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An automatic mobile-health based approach for EEG epileptic seizures detection ☆

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ABSTRACT

In this article, we develop a comprehensive mobile-based approach, which is able to perform the essential processes needed to automatically analyze and detect epileptic seizures using the information contained in electroencephalography (EEG) signals. We first develop and implement an appropriate combination of different algorithms that resample, smooth, remove artifacts, and constantly and adaptively segment signals to prepare them for further processing. We then improve and fully implement a *large* variety of features introduced in the literature of epileptic seizures detection. We also select the relevant features to reduce a feature vector space and improve the classification process by developing two automated filter and wrapper selection algorithms. We thoroughly compare between these selection algorithms in terms of redundant features, execution time and classification accuracy through three experiments. We subsequently exploit the selected features as input to a machine learning classifier to detect epileptic seizure states in a reasonable time. We experimentally and theoretically evaluate the scalability of the whole algorithm respectively on patients' data available in standard clinical database and on 500 EEG recordings including 500 seizures. Having efficient and scabble algorithm, we develop two extra algorithms to dynamically acquire and transmit EEG signals from wireless sensors attached to patients and to visualize on mobile devices the obtained processing and analysis results. We finally integrate all our algorithms together along with an android mobile application to implement an effective mobile-based EEG monitoring system where its accuracy is tested on live EEG data.

1. Introduction

Epilepsy includes a *large* set of brain chronic diseases (also called brain disorders in Sharma & Pachori (2015)) whose essential syndrome is the occurrence of *epileptic seizures* (World Health Organization[WHO]). The most common definition of epileptic seizures was introduced by the International League Against Epilepsy (ILAE) (Beghi et al., 2005; Berg et al., 2010) and was used in Fisher et al. (2005), Subasi (2005) and Sharma and Pachori (2015). In this definition, epileptic seizures are characterized by an unpredictable occurrence pattern and transient dysfunctions of the central nervous system, due to excessive and synchronous (Altunay, Telatar, & Erogul, 2010; Song & Zhang, 2013) abnormal neuronal activity in the cortex. This activity could include several neurons of different locations and sizes. The clinical symptoms of epileptic seizures might affect the motor, sensory, and automatic functions of the body along with the consciousness, cognition, and memory of the patient (WHO, 2012). The epileptic patients' quality of life can be increasingly hindered by the symptoms. Also, patients that are successfully controlling seizures using anti-epileptic drugs have their quality of life significantly deteriorated due to adverse risks of medication (Mormann, Andrzejak, Elger, & Lehnertz, 2007; WHO, 2012). Considering epidemiological data into account, the World Health Organization showed that around 50 million people suffer from epileptic seizures worldwide (WHO, 2012). Moreover, a recent review showed that epileptic seizure is the most serious neurological disorders (Ngugi et al., 2011). The authors specifically reported that the average incidence of epilepsy in the world is about 50.4 per 100,000 people in a year. High-income countries are substantially less affected (45.0 per 100,000 people in a year) than middle- and low-income countries (81.7 per 100,000 people in a year). In the rest of this section, we present the

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electroencephalography (EEG)-based monitoring procedure and the notion of mobile patient monitoring. We also introduce our motivations, challenges, and contributions.

1.1. Mobile-based EEG monitoring system

EEG is the most important neuro-diagnostic procedure (Jansen, 1979; Sanei & Chambers, 2007), which received a lot of attention over several decades. This procedure has some competitive advantages, since it is painless, at a reasonable cost, and efficient temporal resolution of long-term monitoring. Its efficient resolution greatly increases the chance of detecting epileptic seizures. It measures in principle the brain waves in the form of electric activity. EEG has been clinically employed to diagnose various situations such as testing for brain death or coma (Wilkus, 1980), discriminating between epileptic seizures, migraine variant and movement disorders (Akben, Subasi, & Tuncel, 2011), detecting epileptic seizure states (Shoeb & Guttag, 2010), testing for depth anesthesia (Jameson & Sloan, 2006), and authenticating users (Kionovs & Petersen, 2012). EEG can also be utilized in the behavioral sciences ranging from cognitive processes to emotional functions.

