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Sleep stage detection using chaotic feature analysis of Electroencephalography (EEG) signals

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Abstract--The present study was conducted to detect the sleep stages by electroencephalography (EEG) using chaotic features. The method used in this study was the content analysis method. First, the sleep stages and EEG have been analyzed, and the EEG with chaotic features was used to detect the sleep stages. Detection of artifacts in sleep electroencephalography (EEG) is one of the vital tasks in the pre-processing stage. Despite many artifact exploration algorithms over the years, lots of them lose their advantages to use sleep EEG. Types of brain activities can be measured, and the involved brain areas can be detected using EEG. Electroencephalography (EEG) signal includes different rhythms, which are dependent on various sensory and movement conditions. Detection of each rhythm of this signal needs experience and skills. As a result, analysis of the signal recorded by EEG can be used widely for detection and academic purposes.

Keywords--*sleep stages, electroencephalography (EEG), chaotic features.*

Introduction

Emotions play a key role in human life. Due to increased man-computer interaction, recognition of human emotions using computers has been changed into one of the challenging issues of machine learning. Because of the role of the brain in emotions, EEG-based emotion recognition is a vital issue and can be used in various fields (Zahedi Haghighi et al. 2018).

The EEG technique is an appropriate method in terms of size, cost, and using in vitro or field conditions compared to other imaging techniques including fMRI and PET. The signals recorded in the EEG technique appear with the noise caused by blinking and limb movement. Hence, multiple algorithms have been developed to remove the noise from EEG signals. The development of field study-friendly EEG

systems includes advantages, such as using dry electrodes, saving preparation time, and removing the device cable (Johnson et al. 2013).

Continuous neural activity of the brain while sleeping can be controlled by EEG signals. The EEG wave pattern and the frequencies vary in 5 sleep stages. The elegant changes in sleep EEG signals can't be detected easily by visual inspection. To understand the complicated physiologic signals and their chaotic behavior, a wide range of time, frequency, time-frequency, and nonlinear analyses can be applied. A certain range of these features has been reported for five different sleep stages. All nonlinear measures provide significant clinical results. It means that the nonlinear measures can detect the sleep stages (Acharya et al. 2020).

Understanding sleep mechanisms is vital for the diagnosis and treatment of sleep disorders. EEG is one of the most underlying instruments for studying and diagnosing sleep disorders. EEG signals take the interpretation of waveform activity with the visual analysis (a difficult method) (Koley et al. 2012).

Electroencephalography (EEG) is a non-invasive method, in which the electrodes are embedded on the head skin to measure the electric activities of the human brain (Henry, 2006).

Parasuraman et al. (2008) showed that monitoring the brain needs high temporal resolution, and should be cost-effective, sensitive, powerful, and unobtrusive. EEG method observes all of the said principles and helps efficient analysis of capacities in more challenging real-life conditions (Parasuraman et al. 2008).

Theoretical framework

- Sleep stages

Sleeping is a fundamental part of human life, and one-third of every human life is spent in sleep on average. From the time of discovering the electroencephalogram to the date, this signal has been the most vital instrument to detect various conditions and moods of brain activity under different physiologic conditions, such as sleeping. The majority of scholars analyzing sleeping believe that there are three overall modes including awakening, Non-rapid Eye Movement (NREM) sleeping, and Rapid Eye Movement (REM) sleeping. NREM sleeping includes four substages from the lightest (stage 1) to deepest (stage 4) stage (Shepard, 1991).

In stage 1 of NREM sleeping, the EEG signal shows a low range and mixed frequencies. In this stage, the majority of theta waves are seen with a frequency of 3-7Hz, and alpha waves still exist, but take less than 50% in each period. Sharp vertex waves are seen in this sleep stage in the theta frequency limit with a range reaching 200 μ V. Slow and rounding eye movements are evident in this sleep stage. In stage 2, patterns called sleep spindles and K complexes appear on the EEG background. A sleeping spindle is a group of periodic waves with stable frequencies of 12-14Hz with the durability of 0.5sec. The K complexes are begun with a negative upward section, and there is then a positive downward section. The durability of these waves is 0.5sec at least. The delta waves in the EEG signal are waves lasting from 0.5 to 2sec and have the peak-to-peak range higher than

75 μ V. If an epoch of delta waves is created in a range of 20-50%, the epoch belongs to the stage of sleep. In stage 4, more than 50% of every epoch includes delta waves. Stages 3 and 4 of sleeping are called NREM, and Slow Wave Sleep (SWS) stages respectively. The conventional clinical method for evidential classification of sleep stages is looking with eyes and adjusting waveform with a series of waves and special signs based on rules in R&K Standard. This is a time-consuming and boring process and is dependent on the experience of experts on the other hand. Hence, automatic classification of sleep stages can facilitate the time-consuming and boring process (Rechtschaffen, 1968).

