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An EEG Based Sleep Quality Analysis and Music Recommendation System for Insomnia Patients

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Abstract: With the rapid pace of modern life, millions of people suffer from sleep problems. Music therapy, as a non-medication approach to mitigating sleep problems, has attracted increasing attention recently. Sleep disorders, affecting up to 30% of adults, are a common health problem in our society and may result in fatigue, depression, and problems in daytime functioning EEG-based sleep quality recommendation system music therapy offers an alternative healing method, which improves sleep quality by playing back music at bed time. EEG signal of the subject is recorded using the Thought Evoked Potential paradigm. The proposed system automatically sends an alert message to the subject stating that his sleep quality is poor when the power delta value falls less than 5µV2 and recommends a music playlist which improves the sleep quality of the subject. The process is repeated continuously till the sleep quality is improved and the power delta value is changed to 140 µV2.The process repeats continuously till the sleep quality is improved A conclusion is obtained from the standard dataset of 50 trials in the proposed system. The acquired data set is preprocessed to eliminate signal artifacts and the Features are extracted by Fast Fourier Transform to get a conclusive result. Twilio API is used to send alert message to the subject. From the observations made, the results show mixed sleep quality attainment. Among the subjects tested, 16.7% attained good sleep quality within two iterations of playlist shuffle, 66.7% of the subjects required 10 playlist shuffles to attain good sleep quality. The remaining 16.7% of the subjects couldn't attain good sleep quality even after 20 playlist shuffles which implies, they require serious medical attention and they are recommended for medical consultation.

I. INTRODUCTION

Insomnia is one of the most common but neglected family conditions with serious and long-lasting effects on a patient's health. Chronic insomnia was seen in 33% of the adult population sampled. Increasing age and diabetes were significantly associated with insomnia, while other socioeconomic factors and comorbidities were not significantly associated. Twenty-seven percent of patients with insomnia did not perceive the condition, which was statistically significant. About 6% of people have insomnia that is not due to another problem and lasts more than a month. Two-thirds of these patients wake up in the middle of the night, with more than half having difficulty getting back to sleep after waking up in the middle of the night.

Poor sleep quality may occur, such as restless legs, sleep apnea, or severe depression. Poor sleep quality was defined as the individual not reaching stage 3 or delta sleep with restorative properties. Depression leads to changes in the function of the hypothalamic-pituitary-adrenal axis, causing excessive release of cortisol which can lead to poor sleep quality. Most BCI applications have been developed for practical, non-invasive brain signal processing for implementation in real-life situations.

The brain is the most complex part of the human body. This three-pound organ is the seat of intelligence, interpreter of the senses, initiator of body movement, and controller of behavior. The cerebrum (front of brain) comprises gray matter (the cerebral cortex) and white matter at its center. The brainstem is the structure that connects the cerebrum of the brain to the spinal cord and cerebellum. The cerebral cortex is divided lengthways into two cerebral hemispheres connected by the corpus callosum. Traditionally, each of the hemispheres has been divided into four lobes: frontal, parietal, temporal and occipital. The function of each lobe is represented in the below Table 1.1.

Table 1.1: Functions of lobes

LOBE	FUNCTION
Frontal	Decision-making, momentary activities
Parietal	Speech, Sense
Temporal	Vision,Color differentiation, Motion Interpretation
Occipital	Emotion association, Smell Recognition

Table 1.1

Electroencephalography (EEG) is an electrophysiological monitoring method to record electrical activity on the scalp that has been shown to represent the macroscopic activity of the surface layer of the brain underneath. EEG waveforms may also be averaged, giving rise to Evoked Potentials (EPs) and Event-Related Potentials (ERPs), potentials that represent neural activity of interest that is temporally related to a specific stimulus. Neurons are electrically charged by the membrane which transports protein that pumps ions across the membrane. When the wave of ions reaches the electrodes on the scalp they can push or pull electrons on the metal of the electrodes. The 10-20 System of Electrode Placement is a method used to describe the location of scalp electrodes. These scalp electrodes are used to record the electroencephalogram (EEG) using a machine called an electroencephalograph. The 10-20 system is based on the relationship between the location of an electrode and the underlying area of the cerebral cortex and it is represented in the below Figure 1.1.