There are different methods to analyze an EEG signal. It can be visually inspected and reviewed by experienced neurophysiologists to detect epileptic seizure patterns so that the origin and type of seizures can be determined. When the EEG recording is long (i.e., it lasts from several hours to several days or even weeks), the recording and its visual interpretation become an expensive, intensive and tedious error-prone exercise (Sanei & Chambers, 2007; Shoeb, 2009). Also, different neurophysiologists might use different scales, measurements, and labels during the evaluation process. The computer analysis is therefore adopted to satisfy some parts of neurophysiologists' tasks. The computer can carry out tasks, which are not incorporated in the classical EEG analysis. For example, it can measure precisely time relationships between clinical events in two or more EEG signals, design and implement digital filtering without phase distortion, extract descriptive features and display results on a brain's-like map. Computerized analysis offers capabilities to introduce different methods and techniques to digitally store long-term multi-channel EEG signals, pre-process and segment signals, and then extract and select different features from segments.

Traditionally, EEG recording used to be conducted in well equipped hospitals. The reasons are that the required equipments are at least bulky, expensive, and require professional setup and configuration. Recently, several sophisticated, lightweight, and accurate EEG recording devices with wireless transmission have been developed, such as the Emotiv Epoc.[1] These devices are more practical for epileptic patients, offer movement freedom and decrease the infection risks due to percutaneous plugs. The availability of such devices opens the doors wide for the use of electronic health (shortly, e-Health). An e-Health captures the notion of how to deliver healthcare services over the Internet using computerized medical data and communication technology. The e-Health system employs sensors with communication capacities, which transmit data (i.e., observations) to a predefined database storage and processing logic. Given that, suitable experts (e.g., physicians) can instantly check the patient's data and then send notification when the patient demonstrates critical signs. With the tremendous growth in mobile and wireless networking technologies, a sub-field of e-Health, called mobile health (shortly, m-Health), has emerged. A mobile patient monitoring service provides "continuous or periodic measurement and analysis of a mobile patient's bio-signals by employing wireless sensors, mobile computing, wireless communications, and networking technologies" (Pawar, Jones, van Beijnum, & Hermens, 2012). In this context, the patient wearing an appropriate sensor (e.g., Emotiv EEG headset) is able to freely move inside or even outside the home during the continuous monitoring process. In Section 3, we will discuss this approach as well as how the sampled EEG signals can be accurate and reliable. Technically, a mobile-based EEG monitoring system sequentially performs the following processes: Data acquisition, data exchange, data analysis, and results monitoring.

1.2. Motivations and challenges

Our endeavours in this work is to develop a comprehensive mobile-based EEG monitoring approach. Doing so requires implementing the essential processes of this approach in an efficient and effective manner and helping epileptic patients and their physicians automatically detect epileptic seizures. The automated approach is not intended to substitute physicians, but rather to give them an additional decision-taking tool to make their work more efficient and their decisions more accurate. Our approach specifically consists of two different, but fully integrated and interoperable, parts: Back-end part and front-end part. This modular design enables us to: (1) develop efficient algorithms and, in some cases, modify existing algorithms to balance between the performance of algorithms and their computational complexity; (2) ensure lowering the use of mobile resources; and (3) achieve the scalability of the system. The back-end part (core part) focuses on analyzing EEG signals of epileptic patients through five main modules: Pre-processing module, feature extraction module, feature normalization module, feature selection module, and classification module. On the other hand, the front-end part is responsible for acquiring the EEG signal from the patient's scalp, transmitting EEG data, and presenting to the user outputs generated by the back-end part as a result of its analysis. This responsibility is performed by two main modules: Acquisition and transmission module, and visualization module.

1.3. Contributions

The following is a summary of our contributions:

1. The greatest effort was made on studying, designing, and implementing an appropriate combination of different algorithms in the pre-processing module. This module is responsible for preparing EEG signals for further processing. We implemented algorithms that resample and smooth signals as well as removing artifacts from signals. We also implemented two different algorithms to segment EEG signals (specifically, constant and adaptive segmentation algorithms) and compared between their performance in terms of execution time.
2. We implemented required algorithms to extract four types of features: Time and frequency domain features, and entropy-based and wavelet-based features. These features: (1) clinically capture relevant information from EEG data segments; and (2) are obtained from current proposals in the literature of epileptic seizures detection (see for example Aarabi, Wallois, & Grebe (2006, 2007), Bedeeuzzaman, Farooq, & Khan (2010) and Greene et al. (2008)). We technically improved the techniques introduced in Khan, Farooq, and Sharma (2012), Shoeb (2009) and Shoeb and Guttag (2010) to compute wavelet-based features by reducing the decomposition level (more details introduced in Section 3).
3. We developed and implemented two automated filter and wrapper selection algorithms. These algorithms select relevant features from a computed set of features to reduce a

[1] Emotiv Epoc's home page: http://www.emotiv.com/.