Sleep specialists take manual classification with a visual inspection of neurophysiologic signals of the patient collected in sleeping labs. In general, this is difficult, boring, and time-consuming work to do. Limitations of achievement to sleep stage have increased the demand for the development of automatic sleep stage classification systems (ASSC). Sleep stage classification refers to the detection of different sleep stages and is a basic step towards helping physicians to diagnose and treat sleep disorders (Aboalayon et al., 2016).

According to the statistics provided by the World Health Organization (WHO), about 30% of the world's population suffers from sleep disorders. The disorder endangers the working capability and mental health of individuals. The normal level of brain activity can be specified by sleep-waking cycles. Detection of the sleep cycle and the stages of sleeping has various therapeutic and scholarly uses, such as analysis of types of insomnia and the kids' behavior. Nowadays, a high percent of sleep stage separation has been achieved using various data mining and pattern recognition techniques. Detection of sleep stages needs an appropriate method to determine each stage same as manual methods and using available knowledge in this field (Ghuchani et al. 2008).

At the present, sleep disorders have been considered as one of the main problems with human life. There are multiple stable physiologic stages, through which the human brain passes while sleeping. Today, lots of medical signals, such as EEG, ECG, EMG, and EOG provide useful details for clinical settings, which can be used for the diagnosis of sleep disorders. In general, EEG signals can be divided into five bands: delta, theta, alpha, beta, and gamma to define the change in brain situation (Aboalayon et al., 2014).

Pointing the sleep can be one of the most important diagnostic methods in psychology, and neurology. Sleep staging is time-consuming and difficult work to do, which is taken by sleep specialists (Sen et al. 2014).

- Chaotic features

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Emotions play a key role in human life so that a considerable part of the decision-making process is affected by emotions. Hence, the role of emotions is not only formal, but also it is important to recognize that. The ability to recognize emotions can be effective in making machines with emotional traits similar to humans. Hence, scholars have tried to establish a new academic field called emotion-oriented calculations (Picard, 1995).

As the emotional-nervous system is a complicated collection of neural structures below the brain and on both sides of the thalamus, and also the factor of human's emotional life, change in emotions has a significant effect on brain signals. Therefore, the EEG signal is one of the most used signals over the years. However, if an EEG signal can recognize emotions at the same time with analysis of face mood, real emotions can be recognized from the fake face moods, which is mostly used in polygraph. Also, it can be used to help patients, who understand the emotions but they can't show it in their gesture (Savran, 2006).

Although the brain signal processing dynamic can't be perceived in the conscious and unconscious state, nonlinear and chaotic patterns have recently helped the dynamicity (Hosseini, 2016).

- **Electroencephalography (EEG)**

Over the past 100 years, electroencephalography (EEG) has been significantly developed. In 1929, Hans Berger (German neurologist) recorded EEG signals using surface electrodes from the surface of the skull. Currently, many academic foundations of EEG are the result of the efforts of this German researcher. He reported electric changes of different states such as sleeping, anesthesia, lack of oxygen, and some neural diseases like epilepsy. He could record almost small electric potentials, and could also found many basic sciences, and EEG applications during 14 years (Tatum, 2014).

Measurement of EEG has the advantage of high temporal separation, which allows evaluation of the ability to conduct cognitive studies and brain activity. EEG records are non-invasive and can be used many times for sick people, normal adults, and children with no risk or limitation in multiple studies. This method can be also used as a valuable instrument in the field of cognitive ergonomics (understanding, memory, attention, language, emotions, and cognitive workload) (Teplan, 2002).

The waves are usually measured from one peak to another and are normally in the range of 0.5-100 μ V. They are 100 times smaller than cardiac waves in terms of size. EEG signals include different frequency bands, which are relevant to various physical and cognitive states. Analysis of EEG signal spectrum can be done to evaluate the ability in frequency bands: delta (0.4-5Hz), theta (4-8Hz), alpha (8-13Hz), beta (13-20Hz), and gamma (40-5-Hz) (Haas, 2003).

The majority of well-known studies conducted on human brainwaves are relevant to alpha waves. Alpha is stimulated while closing eyes and resting. Also, the alpha waves decrease by opening the eyes, or the stimulations caused by thinking and mental calculations. Considerable changes happen in brainwave patterns when individuals close their eyes, and the waves change from beta to alpha. The main area of alpha production is still unknown. Alpha waves are usually attributed to soma-dendrite potentials (Niedermeyer et al. 2005).

The EEG signal is non-static, and its range changes in different periods. The EEG signal needs to be divided into static sections in many cases. EEG signal segmentation is usually done in preprocessing stage by finding the signal

boundaries at the time of change in statistical information, such as range or frequency. One of the biggest challenges to use EEG signals is a lower signal-to-noise ratio. EEG signal is very sensitive to different forms and sources of noise, and this causes difficulties in the field of analysis and interpretation of EEG signals (Hassan Hassankala et al. 2017).

