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Regularity and Matching Pursuit feature extraction for the detection of epileptic seizures

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HIGHLIGHTS

- Epilepsy detection by EEG analysis is done with state-of-the-art results.
- Hölder regularity and Matching Pursuit are used to extract EEG features.
- The method is simple and can be used in other domains of EEG analysis.

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ABSTRACT

Background: The neurological disorder known as epilepsy is characterized by involuntary recurrent seizures that diminish a patient's quality of life. Automatic seizure detection can help improve a patient's interaction with her/his environment, and while many approaches have been proposed the problem is still not trivially solved.

Methods: In this work, we present a novel methodology for feature extraction on EEG signals that allows us to perform a highly accurate classification of epileptic states. Specifically, Hölderian regularity and the Matching Pursuit algorithm are used as the main feature extraction techniques, and are combined with basic statistical features to construct the final feature sets. These sets are then delivered to a Random Forests classification algorithm to differentiate between epileptic and non-epileptic readings.

Results: Several versions of the basic problem are tested and statistically validated producing perfect accuracy in most problems and 97.6% accuracy on the most difficult case. Comparison with existing methods: A comparison with recent literature, using a well known database, reveals that our proposal achieves state-of-the-art performance.

Conclusions: The experimental results show that epileptic states can be accurately detected by combining features extracted through regularity analysis, the Matching Pursuit algorithm and simple time-domain statistical analysis. Therefore, the proposed method should be considered as a promising approach for automatic EEG analysis.

1. Introduction

Epilepsy is a type of neurological disorder that it is characterized by an enduring predisposition to generate unprovoked seizures, each occurring more than 24 h apart (Fisher et al., 2014). Normal brain activity is considered to be non-synchronous, but during epileptic seizures a group of neurons begins firing in an abnormal, excessive and synchronized manner. This is opposed to what normally happens, when an excitatory neuron fires it becomes resilient to firing again for a short period of time (Else and Hammer, 2013). There are approximately 65 million people worldwide living with epilepsy (Thurman et al., 2011). It varies from region to region, for instance in the United States the annual incidence of epilepsy is 48 per 100,000 inhabitants, whereas the prevalence approximates 710

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per 100,000 (Hirtz et al., 2007). Diagnosing epilepsy after a single unprovoked seizure, when there is a high risk for recurrence, may or may not lead to a decision to initiate treatment by the epileptologist. Nonetheless, the diagnosis helps the physician assess the balance between the possible avoidance of a second seizure and the associated risks of actually occurring. According to Eadie (2012) about 70% of the cases can be controlled by medication, but even then the patient might suffer negative side effects.

Automated systems can help develop an appropriate therapy plan that could eventually improve the balance of the associated risks and potentially enhance the patient's quality of life (Fisher et al., 2014). Such systems would be able to detect a bodily response that matches the epileptic symptoms, and distinguish them from signals present during a patient's regular activity. There are non-invasive methods that can sense epileptic states before they manifest, as well as to detect the seizure physiologic state, which is also known as the Ictal state. One such method is the Electroencephalogram (EEG), which records electrical brain activity along the scalp. Other methods are also available, such as the Electrocorticogram (ECoG) that is recorded by electrodes that are inserted trough the skull (Sotelo et al., 2013, 2015). ECoG provides more localized readings but can be undesirable for the patient since it is invasive (Ball et al., 2009).

EEGs are very popular because they have several advantages compared to other methods (Tzallas et al., 2009; Übeyli and Güler, 2007; Güler and Ubeyli, 2005; Rajendra Acharya et al., 2012; Acharya et al., 2012a; Guler et al., 2005; Ahammad et al., 2014; Orhan et al., 2011; Guo et al., 2010; Kamath, 2015; Lima et al., 2010), these are: (1) hardware costs are relatively low; (2) electrodes can be positioned based on application needs; (3) it does not expose the patient to high-intensity magnetic fields like magnetoencephalography; and (4) it is non-invasive, relative with other methods. There are some drawbacks as well, like the inherent presence of noise in the signals. Nevertheless, the present work focuses on the use of EEG recordings for automatic epilepsy analysis.

Epileptic seizures can be identified in EEG signals by experienced physicians, but automatic recognition is still not a trivial task. Research for the development of computational systems that perform these tasks usually focuses on three fronts. Either by exploiting the morphology of the signals recorded during the epileptic crisis (Yadav et al., 2012), by applying analytic or numerical methods (Ramgopal et al., 2014), or a combination of the two (Tzallas et al., 2009; Übeyli and Güler, 2007; Güler and Ubeyli, 2005; Rajendra Acharya et al., 2012; Acharya et al., 2012a; Guler et al., 2005; Ahammad et al., 2014; Orhan et al., 2011; Guo et al., 2010; Kamath, 2015; Lima et al., 2010; Murugavel and Ramakrishnan, 2014; Divya, 2015; Kumar et al., 2014).

