showed that the simulated seizures were visually similar to the epileptic one. The multi-modal intelligent seizure acquisition (MISA) system showed high sensitivity, short detection latency and low false detection rate. The results showed superiority of the multi-modal detection system compared to the uni-modal one. The presented system has a promising potential for seizure detection based on multi-modal data.

1. Introduction

Epilepsy is a functional disorder of the brain caused by excessive discharges of groups of neurons clinically characterized by repeated unprovoked seizures lasting from seconds to minutes. About 1% of the world's population has epilepsy. Seizure manifestations can be motor (tonic, clonic, tonic–clonic, etc.), sensory, psychic or vegetative, and consciousness may be retained or altered, sometimes with automatic behavior. In spite of much progress with pharmacological, surgical and other treatments, about 25% of epilepsy patients continue to have seizures. For many of these patients, seizure onset is unpredictable, impairing independent living and increasing the risk of injuries, e.g. by falls or burns. Therapy resistant patients with generalized tonic–clonic seizures have an increased risk of dying as a consequence of a seizure, especially when they live alone and the seizures occur during sleep [1,2]. An automatic seizure detection system that alerts relatives or other helpers of an on-going seizure would alleviate several of these problems. The earlier a seizure is detected,

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the more useful the system would be. It could also be beneficial in determining therapeutic success or failure in patients who live alone and cannot reliably report whether they still have seizures. A clinically feasible detection system needs to be both reliable and comfortable.

Today the diagnostic gold standard in epilepsy is electroencephalography (EEG) with simultaneous video surveillance. EEG is known to be reliable for detection of seizures [3–5]. EEG-recordings require, however, either an invasive recording (intracranial electrodes) or the placement of several scalp-electrodes, which is less stable over time. The patient might also be uncomfortable wearing electrodes on the scalp, which are very noticeable for others, and thereby stigmatizing the patient further. Despite the EEG method being the gold standard, it does not necessarily seem to be the best option for a seizure alarm outside the hospital. It has been attempted to use video recordings for seizure detection [6], but they had too many restrictions and limitations (obstacle-free area of movement covered by light and camera).

Nijsen et al. [7] used accelerometers (ACM) for seizure detection. The visual analysis of the movement data recorded with these sensors showed promising results (91% of the seizures with motor phenomena were detected), and was considered feasible for detection of seizures. Others [8,9] have tried to detect seizures based on ACM data, but an ideal method has not yet been presented.

Earlier studies [7–9] on detecting seizures from ACM data did not report on aspects concerning the time between seizure onset and the detection, but only on detection versus no detection. It is highly desirable to achieve an early detection of seizures (i.e. with only a few seconds of delay) to make possible an intervention to stop the seizures and/or prevent injuries during the seizures. To make such a system reliable for detection of seizures we decided to work with multi-modal data, so we extended the system from using only ACM to combine it with sEMG and gyroscopes (angular velocity (ANG) data). Gyroscopes provide information on the rotation of each joint, so this data covers e.g. movements where the limbs are accelerated less, but still rotated. In a preliminary study [10] we found that the three modalities sEMG, ACM and ANG provided complementary information with potential improvement of classification accuracy. The next issue was to identify the most promising features to distinguish between seizures and normal activities and furthermore identify the most appropriate classifier to automatically differentiate between the two classes based on the feature vectors. Nijsen et al. [11] showed through a visual analysis that the continuous wavelet transformation (CWT) seems to be a better feature than short time Fourier transformation (STFT) for ACM data. Seizure detection from sEMG signals is a rather unexplored field, but from a visual inspection of the data it seems that both the amplitude and the frequencies of the signal during seizures are different from normal activities. The discrete wavelet transformation (DWT) seems to be a good choice as a feature extraction method, since it provides a good frequency resolution at low frequencies and furthermore a good time resolution at the high frequencies. Based on this we used DWT for feature extraction and support vector machines (SVM) as a classifier in a pilot study [12], including both sEMG, ACM and ANG data, with very promising results on distinguishing between seizures/simulated seizures and normal activities.

In this paper we search for the best feature extraction method based on the wavelet transformation to separate simulated seizures from normal activity. The wavelet transformation is good at describing both the morphology and the spatial distribution in the movement signals. Compared to the DWT, the wavelet packet transformation (WPT) provides equal time and frequency resolution for all frequencies. Besides DWT we have therefore also tested the WPT as a method for extracting features for all modalities in this automatic multi-modal intelligent seizure acquisition (MISA) system. To classify our data into the two groups, seizures and normal activities, we used SVM [13] (as in our pilot study [12]) as a binary classifier trained on feature vectors from both classes, since it is well known to function better than other classifiers when the data classes are of unequal sizes. We used data from healthy subjects who simulated seizures (as instructed by a physician) to develop our algorithm upon. To assess the similarity between the simulated seizures and a real one, we have visually compared the raw data from the simulated seizures with a real seizure from a patient for all modalities.

This paper is organized as follows: the recordings are presented in Section 2; data presentation is given in Section 3; the method in details in Section 4 and the results in Section 5. At last Sections 6 and 7 encompass the discussion and the conclusion, respectively.

2. Recordings

The goal of the project was to detect simulated seizures from multi-modal signals based on movement data (sEMG, ACM and ANG). To be able to statistically explore whether the automatic detection algorithm is functioning, the number of simulated seizures for each healthy subject had to be more than five. The reason for initially using healthy subjects (who simulated seizures) instead of epileptic patients was the difficulty in the patient recruitment. Most patients with more than five seizures with motor manifestations within a few days are mentally retarded and therefore have difficulties in cooperating, when wearing the suit containing the movement sensors. Therefore it has yet only been possible to collect seizure data from one patient and we only succeeded in obtaining one seizure from this patient. Ten healthy subjects who were instructed to simulate seizures are therefore monitored with all modalities and used for the project.

The project had been approved by the ethics committee of Region Zealand, Denmark. All subjects involved received information on the project and gave their written consent to participate in the study.

The recordings on healthy subjects were made at the Danish Epilepsy Centre in Dianalund, Denmark. Ten healthy subjects aged 23–30, both male and female, were included. It is assumed that there is no effect of gender. The measurements lasted 1.5–3 h for each healthy subject. All of the healthy subjects were asked to simulate three types of seizures and some normal activities. They were given a description of the seizures, and they watched seizures on a video. Before the recording the healthy subjects trained simulating the seizures