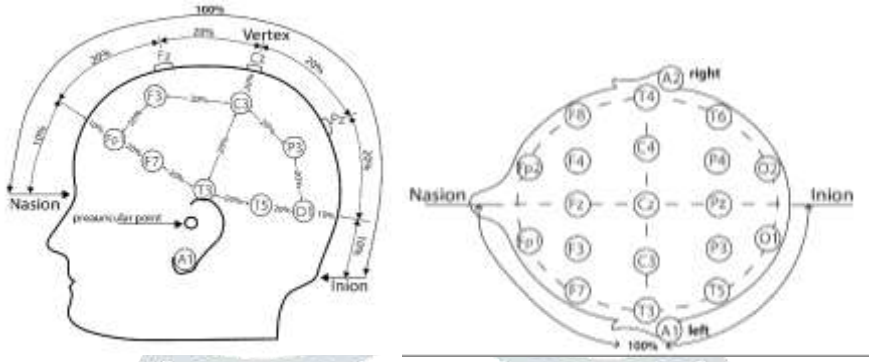

Figure 1.1

II. LITERATURE REVIEW

Sleep Quality Analysis Using EEG Signals

Min Shi, Chengyi Yang, and Dalu Zhang (2021), proposed a sleep quality detection and management method based on electroencephalogram (EEG). The detection of sleep quality is mainly achieved by staging sleep EEG signals. Wavelet Packet Decomposition (WPD) preprocesses the collected original EEG to extract the four rhythm waves of EEG. The relative energy characteristics and nonlinear characteristics of each rhythm wave are extracted. The Multi Scale Entropy (MSE) values of different scales are calculated as the main features, and the rest are auxiliary features.

Wu wen (2021) demonstrated the purpose of sleep quality detection based on EEG signals. This method first preprocesses the EEG signals and then uses the Discrete Wavelet Transform (DWT) for feature extraction. Finally, the Transfer Support Vector Machine (TSVM) algorithm is used to classify the feature data.

Xing-Zan, ZhangWei-Long, ZhengBao-Liang Lu (2017) illustrated a subject independent approach with deep transfer learning to evaluate the last-night sleep quality using EEG data. One is to find a subspace by matrix decomposition and regularization theory, and the other is to learn the common shared structure with the deep autoencoder.

Yu Zhang, Bei Wang, Jin Jing, Jian Zhang, Junzhong Zou and Masatoshi Nakamura (2017) proposed a technique using multi-domain feature extraction based on time domain analysis, nonlinear analysis, and frequency domain analysis. The objective is to eliminate the clutter waveform and highlight the characteristic waveform for further analysis.

Li Wang, Wei-Long Zheng, Hai-Wei Ma, and Bao-Liang Lu (2016) designed a sleep experiment to collect waking EEG signals from eight subjects under three different sleep conditions: 8 hours sleep, 6 hours sleep, and 4 hours sleep. Three machine learning approaches, k-Nearest Neighbor (kNN), Support Vector Machine (SVM), and discriminative Graph regularized Extreme Learning Machine (GELM) are used to classify extracted EEG features of Power Spectral Density (PSD).

Sleep Quality Analysis Based on Music

Maren Jasmin Cordi, Sandra Ackermann & Björn Rasch (2019) demonstrated a method involving music. Music consistently improves subjective sleep quality, whereas results for objective sleep parameters diverge. Here, 27 female subjects listened to either music or a control text before a 90 minutes nap in a within-subjects design. Usage of music improved subjective sleep quality as compared to the text condition. In all participants, music resulted in a reduced amount of sleep stage N1 during the nap. In addition, music significantly increased the amount of slow-wave sleep (SWS) and increased the low/high frequency power ratio.

III. METHODOLOGY

Objective:

- To design an experimental protocol for acquiring EEG signals using TEP paradigms.
- To develop a suitable pre-processing algorithm
- To implement suitable feature extraction technique.
- To develop an alert system

The proposed system obtains the conclusion from the TEP The EEG of the patient will be monitored in real time. The recorded signal will be Pre-Processed, Feature Extracted, and Classified. If the real time signal frequency components match with the prerecorded dataset the proposed system gives a conclusion that the person's sleep quality is poor and a Python text message API (Application Programming Interface) sends an alert message and recommends him a music playlist link via the text message. The flow diagram of the proposed system is depicted in Figure 3.1.

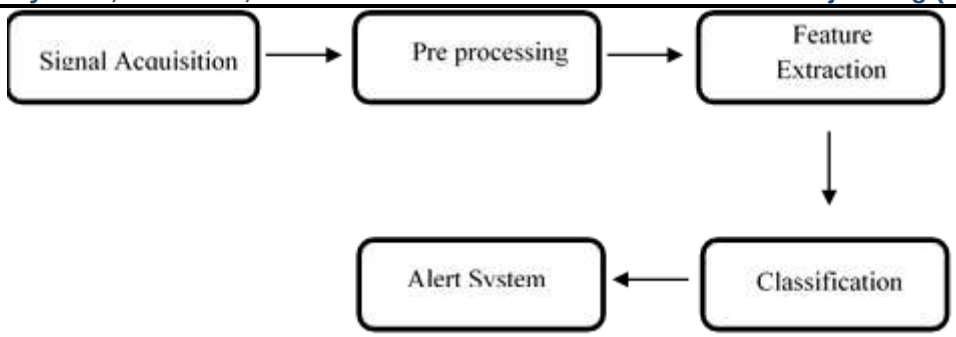

Figure 3.1

Signal Acquisition:

EEG signals are recorded due to electrical activity of the brain. Data Acquisition is the process of recording the EEG signal of the subject via the electrodes and store them as raw data. Here subjects under two categories are taken into account one with good sleep quality and other with poor sleep quality. The EEG of the subject is recorded using TEP paradigm. The term thought evoked potential (TEP) refers to electrical potentials recorded from scalp overlying visual cortex that have been extracted from the electroencephalogram by signal averaging. Usually, the recording electrode is placed on the midline of the frontal scalp at the back of the head. Which is F1, F2, F3, F4, F5, F6, F7, F8 positions respectively. The Electrode Placement for TEP Paradigm is depicted in Figure 3.2

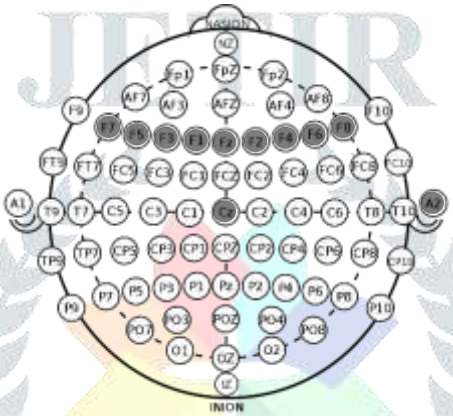

Figure 3.2

The connectivity of the EEG amplifier is checked and the subject is made comforted for the recording. The Electrode cap and placement of electrode are done at Occipital lobe. The conductivity gel is applied and placed on the scalp. The impedance level is checked and verified that it is lesser than 10 kΩ. The signal is checked for artifacts and lags in continuity. The recording is repeated to attain multiple trials. The EEG recordings of the subjects with different sleep qualities is measured and the plot is depicted in Figure 3.3

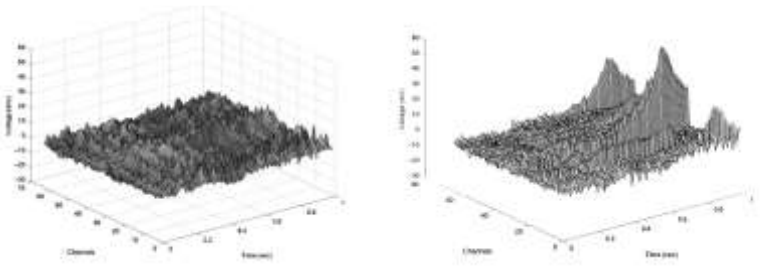

Figure 3.3

Preprocessing

The aim of this step is to de-noise the input data so that the actual relevant information present in the input signal to be enhanced. The non-cerebral source of electrical signals detected along with EEG, are called artifacts. EEG data is mostly susceptible to such artifacts. The amplitude of artifacts can be quite large relative to the size of amplitude of the cortical signals of interest. It is divided into two categories biological artifacts are generated internally from the body such as eye blinks, eye muscle

movement, cardiac, muscular artifacts. Non-biological artifacts are generated externally e.g., Electromagnetic (EM) spikes, noise. Some of them are Direct Current (DC) offset drift, thermal noise. The EEG signals are noisy in nature due to the artifacts. Although it is manual and time consuming, Independent Component Analysis (ICA) is often used to clean the signal. However, few automatic artifact removal techniques are also introduced by the researchers. These methods only focus on removing particular artifacts such as Electrooculogram (EOG) and ballistocardiogram (BCG).

Preprocessing

Feature extraction is an important step in the process of electroencephalogram (EEG) signal classification. Technically, a feature represents a distinguishing property, a recognizable measurement, and a functional component obtained from a section of a pattern. Extracted features are meant to minimize the loss of important information embedded in the signal.