Electroencephalography is a domain in the field of recording and interpreting electroencephalograms. Electroencephalogram (EEG) refers to the electric signal records produced by the common function of brain cells or the period of extracellular field potentials produced by their simultaneous effect. Electroencephalogram is originated in Greek words of enkephalo (brain), and Graphine (to write). The EEG can be measured using the electrodes embedded on the head skin or directly on the cortex. In the second mode, it is sometimes called electrocorticogram (ECoG). The electric fields measured from the inside of the cortex are called Local Field Potentials (LFP). The recorded EEG can be called automatic EEG in case of interference of no external stimulation. The produced EEG as a response to internal or external stimuli is called Event-related Potential (ERP). The EEG range of a normal subject in waking state recorded by head skin electrodes is equal to 10-100 μ M (Blinowska et al. 2006).

Electroencephalography is sensitive to persistent brain states caused by stress, consciousness, resting, and sleeping. In the normal state of waking with open eyes, beta waves are dominant, and alpha waves would be increased while resting or being sleepy. Low-frequency bands also appear while sleeping. The findings of Beck Ford and clinical uses of EEG in human and animal include:

- Monitoring consciousness, coma, and brain death
- Local injuries of cerebral areas caused by head injuries, tumors, etc.
- Potential Evoked Test
- Creation of biofeedback conditions
- Controlling deep anesthesia
- Analysis of epilepsy, and local brain attacks
- Examining the effects of epilepsy drugs
- Monitoring human and animal brain development
- Examining drugs with seizure side effects
- Analysis of sleep and physiology disorders (Teplan, 2002)

Table 1. The Beck Ford and clinical uses of EEG in human and animals

Beck Ford and clinical applications of EEG in human and animals	
Monitoring consciousness, coma, and brain death	Potential Evoked Test
Local injuries of cerebral areas caused by head injuries, tumors, etc.	Analysis of sleep and physiology disorders
Creation of biofeedback conditions	Controlling deep anesthesia
Analysis of epilepsy, and local brain attacks	Examining the effects of epilepsy drugs
Monitoring human and animal brain development	Examining drugs with seizure side effects

Source: author

Vital signals such as EEG signals have been used in clinical applications for many years. Today, according to the advancement of technology, and the importance of preserving the security of information, biometric application of these signals has gained the attention of scholars. The EEG signal is biometric, which can't be forgotten or forged easily. There are two approaches to use EEG signals in biometric applications: the first approach is using signal while resting, and brain background signals and the other approach is the extraction of ERP obtained from brain stimulation using audiovisual stimuli. In this study, auditory evoked potentials have been used. Auditory evoked potentials are electric potentials created in response to auditory stimulation in the brain cortex. The advantage of the proposed method compared to background EEG signals is the variance of these signals with change in auditory stimulant, which is used to help physicians to diagnose and treat sleep disorders.

Electroencephalography (EEG) is one of the key instruments to monitor brain activity and can be used in many clinical fields.

Methodology

Content analysis is one of the research methods used for objective, regular, and quantitative analysis of communicative messages. The method was firstly used in the communication sciences and is being currently used in media analysis in a wide range. Over the years, the method has been also used in other fields of science. According to scholars, content analysis is a method used to express certain concepts or words in a text or a series of texts. Some others have defined it as a data analysis method. The text can include a book, chapter or chapters of a book, proses, interviews, conversation, titles, media articles, and historical documents. The scholar analyzes the existence of concepts and the relation between the words or concepts using content analysis. Also, the method can be used to conclude the messages in a text, the author, audiences, and even the culture, and time of the work. Content analysis can be used in both qualitative and quantitative studies (Zeighami et al., 2008).

In terms of method, this is a descriptive-analytical study, and in terms of nature and the studies indicators, this is a survey conducted using documentary and library studies.

Conclusion

The impact of depression on the quality of life is vital, especially on individuals suffering from sleep disorders. Sleep stage classification refers to the detection of different sleep stages and can be a basic step toward helping physicians to diagnose and treat sleep disorders. The EEG signals are widely used to analyze brain activity, such as the determination of sleep stages. The EEG signals have nonlinear and non-static nature. Taking sleep staging is hard to do using visual interpretation and linear techniques. The EEG signal can recognize emotions properly. Electroencephalography is one of the main instruments widely used for imaging vital waves in the clinical field and applied researches like sleep stages. The EEG signals include different brainwaves reflecting the electric brain activity based on embedding the electrodes and different brain areas. In this study, the sleep stages were detected using EEG signals. The authors interested in this field can use that, and the qualitative attitude and ideas of experts were used to correct the labeling of brain signals.

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