We propose a new methodology for feature extraction, which incorporates two powerful signal analysis tools to construct specialized domain features, namely Hölderian regularity (Mallat and Hwang, 1992) and the Matching Pursuit (MP) algorithm (Mallat, 1993). Each of these tools tackles the posed problem from different perspectives. The former incorporates a local signal regularity measure while the latter employs a time-frequency analysis. These two methods are related, since MP can be seen as a global regularity measure. Both of these techniques are considered to be highly nonlinear in their core design, thus the proposed methodology is well suited to analyze a nonlinear process, like the one that produces an epileptic seizure. Moreover, we combine these nonlinear features with much simpler features computed as statistics of the raw signals in time domain, which have been shown to be useful in related tasks (Sotelo et al., 2013).

After the proposed feature extraction process, a classifier is used to solve the automatic detection problem. Experimental results achieve a perfect performance for three of the four tested problem instances. Moreover, on the fourth test case, the most complex, classification accuracy is 97.6%, competitive with the state-of-the-art (Tzallas et al., 2009, 2007; Übeyli and Güler, 2007; Güler and Ubeyli, 2005; Rajendra Acharya et al., 2012; Acharya et al., 2012a; Guler et al., 2005; Ahammad et al., 2014; Orhan et al., 2011; Guo et al., 2010; Kamath, 2015; Lima et al., 2010; Guler and Ubeyli, 2007). All of these conclusions are derived from a rigorous experimental validation and comprehensive statistical tests.

In the following sections a brief description of epileptic states is presented, as well as a short review of previous works related to techniques employed for EEG analysis.

1.1. Epileptic states

Epileptic seizures are unintentional and disruptive events of mental activity that impair a patient's motor, sensorial and autonomic functions. Seizures develop over several states (Franaszczuk et al., 1998): (1) the Basal state; (2) the Pre-Ictal state; (3) the Ictal state; (4) the Post-Ictal state; and (5) the Inter-Ictal state. These states can be identified by the symptoms exhibited by the patient and the morphology of the EEG signals. The Basal state corresponds to normal brain functions, in this state brain signals are characterized by a low amplitude and a relatively high frequency. The Pre-Ictal state refers to the time period before the seizure symptomatology is evident. Here, the signal amplitude is higher than in the Basal state, with the presence of spikes and transitory activity, also called recruiting rhythms (Kohsaka et al., 2002). The Ictal state is the prominent period where the symptomatology is evident. The EEG signal magnitude is higher than in any other state and displays a dominant low frequency rhythm. The Post-Ictal state refers to the span of time when an altered state of consciousness exists after the active portion of the seizure ended. This period is variable and depends of the seizure duration. The overall amplitude of the signal decreases and the frequency increases. Several symptoms appear during this state, like migraines, depression and a loss of motor functions (Fisher and Schachter, 2000). Finally, the Inter-Ictal state refers to the period of time between seizures.

The problem of automatically detecting the states of epileptic seizures can be posed in different ways (Sotelo et al., 2013, 2015). Here, we recognize that the identification of Ictal states is an important task, as a way to prevent or prepare for a seizure. Moreover, the effects on the patient are most severe in this state. Consequentially, this work focuses on the automatic recognition of Ictal activity among other EEG readings. For this work, we use the Bonn data set (Andrzejak et al., 2001), a public database that contains several types of EEG recordings, to test the proposed approach.

1.2. Previous work

The automatic classification of epileptic seizures has received much attention over recent years. The problem has been handled from many perspectives, focusing on different aspects of the problem, while using a variety of signal processing and pattern recognition paradigms. Since the number of reported studies is large, here we review the most recent and relevant examples. Moreover, for comparative reasons, we mostly limit to works based on the Bonn data set (Andrzejak et al., 2001). Acharya et al. (2013) present an extensive survey that summarizes a variety of different methods on how this problem has been addressed. In that survey, the authors also summarize the classification accuracy from each reviewed work, comparing their quality and experimental work. Even though some works achieve strong performance, there is still room for developing new domain-specific patterns recognition methods. Moreover, the insights gathered in epileptic states detection might be extended to other areas of EEG analysis or application domains (Vezard et al., 2014).