Wave Patterns

The number of wave cycles or peaks that occurs in EEG pattern in a set period of time is frequency the pictorial representation of basic EEG patterns is depicted in Figure 3.4

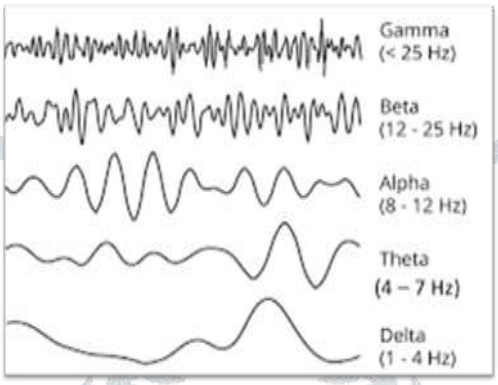

Figure 3.4

Delta Waves is the frequency range up to 4 Hz. It tends to be the highest in amplitude and the slowest waves. It may occur focally with subcortical lesions and in general distribution with diffuse lesions, metabolic encephalopathy hydrocephalus or deep midline lesions. Theta is the frequency range from 4 Hz to 7 Hz. Theta is seen normally in young children. It may be seen in drowsiness or arousal in older children and adults; it can also be seen in meditation. Alpha is the frequency range from 7 Hz to 13 Hz. This was the "posterior basic rhythm" seen in the posterior regions of the head on both sides, higher in amplitude on the dominant side. Alpha is the frequency range from 7 Hz to 13 Hz. This was the "posterior basic rhythm" seen in the posterior regions of the head on both sides, higher in amplitude on the dominant side. Gamma is the frequency range approximately 30–100 Hz. Gamma rhythms are thought to represent binding of different populations of neurons together into a network for the purpose of carrying out a certain cognitive or motor function.

Alert System

The subject with poor sleep quality has the EEG pattern in Beta Waves. The proposed system monitors the EEG of the subject and alerts when Beta Pattern is detected and terminates when the person attains Delta state. The PSD of subject who is awake lies below 5 μV2 [5]. The core aim of alert system is to continuously monitor the pattern of the user's EEG and to send a text alert containing the hyperlink of music playlist when the sleep quality of the user is poor. The playlist sent will induce sleep.

Twilio API

Twilio is an American Cloud Communications Platform as A Service (CPaaS) company. Twilio allows software developers to programmatically make and receive phone calls, send and receive text messages, and perform other communication functions using its web service APIs. Twilio uses Amazon Web Services to host telephone infrastructure and provide connectivity between HTTP and the public switched telephone network (PSTN) through its APIs. Twilio Account SID as the username and your Auth Token as the password for HTTP Basic authentication with Twilio. The classifier output of Power Spectral Density from MATLAB is passed on to a conditional statement. If the Power Spectral Density is less than 50 MATLAB automatically runs the Python file which initiate the Twilio API and sends the playlist link to user.

IV. RESULTS AND DISCUSSION

EEG signal has been recorded using the EEG amplifier under two different sleep quality for several trials by thought evoked potential. Analysis has been carried out as per the steps discussed in the previous chapters and the results are discussed.

Experiments for 10 subjects of age group 20-22 are taken into account with each 5 trials has been carried out and the sleep quality determined for the respective subjects are represented in Table 4.1.

Table 4.1: Dataset Description

NO OF SUBJECTS	GENDER		NO OF TRIALS	GOOD SLEEP QUALITY	POOR SLEEP QUALITY
10	Male 4	Female 6	5 Trials each TOTAL=50	3	7

The subjects having good sleep quality have power spectral density in the range of 120 – 140 μV2 and the subject's power spectral density having bad sleep quality lies in the range of 3-5 μV2. Out of 6 testing subjects 1 subject had wave pattern similar to Alpha wave (8-12 Hz). The proposed system's music recommendation made the subject to move to Theta state (4-7 Hz) within 2 playlist shuffles. 4 subjects had frequency pattern similar to Beta wave (12-25 Hz) they were able to move to Theta state within 5-10 playlist shuffles.1 subject had a wave pattern similar to Gamma wave after repeated iterations of shuffle the subject couldn't attain a sleepy condition. So, they are recommended for suitable medications.

V. CONCLUSION

People with insomnia doesn't fall asleep easily or couldn't get enough restful slumber which has adverse effect in physical as well as mental health. Several studies have proved that music induces sleep. This EEG based solution suggests them a music playlist when their sleep quality is poor. The recorded signal is preprocessed and transformed in frequency domain using FFT (Fast Fourier Transform) using MATLAB and the power spectral density of the same is obtained to find the sleep quality of the patient to evoke the alert system to send a playlist as SMS to the user. Chronic Insomnia has adverse effects and health risks that includes several medical complications like stroke, asthma attacks, seizures, obesity, high blood pressure, heart disease, depression, anxiety it also has increased risk of accidents if the sleep quality is poor. Music improves sleep through calming the parts of the autonomic nervous system, leading to slower breathing, lower heart rate, and reduced blood pressure. Many people with poor sleep associate their bedrooms with frustration and sleepless nights. Music can counteract this, distracting from troubling or anxious thoughts. Hence this system helps insomniac patients to recover and help their mental health.

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